NUREG/CP-0194
Volume 3 of 3

EPRI 1020621
Final Report

Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES)-2008

NRC-RES/EPRI Fire Workshop

Volume 3

Module 3: Fire Analysis

Based on the Joint
NRC-RES/EPRI Training Workshops
Conducted in 2008

September 28 – October 2, 2008, and
November 17-20, 2008, Bethesda, MD

David Stroup
Felix Gonzalez
Hugh Woods

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, DC 20555-0001

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA 94303

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Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES)-2008

NRC-RES/EPRI Fire PRA Workshop

Volume 3 - Module 3: Fire Analysis

NUREG/CP-0194 **EPRI 1020621**

Final Report

July 2010

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research (RES)
Washington, DC 20555-0001

U.S. NRC-RES Project Manager
M. H. Salley

Electric Power Research Institute (EPRI)
3420 Hillview Avenue
Palo Alto, CA 94303

EPRI Project Manager
R. P. Kassawara

COURSE TRAINING INSTRUCTORS AND PROJECT MANAGERS

Sandia National Laboratories (SNL)
1515 Eubank SE
Albuquerque, NM 87185

Steven Nowlen

Mardy Kazarians (Kazarians & Associates)

Frank Wyant

Jeff LaChance

J.S. Hyslop/ Kendra Hill

U.S. NRC-RES Project Managers

Science Applications International Corp. (SAIC)
1671 Dell Ave, Suite 100
Campbell, CA 95008

Bijan Najafi

Francisco Joglar-Biloch

Dan Funk (EDAN Engineering)

Richard Anoba (Anoba Consulting Services)

R.P. Kassawara

EPRI Project Manager

CITATIONS

This report was prepared by:

U.S. Nuclear Regulatory Commission,
Office of Nuclear Regulatory Research (RES)
Washington, DC 20555-0001

Principal Investigators:
D. Stroup
F. Gonzales

Electric Power Research Institute (EPRI)
3420 Hillview Avenue
Palo Alto, CA 94303

Principal Investigator:
R. Kassawara

This report describes research sponsored jointly by the U.S. Nuclear Regulatory Commission, RES, and EPRI.

The report is a corporate document that should be cited in the literature in the following manner:

Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES), NRC-RES/EPRI Fire PRA Workshop, Volume 3 – Module 3: Fire Analysis, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research (RES), Washington, DC 20555-0001, and Electric Power Research Institute (EPRI), Palo Alto, CA, NUREG/CP-0194 and EPRI 1020621.

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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) approved the risk-informed and performance-based alternative regulation 10 CFR 50.48(c) in July 2004, which allows licensees the option of using fire protection requirements contained in the National Fire Protection Association (NFPA) Standard 805, "Performance Based Standard for Fire Protection for Light-Water Reactor Electric Generating Plants, 2001 Edition," with certain exceptions. To support licensees's use of that option, NRC and the Electric Power Research Institute (EPRI) jointly issued NUREG/CR-6850 (EPRI 1011989) "Fire PRA Methodology for Nuclear Power Facilities," in September 2005. That report documents the state-of-the art methods, tools, and data for conducting a fire probabilistic risk assessment (PRA) in a commercial nuclear power plant (NPP) application. The report is intended to serve the needs of a fire risk analysis team by providing a general framework for conduct of the overall analysis as well as specific recommended practices to address each key aspect of the analysis. Participants from the U.S. nuclear power industry supported demonstration analyses and provided peer review of the program. Methodological issues raised in past fire risk analyses, including the Individual Plant Examination of External Events fire analyses, are addressed to the extent allowed by the current state-of-the-art and the overall project scope. Although the primary objective of the report is to consolidate existing state-of-the-art methods, in many areas, the newly documented methods represent a significant advance over previous methods.

NUREG/CR-6850 does not constitute regulatory requirements, and NRC participation in this study neither constitutes nor implies regulatory approval of applications based on the analysis contained in this document. The analyses/methods documented in this report represent the combined efforts of individuals from RES and EPRI. Both organizations provided specialists in the use of fire PRA to support this work. The results from this combined effort do not constitute either a regulatory position or regulatory guidance.

In addition, NUREG/CR-6850 can be used for risk-informed, performance-based approaches and insights to support fire protection regulatory decision-making in general.

On 14-16 June 2005, NRC's Office of Nuclear Regulatory Research (RES) and EPRI conducted a joint public workshop for about 80 attendees at the EPRI NDE Center in Charlotte, NC. A second workshop was held the following year, on 24-26 May 2006, in NRC's Two White Flint North Auditorium in Rockville, MD. About 130 people attended the second workshop. Based on the positive public response to these two workshops, a more detailed training class was developed by the authors of NUREG/CR-6850. Two detailed training workshops were conducted in 2007: on 23-27 July and again on 27-30 August, both at EPRI in Palo Alto, CA. About 100 people attended each of these workshops. In 2008, two more workshops were held from 29 September through 2 October, and again from 17-20 November in Bethesda, MD, near NRC Headquarters. The two workshops attracted about 170 participants including domestic representatives from NRC Headquarters and all four regional offices, U.S. Department of Energy, National Aeronautics and Space Administration, EPRI, NPP licensees/utilities, Nuclear Steam Supply System vendors, consulting engineering firms, and universities. Also in

attendance were international representatives from Belgium, Canada, France, Japan, South Korea, Spain, and Sweden.

The material in this NUREG/CP was recorded at the workshops in 2008 and adapted by RES Fire Research Branch members for use as an alternative training method for those who were unable to physically attend the training sessions. This report can also serve as a refresher for those who attended one or more training sessions and would be useful preparatory material for those planning to attend a session.

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CONTENTS OF VOLUME 3

CONTENTS OF VOLUME 3 (CONTINUED)

Acknowledgements

The authors of this report greatly appreciate the efforts and contributions made by Carli Follett, David Yates, and Thomas DeBold, summer interns from the University of Maryland's Fire Protection Engineering Department, during development of this NUREG/Conference Proceedings report. As part of their summer internship, they were tasked to analyze, evaluate, organize, and edit information in the videos of this report and to develop its first draft under direct supervision of the authors. They compiled all the video files and presentation materials used during the training sessions and used their knowledge to create, organize, edit, and deliver a user-friendly report of the highest quality possible.

We also acknowledge the other Fire Research Branch members Kendra Hill, Aixa Belen-Ojeda, Jason Dreisbach, Jessica Kratchman, Gabriel Taylor, J.S. Hyslop, and Mark Henry Salley for their support and contributions during its development. Their input and encouragement facilitated its timely completion and greatly benefited the final product.

In addition, we want to extend our gratitude to Nathan White and Thomas Kardaras of the Information Technology and Infrastructure Branch for their quick responses addressing all our computer needs and issues during development of the report. We greatly appreciate the support of Linda Stevenson (the agency publication specialist) and Guy Beltz (the agency printing specialist) whose invaluable support and expertise were critical to ensuring the published report's quality.

Also, several other 2009 Office of Nuclear Regulatory Research summer interns, specifically Minh Dang, Daniel Breedlove, Ashley Carnes, and Anders Gilbertson, made valuable contributions to this project, both technical and editorial, that contributed to its overall quality.

LIST OF ACRONYMS

ACB	Air-cooled Circuit Breaker
ACRS	Advisory Committee on Reactor Safeguards
AEP	Abnormal Event Procedure
AFW	Auxiliary Feedwater
AGS	Assistance General Supervisor
AOP	Abnormal Operating Procedure
AOV	Air Operated Valve
ATHEANA	A Technique for Human Event Analysis
ATS	Automatic Transfer Switch
ATWS	Anticipated Transient Without Scram
BAT	Boric Acid Tank
BNL	Brookhaven National Laboratory
BWR	Boiling-Water Reactor
CBDT	Causal Based Decision Tree
CCDP	Conditional Core Damage Probability
CF	Cable (Configuration) Factors
CCPS	Center for Chemical Process Safety
CCW	Component Cooling Water
CDF	Core Damage Frequency
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
CLERP	Conditional Large Early Release Probability
CM	Corrective Maintenance
CR	Control Room
CRS	Cable and Raceway (Database) System
CST	Condensate Storage Tank
CVCS	Chemical and Volume Control System
CWP	Circulating Water Pump
DC	Direct Current
EDG	Emergency Diesel Generator
EDS	Electrical Distribution System
EF	Error Factor
EI	Erroneous Status Indicator
EOP	Emergency Operating Procedure
EPR	Ethylene-Propylene Rubber
EPRI	Electric Power Research Institute

FEDB	Fire Events Database
FEP	Fire Emergency Procedure
FHA	Fire Hazards Analysis
FIVE	Fire-Induced Vulnerability Evaluation (EPRI TR 100370)
FMRC	Factory Mutual Research Corporation
FPRAIG	Fire PRA Implementation Guide (EPRI TR 105928)
FRSS	Fire Risk Scoping Study (NUREG/CR-5088)
FSAR	Final Safety Analysis Report
HEAF	High Energy Arcing Fault
HEP	Human Error Probability
HFE	Human Failure Event
HPI	High-Pressure Injection
HPCI	High-Pressure Coolant Injection
HRA	Human Reliability Analysis
HRR	Heat Release Rate
HTGR	High Temperature Gas-cooled Reactor
HVAC	Heating, Ventilation, and Air Conditioning
ICDP	Incremental Core Damage Probability
ILERP	Incremental Large Early Release Probability
INPO	Institute for Nuclear Power Operations
IPE	Individual Plant Examination
IPEEE	Individual Plant Examination of External Events
IS	Ignition Source
ISLOCA	Interfacing Systems Loss of Coolant Accident
KS	Key Switch
LCO	Limiting Condition of Operation
LERF	Large Early Release Frequency
LFL	Lower Flammability Limit
LOC	Loss of Control
LOCA	Loss-of-Coolant Accident
LPG	Liquefied Petroleum Gas
LWGR	Light-Water-cooled Graphite Reactors (Russian design)
MCB	Main Control Board
MCC	Motor Control Center
MCR	Main Control Room
MG	Motor-Generator
MFW	Main Feedwater
MOV	Motor-Operated Valve
MQH	McCaffrey, Quintiere and Harkleroad's Method
MS	Main Steam
MSIV	Main Steam Isolation Valve
NC	No Consequence
NEI	Nuclear Energy Institute
NEIL	Nuclear Electric Insurance Limited
NFPA	National Fire Protection Association
NPP	Nuclear Power Plant

NPSH	Net Positive Suction Head
NQ cable	Non-Qualified (IEEE-383) cable
NRC	U.S. Nuclear Regulatory Commission
P&ID	Piping and Instrumentation Diagram
PE	Polyethylene
PM	Preventive Maintenance
PMMA	Polymethyl Methacrylate
PORV	Power-Operated Relief Valve
PRA	Probabilistic Risk Assessment
PSF	Performance Shaping Factor
PTS	Pressurized Thermal Shock
PVC	Polyvinyl Chloride
PWR	Pressurized-Water Reactor
Q cable	Qualified (IEEE-383) cable
RBMK	Reactor Bolshoy Moshchnosty Kanalny (high-power channel reactor)
RCIC	Reactor Core Isolation Cooling
RCP	Reactor Coolant Pump
RCS	Reactor Coolant System
RDAT	Computer program for Bayesian analysis
RES	Office of Nuclear Regulatory Research (at NRC)
RHR	Residual Heat Removal
RI/PB	Risk-Informed / Performance-Based
RPS	Reactor Protection System
RWST	Refueling Water Storage Tank
SCBA	Self-Contained Breathing Apparatus
SDP	Significance Determination Process
SGTR	Steam Generator Tube Rupture
SI	Safety Injection
SMA	Seismic Margin Assessment
SNPP	Simplified Nuclear Power Plant
SO	Spurious Operation
SOV	Solenoid Operated Valve
SRV	Safety Relief Valve
SSD	Safe Shutdown
SSEL	Safe Shutdown Equipment List
SST	Station Service Transformer
SUT	Start-up Transformer
SW	Service Water
SWGR	Switchgear
T/G	Turbine/Generator
THERP	Technique for Human Error Rate Prediction
TGB	Turbine-Generator Building
TSP	Transfer Switch Panel
UAT	Unit Auxiliary Transformer
VCT	Volume Control Tank
VTT	Valtion Teknillinen Tutkimuskeskus (Technical Research Centre of Finland)

VVER	The Soviet (and now, Russian Federation) designation for light-water pressurized reactor
XLPE	Cross-Linked Polyethylene
ZOI	Zone of Influence

1 INTRODUCTION – FIRE ANALYSIS OVERVIEW

Within the context of a nuclear power plant (NPP), fires present a special hazard because fire can damage multiple equipment intended to mitigate core damage. This determination of fire damage is made through fire modeling using simple empirical approaches to complex computer codes such as CFAST or FDS. NUREG/CR-6850 provides the framework for including fire models in fire probabilistic risk assessment (PRA) and describes simple empirical models to assess fire damage. Extensive information on the more complex approaches such as CFAST and FDS is referred to NUREG-1824, the verification and validation of several fire models.

Cables are important fire damage targets in fire PRA models. Simple empirical models to evaluate cable damage, including damage to cables in different trays, are included in the methods presented. Thresholds for cable damage, primarily to thermoset and thermoplastic cables, are also discussed. Besides simple empirical models, more complex rule sets to evaluate high-energy arcing faults are also presented in this part of the training.

The treatment of heat-release rates has been expanded in NUREG/CR-6850, and distributions of heat-release rates for many types of fire sources have been provided. For example, heat-release rates for electrical cabinets depend on the configuration of cables in the cabinet and the cabinet itself. In addition, the severity factor concept, which refers to that portion of the heat-release rate above which damage occurs, has been improved.

Besides explicit fire modeling, the "Fire" portion of this training describes how fire-suppression activities are treated and evaluated. Fire suppression includes prompt suppression, such as for hot work, and automatic and manual fire suppression. Fire damage is generally evaluated in fire PRA under success and failure of fire suppression.

This module also describes how to divide the plant into regions to be used for analysis. A fire compartment is a common region applied in fire PRA. Fires producing damage across regions are also considered. Moreover, guidance on counting components and transferring those counts to fire frequency is provided. Guidance for a qualitative assessment of seismic-fire interactions is included.

1.1 EPRI Perspective

"Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES)" is a collection of the materials that are presented at the fire PRA course provided by the Electric Power Research Institute (EPRI) and the U.S. Nuclear Regulatory Commission's (NRC's) Office of Nuclear Regulatory Research (RES). The training and resulting presentation material is detailed and represents in excess of 60 hours of classroom instruction. The training focuses on the fire PRA methods documented in the joint EPRI/RES publication 1011989 and NUREG/CR-6850 along with clarifications, enhancements, and additions provided via the Frequently Asked Question (FAQ) process for NFPA 805.

The intent of the publication is to provide to the public the training material used at the fire PRA training. This material is not intended to be a substitute for direct interaction that is provided in the periodically offered fire PRA courses; rather, it is meant to augment that training and to serve as a reference. Enthusiastic future students can use the material to become familiar with the general principles of fire PRA prior to arrival at the course. Students who have already taken the course can use the material for reference. The material consists of a series of reports that document the presentations including some speakers' notes and text. In addition, an edited version of a recorded training session is also available via a separate product number. This video version can be used in a similar manner to the documentation (e.g., for reference or in preparation for the course) and includes the actual recorded and edited course.

This material is being provided with the hope that those who plan to attend the course can arrive more informed, those who have already attended can have a reference, and those who have been unable to attend can have a resource to gain a more complete understanding of the intent and goals of EPRI 1011989 and NUREG/CR-6850.

2 FIRE ANALYSIS SLIDES

Session 1a: Plant Partitioning

Slide 1

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EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 1: Plant Partitioning

Joint RES/EPRI Fire PRA Workshop
September, 2008
Washington, DC

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Notes:

Slide 2

Plant Partitioning
Scope

The following topics are covered:

- Task 1: Plant Partitioning Analysis
  - Define Global Analysis Boundary
  - Partition into physical analysis units or Compartments
  - Problem sets from the Sample Problem

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Task 1: Plant Partitioning

Slide 2

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Notes:

Slide 3

Notes:

Support Task A: Plant Walkdowns
Just a Quick Note....

- You *cannot* complete a Fire PRA without walkdowns
- Expect to conduct a number of walkdowns, especially for key areas (e.g., those analyzed in detail)
- Walkdowns can have many objectives and support many tasks:
  - Partitioning features, equipment/cable mapping, fire ignition source counting, fire scenario definitions, fire modeling, detection and suppression features, recovery actions HRA
- Walkdowns are generally a team activity so coordinate them to optimize personnel time and resources

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Task 1: Plant Partitioning
Slide 3
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Slide 4

Notes:

Plant Partitioning
General Comment/Observation

- The recommended practice for Task 1 has changed little from prior methods.
  - That means you can likely benefit from a previous analysis
    - e.g., your IPEEE fire analysis
    - However: watch out for new equipment/cables, new initiators when screening

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Task 1: Plant Partitioning
Slide 4
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Slide 5

Task 1: Plant Partitioning
Key Definitions: Compartment vs. Fire Area/Zone

- We talk mainly about Fire Compartments which are defined in the context of the Fire PRA only
  - Defining Fire Compartments is necessary for analysis management
  - Also known as Physical Analysis Units
- Fire Areas are defined in the context of your regulatory compliance fire protection program
- Fire Zones are generally defined in the context of fire protection features (e.g., detection, suppression, hazards)
  - Fire zones have no direct meaning to the Fire PRA context and we avoid using this term
- Physical Analysis Unit is another term coined lately

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Task 1: Plant Partitioning

Slide 5

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Slide 6

Task 1: Plant Partitioning
Task Objectives and Output

- There are two main objectives to Task 1:
  1. Define the Global Analysis Boundary
     - The maximum physical extent of the plant that will be considered in the Fire PRA
  2. Divide the areas within the Global Analysis Boundary into analysis Compartments (Physical Analysis Units)
     - The basic physical units that will be analyzed and for which risk results will be reported
- Task output is the definition of these two aspects of the analysis

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Task 1: Plant Partitioning

Slide 6

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Notes:

Slide 7

Task 1: Plant Partitioning
Task Input

- No real input from any other task is required (it is, after all, Task 1)
  - There *is* a link to the equipment and cable selection Tasks 2 and 3
  - You may also find yourself iterating back to this task later in the analysis – that is fine, just be careful to track any changes
- What do you need to support this Task?
  - Layout drawings that identify major structures, walls, openings
    - Drawings that identify Fire Areas are especially helpful
  - Plan and elevation drawings are helpful
  - You *will* need to do a walkdown to support/verify decisions

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Task 1: Plant Partitioning

Slide 7

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Slide 8

Task 1: Plant Partitioning
Task Breakdown in Steps

- Task 1 is defined in terms of the following steps:

Step 1: Selection of Global Plant Analysis Boundary

Step 2: Plant Partitioning

Step 3: Compartment Information Gathering and Characterization

Step 4: Documentation

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Task 1: Plant Partitioning

Slide 8

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Notes:

Slide 9

Task 1: Plant Partitioning
Selection of Global Plant Analysis Boundary

- We want a *Liberal* definition of the global analysis boundary
  - It's OK to include obviously unimportant areas, we'll drop them quickly, but better to do this formally
- Encompass all areas of the plant associated with both normal and emergency reactor operating and support systems, as well as power production
- Sister Units should be included unless they are physically and functionally separated
  - No shared areas, no shared systems, no shared components and associated cables, no conjoined areas (e.g., shared walls)

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Task 1: Plant Partitioning
Slide 9
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Notes:

Slide 10

Task 1: Plant Partitioning
Selection of Global Plant Analysis Boundary (2)

- Begin with your protected area: everything within the protected area should be included in the Global Analysis Boundary
  - In most cases that will capture all risk-important locations
- If necessary, expand the boundary to include any other locations that house equipment or cables identified in Tasks 2 or 3
  - This is the Task 2/3 link mentioned before!
  - Example: If your offsite power related equipment is outside the protected area, you need to expand Global Analysis Boundary to capture it

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Task 1: Plant Partitioning
Slide 10
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Notes:

Slide 11

Task 1: Plant Partitioning
Selection of Global Plant Analysis Boundary (3)

- Problem Set 01-01

- By the end of the analysis, you need to provide a fire risk disposition for all locations within the global analysis boundary
  - That may be anything from screened out qualitatively to a detailed risk quantification result

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Task 1: Plant Partitioning

Slide 11

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Notes:

Slide 12

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments (1)

- We divide the Global Analysis Boundary into smaller pieces (compartments) for the purpose of tracking and reporting risk results

- A compartment can be many things, but when it comes down to it, a compartment is:

  A well-defined volume within the plant … that is expected to substantially contain the adverse effects of fires within the compartment.

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Task 1: Plant Partitioning

Slide 12

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Notes:

Slide 13

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments (2)

- This task is often subjective – judgment *is* required
- Ideally: Compartments = Rooms
  - Locations that are fully defined by physical partitioning features such as walls, floors, and ceilings
- But the ideal is not the only solution - other features and elements may be credited in partitioning
  - That's where judgment comes into play!
  - What will you credit as a Partitioning Feature?

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Task 1: Plant Partitioning
Slide 13
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Notes:

Slide 14

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments (3)

- A good starting point is your Fire Areas, but you are *by no means limited* to equating Fire Compartments to Fire Areas
  - A Fire Area may be partitioned to two or more Compartments
  - You may combine two or more Fire Areas into a single Compartment
- In the end: { ∑ Compartments } = { Global Analysis Bnd. }
  - No omissions
  - No overlap!

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Task 1: Plant Partitioning
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Notes:

Slide 15

Notes:

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments (4)

- So what can you credit as a partitioning feature:
  - Bottom line: anything you can justify – see text for examples
    - You do need to justify your decisions with the exception of structural elements maintained as rated fire barriers
  - In the end, your partitioning decisions should not affect the risk results, but . .
  - Don't go crazy – there are disadvantages to over-partitioning
  - General guideline: try to minimize the need to develop and analyze multi-compartment scenarios

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Task 1: Plant Partitioning

Slide 15

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Slide 16

Notes:

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments (6)

- There are some things that you should not credit in partitioning:
  - Partial height walls
  - Radiant energy shields
  - Beam pockets
  - Equipment obstructions (e.g., pipes)
  - (ANS Standard says: Raceway or other localized fire barriers *may not be credited* in partitioning)
- *Problem Set 01-02*

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Task 1: Plant Partitioning

Slide 16

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Slide 17

Notes:

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments (7)

- Final Point: You need a system to identify/name your Fire Compartments
  - Something both consistent and logical – but whatever works for your application and plant
  - Often makes sense to use Fire Area designations in naming schemes
    - Example: Fire Area 42 might become Fire Compartments 42A, 42B...
  - Use your naming scheme consistently throughout the Fire PRA
    - Documentation, equipment/cable tracing, database, etc.

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Task 1: Plant Partitioning

Slide 17

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Slide 18

Notes:

Task 1: Plant Partitioning
Compartment Information Gathering and . . . (1)

- Later tasks need certain information about each compartment. They include, but are not limited to the following:
  - Compartment boundary characteristics
  - Ventilation features, and connections
  - Fire protection features
  - Fire source hazards
  - Identification of all adjacent compartments
  - Identification of components/systems/cables
  - Access routes to the fire compartment
  - SSD human actions credited in each compartment

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Task 1: Plant Partitioning

Slide 18

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Slide 19

Task 1: Plant Partitioning

Compartment Information Gathering and . . . (1)

- A thorough plant walkdown is needed to confirm and gather information about each fire compartment.
- Initially it is not expected that all information pieces to be collected and documented.
- As work on fire PRA progresses, additional information, as needed, is collected and documented
- This task, similar to other later tasks, is expected to be revisited and compartment definitions modified as additional information is obtained.

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Task 1: Plant Partitioning

Slide 19

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Notes:

Slide 20

Task 1: Plant Partitioning

Compartment Information Gathering and . . . (2)

Fire Compartment ID #	9
Fire Compartment	Switchgear Access Room
Building	Auxiliary Building
Boundary Characteristics	The compartment is bounded by 3-hr rated fire walls, ceiling and floor.
Ventilation Features	The ventilation is provided by the Auxiliary Building HVAC system(1). The equipment housed in this compartment can function properly and perform their safe shutdown duties in case of total loss of the HVAC system.
Fire Protection Features	The fire protection features of this compartment includes: 1. Handheld extinguishers inside the compartment (2 units)(1) 2. Wet hose reel outside the door inside the stairwell(1) 3. Smoke detectors attached to the ceiling (6 units)(1)
Fire Sources	The following ignition sources were identified in this compartment. 1. MCC-A 2. MCC-B 3. 125VAC-A 4. 125VAC-B 5. ATS 6. Lighting Fixtures (10 units)(1) Additionally the following combustibles are present: 1. Cable trays containing thermoset control cables 2. Wooden desk used by the electrical department(1)
Adjacent Compartments	The following compartments share a wall, ceiling or floor with this compartment: 1. Switchgear Room A 2. Switchgear Room B 3. Stairwell 4. Charging pump room 5. Cable spreading room
Access Routes	1. This room can be accessed from outside through the stairwell 2. Switchgear Rooms A and B are accessed through this room
Components/Systems/Cables Present	See the component and cable lists provided in Tasks 2 and 3.
SSD Human Actions Credited in this Compartment	To be completed after Task 12 is completed.

(1) Provided here to demonstrate how this part of the step may be addressed. These features are not intended to be included in the fire PRA of this example plant.

Notes:

Slide 21

Notes:

Task 1: Plant Partitioning
Summary

- Plant Partitioning is the first step of fire PRA.
- Done in three steps
  1. Define global plant analysis boundaries to include all those area that will be addressed by the fire PRA
  2. Define fire compartments in such a way that all the areas identified in the preceding step are covered, there are no overlaps and there is a balance between size and number of compartments selected
  3. Confirm the selected compartments through a walkdown and record important information that will be used later.

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Task 1: Plant Partitioning

Slide 21

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Session 1b: Example Problems

Workshop Problem Set 01-01

Step 1 - Selection of Global Plant Analysis Boundary: Using Drawing # 01 in the Sample Package and the information provided in other drawings, identify the Global Plant Analysis Boundaries in terms of plant areas. Make a complete list of plant areas shown on Drawing #01 in the matrix provided below. Specify whether or not the area shall be included within the Global Plant Analysis Boundaries and then provide the basis of your decision.

Plant Area	Included?	Basis

Plant Area	Included?	Basis

Workshop Problem Set 01-02

Step 2: Plant Partitioning: Using the drawings provided in the Sample Package, identify the set of fire compartments that you will consider for the fire PRA. In the following matrix (1) list selected compartments, (2) give each an identification number, (3) identify the associated plant area for each compartment from the Solution Statement for Problem Set 01-01. Provide comments where warranted.

Fire Comp. ID #	Fire Compartment Descriptor	Plant Area	Comments

Fire Comp. ID #	Fire Compartment Descriptor	Plant Area	Comments

Session 2a: Fire Ignition Frequency

Slide 1

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EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 6: Fire Ignition Frequency

Joint RES/EPRI Fire PRA Workshop
September, 2008
Washington DC

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Notes:

Slide 2

FIRE IGNITION FREQUENCIES
Purpose of Task 6

In Task 6, the ignition frequencies associated with fire ignition sources are established.

- Generic frequencies
- Plant specific experience
- Uncertainties

To be presented in two parts:

- 1. How to estimate location specific frequencies
- 2. How generic frequencies were put together

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Task 6: Fire Ignition Frequency

Slide 2

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Notes:

Slide 3

Notes:

FIRE IGNITION FREQUENCIES
Assumptions

The model developed for estimating fire ignition frequencies is based on the following assumptions:

- Frequencies remain constant over time
- Total ignition frequency for an equipment type is the same for all plants
- Within each plant, ignition frequency is the same for all equipment of the same type.

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Task 6: Fire Ignition Frequency

Slide 3

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Slide 4

Notes:

FIRE IGNITION FREQUENCIES
General Approach

To establish the fire frequency of a fire compartment, the ignition frequencies associated with each ignition source of the compartment are added together.

- $\lambda_{J,L} = \Sigma \lambda_{IS} W_L W_{IS,J,L}$
  summed over all ignition sources

  Where:

  $\lambda_{J,L}$: Fire frequency associated with compartment J at location L

  λ_{IS}: Plant level fire ignition frequency associated with ignition source IS

  W_L: Location weighting factor

  $W_{IS,J,L}$: Ignition source weighting factor

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Task 6: Fire Ignition Frequency

Slide 4

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Slide 5

Notes:

FIRE IGNITION FREQUENCIES
Plant Level Frequency (λ_{IS})

Plant level fire ignition frequency covers all the equipment of the same type in the entire unit.

Examples:

- 2.1E-02 is the frequency per year of fires within a unit that involve pumps.
- 7.4E-03 is the frequency per year of transient fires within the turbine building of a unit.

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Task 6: Fire Ignition Frequency

Slide 5

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Slide 6

FIRE IGNITION FREQUENCIES
Plant Level Frequencies (λ_{IS})

Table 6-1
Fire Frequency Bins and Generic Frequencies

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type: Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
1	Battery Room	Batteries	All	7.5E-04	1.0	0	0	0	0	0
2	Containment (PWR)	Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
4	Control Room	Main Control Board	All	2.5E-03	1.0	0	0	0	0	0
8	Diesel Generator Room	Diesel Generators	All	2.1E-02	0.16	0.84	0	0	0	0
11	Plant-Wide	Cable fires caused by [illegible]tting	Power	2.0E-03	0	0	0	1.0	0	0
[illegible]	[illegible] Components	[illegible]	All	4.6E-03	1.0	0	0	0	0	0
15	Plant-Wide Components	Electrical Cabinets	All	4.5E-02	1.0	0	0	0	0	0
20	Plant-Wide Components	Off-gas/H2 Recombiner (BWR)	Power	4.4E-02	0	0	0	0	1.0	0
27	Transformer Yard	Transformer – Catastrophic[2]	Power	6.0E-03	1.0	0	0	0	0	
32	Turbine Building	Main Feedwater Pumps	Power	1.3E-02	0.11	0.89	0	0	0	0

1. See Appendix M for a description of high-energy arcing fault (HEAF) fires.
2. See Section 6.5.6 below for a definition.

Ignition Frequency Bin

Notes:

FIRE IGNITION FREQUENCIES
Plant Level Frequencies (λ_{IS})

Table 6-1
Fire Frequency Bins and Generic Frequencies

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type: Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
1	Battery Room	Batteries	All	7.5E-04	1.0	0	0	0	0	0
2	Containment (PWR)	Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
4	Control Room	Main Control Board	All	2.5E-03	1.0	0	0	0	0	0
8	D R				.16	0.84	0	0	0	0
11	P C				0	0	0	1.0	0	0
14	P C				1.0	0	0	0	0	0
15	P C				1.0	0	0	0	0	0
20	P C				0	0	0	0	1.0	0
27	T				1.0	0	0	0	0	
32	T				.11	0.89	0	0	0	0

1. See Ap
2. See Se

ID	Location
1	Battery Room
2	Containment (PWR)
4	Control Room
8	Diesel Generator Room

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Task 6: Fire Ignition Frequency

Slide 7

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Notes:

Slide 8

FIRE IGNITION FREQUENCIES
Plant Level Frequencies (λ_{IS})

Table 6 -1
Fire Frequency Bins and Generic Frequencies

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type: Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
1	Battery Room	Batteries	All	7.5E-04	1.0	0	0	0	0	0
2	Containment (PWR)	Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
4	Control Room	Main Control Board	All	2.5E-03	1.0	0	0	0	0	0
8	Diesel Ge Room									
11	Plant-Wid Compone									
14	Plant-Wid Compone									
15	Plant-Wid Compone									
20	Plant-Wid Compone									
27	Transforn									
32	Turbine B									

1. See Appendix M
2. See Section 6.5.6 below for a definition.

ID	Location	Ignition Source (Equipment Type)
1	Battery Room	Batteries
2	Containment (PWR)	Reactor Coolant Pumps
4	Control Room	Main Control Boards
8	Diesel Generator Room	Diesel Generators

Notes:

FIRE IGNITION FREQUENCIES

Plant Level Frequencies (λ_{IS})

Table 6 -1
Fire Frequency Bins and Generic Frequencies

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
					Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
1	Battery Room	Batteries	All	7.5E-04	1.0	0	0	0	0	0
2	Containment (PWR)	Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
4	Control Room	Main Control Board	All	2.5E-03						
32	Turbine Building	Main Feedwater Pumps	Power	1.3E-02	0.11	0.89	0	0	0	0

1. See Appendix M for a description of high-energy arcing fault (HEAF) fires.
2. See Section 6.5.6 below for a definition.

Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
			Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
Batteries	All	7.5E-04	1.0	0	0	0	0	0
Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
Transients and Hotwork	Power	2.0E-03	0	0	0.44	0.56	0	0
Main Control Board	All	2.5E-03	1.0	0	0	0	0	0

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Task 6: Fire Ignition Frequency

Slide 9

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Notes:

Slide 10

Notes:

FIRE IGNITION FREQUENCIES
Location Weighting Factor (W_L)

Location weighting factor adjusts the plant level frequencies for those cases where a common location is shared among units of the same plant.

- All frequencies were developed per unit basis
- Examples: Turbine Building, Auxiliary Building, Control Room
- Example: W_L = 2.0 if the Turbine Building is shared between two units

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Task 6: Fire Ignition Frequency

Slide 10

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Slide 11

Notes:

FIRE IGNITION FREQUENCIES
Ignition Source Weighting Factor ($W_{IS,J,L}$)

Ignition source weighting factor is the fraction of an ignition source type found in a specific compartment.

- Need to count all the items belonging to one ignition source type in one unit
  - Necessitates a thorough plant walk-down and review of engineering documents
- Example: if there are two battery rooms in one unit, each housing one battery set, $W_{IS,J,L}$ = 0.5
- Transients and cables are based on specific models

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Task 6: Fire Ignition Frequency

Slide 11

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Slide 12

Notes:

FIRE IGNITION FREQUENCIES
Procedure

The following procedure can be used to estimate location specific fire ignition frequencies:

- Step 1. Mapping plant ignition sources to generic sources,
- Step 2. Plant fire event data collection and review,
- Step 3. Plant specific updates of generic ignition frequencies,
- Step 4. Mapping plant-specific locations to generic locations,
- Step 5. Location weighting factors,
- Step 6. Fixed fire ignition source counts,
- Step 7. Ignition source weighting factors, and
- Step 8. Ignition source and compartment fire frequency evaluation.

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Task 6: Fire Ignition Frequency

Slide 12

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Slide 13

Notes:

FIRE IGNITION FREQUENCIES
Step 1. Mapping Plant Ignition Sources

Every plant equipment item should be mapped to one of the ignition frequency bins.

- Must be capable of initiating a fire
- Must be located in the buildings, compartments and plant areas considered for fire risk analysis
- If no matching bin, then the following approach may be used:
  - Characteristics of the source
  - Percentage of the time in operation
  - Past fire histories within the plant
  - Relevant past fire histories or frequency estimates not associated with the plant

- *Problem Set 06-01*

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Task 6: Fire Ignition Frequency

Slide 13

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Slide 14

Notes:

FIRE IGNITION FREQUENCIES
Step 2. Plant Fire Event Data Collection

Plant specific fire event data is needed to establish plant specific fire ignition frequencies.

- Are plant specific fire ignition frequencies warranted?
  - Repeated set of events
  - Events that cannot be mapped to a bin
- Unusual fire occurrence patterns
- May be selective in plant specific frequencies

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Task 6: Fire Ignition Frequency

Slide 14

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Slide 15

Notes:

FIRE IGNITION FREQUENCIES
Step 2. Plant Fire Event . . . (2)

Example:

- The following events have taken place:
  - Event 1: Fire in MCC-A because of breakers not properly engaging the bus bars.
  - Event 2: Fire in 125VAC-A panel. The fire was extinguished when 4kV bus-A was de-energized from the control room. Fire resulted from arcing of supply lead to one of the fittings connecting to a controller to the bus.
- Both fires can be included in the frequency analysis.
- Plant has been in commercial operation for 10 years.
- Both events should be mapped to Bin # 15 "Electrical Cabinets"
- 2/10 = 0.2, is 4 time greater than 0.045, Bin #15 frequency

• *Problem Sets 06-02 and 06-03 (Examples)*

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Task 6: Fire Ignition Frequency

Slide 15

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Slide 16

Notes:

FIRE IGNITION FREQUENCIES
Step 3. Plant Specific Frequencies (λ_{IS})

Bayesian approach can be used to estimate plant specific fire ignition frequencies.

- Uncertainty distributions of generic frequencies as the prior
- Possible double accounting of FEDB events

Slide 17

FIRE IGNITION FREQUENCIES
Steps 4/5. Plant-Specific Locations and W_L

Plant specific locations should be mapped to the bin definition locations.

Example:

Plant Specific Location	Bin Location	W_L
Emergency Battery Enclosure	Battery Room	Number of site units that share common set of batteries.
Main Control Room	Control Room	Number of site units that share the same control room.
Control Building	Control / Auxiliary / Reactor Building	Number of site units that share the same building type.
Primary Auxiliary Building		

- *Problem Sets 06-04 and 06-05*

Notes:

Slide 18

Notes:

FIRE IGNITION FREQUENCIES
Step 6. Fixed Fire Ignition Source Counts

To establish ignition source weighting factor, $W_{IS,J}$, for each compartment, it is necessary to obtain the total number of relevant items per bin.

- For shared locations, entire site should be considered
- Visual examination (recommended approach)
- Document review or computerized database
- Counting method for each bin

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Task 6: Fire Ignition Frequency

Slide 18

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Slide 19

Notes:

FIRE IGNITION FREQUENCIES
Step 6. (cont'd)

Examples:

- *Bin 1– Batteries:* Each bank of interconnected sets of batteries located in one place should be counted as one battery set. Cells may not be counted individually.
- *Bin 5– Cable Fires Caused by Welding and Cutting: . . .* Assume that all exposed cables (i.e., cables that are not in conduits or wrapped by noncombustible materials) have an equal likelihood of experiencing a fire caused by welding and cutting across the entire location. . . .
- *Bin 14– Electric Cabinets:* Electrical cabinets represent . . switchgears, motor control centers, DC distribution panels, relay cabinets. . . . Free standing electrical cabinets should be counted by their vertical segments, . . .

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Task 6: Fire Ignition Frequency

Slide 19

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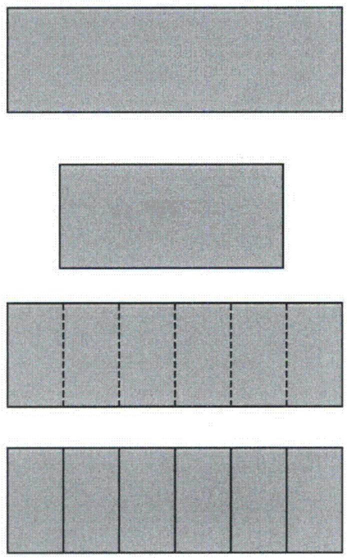
Slide 20

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs

- FAQ 06-0016 - Ignition source counting guidance for electrical cabinets. (Status: Closed)



Cabinet is not an outlier – Count = 1

Cabinet is same as standard – Count = 1

Internal dividers are not solid – Count = 6

Internal dividers are solid – Count = 6

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Task 6: Fire Ignition Frequency

Slide 20

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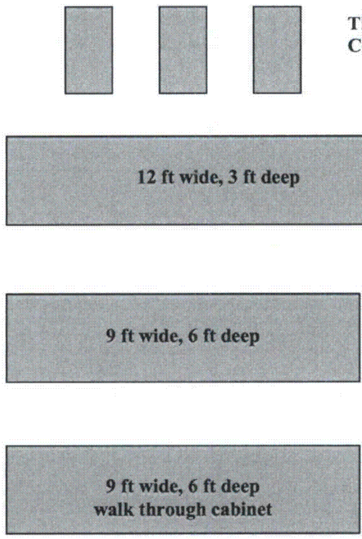
Notes:

Slide 21

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs (cont'd)

- FAQ 06-0016 - Continued.



Three independent cabinets – Count = 3

Panel is an outlier, using a 4' standard cabinet – Count = 3

Cabinet is an outlier, no evaluation of contents, based on reference cabinet – Count = 3 due to variation from the standard length and depth

The counts should depend on the cable termination load and devices in the panel by comparing it with a reference cabinet.

Notes:

Slide 22

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs (cont'd)

- FAQ 06-0017 - Ignition source counting guidance for high energy arcing faults. (Status: Closed)
  - Split Bin # 16 into:
    - Bin 16a – Low-voltage panels (480 to 1,000 V) - 4.8E-04/ry (mean)
    - Bin 16b – medium-voltage panels (> 1,000V) – 1.4E-03/ry (mean)
  - Counting method remains unchanged (i.e., vertical sections)
  - Self consistent within each new bins
- FAQ 06-0018 - Ignition source counting guidance for main control board. (Status: Closed)
  - There is a one-to-one correspondence between App. L and Bin 4.
  - Main Control Board is just the horseshoe.
  - All other electrical cabinets in the Main Control Room should be counted with other cabinets in the plant.

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Task 6: Fire Ignition Frequency

Slide 22

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Notes:

Slide 23

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs (cont'd)

- FAQ 06-0031: Ignition source counting guidance clarifications and extensions (Status: Closed)
  - **Bin 14 – Electric motors**: clarifies guidance, provides for excluding small motors of 5hp or less and totally enclosed motors.
  - **Bin 21 – Pumps**: provides for excluding small sampling pumps, and other pumps of 5hp or less
  - **Bin 23 – Transformers**: provides for excluding dry transformers of 45KVA or less
  - **Bin 26 – Ventilation subsystems**: clarifies that intent is to exclude small subsystems powered by motors of 5hp or less (consistent with electric motors bin 14)

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Task 6: Fire Ignition Frequency

Slide 23

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Notes:

Slide 24

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs (cont'd)

- FAQ 07-0035: High energy arc faults in bus ducts (Status: Open)
  - Issue:
    - Guidance document is silent on topic
  - General approach to resolution:
    - Acknowledge potential for such events (e.g., Diablo Canyon 5/2000)
    - Provide plant wide frequency and counting/partitioning guidance
    - Provide zone of influence and scenario development guidance
  - Status:
    - FAQ resolution has been drafted and reviewed
    - Final revisions in process

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Task 6: Fire Ignition Frequency

Slide 24

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Notes:

Slide 25

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs (cont'd)

- FAQ 08-0042: Cabinet Fire Propagation (Status: Open)
  - Issue:
    - Guidance provides conflicting language regarding propagation of fire from cabinets (Chapter 6 versus Appendix G) and definition of "well-sealed cabinets)
    - Implication for Step 6: you exclude well-sealed cabinets from cabinet count if contents are below 440V (see Vol. 2, Page 6-17)
  - General approach to resolution:
    - Clarify and expand definition of "well-sealed and robustly secured cabinets" (which will not propagate fires)
  - Status:
    - FAQ resolution has been drafted and reviewed by RES/EPRI team
    - Industry and NRC staff reviews pending

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Task 6: Fire Ignition Frequency

Slide 25

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Notes:

Slide 26

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs (cont'd)

- FAQ 08-0048 Fire Frequency Trends (Status: Open)
  - Issue:
    - Fire frequency analysis may not reflect industry trends (i.e., towards reduced fire frequencies)
  - General approach to resolution:
    - Work is under way within EPRI team to determine if statistically significant fire frequency trends can be demonstrated
    - Fire frequencies for one or more ignition source bins may be modified (up or down depending on trends)
  - Status:
    - Work to date remains largely within the EPRI team
    - Review/input by RES team pending

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Task 6: Fire Ignition Frequency
Slide 26
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Notes:

Slide 27

FIRE IGNITION FREQUENCIES
Step 7. Ignition Source Weighting Factor ($W_{IS,J,L}$)

Ignition source weighting factors are evaluated for all the compartments identified in Task 1 and for all ignition sources identified in Step 1 of this Task.

- Countable items
  - Example: 2 pumps in compartment J of 50 pumps in the unit
    $W_{IS,J,L}$ = 2/50 = 0.04
- Transients – apportioned based on maintenance, occupancy and storage
- Large systems – ad-hoc method based on specific characteristics of the system
  - Examples: hydrogen gas distribution system, turbine/generator oil system

- *Problem Sets 06-08, 06-09 and 06-10*

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Task 6: Fire Ignition Frequency
Slide 27
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Notes:

Slide 28

FIRE IGNITION FREQUENCIES

Step 7. $W_{IS,J,L}$ – Transients

Transient fire frequencies are apportioned based on qualitatively estimated rating levels for (1) maintenance activities, (2) occupancy level and traffic density and (3) storage (temporary and permanent) of combustible and flammable materials.

- Five rating levels are used:
  - No (0) - Can be used only for those compartments where transients are precluded by design (administrative restrictions do not apply).
  - Low (1)–Reflects minimal level of the factor.
  - Medium (3)–Reflects average level of the factor.
  - High (10)–Reflects the higher-than-average level of the factor.
  - Very high (50)–Reflects the significantly higher-than-average level of the factor (only for "maintenance" influencing factor).

Notes:

Slide 29

FIRE IGNITION FREQUENCIES
Step 7. $W_{IS,J,L}$ – Transients (2)

Table 6-3
Description of Transient Fire Influencing Factors

Influencing Factor	No (0)	Low (1)	Medium (3)
Maintenance	Maintenance activities during power operation are precluded by design.	Small number of PM/CM work orders compared to the average number of work orders for a typical compartment.	Average number of PM/CM work orders.
Occupancy	Entrance to the compartment is not possible during plant operation.	Compartment with low foot traffic or out of general traffic path.	Compartment not continuously occupied, but with regular foot traffic.

Notes:

Slide 30

FIRE IGNITION FREQUENCIES
Step 7. $W_{IS,J,L}$ – Transients (3)

The following normalization equations are used:

- For *General Transients:*

  $W_{GT,J,L} = (n_{m,J,L} + n_{o,J,L} + n_{s,J,L})/N_{GT,L}$

  $N_{GT,L} = \Sigma (n_{m,i,L} + n_{o,\ i,L} + n_{s,\ i,L})$

  (summed over i, all compartments of location L)
- For *Transient Fires Caused by Welding and Cutting:*

  $W_{WC,J,L} = n_{m,J}/N_{WC}$

  $N_{WC} = \Sigma n_{m,i,L}$

  (summed over i, all the compartments of location L)
- For *Cable Fires Caused by Welding and Cutting:*

  $W_{CF,J} = n_{m,J}\, W_{Cable,J}/N_{CF}$

  $N_{CF} = \Sigma n_{m,i,L}\, W_{Cable,I}$

  (summed over i, all compartments of location L)

- *Problem Sets 06-11*

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Task 6: Fire Ignition Frequency

Slide 30

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Notes:

Slide 31

FIRE IGNITION FREQUENCIES
Step 8. Fire Frequency Evaluation

The fire frequency (generic or plant-specific) for each ignition source, $\lambda_{IS,J}$, can now be calculated using the data quantified in the preceding steps.

$$\lambda_{J,L} = \Sigma\, \lambda_{IS} W_L W_{IS,J,L}$$

summed over all ignition sources

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Task 6: Fire Ignition Frequency

Slide 31

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Notes:

Slide 32

Notes:

FIRE IGNITION FREQUENCIES
Determination of Generic Fire Frequencies

The generic fire frequencies are based on the collective experience of U.S. nuclear power industry.

- Large uncertainties
- Two stage Bayesian approach
- EPRI Fire Event Database (FEDB)
- Analysis of each event

• FAQ 08-0048 - Fire Ignition Frequency (in process)

Slide 33

Notes:

FIRE IGNITION FREQUENCIES
Fire Event Data

EPRI's Fire Event Data Base (FEDB) was used to establish the historical fire events for generic fire frequency estimation.

- Licensee event reports
- Industry sources (e.g., NEIL and ANI)
- Various studies
- Specific plant data
- Individual event follow-up

Slide 34

Notes:

FIRE IGNITION FREQUENCIES
Event Data Analysis

For each event, information was reviewed and the following were established:

Event Report Contents
- Occurrence date
- Plant type (i.e., PWR vs. BWR)
- Plant status (operating mode)
- Fire Location
- Fire Cause
- Initiating equipment and combustibles
- Detection and suppression information
- Severity related information
- Event description (narrative)

Event Analysis and Assignments
- Challenging?
- Location
- Ignition source
- Operating mode
- High energy arcing (electrical cab.)
- Suppression data
  - Prompt?
  - Supp. Curve Category (e.g. electrical)
  - Duration

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Task 6: Fire Ignition Frequency

Slide 34

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Slide 35

FIRE IGNITION FREQUENCIES
Number of Events

For each plant and bin combination, the number of events were estimated using the following eight possible event classifications:

Table C-1
Fire Event Classifications and Frequency Estimation Action

Class. #	Information Deficiencies			Frequency Estimation Action	
	Known Plant	Known Op. Mode	Challenging Fire	Multiplier	Method of inclusion
1	Yes	Yes	Yes	1	As is
2	Yes	Yes	Undetermined	q	As is
3	Yes	No	Yes	p	As is
4	Yes	No	Undetermined	qp	As is
5	No	Yes	Yes	1	Distribute among units
6	No	Yes	Undetermined	q	Distribute among units
7	No	No	Yes	p	Distribute among units
8	No	No	Undetermined	qp	Distribute among units

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Task 6: Fire Ignition Frequency

Slide 35

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Notes:

Slide 36

FIRE IGNITION FREQUENCIES
Reactor Years

For each plant, two time periods were established – (1) power production mode and (2) low power or shutdown mode

- Assumed 62% capacity factor prior to 1994
- NUREG-1350 data for post 1994 capacity factors
- Total reactor years since initial commercial operation
- Added the reactor years of the units for multi-unit sites

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Task 6: Fire Ignition Frequency

Slide 36

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Notes:

Slide 37

FIRE IGNITION FREQUENCIES
Generic Fire Ignition Frequencies

#	Location	Ignition Source	# of Events	Total Reactor Years	RDAT Output			
					Mean	5%	50%	95%
1	Battery Room	Batteries	1.0	2486	7.5E-04	2.0E-05	3.2E-04	2.4E-03
2	Containment (PWR)	Reactor Coolant Pump	6.5	1089	6.1E-03	3.1E-04	3.6E-03	1.7E-02
3	Containment (PWR)	Transients and hotwork	2.4	1089	2.0E-03	1.3E-04	1.1E-03	5.9E-03
4	Control Room	Main control board	5.5	2486	2.5E-03	8.4E-05	1.2E-03	7.3E-03
5	Control/Auxiliary/Reactor Building	Cable fires caused by welding and cutting	2.0	1674	1.6E-03	3.1E-05	6.4E-04	5.0E-03
6	Control/Auxiliary/Reactor Building	Transient fires caused by welding and cutting	12.6	1674	9.7E-03	8.9E-05	2.4E-03	3.3E-02
7	Control/Auxiliary/Reactor Building	Transients	6.0	1674	3.9E-03	1.6E-04	2.2E-03	1.1E-02
8	Diesel Generator Room	Diesel generators	49.5	2486	2.1E-02	1.9E-03	1.2E-02	6.6E-02
9	Plant-Wide Components	Air compressors	5.0	2486	2.4E-03	3.8E-05	9.0E-04	7.9E-03

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Task 6: Fire Ignition Frequency

Slide 37

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Notes:

Slide 38

Notes:

FIRE IGNITION FREQUENCIES
Concluding Remarks

Fire ignition frequency evaluation (Task 6) uses a mix of plant specific and generic information to establish the ignition frequencies for specific compartments and from that for specific fire scenarios.

- Generic fire ignition frequencies based on industry experience
- Elaborate data analysis method
- Frequencies binned by equipment type
- Methodology to apportion frequencies according to relative characteristics of each compartment

Session 2b: Example Problems

Workshop Problems for Task 6: Fire Ignition Frequency

Workshop Problem Set 06-01

Step 1: Mapping plant ignition sources to generic sources: Using the information provided in this Sample Package, map the items listed in the following table to generic sources.

Equipment ID	Equipment Description	Equipment Type	Bin #	Bin Description / Comment\
HPI-B	High pressure safety injection pump B			
MOV-1	HPI valve			
MOV-5	RWST isolation valve			
BAT-B	Train B Battery			
RCP-1	Reactor coolant pump 1			
AOV-1 / (SOV-1)	Pilot operated relief valve			
PT-1	RCS pressure transmitter			
EDG-A	Train A Emergency Diesel Generator			
MCC-B1	Train B 480 V Motor Control Center			
ATS-1	Automatic Transfer Switch Panel			
VITAL-A	Train A 120 VAC Vital Bus			
SWGR-A	Train A 4160 V Bus			
LC-A	Train A 480 V Load Center			
SST-A	Train A Station Service Transformer			
BC-A	Train A Battery Charger			
DC BUS-A	Train A 125 VDC Bus			
PNL-A	Train A 125 VDC Panel			
INV-A	Train A Inverter			
AFW-A	Motor driven AFW pump A			
AFW-B	Steam driven AFW Pump B			
SUT-1	Startup Transformer			

Workshop Problem Set 06-02 (Example)

Step 2: Plant Fire Event Data Collection and Review: The following tables provide examples of fire events data collected for the sample nuclear power plant.

Fire Event # 1

Event date: January 1, 2007

Event Description: At approximately 16:49, a fire resulted from a short caused by the slabs on the MCC-A breakers not properly engaging the bus bars. As a result of a short, insulation on some wires ignited, resulting in a fire. The fire was discovered immediately by employees who extinguished the blaze with portable fire extinguishers. Damage was confined to the cabinet where the fire occurred, located inside the motor control center.

Should this event be considered in fire frequency calculation? Yes

Basis: The event occurred during power operation. Extent of damage was sufficient to render the ignition source inoperable and the flames and hot gases threatened the integrity of other items nearby.

Associated Bin ID # per Table 6-1 of Ref.1: 15

Bin Location: Plant-wide components

Bin Description: Electrical Cabinets

Basis: The fire was initiated in an MCC. An MCC is considered an electrical cabinet.

Fire Event # 2

Event date: February 1, 2007

Event Description: A fire occurred in the 120VAC-A panel. The fire was extinguished when 4kV bus-A was de- energized from the control room. Fire resulted from arcing of supply lead to one of the fittings connecting to a controller to the bus. Problems have been previously experienced with this type of devices in other plants.

Should this event be considered in fire frequency calculation? Yes

Basis: The event occurred during power operation. Extent of damage was sufficient to render the ignition source (i.e., 120VAC bus) inoperable and threaten the integrity of other items nearby.

Associated Bin ID # per Table 6-1 of Ref.1: 15

Bin Location: Plant-wide components

Bin Description: Electrical Cabinets

Basis: The fire was initiated in a 120VAC panel, which is considered as an electrical cabinet.

Workshop Problem Set 06-03 (Example)

Step 3: Plant Specific Updates of Generic Ignition Frequencies: The following bullets provide a sample discussion of how the fire events presented in the previous sections were treated in the Fire PRA.

- The two events identified in the preceding step are certainly significant and should be included in a statistical analysis of fire frequency (e.g., Bayesian update of generic frequencies.)
- Plant has been in commercial operation for 10 years.
- Both events should be mapped to Bin # 15 "Electrical Cabinets"
- The resulting frequency can be approximated by 2/10 = 0.2 per electrical cabinet year.
- The estimated frequency is 4 times greater than 0.045, Bin #15 generic frequency
- Fire PRA analysts decided not to include this plant specific experience in the fire frequency analysis. The decision is based on the following: "The two events do not point out an unusual trend in electrical cabinet fires. The two panels where the fires had occurred were dissimilar items. Therefore, the plant experience is not deemed to be indicative of unusually high electrical cabinet fire tendency at this plant."
- For all other bins, the experience is no events in 10 years (both power and shutdown) or 8 years (assuming 20% outages). If subjected to Bayesian update, the impact of this experience on bin frequencies is minimal.

Workshop Problem Set 06-04

Step 4: Mapping Plant-Specific Locations to Generic Locations: Using the information provided in this Sample Package, map the items listed in the following table to the applicable generic locations provided in NUREG/CR 6850. Note that some of the compartments may map to more than one Generic Location.

Step 5: Location Weighting Factors: Assign the location weighting factors of the Fire Compartments in the following table.

Fire Comp. #	Plant Fire Compartment	Plant Area	Generic Location	W_L
1	Main Control Room	Auxiliary Building		
2	Aux Bldg El. 0 Ft	Auxiliary Building		
3	Cable Spreading Room	Auxiliary Building		
4A	RHR Pump Room	Auxiliary Building		
4B	AFW Pump Room	Auxiliary Building		
5	Battery Room A	Auxiliary Building		
6	Battery Room B	Auxiliary Building		
9	SWG Access Room	Auxiliary Building		
10	Switchgear Room A	Auxiliary Building		
11	Switchgear Room B	Auxiliary Building		
14	Stairway	Auxiliary Building		
7	Containment	Containment		
8A	DG-A Room	DG Bldg.		
8B	DG-B Room	DG Bldg.		
12	Turbine Bldg El. 0 Ft	Turbine Building		
15	Battery Room 1	Turbine Building		
13	Yard	Yard		
14	Intake Structure	Intake Structure		

Workshop Problem Set 06-05

Step 5: Location Weighting Factors: At a two-unit nuclear power plant, the Main Control Room is shared between the two units. The control room consists of two separate Main Control Boards that do not share any controls and are dedicated to one unit each. There are 5 electrical cabinets in the control room in addition to the Main Control Boards that are shared between the two units.

a. For Unit 1, establish the Location Weighting Factor of the Main Control Board

b. For Unit 1, establish the Location Weighting Factor of the electrical cabinets.

c. For Unit 1, establish the Location Weighting Factor of transient fires in the Main Control Room

Workshop Problem Set 06-06

Step 6: Fixed Fire Ignition Source Counts: Estimate the ignition source counts for only those items that are noted under each picture and are visible in the foreground of the picture:

Electrical Panels: ________________

Electrical Panels: ________________

Transformers: ________________

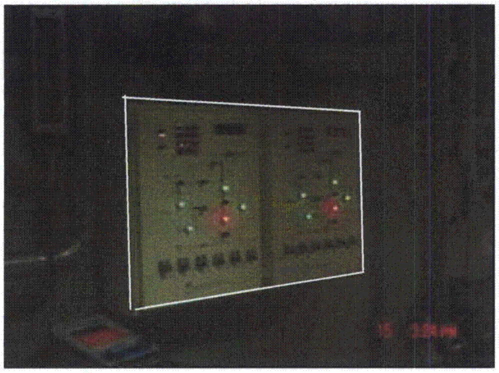
Transformers: ________________

Electrical Panels: ________________

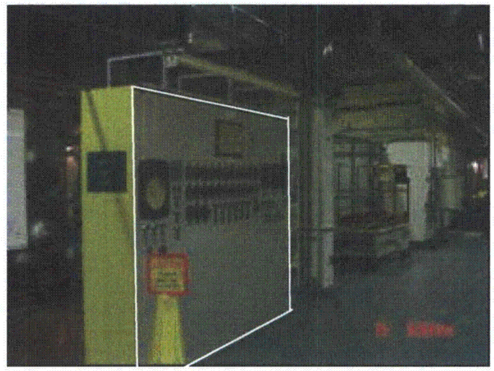
Transformers: ________________

Electrical Panels: ________________

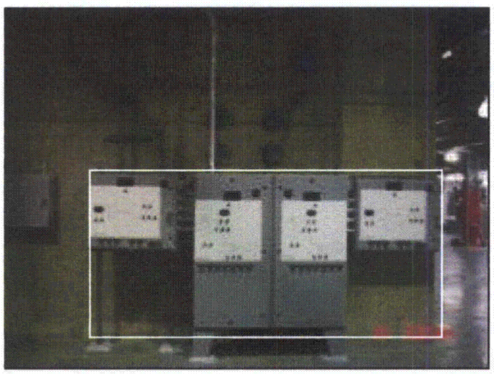
Electrical Panels: ________________



Electrical Panels: ________________



Electrical Panels: ________________



Electrical Panels: ________________

(These are sealed panels with low voltage circuits)

Workshop Problem Set 06-07

Step 6: Fixed Fire Ignition Source Counts: Estimate the ignition source counts for the components identified in Step 1 above.

			Bin # and Description (per Table 6-1)												
			1	2	8	4	9	10	14	15	16	21	23a	23b	29
			Batteries	Reactor Coolant Pump	Diesel Generators	Main Control Board	Air Compressors	Battery Chargers	Electric Motors	Electrical Cabinets	High Energy Arcing Faults	Pumps	Transformers (Dry)	Transformers (Oil filled)	Yard transformers (Others)
#	**Compartment**	**Plant Area**	**BAT**	**RCP**	**DG**	**MCB**	**AC**	**BC**	**EM**	**EC**	**HEAF**	**PMP**	**XFMR-Dry**	**XFMR-Oil**	**XFMR-Yard**
1	Main Control Room	Control/Aux/Reactor Building													
2	Aux Bldg El. 0 Ft	Control/Aux/Reactor Building													
3	Cable Spreading Room	Control/Aux/Reactor Building													
4A	RHR Pump Room	Control/Aux/Reactor Building													
4B	AFW Pump Room	Control/Aux/Reactor Building													
5	Battery Room A	Plant Wide Components													
6	Battery Room B	Plant Wide Components													
9	SWG Access Room	Plant Wide Components													
10	Switchgear Room A	Plant Wide Components													
11	Switchgear Room B	Plant Wide Components													
14	Stairway	Plant Wide Components													
7	Containment	Containment													
8A	DG-A Room	Plant Wide Components													
8B	DG-B Room	Plant Wide Components													
12	Turbine Bldg El. 0 Ft	Plant Wide Components													
15	Battery Room 1	Plant Wide Components													
13	Yard	Plant Wide Components													
14	Intake Structure	Plant Wide Components													
		Total													

Workshop Problem Set 06-08

Step 7: Ignition Source Weighting Factors: For an NPP, the fire PRA analysts have counted 23 pumps within the Plant Analysis Boundary.

- For RHR Pump RHRP-C located in RHR Pump room (FZ-03A), which in turn is located in the Auxiliary Building, establish the IS, J and L subscripts of:

  $W_{IS,J,L}$ =

- For the same RHR Pump, RHRP-C, calculate the Ignition Source Weighting Factor

  W =

- RHR Pump room FZ-03A contains three pumps. Calculate the ignition source weighting factor for the pumps in this compartment.

  W =

Workshop Problem Set 06-09

Step 7: Ignition Source Weighting Factors: For an NPP, the fire PRA analysts have counted 351 electrical cabinet vertical sections within the Plant Analysis Boundary.

- 480VAC MCC-A is composed of 32 breakers arranged in 8 vertical segments. Calculate the ignition source weighting factor for this MCC.

  W_{MCC-B} =

- 4kV non-1E Switchgear 1 is composed of 8 breakers. Each breaker takes up one vertical segment of the switchgear. Calculate the ignition source weighting factor for this electrical panel.

  W_{SWG-1} =

- The local control panel, CP-1, for the chemicals addition system located in the Reactor Building has the following dimensions: 2' Deep, 12'Long, 8'High. There are no partitions within the panel. Calculate the ignition source weighting factor for this electrical panel.

  W_{CP-1} =

Workshop Problem Set 06-10

Step 7: Ignition Source Weighting Factors: Using the information provided in the solution for Problem Set 06-07, calculate the component weighting factors for the components listed below.

			Bin # and Description (per Table 6-1)												
			1	2	8	4	9	10	14	15	16	21	23a	23b	29
			Batteries	Reactor Coolant Pump	Diesel Generators	Main Control Board	Air Compressors	Battery Chargers	Electric Motors	Electrical Cabinets	High Energy Arcing Faults	Pumps	Transformers (Dry)	Transformers (Oil filled)	Yard transformers (Others)
#	Compartment	Plant Area	BAT	RCP	DG	MCB	AC	BC	EM	EC	HEAF	PMP	XFMR-Dry	XFMR-Oil	XFMR-Yard
1	Main Control Room	Control/Aux/Reactor Building													
2	Aux Bldg El. 0 Ft	Control/Aux/Reactor Building													
3	Cable Spreading Room	Control/Aux/Reactor Building													
4A	RHR Pump Room	Control/Aux/Reactor Building													
4B	AFW Pump Room	Control/Aux/Reactor Building													
5	Battery Room A	Plant Wide Components													
6	Battery Room B	Plant Wide Components													
9	SWG Access Room	Plant Wide Components													
10	Switchgear Room A	Plant Wide Components													
11	Switchgear Room B	Plant Wide Components													
14	Stairway	Plant Wide Components													
7	Containment	Containment													
8A	DG-A Room	Plant Wide Components													
8B	DG-B Room	Plant Wide Components													
12	Turbine Bldg El. 0 Ft	Plant Wide Components													
15	Battery Room 1	Plant Wide Components													
13	Yard	Plant Wide Components													
14	Intake Structure	Plant Wide Components													

Workshop Problem Set 06-11

Transient Ignition Source Weighting Factors: An NPP is composed of three compartments with the following characteristics:

Compartment 1:

- Houses the Steam Driven Auxiliary Feedwater Pump
- The pump has required major maintenance once per year
- The room is at a corner of the Auxiliary Building separated from other parts of the building with 3-hour rated walls and one access door
- The lubricating oils of this and other large safety related pumps are stored in this room.
- All cables are in open bottom and open top cable trays
- The total amount of cables in the room is 1,000 lbs.

Compartment 2:

- Houses the one of three High Pressure Injection Pumps
- The pump has required major maintenance once per three years
- The room is at a corner of the Auxiliary Building separated from other parts of the building with 3-hour rated walls and one access door
- There are no other items in this room except for the pump.
- All cables are inside conduits
- The total amount of cables in the room is 1,000 lbs.

Compartment 3:

- Houses 480VAC MCC
- The MCC has never required any major maintenance since installation 15 years ago
- The room is the passageway between the radiation control and other parts of the Auxiliary Building
- The room contains coveralls and other radiation protection related clothing items
- All cables are in open bottom and open top cable trays
- The total amount of cables in the room is 10,000 lbs.

A. Enter the influencing factors for each compartment and category:

	Influencing Factor			Cable Run (self-ignited cable fires)
Compartment	Maintenance	Occupancy	Storage	
Compartment 1				
Compartment 2				
Compartment 3				
Total				

B. Calculate the ignition source weighting factors for each compartment

Compartment	General Transients	Transients fires caused by welding and cutting	Cable fires caused by welding and cutting	Cable Run (self-ignited cable fires)
Compartment 1				
Compartment 2				
Compartment 3				
Total				

C. Calculate the ignition frequencies for each compartment

	General Transients	Transients fires caused by welding and cutting	Cable fires caused by welding and cutting	Cable Run (self-ignited cable fires)
Total Location Frequency (/ry)	*3.90E-03*	*9.70E-03*	*1.60E-03*	*4.40E-03*
Compartment 1				
Compartment 2				
Compartment 3				

Transients and Cable Fire (Count, Ignition Source Weighting Factor and Frequency)

	Count					Weighting Factors			Frequency		
	Cable Run (10^6 BTU)	Maintenance	Storage	Occupancy	Cable Quantity x Maintenance	General Transients	Cable Fires Due to Hotwork	Transients due to Hotwork	General Transients	Cable Fires Due to Hotwork	Transients due to Hotwork
	Control / Aux. / Reactor Building										
1 Main Control Room	300	1	10	10	300	0.64	3.5E-01	0.2	2.5E-03	5.6E-04	1.9E-03
2 Aux Bldg El. 0 Ft	6	1	1	1	6	0.09	7.0E-03	0.2	3.5E-04	1.1E-05	1.9E-03
3 Cable Spreading Room	549	1	1	1	549	0.09	6.4E-01	0.2	3.5E-04	1.0E-03	1.9E-03
4A RHR Pump Room	1	1	1	1	1	0.09	1.2E-03	0.2	3.5E-04	1.9E-06	1.9E-03
4B AFW Pump Room	1	1	1	1	1	0.09	1.2E-03	0.2	3.5E-04	1.9E-06	1.9E-03
Total		*5*	*14*	*14*	*857*				*3.90E-03*	*1.60E-03*	*9.70E-03*
	Plant Wide Components										
5 Battery Room A	1	1	1	1	1	0.05	4.2E-04	0.03	4.5E-04	8.3E-07	1.5E-04
6 Battery Room B	0	1	1	1	0	0.05	--	0.03	4.5E-04	--	1.5E-04
9 SWG Access Room	1.6	1	1	1	1.6	0.05	6.7E-04	0.03	4.5E-04	1.3E-06	1.5E-04
10 Switchgear Room A	10	3	1	3	30	0.11	1.3E-02	0.09	1.1E-03	2.5E-05	4.6E-04
11 Switchgear Room B	80	3	1	3	240	0.11	1.0E-01	0.09	1.1E-03	2.0E-04	4.6E-04
14 Stairway	0	1	1	3	0	0.08	--	0.03	7.5E-04	--	1.5E-04
7 Containment	0	1	1	1	0	0.05	--	0.03	4.5E-04	--	1.5E-04
8A DG-A Room	218	3	1	1	654	0.08	2.7E-01	0.09	7.5E-04	5.5E-04	4.6E-04
8B DG-B Room	218	3	1	1	654	0.08	2.7E-01	0.09	7.5E-04	5.5E-04	4.6E-04
12 Turbine Bldg El. 0 Ft	80	10	1	3	800	0.21	3.3E-01	0.31	2.1E-03	6.7E-04	1.5E-03
15 Battery Room 1	0	1	1	1	0	0.05	--	0.03	4.5E-04	--	1.5E-04
13 Yard	0	1	1	1	0	0.05	--	0.03	4.5E-04	--	1.5E-04
14 Intake Structure	6	3	1	1	18	0.08	7.5E-03	0.09	7.5E-04	1.5E-05	4.6E-04
Total		*32*	*13*	*21*	*2398.6*				*9.90E-03*	*2.00E-03*	*4.90E-03*

Ignition Frequencies by Bin and Compartment (part 1 of 2)

			Batteries	Reactor Coolant Pump	Diesel Generators	Air Compressors	Battery Chargers	Electric Motors	Electrical Cabinets	High Energy Arcing Faults	Pumps	Transformers (Dry)	Transformers (Oil filled)
Generic Frequency			7.5E-04	6.1E-03	2.1E-02	2.4E-03	1.8E-03	4.6E-03	4.5E-02	1.5E-03	2.1E-02	9.9E-03	9.9E-03
Compartment and Associated Freq.													
1	Main Control Room	1.1E-02							3.3E-04				
2	Aux Bldg El. 0 Ft	7.2E-03						2.0E-03			6.0E-03		
3	Cable Spreading Room	6.2E-03											
4A	RHR Pump Room	7.2E-03						2.0E-03			3.0E-03		
4B	AFW Pump Room	6.4E-03									6.0E-03		
5	Battery Room A	4.7E-04	2.5E-04										
6	Battery Room B	9.1E-04	2.5E-04										
9	SWG Access Room	1.1E-02							9.9E-03				
10	Switchgear Room A	1.5E-02					6.0E-04		7.9E-03	3.8E-04		5.0E-03	
11	Switchgear Room B	1.7E-02					6.0E-04		7.9E-03	3.8E-04		5.0E-03	
14	Stairway	6.6E-04											
7	Containment	3.2E-03						6.6E-04			3.0E-03		
8A	DG-A Room	1.8E-02			1.1E-02								
8B	DG-B Room	1.8E-02			1.1E-02								
12	Turbine Bldg El. 0 Ft	6.5E-02	2.5E-04			2.4E-03	6.0E-04		1.9E-02	7.5E-04	3.0E-03		9.9E-03
15	Battery Room 1	4.5E-04											
13	Yard	2.6E-03											
14	Intake Structure	1.1E-03											

Ignition Frequencies by Bin and Compartment (part 2 of 2)

	Yard transformers (Others)	Main Control Board	Cable Run	Junction Box	MG Sets	MFW Pumps	TG Oil	TG Exciter	TG Hydrogen
Generic Frequency	2.2E-03	2.5E-03	4.4E-03	1.9E-03	1.6E-03	1.3E-02	9.5E-03	3.9E-03	6.5E-03
Compartment									
1 Main Control Room		2.5E-03	9.0E-04						
2 Aux Bldg El. 0 Ft			1.8E-05	7.7E-06					
3 Cable Spreading Room			1.6E-03	7.1E-04					
4A RHR Pump Room			3.0E-06	1.3E-06					
4B AFW Pump Room			3.0E-06	1.3E-06					
5 Battery Room A			3.0E-06	1.3E-06					
6 Battery Room B									
9 SWG Access Room			4.8E-06	2.1E-06					
10 Switchgear Room A			3.0E-05	1.3E-05					
11 Switchgear Room B			2.4E-04	1.0E-04					
14 Stairway									
7 Containment									
8A DG-A Room			6.5E-04	2.8E-04					
8B DG-B Room			6.5E-04	2.8E-04					
12 Turbine Bldg El. 0 Ft			2.4E-04	1.0E-04			9.5E-03	3.9E-03	6.5E-03
15 Battery Room 1									
13 Yard	2.2E-03								
14 Intake Structure			1.8E-05	7.7E-06					

Session 3: Scoping Fire Modeling

Slide 1

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EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III: Scoping Fire Modeling Task 8 and Appendix F

Joint RES/EPRI Fire PRA Course
September and November 2008
Bethesda, MD

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Notes:

Slide 2

SCOPING FIRE MODELING
Objectives

The objectives of this module are:

- Describe the process of screening ignition sources
- Describe the concept of zone of influence (ZOI)
- Describe the recommended walk down
- Review the walk down forms
- Describe how to update the fire ignition frequencies calculated in Task 6 with the screening results

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Slide 3

SCOPING FIRE MODELING
Interfaces

- Inputs for this task
  - PRA equipment list, Task 2
  - List of ignition sources in each compartment, Task 6
  - Room geometry
  - Types of ignition sources and targets
- Output from this task
  - Revised compartment fire ignition frequencies
  - List of potential fire scenarios to be analyzed in Task 11

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Slide 4

SCOPING FIRE MODELING
Screening Ignition Sources

Any ignition source can be screened if a postulated fire will not damage or ignited equipment in the compartment.

- By screening the ignition source, its frequency contribution is eliminated, reducing the compartment frequency.
- It is recommended to use the 98^{th} percentile of the probability distributions for peak HRR.
- A walk down is strongly recommended.

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Module #: Scoping Fire Modeling Task 8 & Appendix F

Slide 4

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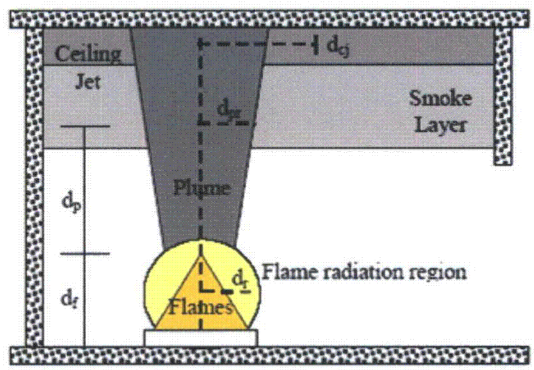
Slide 5

SCOPING FIRE MODELING
The Zone of Influence (ZOI)

The zone of influence is the region in the compartment where a target will be damaged if exposed to fire conditions generated by a specific ignition source.

- The ZOI has 5 distinct regions:
  - Flames
  - The fire plume
  - The ceiling jet
  - The hot gas layer
  - Flame radiation region



Notes:

Slide 6

Notes:

SCOPING FIRE MODELING
Task 8: Recommended Steps

5 steps for conducting Task 8

1. Preparation for walk down
2. Plant walk down and screen ignition sources
3. Verification of screened ignition sources
4. Calculation of severity factors
5. Calculation of revised fire frequency

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Slide 7

Notes:

SCOPING FIRE MODELING
Step 1: Preparation for Walk down

It is recommended that walk down forms are prepared for each compartment to be visited

- Create a list of ignition sources in each compartment.
  - Equipment counted in Task 6
  - Flag equipment in the PRA equipment list created in Task 2
  - Assigned a HRR to each ignition source (98th percentile of the pdf)
- Workshop Problem 08-01
- Collect damage criteria information for the equipment in the room
  - Qualified/Unqualified cables, solid state equipment etc.
- Workshop Problem 08-02
- Develop and document zone of influences in each compartment

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Slide 7
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SCOPING FIRE MODELING
Step 1: Example of ZOI Form

Plant ____________
Fire Area ____________
Compartment ____________

Room Geometry

Opening area [m2]	2.0
Height of opening [m]	2.0
Room length [m]	32.0
Room width [m]	32.0
Room height [m]	6.4
Ambient temperature [C]	20

Material	Concrete
Thermal conductivity [kW/mK]	0.001
Density [kg/m3]	2000
Specific heat [kJ/kg]	0.88
Wall thickness [m]	0.30

Damage Criteria	UQ	Q
Temperature [C]	205	330
Heat flux [kW/m2]	6	11

Ignition Source

Fire duration [sec]	600
Fire diameter [m]	0.60
Fire location factor	1.00
Fire elevation [m]	0.00
Radiated fraction	0.40

ZONE OF INFLUENCE

PE/PVC Cable	Vertical cabinets with qualified cable, fire limited to one cable bundle	Vertical cabinets with qualified cable, fire in more than one cable bundle	Vertical cabinets with unqualified cable, fire limited to one cable bundle	Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	Pumps	Motors	Transient combustibles
98th Per HRR (kW)	211	702	211	464	1002	211	69	317
Flames (m)	1.4	2.6	1.4	2.1	3.1	1.4	0.7	1.7
Plume (m)	2.2	3.9	2.2	3.2	4.6	2.2	1.2	2.7
Ceiling Jet (m)	0.1	0.2	0.1	0.1	0.3	0.1	0.02	0.1
Flame Radiation (m)	1.1	1.9	1.1	1.6	2.3	1.1	0.6	1.3
Smoke Layer (kW)	3198	3198	3198	3198	3198	3198	3198	3198

Qualified Cable

Qualified Cable	Vertical cabinets with qualified cable, fire limited to one cable bundle	Vertical cabinets with qualified cable, fire in more than one cable bundle	Vertical cabinets with unqualified cable, fire limited to one cable bundle	Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	Pumps	Motors	Transient combustibles
98th Per HRR (kW)	211	702	211	464	1002	211	69	317
Flames (m)	1.4	2.6	1.4	2.1	3.1	1.4	0.7	1.7
Plume (m)	1.6	3.0	1.6	2.5	3.6	1.6	0.8	2.0
Ceiling Jet (m)	0.03	0.10	0.03	0.07	0.14	0.03	0.01	0.04
Flame Radiation (m)	0.8	1.4	0.8	1.2	1.7	0.8	0.4	1.0
Smoke Layer (kW)	6938	6938	6938	6938	6938	6938	6938	6938

Notes:

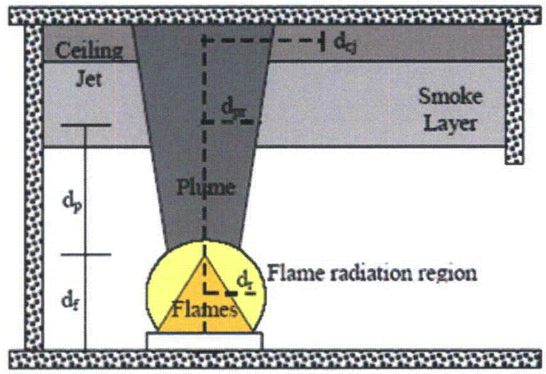
Slide 9

SCOPING FIRE MODELING
Step 1: Alternative Models for Zone of Influence

- Smoke or hot gas layer: MQH model

$$T = T_{amb} + 6.85 \cdot \left(\frac{\dot{Q}_f^2}{A_o \sqrt{H_o} h_k A_T} \right)^{1/3}$$

$$h_k = \begin{cases} \sqrt{\dfrac{k \cdot d_m \cdot c_p}{t}} & t < t_p \\ \dfrac{k}{th} & t \geq t_p \end{cases} \qquad t_p = \frac{th^2}{4 \cdot \left(k / (d_m \cdot c_p) \right)}$$



Input Parameters:
- T_{amb}: Ambient temperature (°C)
- Q_f: Fire heat release rate (kW)
- A_o: Opening area (or sum of opening areas) (m²)
- H_o: Height of opening [m]
- A_T: Internal surface area of the room (not including opening area) (m²)
- k: Thermal conductivity of wall material (kW/m-°C)
- d_m: Density of wall material (kg/m³)
- c_p: Specific heat of wall material (kJ/kg-°C)
- th: Wall thickness (m)
- t: Time value (sec)

Notes:

Slide 10

SCOPING FIRE MODELING
Step 1: Example Calculation for Room Temperature

$$T = T_{amb} + 6.85 \cdot \left(\frac{\dot{Q}_f^2}{A_o \sqrt{H_o} h_k A_T} \right)^{1/3}$$

$$h_k = \begin{cases} \sqrt{\dfrac{k \cdot d_m \cdot c_p}{t}} & t < t_p \\ \dfrac{k}{th} & t \geq t_p \end{cases} \qquad t_p = \frac{th^2}{4 \cdot \left(k / (d_m \cdot c_p) \right)}$$

MQH Temperature Correlation	
Inputs	
Ambient temperature [C]	20
Duration [sec]	1200
Opening area [m2]	3
Height of opening [m]	3
Room length [m]	37
Room width [m]	37
Room height [m]	8
Thermal conductivity [kW/mK]	0.0014
Density [kg/m3]	2000
Specific heat [kJ/kg]	0.88
Wall thickness [m]	0.6
HRR [kW]	9500
Results	
Room Temp [C]	**327**

Notes:

Slide 11

SCOPING FIRE MODELING
Step 1: Alternative Models for Zone of Influence

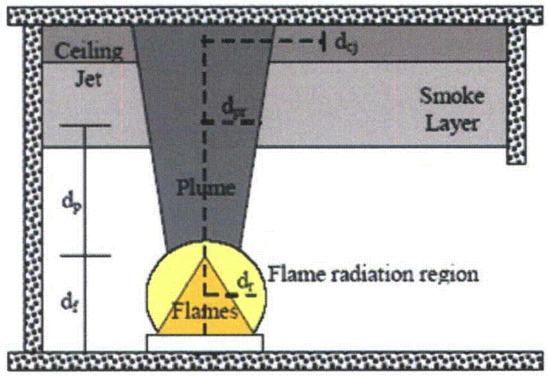
- Flame height and fire plume: Heskestad's models

$$L = 0.235\dot{Q}_f^{2/5} - 1.02D$$

Input Parameters:
- Q_f: Fire heat release rate (kW)
- D: Fire diameter (m)

$$T_{pl} = T_{amb} + 25\left(\frac{\left(k_f \dot{Q}_f (1-\chi_r)\right)^{2/5}}{\left((H_p - F_e) - z_o\right)}\right)^{5/3}$$

$$z_o = 0.083\dot{Q}_f^{2/5} - 1.02D$$



Input Parameters:
- T_{amb}: Ambient temperature (°C)
- k_f: Fire location factor
- Q_f: Fire heat release rate (kW)
- F_e: Fire elevation (m)
- H_p: Target height measured from the floor (m)
- X_r: Irradiated fraction of the heat release rate (FIVE recommends 0.4)
- D: Plume diameter (m)

Notes:

Slide 12

SCOPING FIRE MODELING
Step 1: Example Calcs for Flame Height and Plume Temp

$$L = 0.235\dot{Q}_f^{2/5} - 1.02D$$

$$T_{pl} = T_{amb} + 25\left(\frac{\left(k_f \dot{Q}_f (1-\chi_r)\right)^{2/5}}{\left((H_p - F_e) - z_o\right)}\right)^{5/3}$$

$$z_o = 0.083\dot{Q}_f^{2/5} - 1.02D$$

Heskdestad's Flame Height Correlation	
Inputs	
Fire diameter [m]	0.6
HRR [kW]	250
Results	[m]
Flame height [m]	**1.5**

Heskestad's Plume Temperature Correlati	
Inputs	
Ambient temperature [C]	20
Fire location factor	1
HRR [kW]	1375
Fire elevation [m]	0
Target Elevation [m]	3.7
Radiation Fraction	0.40
Fire Diameter [m]	1
Results	
Plume Temp [C]	**328**

Notes:

Slide 13

Notes:

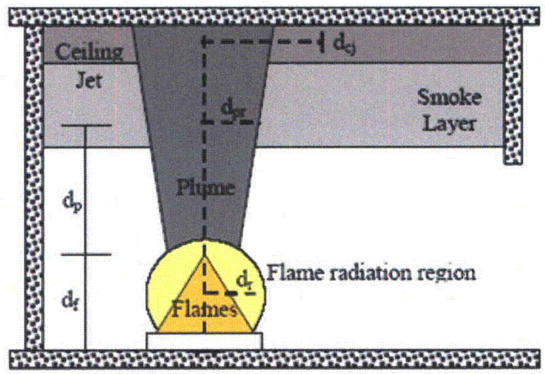
SCOPING FIRE MODELING
Step 1: Related FAQ

- FAQ 08-0043
  - Issue:
    - Guidance for placement of a cabinet fire (the source location) suggests inspecting cabinet contents and placing fire at fuel location
    - Applicants would prefer a "one size" approach less conservative than placing on top of cabinet that would not require internal inspection
  - General approach to resolution:
    - RES/EPRI teams are debating merits of general application of fire protection SDP approach – place fire 1 foot below cabinet top (unless top is unsealed or vented)
  - Status: Open
    - Team position has been drafted and is under review
    - Staff final review pending

SCOPING FIRE MODELING
Step 1: Alternative Models for Zone of Influence

- Flame Radiation: Point Source Model

$$\dot{q}''_{irr} = \frac{\dot{Q}_f \chi_r}{4\pi R^2}$$



Input Parameters:
- Q_f: Fire heat release rate (kW)
- R: Distance from flames (m)
- X_r: Irradiated fraction of the heat release rate (FIVE recommends 0.4)
- D: Fire diameter (m)

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Module #: Scoping Fire Modeling Task 8 & Appendix F

Slide 14

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Notes:

SCOPING FIRE MODELING
Step 1: Example calculation for flame radiation

$$\dot{q}''_{irr} = \frac{\dot{Q}_f \chi_r}{4\pi R^2}$$

Point Source Flame Radiation Model	
Inputs	
Fire heat release rate [kW]	317
Radiation fraction	0.40
Distance from flames [m]	1.5
Results	
Heat flux [kW/m2]	**4.5**

- Workshop problem 08-03

Notes:

Slide 16

Notes:

SCOPING FIRE MODELING
Step 2: Plant Walk down and Screening IS

During the walk down, equipment in the room is subjected to fire conditions from each ignition source using the ZOI.

- Take the opportunity to verify & improve task 6 counting
- Document location of ignition sources and reasons for screen/no-screen decisions
- If ignition sources are not screened, document location of affected equipment and which fire generated condition affected it.
- Do not screen:
  - Oil fires
  - Cables
  - Interconnected cabinets
- Workshop problem 08-04

Slide 17

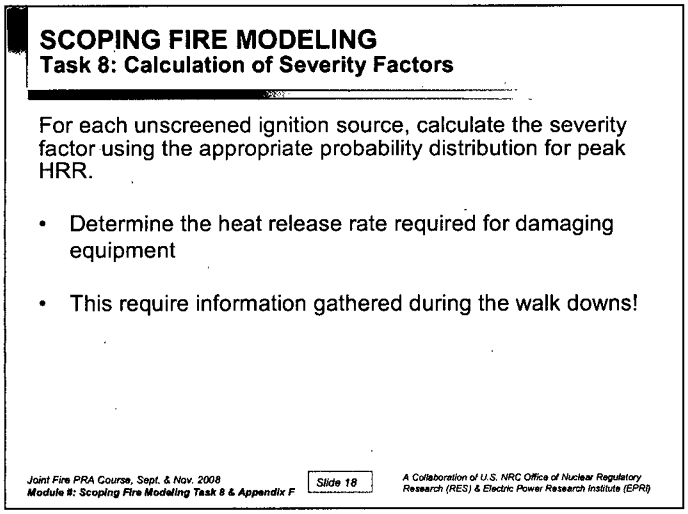
Notes:

SCOPING FIRE MODELING
Step 3: Verification of Screened IS

It is important to verify that fire damage to the ignition source itself is not risk significant

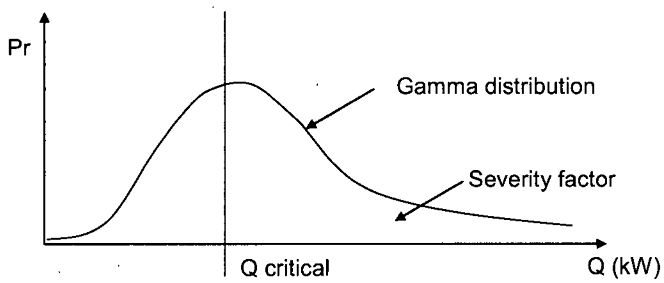
1. Do not screen equipment in the PRA equipment list
2. If loss of the ignition source results in a trip (automatic or manual) but no equipment contributing to the CCDP are lost, compare the ignition source fire frequency with the random frequency of the trip it causes.
3. If loss of the ignition source results in both a trip (automatic or manual) and loss of one or more components contributing to the CCDP, add a fire-induced sequence using the ignition source fire frequency and the corresponding CCDP model with the damaged components set to fail.

Slide 18



Notes:

SCOPING FIRE MODELING
Task 8: Calculation of Severity Factors



Case	Ignition Source	HRR kW (Btu/s)		Gamma Distribution	
		HRR	98th	α	β
1	Vertical cabinets with qualified cable, fire limited to one cable bundle	69	211	0.84	59.3
2	Vertical cabinets with qualified cable, fire in more than one cable bundle	211	702	0.7	216
3	Vertical cabinets with unqualified cable, fire limited to one cable bundle	90	211	1.6	41.5
4	Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	232	464	2.6	67.8
5	Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	232	1002	0.46	386
6	Pumps (electrical fires)	69	211	0.84	59.3
7	Motors	32	69	2	11.7
8	Transient Combustibles	142	317	1.8	57.4

Table E-5
Discretized Distribution for Case 4 Heat Release Rate (Vertical Cabinets with Unqualified Cable, Fire in more than One Cable Bundle Closed Doors)

Bin	Heat Release Rate - kW (Btu/s)			Severity Factor (P)
	Lower	Upper	Point Value	
1	0 (0)	53 (50)	36 (34)	0.082
2	53 (50)	106 (100)	80 (76)	0.213
3	106 (100)	158 (150)	131 (124)	0.224
4	158 (150)	211 (200)	184 (174)	0.177
5	211 (200)	264 (250)	236 (223)	0.122
6	264 (250)	317 (300)	288 (273)	0.077
7	317 (300)	369 (350)	341 (323)	0.046
8	369 (350)	422 (400)	394 (373)	0.027
9	422 (400)	475 (450)	446 (423)	0.016
10	475 (450)	528 (500)	499 (473)	0.008
11	528 (500)	580 (550)	552 (523)	0.004
12	580 (550)	633 (600)	603 (572)	0.002
13	633 (600)	686 (650)	656 (622)	0.001
14	686 (650)	739 (700)	709 (672)	0.001
15	739 (700)	Infinity	816 (773)	0.001

- Workshop problem 08-05

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Module #: Scoping Fire Modeling Task 8 & Appendix F

Slide 19

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Notes:

SCOPING FIRE MODELING

Task 8: Calculation of Revised Fire Frequency

Plant	
Fire Area	
Compartment	

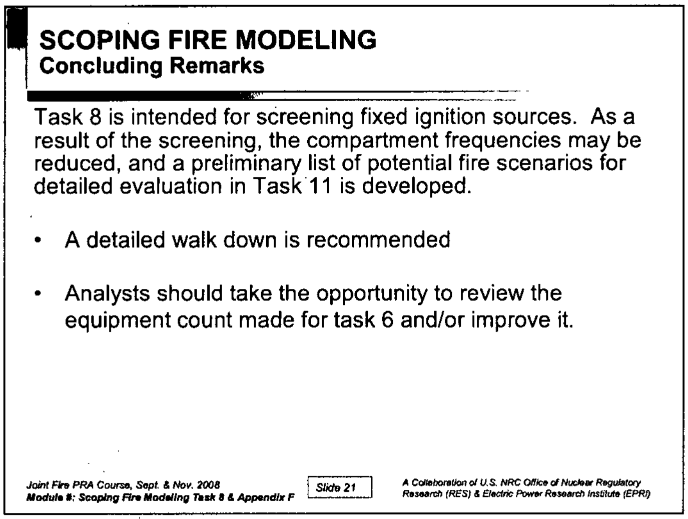
Dmage Criteria	
Temperature [C]	205
Heat flux [kW/m2]	6

Pre-Walkdown Inputs		WALKDOWN INPUTS						Input	
Equip ID	HRR PDF	Fire Condition	Dist to Target (m)	Calculated HRR [kW]	Critical 98th HRR [kW]	Screen ?	SF	(Task 6) λ	Adjusted λ
Cabinet A	1	Flames	0.5	49	211	No	3.4E-01	1.0E-04	3.44E-05
Cabinet B	1	Plume	3	401	211	Yes	0.0E+00	1.0E-04	0
Cabinet C	3	Ceiling jet	1.5	4870	211	Yes	0.0E+00	1.0E-04	0
Pump	6	Plume	2	179	211	No	3.0E-02	1.0E-04	2.97E-06
Motor	7	Flame radiation	2.5	1178	69	Yes	0.0E+00	1.0E-04	0
					Adjusted compartment frequency, λ_c =				3.7E-05

Notes:

Slide 21

Notes:



Session 4: Heat Release Rate

Slide 1

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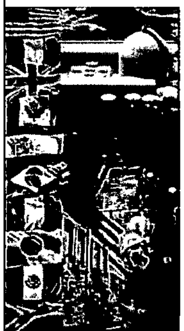

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III: Heat Release Rates
Appendix G

Joint RES/EPRI Fire PRA Course
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Notes:

Slide 2

HEAT RELEASE RATES
Objectives

The objectives of this module are:

1. Define heat release rate and heat release rate profile
2. Review the recommended peak heat release rate values for typical ignition sources in NPP
3. Describe the method provided for developing heat release rate profiles for fixed and transient ignition sources in NPP

NOTE: Appendix G recommends values for ignition sources only. Heat release rates associated with fires propagating outside of the ignition source have to be evaluated accordingly.

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Module III: Heat Release Rates Appendix G

Slide 2

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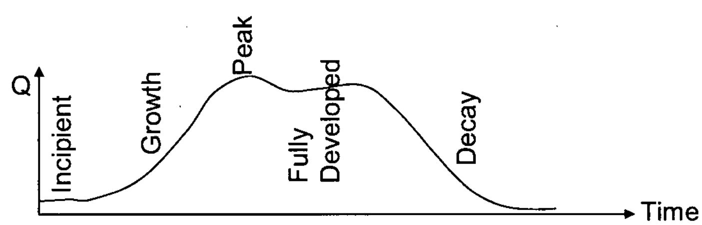
Notes:

HEAT RELEASE RATES
Definition

Definition: Heat generated by a burning object per unit time.

- $\dot{Q} = \dot{m}'' \cdot \Delta H_c \cdot A$ BTU/sec or KW
- m" is burning rate [kg/s-m^2], ΔH_c is heat of comb [kJ/kg], A is area [m^2]
- Equivalent terms: energy release rate, fire intensity, fire power
- HRR profile describes fire intensity (Q) as a function of time



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Module III: Heat Release Rates Appendix G

Slide 3

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Notes:

Slide 4

Notes:

HEAT RELEASE RATES
HRR Profile

The HRR profile can be expressed as a constant or as a function of time

- Incipient stage: Not recommended to be modeled
  - Duration and intensity are uncertain
- Growth: Depends on the fuel and geometry of the scenario
  - Based on engineering judgment and/or experimental observations
- Fully developed: Usually after the fire reaches its peak intensity
  - Also known as steady burning
  - Starts at ignition if the growth period is not considered
  - A constant fire intensity should the the peak heat release rate of the profile
- Decay: In general, less hazardous conditions than the growth and fully developed stage

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Module III: Heat Release Rates Appendix G

Slide 4

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Slide 5

Notes:

HEAT RELEASE RATES
HRR Profile – Related FAQs

- FAQ 08-0045 Cabinet Fires (Status: Open)
  - Issue:
    - Fire growth recommendations for electrical cabinets does not include consideration of an incipient stage (e.g., pre-ignition heating and generation of un-burned pyrolysates which might be detected)
  - General approach to resolution:
    - No clear resolution approach has yet been developed
  - Status:
    - A problem statement has been generated
    - FAQ may be withdrawn - not amenable to short-term solution

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Module III: Heat Release Rates Appendix G

Slide 5

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Slide 6

Notes:

HEAT RELEASE RATES
HRR Profile – Related FAQs (continued)

- FAQ 08-0052 Transient Fires (Status: Open)
  - Issue:
    - No guidance on fire growth times for transient fires
    - Guidance not clear as to which non-suppression curve would apply to transient fires in the MCR (i.e., transient curve or MCR curve)
  - General approach to resolution:
    - Review existing test data and develop guidance for transient fire growth times
    - Clarify non-suppression curve application for this case
  - Status:
    - Initial team position drafted and undergoing review within the teams
    - Staff and industry reviews pending

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Slide 6
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Slide 7

Notes:

HEAT RELEASE RATES
HRR Profile – Related FAQs *(continued)*

- FAQ 08-0044 Pump Oil Fires (Status: Open)
  - Issue:
    - Guidance for large oil spill and fire is generating conservative results especially in the case of MFW pump fires (high frequency of large release compared to experience base)
  - General approach to resolution:
    - Provide an alternative approach and revised fire frequencies for leaks and spills from higher volume circulating oil/lubrication systems
  - Status:
    - General consensus that a revised treatment is appropriate and needed
    - RES/EPRI team discussion of the specific resolution approach continues, reviews ongoing
    - NRC 805 team and industry 805 task force reviews pending

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Slide 8

Notes:

HEAT RELEASE RATES
Fixed Ignition Sources

The methodology recommends heat release rate values for various fixed ignition sources

- Vertical cabinets
  - Open/closed
  - Qualified/Unqualified cables
- Pumps (electrical fires)
- Electric motors
- HRR for flammable liquid fires should be calculated as $\dot{Q} = \dot{m}'' \cdot \Delta H_c \cdot A$
- Separate guidance for cables, pressurized oil and hydrogen fires

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Slide 9

Notes:

HEAT RELEASE RATES
Recommended Peak HRR Values

Recommended peak HRR values were developed based on expert judgment

- Expert panel included the EPRI/NRC-RES Fire Risk Re-quantification Study research team with expertise in fire behavior/phenomena.
- Values are expressed as probability distributions. The panel identified the 75th and 98th percentiles of the distribution for peak HRR.
- Primary sources of information included NUREG/CR 4527 and VTT publications
- Gamma distribution selected:
  - Only positive values starting at 0 kW
  - Values in the same order of magnitude

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Slide 9
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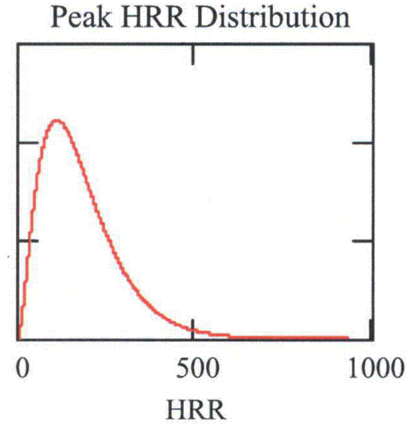
Slide 10

HEAT RELEASE RATES
Recommended Peak HRR Values

Example distribution developed by the expert panel

- 75^{th} = 232 kW
- 98^{th} = 464 kW
- α = 2.6
- β = 67.8



Notes:

Slide 11

HEAT RELEASE RATES
Recommended Peak HRR Values

Ignition Source	HRR kW (Btu/s)		Gamma Distribution	
	75th	98th	α	β
Vertical cabinets with qualified cable, fire limited to one cable bundle	69 [1] (65)	211 [2] (200)	0.84 (0.83)	59.3 (56.6)
Vertical cabinets with qualified cable, fire in more than one cable bundle	211 [2] (200)	702 [3] (665)	0.7 (0.7)	216 (204)
Vertical cabinets with unqualified cable, fire limited to one cable bundle	90 [4] (85)	211 [2] (200)	1.6 (1.6)	41.5 (39.5)
Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	232 [5] (220)	464 [6] (440)	2.6 (2.6)	67.8 (64.3)
Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	232 [5] (220)	1002 [7] (950)	0.46 (0.45)	386 (366)
Pumps (electrical fires)	69 (65)	211 [2] (200)	0.84 (0.83)	59.3 (56.6)
Motors [8]	32 (30)	69 (65)	2.0 (2.0)	11.7 (11.1)

*See report for footnotes

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Slide 11

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Slide 12

HEAT RELEASE RATES
Fire Growth in Electrical Cabinets

The methodology suggests a fire growth rate for electrical cabinet fires

- The fire grows to its peak HRR in approximately 12 min
- The fire burns at its peak HRR for approximately 8 min
- Based on experiments reported in NUREG/CR4527

Test	Units in Minutes		
	Time to Peak	Steady Burning	Time to Decay
ST1	7	8	15
ST2	6	11	17
ST3	10	8	18
ST4	14	3	17
ST5	8	9	17
ST6	8	17	25
ST7	18	7	25
ST8	10	20	30
ST9	10	10	20
ST10	10	20	30
ST11	18	2	20
PCT1	11	10	21
PCT2	12	2	14
PCT3	13	14	27
PCT4a	16	0	16
PCT4c	16	0	16
PCT5	17	0	17
PCT6	11	0	11
Test 21	4	14	18
Test 22	9	2	11
Test 23	10	0	10
Test 24	12	0	12
Average	11.4	7.1	19

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Slide 12

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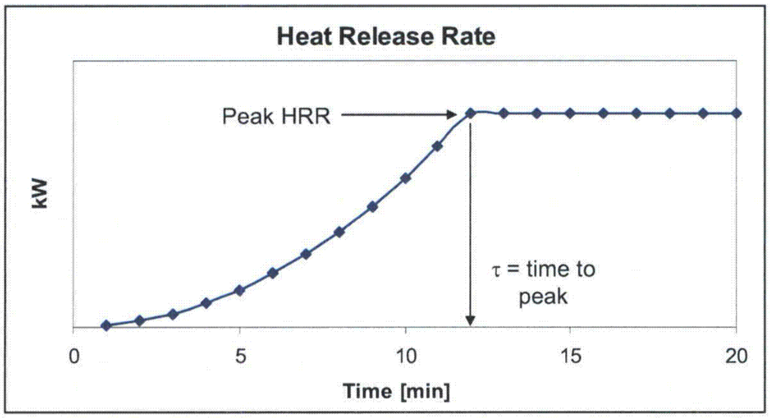
Notes:

Slide 13

HEAT RELEASE RATES
Fire Growth in Electrical Cabinets

The t^2 function is recommended for modeling the growth phase of the fire

$$\dot{Q}(t) = Min\left(\dot{Q}_{peak}, \dot{Q}_{peak} \cdot \left(\frac{t}{\tau}\right)^2\right)$$



Notes:

Slide 14

HEAT RELEASE RATES
Assigning HRR Values to Electrical Cabinets

A visual examination of the interior of the cabinet is recommended

- Identify openings in the cabinet walls
- Identify type of cable: qualified/unqualified
- Identify cable bundles
- Qualitatively determine if a fire can propagate from one bundle to another
- Select the appropriate peak HRR probability distribution

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Slide 14

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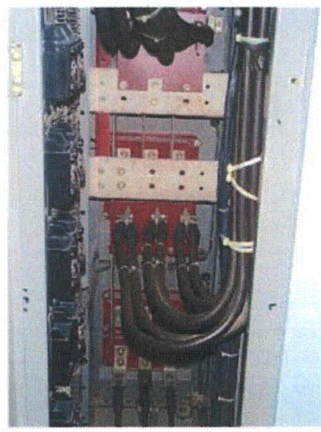
Notes:

Slide 15

HEAT RELEASE RATES
Examples

By visual examination:

- More than one cable bundle
- Assuming qualified cable, select distribution with 75th = 211 kW, 98th =702 kW



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Slide 15

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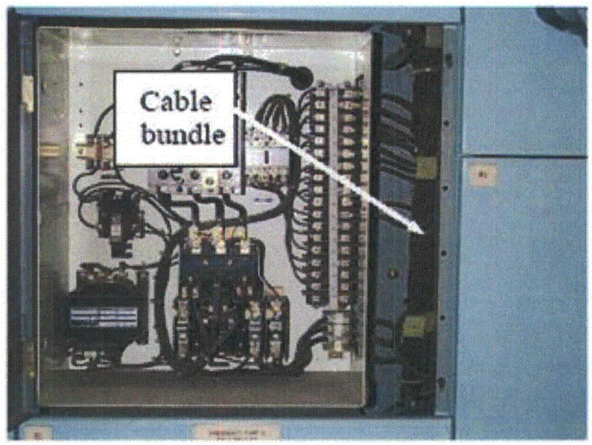
Slide 16

HEAT RELEASE RATES
Examples

By visual examination:

- Only one cable bundle
- Assuming qualified cable, select distribution with 75^{th} = 69 kW, 98^{th} = 211 kW



Notes:

Slide 17

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HEAT RELEASE RATES
Transient Ignition Sources

The peak HRR for transient fires is also characterized with a gamma probability distribution

- Gamma distribution:
  - 75^{th} = 135 BTU/s, 98^{th} = 300 BTU/s
  - $\alpha = 1.9$, $\beta = 53.7$
- Applicable only to localized transient combustibles (trash cans, etc.)
- Not applicable to flammable liquid transient fires

Slide 18

Notes:

HEAT RELEASE RATES
Concluding Remarks

Peak HRR values are recommended for some typical fixed and transient ignition sources in NPP fire scenarios

- Values are for localized ignition source (not for fires propagating outside the ignition source)
- HRR for flammable liquid fires can be calculated from fundamental equations
- HRR for "solid" ignition sources are generally expressed as probability distributions based on experimental data and expert judgment

Session 5: Fire Severity

Slide 1

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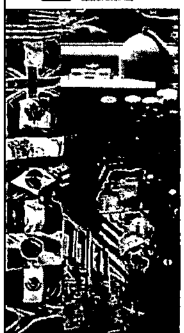

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III: Fire Severity

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Notes:

Slide 2

FIRE SEVERITY
Purpose

- A uniform methodology has been developed to define the severity of a fire.
  - Severity factor concept
  - Based on heat release rate
  - Standardized cases

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Slide 2

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Notes:

Slide 3

Notes:

FIRE SEVERITY
Severity Factor Concept

- Severity Factor is . .
  - A simplified, one parameter representation of a very complex phenomenon (i.e., fire) influenced by a large number of factors.
  - Defined as the conditional probability that given a fire has occurred, it is of certain severity (it is defined here through heat release rate).
  - Quantified in combination with *Non-Suppression Probability*.

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FIRE SEVERITY
Severity Factor Concept (cont'd)

The combination of *Severity and Non-Suppression Factors* are calculated from the following equation:

$$SF_k \cdot P_{NS,k} = \int_{All\, t_{damage}} \frac{dP_{dam}(t)}{dt} P_{\sup p}(t_{\sup p} > t)dt$$

Where:

$P_{dam}(t)$: The probability of target set damage before time t.

P_{supp} (t_{supp} > t): Probability of suppression taking place after time t

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Slide 4

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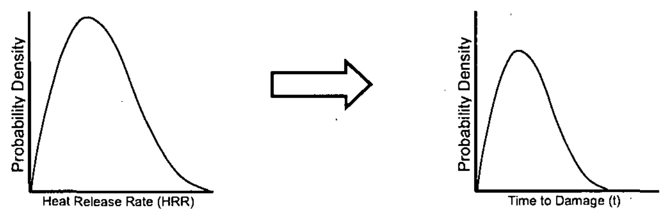
Slide 5

FIRE SEVERITY
Probability of Damage Estimation

- Probability of damage before time t is estimated using complex fire spread and propagation models.
  - Heat release rate is a key parameter of the analysis
  - Assuming a known heat release rate, specific features of the compartment, ignition source, and target set configuration, time to damage can be calculated.
  - Since heat release rate is expressed with a probability distribution, the time to damage can be expressed with a probability distribution



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Slide 5

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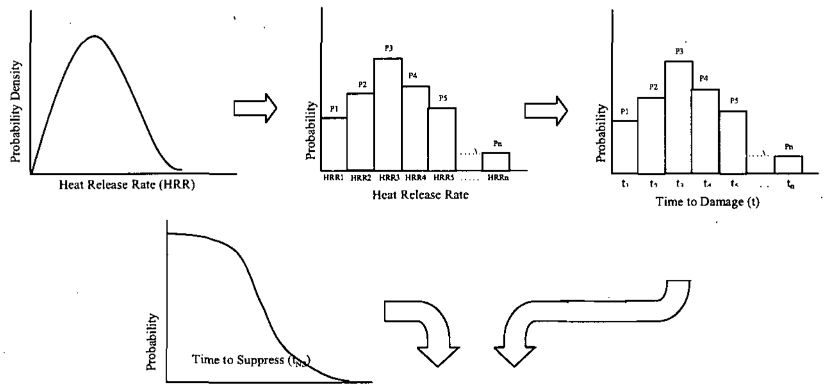
Slide 6

FIRE SEVERITY
Severity Factor Estimation Process

Severity factor is estimated using discretized probability distributions for heat release rate and non-suppression.



HRR Values	HRR1	HRR2	HRR3	HRR4	....	HRRn
Individual Severity Factor	P_1	P_2	P_3	P_4	....	P_n
Time to damage	t_1	t_2	t_3	t_4	....	t_n
Prob. of supp. after damage	P_{NS1}	P_{NS2}	P_{NS3}	P_{NS4}	....	P_{NSn}

Notes:

FIRE SEVERITY
Heat Release Rate Distributions

The heat release rate of the following equipment classes have been defined:

Case	Ignition Source	HRR (Btu/s)	
		75th	98th
1	Vertical cabinets with qualified cable, fire limited to one cable bundle	65	200
2	Vertical cabinets with qualified cable, fire in more than one cable bundle	200	665
3	Vertical cabinets with unqualified cable, fire limited to one cable bundle	85	200
4	Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	220	440
5	Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	220	950
6	Pumps (electrical fires)	65	200
7	Motors	30	65
8	Transient Combustibles	135	300

Notes:

FIRE SEVERITY
Heat Release Rate Distribution - Example

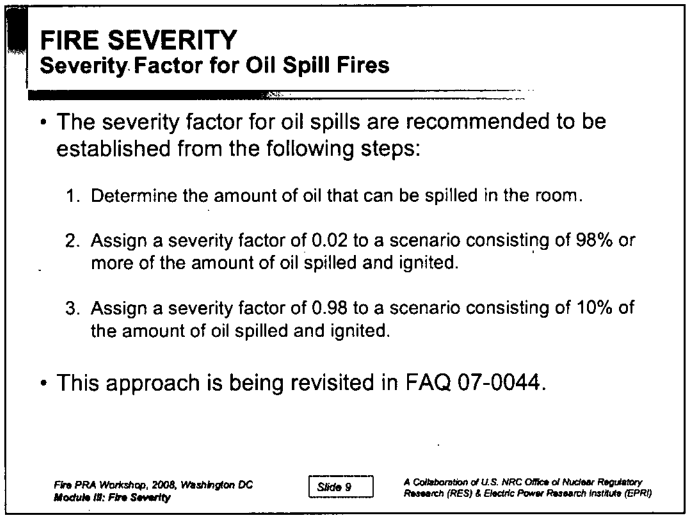
Table E-1
HRR Distribution for Vertical Cabinets with Qualified Cables, Fire Limited to One Cable Bundle

Bin	Heat Release Rate (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0	25	10.5	0.446
2	25	50	36	0.219
3	50	75	61	0.129
4	75	100	87	0.078
5	100	125	112	0.048
6	125	150	137	0.030
7	150	175	162	0.019
8	175	200	187	0.012
9	200	225	212	0.007
10	225	250	237	0.005
11	250	275	262	0.003
12	275	300	287	0.002
13	300	325	312	0.001
14	325	350	337	0.001
15	350	Infinity	405	0.001

Notes:

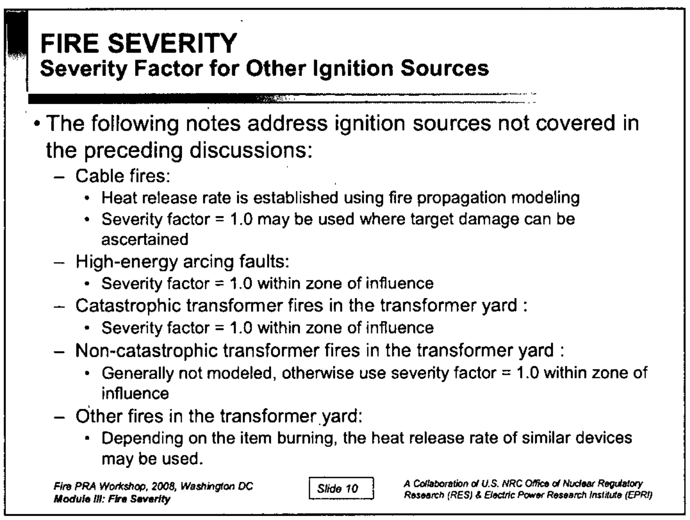
Slide 9

Notes:



Slide 10

Notes:



Slide 11

FIRE SEVERITY
Frequency Bins and HRR Distributions

Table 11-1 Recommended Severity Factors . . . for Ignition Sources in the Frequency Model			
ID	**Location**	**Ignition Source**	**HRR Distribution Category**
1	Battery Room	Batteries	Electric motors
2	Containment (PWR)	Reactor coolant Pump	Pumps (Electrical)/Oil spills
4a	Control Room	Electrical cabinets	Applicable electrical cabinet
4b	Control Room	Main control board	See Appendix L
5	Control/Auxiliary/ Reactor Building	Cable fires caused by welding and cutting	Assume 1.0
6	Control/Auxiliary/ Reactor Building	Transient fires caused by welding and cutting	Transients
21	Plant-Wide Components	Pumps	Pump (Electrical)/Oil spills

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Slide 11

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Notes:

Slide 12

Notes:

FIRE SEVERITY
Concluding Remarks

- Severity Factor provides an adjustment to ignition frequency to account for the severity of the fire.
  - It is tied to the heat release rate
  - It is estimated in concert with probability of non-suppression
  - Specific cases have been developed
  - Guidance is provided for other cases

Session 6a: Damage Criteria

Slide 1

Notes:

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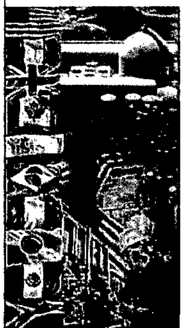

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III: Damage Criteria

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Slide 2

Notes:

Damage Criteria
Damage Thresholds

- Damage (or Failure) Threshold: the minimum value of an exposure environment parameter that *can* lead to the failure of the damage target of interest within the timescale of the fire
  - Can be a temperature – exposure to high temperatures such as in a hot gas layer or fire plume
  - Can be a radiant heat flux – generally due to direct radiant heating from the luminous flame zone of a fire
  - In theory, it could be a minimum smoke density, but we aren't that smart (more on smoke shortly)

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Slide 2

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Slide 3

Damage Criteria
Damage Thresholds

- Damage thresholds are of primary interest to Task 8 – Scoping Fire Modeling
  - We use damage thresholds mainly when screening out specific fire ignition sources
    - If a fire source cannot damage any target, or ignite any secondary combustible, then we screen that source out of the analysis as non-threatening (more on Task 8 later)
  - *Also Note:* If an electrical cable is damaged, we assume that it will also be ignited
    - Arcing when a cable short circuits will ignite the cable based on testing experience

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Module III: Damage Criteria

Slide 3

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Notes:

Slide 4

Damage Criteria
Damage Thresholds

- Damage Threshold is specific to the damage target and procedure deals mainly with the following:
  - Electrical Cables
    - Thermoset
    - Thermoplastic
  - Electronics and integrated circuit devices
- For other devices (e.g., motors, switchgear, etc.) look at the cables and supporting controls or electronics
  - Example: A pump is fed by power cables, and those cables are generally more vulnerable to fire damage than the pump itself

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Slide 4

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Notes:

Slide 5

Damage Criteria
Damage Thresholds

- Some items are considered invulnerable to fire-induced damage:
  - Ferrous metal pipes and tanks
  - Passive components such as flow check valves
  - Concrete structural or partitioning elements except when considering random failure likelihood in multi-compartment scenarios
    - i.e., we *do not* consider fire-induced structural failure of concrete
- Things you still need to watch for:
  - Soldered piping (e.g., air/gas lines that are soldered copper)
  - Flexible boots/joints/sleeves on piping (e.g., the Vandellos scenario)
  - Exposed structural steel given a very large fire source (e.g., catastrophic loss of the main TG set – more later)

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Slide 5

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Notes:

Slide 6

Damage Criteria
Damage Thresholds

- The following are defined as generic damage thresholds for the most common damage targets – cables:

Table H-1ſ Damage Criteria for Electrical Cables – Generic Screening Criteria for the Assessment of the Ignition and Damage Potential of Electrical Cables [See Ref 8-1]

Cable Type	Radiant Heating Criteria	Temperature Criteria
Thermoplastic	6 kW/m² (0.5 BTU/ft2s)	205°C (400°F)
Thermoset	11 kW/m² (1.0 BTU/ft2s)	330°C (625°F)

- And electronics:
  - 3 kW/m² (0.25 BTU/ft²) and 65°C (150°F)
  - If needed, assume ignition properties same as thermoplastic cables: 6 kW/m² (0.5 BTU/ft²) and 205°C (400°F).

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Slide 6

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Notes:

Slide 7

Notes:

Damage Criteria
Damage Thresholds

- For additional rules related to damage criteria, see H.1.1; e.g.:
  - Cables in conduit: potential damage targets, but will not contribute to fire growth and spread – no credit to conduit for delaying the onset of thermal damage.
  - Cables coated by a fire-retardant coating: treat as exposed cables for damage purposes – coating may slow the subsequent spread of fire, but we are NOT specific here.

Damage Criteria
Damage Thresholds

- Plant-specific or product-specific damage thresholds *may be used* if appropriate basis is established
  - Report provides some references for information specific to many popular types and brands of cables
  - Example:

Table H-4
Failure Temperatures for Specific Cable Products as Reported in Table 5 of Reference H.2

Cable Manufacturer	Description of Cable Tested	Failure Threshold (°C)
Brand Rex	Cross-linked polyethylene (XLPE) Insulation, Chlorosulfonated Polyethylene (CSPE) Jacket, 12 AWG, 3-Conductor (3/C), 600 Volt (V)	385
Rockbestos	Firewall III, Irradiation XLPE Insulation, Neoprene Jacket, 12 AWG, 3/C, 600 V	320-322
Raychem	Flamtrol, XLPE Insulation, 12 AWG, 1/C, 600 V	385-388
Samuel Moore	Dekoren Polyset, Cross-Linked Polyolefin (XLPO) Insulation, CSPE Jacket, 12 AWG, 3/C and Drain	299-307
Anaconda	Single Conductors Removed From: Anaconda Y Flame- Guard Flame Retardant (FR) Ethylene Propylene (EP), Ethylene Propylene Rubber (EPR) Insulation, Chlorinated Polyethylene (CPE) Jacket, 12 AWG, 3/C, 600 V	381
Anaconda	Anaconda Flame-Guard EP, EPR Insulation, Individual CSPE Jacket, Overall CSPE Jacket, 12 AWG, 3/C, 1000 V	334
Okonite	Okonite Okolon, EPR Insulation, CSPE Jacket, 12 AWG, 1/C, 600 V	387

Notes:

Slide 9

Notes:

Damage Criteria
Damage Time

- It is both appropriate and desirable to consider damage time during Task 11 – Detailed Fire Modeling
  - At the threshold exposure condition, damage times may be prolonged (e.g., 30 minutes or more)
  - As exposure conditions increase in severity, time to damage decreases (e.g., to as little as a few seconds)
  - Consideration of time to damage allows for a more realistic assessment of the non-suppression probability
    - How long do you have to put the fire out before damage occurs?

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Slide 10

Notes:

Damage Criteria
Damage Time

- Two general approaches to damage time analysis:
  - Direct modeling of target thermal response
    - Use a fire model to predict the temperature response of the target
    - When the predicted temperature of the target reaches the damage threshold, assume target failure
    - Catch: need fire model that does target response calculation
  - Empirical approach (e.g. SDP)
    - Predict the peak exposure condition (temperature or heat flux)
    - Use a look-up table to estimate time to damage
    - Catch: look-up tables currently only available for generic thermoset and thermoplastic cables

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Damage Criteria
Damage Time

- Example of the Time to Damage look-up tables:

Table H-5: Failure Time-Temperature Relationship for Thermoset cables (Table A.7.1 from reference H.6).

Exposure Temperature		Time to Failure (minutes)
°C	°F	
330	625	28
350	660	13
370	700	9
390	735	7
410	770	5
430	805	4
450	840	3
470	880	2
490 (or greater)	915 (or greater)	1

Notes:

Slide 12

Notes:

Damage Criteria
Smoke Damage

- Appendix T provides an extended discussion of current knowledge regarding smoke damage
  - This is about smoke and the failure of equipment
  - It is not about the impact of smoke on people
- We are interested in short-term damage
  - Within the time scale of the fire scenario including plant shutdown
  - We do not consider longer term issues such as corrosion leading to failure some days or weeks after a fire

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Slide 13

Notes:

Damage Criteria
Smoke Damage

- Bottom Line: Some components are known to be vulnerable to smoke damage, but it takes a dense exposure to cause short term damage
- So what are the vulnerable components?
  - High voltage switching equipment (arcing)
  - High voltage transmission lines (arcing)
  - Devices such as strip chart recorders that are dependent on fine mechanical motion (binding)
  - Un-protected printed circuit cards (deposition and shorting)
    - e.g., exposed within a panel and not provided with a protective coating

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Slide 13

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Slide 14

Notes:

Damage Criteria
Smoke Damage

- Smoke damage is assessed on an empirical basis:
  - We don't set quantitative thresholds
  - We don't try to use fire models
  - You should consider the potential failure of vulnerable components due to smoke as a part of your damage target set

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Slide 15

Notes:

Damage Criteria
Smoke Damage

- Assume that vulnerable components adjacent to or connected to the fire source will be damaged by smoke:
  - Within the same electrical cabinet or housing as a fire source
    - e.g. given a panel fire, the whole panel is lost due to smoke and/or heat
  - In an adjacent cabinet if the cabinet-to-cabinet partitions is not well-sealed
  - In a common *stack* of electrical cubicles
  - In a nearby cabinet with a direct connection to the fire source
    - e.g., a shared or common bus-duct

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Session 6b: Example Problems

Workshop Problems on Task 8: Scoping Fire Modeling

This handout includes workshop problems on the different steps of Task 8: Scoping Fire Modeling. Problems are grouped by steps.

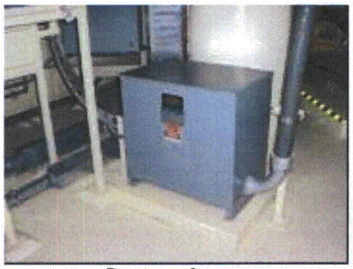
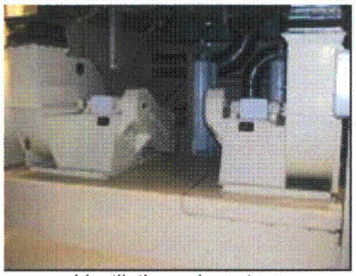
Step 1: Preparation for Walkdown

Step 1 has three sub-steps: 1) Estimate heat release rate for fixed ignition source screening, 2) Target and intervening combustibles damage or ignition criteria, and 3) Develop a zone of influence.

Workshop problem 08-01:

Step 1.1: Estimate heat release rate for fixed ignition source screening: Assign a heat release rate to the ignition sources depicted in the pictures of the following Table 08-01. For this exercise, assume that the plant has a mix of qualified and unqualified cables. The heat release rates are listed in Table E-1 of NUREG/CR-6850.

Table 08-01: Inputs for Workshop problems 1

Ignition Source	Table E-1 Case	98th Percentile HRR	Justification
 Dry transformer			
 Fire protection panel			
 Ventilation sub-system			

Ignition Source	Table E-1 Case	98th Percentile HRR	Justification
 Pumps			

Workshop Problem Set 08-02:

Step 1.2: Target and intervening combustible damage and ignition criteria: Assign damage criteria to the ignition sources depicted in Table 08-01. For this exercise, assume that the plant has a mix of thermoset and thermoplastic cable. Generic damage criteria are listed in Table H-1 of NUREG/CR-6850.

Table 08-02: Inputs for workshop problem 2

Target/Intervening Combustible	Damage Criteria	Justification
Cables in a ladder back tray		
Cables in a solid tray		
Theromset cable in a conduit		
Motor operated valve (MOV).		
Cabinet with a solid state device		

Workshop Problem Set 08-03

Step 1.3: Develop zone of influence: Calculate the heat release rate required for generating target damage for the following ignition source/target combination and determine if the ignition source can be screened. Use the engineering calculations described in NUREG-1805 for determining the heat release rate value.

- Target in the hot gas layer:
  - A cable tray target is located near the ceiling in a room approximately 21' by 7' and has a normally closed door on each end. The room is approximately 20' high. The inside walls of the MCC room are reinforced concrete. There is one MCC cabinet in the room. The MCC cabinet has unqualified cable.

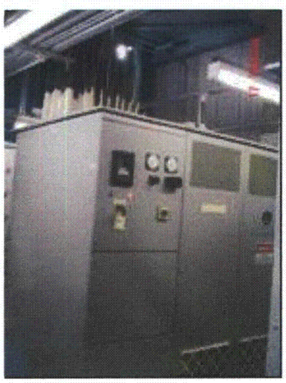
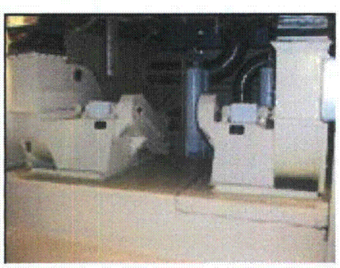
- Target subjected to flame impingement or fire plume temperatures:
  - A vertical cable tray is located 5' ft from a floor based ventilation subsystem.

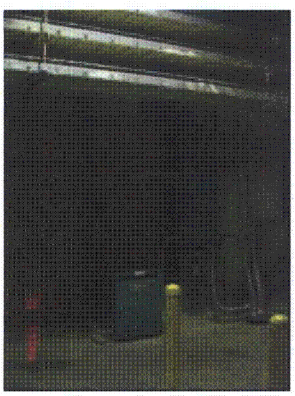
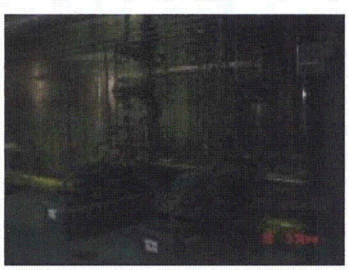
- Target subjected to flame radiation:
  - A conduit is located 3 ft from a battery charger with qualified cable.

Workshop Problem Set 08-04

Step 2: Plant Walkdown: Inspect the ignition source and target combination in the pictures included in Table 08-03 and determine the appropriate zone of influence calculation necessary.

Table 08-03: Inputs for Workshop problems 1

Ignition Source	Ignition Source/Target	Zone of Influence	Distance
			
			
			

Ignition Source	Ignition Source/Target	Zone of Influence	Distance
			
			
			
			

Step 3: Verification of Screened Ignition Sources

No workshop problem for Step 3.

Workshop Problem Set 08-05

Step 4: Calculation of Severity Factors: Calculate the severity factors for the ignition source and target combinations listed in Workshop Problem 08-03. Use the results of Workshop Problem Set 08-03 as inputs to this exercise.

- Target in the hot gas layer

- Target subjected to flame impingement or plume temperatures

- Target subjected to flame radiation

Workshop Problem Set 08-06

Step 5: Calculation of Revised Compartment Fire Frequency: Determine a revised compartment ignition frequency for switchgear room A assuming the walkdown results listed in Table 08-04.

Table 08-04: Summary of Task 8 calculations

Equipment Description	Count	Fire Condition	Measured Distance (ft)	Table E-1 Case	Critical HRR (Table E-1)	Room Area (ft2)	Room Height (ft)	Calculated HRR (kW)	Room Temp (F)	Screened	Severity Factor	Count Task 8
Train A 4160 V Bus	8	flame or plume	1.7	9	Do Not Screen	1350	20	7	N/A	No	**1.00**	**8.00**
Train A 480 V Load Center	6	flame radiation	4.9	9	Do Not Screen	1350	20	401	N/A	No	**1.00**	**6.00**
Train A Station Service Transformer	1	flame radiation	4.5	9	Do Not Screen	1350	20	336	N/A	No	**1.00**	**1.00**
Train A Battery Charger	1	flame or plume	2.9	4	464	1350	20	25	264	No	**0.98**	**0.98**
Train A 125 VDC Bus	8	flame or plume	0.7	4	464	1350	20	1	264	No	**1.00**	**8.00**
Train A 125 VDC Panel	1	flame radiation	2.8	4	464	1350	20	129	264	No	**0.60**	**0.60**
Train A Inverter	1	flame radiation	2.0	4	464	1350	20	64	264	No	**0.88**	**0.88**

Table 08-05: Comparison of switchgear room A ignition frequency

Task 6	Switchgear Room A	**≈ 1.5E-02**
Task 8	Switchgear Room A	**≈ 1.5E-02**

Session 7: Detailed Fire Modeling and Single Compartment Scenarios

Slide 1

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SAIC Science Applications International Corporation

EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III: Task 11a - Detailed Fire Modeling and Single Compartment Fire Scenarios

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September and November 2008
Bethesda, MD

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Slide 2

Module II-10: TOPICS

The objectives of this module are:

- Describe the process of fire modeling for a single fire compartment
- The outcome of this activity is the extent and timing of fire damage within the compartment

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Slide 3

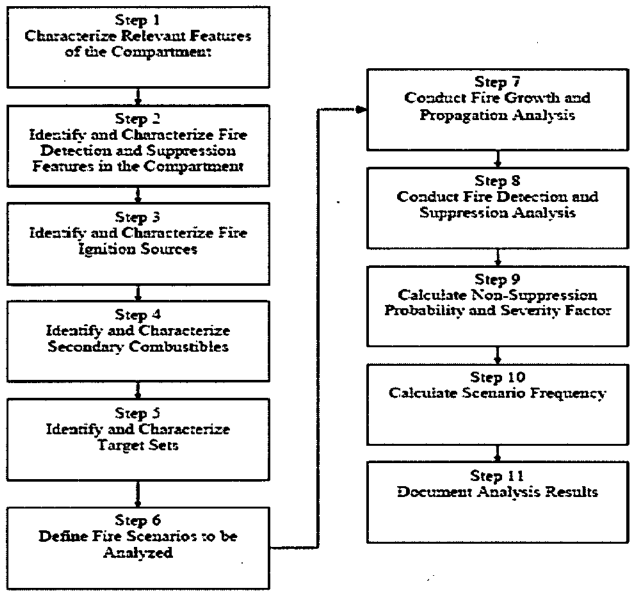
Module II-10: FIRE MODELING
Role and Scope

- **Fire modeling:** An approach for predicting various aspects of fire generated conditions
  - Requires idealization and/or simplifications of the physical processes involved
  - Departure of the fire system from this idealization can affect the accuracy and validity
- **Fire scenario:** A set of elements representing a fire events
  - Fire source/initiation
  - Fire growth
  - Fire propagation (room heating, HEAF, intervening combustibles, etc.)
  - Active fire protection features, e.g., detection/suppression
  - Passive fire protection features, e.g., fire stops
  - Target sets, i.e., cables, habitability, etc.

Notes:

Slide 4

Module II-10: PROCESS
General Task Structure



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Slide 5

Notes:

Module II-10: PROCESS
Characterize Fire Compartment

- Information on compartment geometry that can impact fire growth
  - Size and shape, e.g., ceiling soffit or beam pocket
  - Boundary construction and material
  - Ventilation
- Fire protection systems and features
  - Fixed detection systems
  - Fixed fire suppression systems, water or gaseous
  - Manual detection
  - Fire brigade
  - Internal fire barriers and stops, e.g., ERFBS
- Problem 11a-01, 11a-02

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Slide 6

Notes:

Module II-10: PROCESS
Identify/Characterize Fire Sources

- Location within the compartment, type, size, initial intensity, growth behavior, severity/likelihood relationship, etc.
- Estimate frequency of ignition for the ignition source.
- Example of fires events involving typical ignition sources
  - Oil or liquid spill fires (Characterization described in appendix G)
  - Oil or flammable liquid spray fires (Characterization described in appendix G)
  - General fires involving electrical panels (Characterization described in appendices G, L & S)
  - High energy arcing faults events (Characterization described in appendix M)
  - Cable fires (Characterization described in appendix R)
  - Hydrogen fires (Characterization described in appendix N)
  - Transient fuel materials (Characterization described in appendices G & S)
- Problem 11a-03

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Slide 7

Module II-10: PROCESS
Identify/Characterize Secondary (intervening) Combustibles

- May include,
  - Overhead raceways,
  - Cable air-drops,
  - Stored materials,
  - Electrical panels,
  - Construction materials, etc.
- The information provided should describe
  - Relative proximity of the secondary combustibles to the fire ignition source
  - Configuration of the secondary combustible.
- Example problem on step 4

Notes:

Slide 8

Module II-10: PROCESS
Identify/Characterize Target Sets

- Each target set should be a subset of the fire PRA components and circuits (i.e., cables) present in the compartment.
  - Target sets associated to PRA components can be identified by examining the associated CCDP.
  - Those subgroups with very small CCDP may be ignored as insignificant contributors to fire risk.
  - Check for possibility of spurious actuations due to cable fires inside the compartment under analysis. Spurious actuations may generate the need of evaluating important scenarios.
- Fire modeling should have information on target location within the compartment available.
  - If complete routing information is not available, the analyst must justify target selection process and the corresponding impacts in the Fire PRA model.
  - Routing by exclusion OK (from a compartment, from a set of raceways…)
- Identify failure modes of equipment due to fire damage to the equipment or associated circuits.
- Example problem on Step 5

Notes:

Slide 9

Notes:

Module II-10: PROCESS
Select Fire Scenarios

- Fire scenarios should take the following into consideration:
  - Selected scenarios should reflect the objective of fire modeling, in this case impacting the components and circuits of interest to safety
  - Selected scenarios should represent a complete set of fire conditions that are important to the objective
  - Selected scenarios should challenge the conditions being estimated, e.g., scenarios that challenge habitability if manual action is of interest
  - The list of postulated fire scenarios should include those involving fixed and transient ignition sources

Slide 10

Notes:

Module II-10: PROCESS
Select Fire Scenarios (cont'd)

- Approach to selection of fire scenarios is highly dependent on fire compartment hazard profile, i.e., location and amount of fire source and combustibles and the location and number of potential targets. In general,
  - In compartment with few fire source and many target sets (e.g., a switchgear room), start with an ignition source, postulate potential growth and propagation to other combustibles and postulate damage to the closest target set that may be exposed to the specific fire
  - In compartments with many fire sources and few potential targets (e.g., a PWR turbine building), start with potential target sets
  - In compartments with many fire sources and many potential target (e.g., a PWR auxiliary building),
    - Close source/target combinations, and
    - Always include that fire scenario most likely (all factors considered) to cause wide-spread damage (may be driven by fire source characteristics, fire spread potential, or by fire protection systems and features)
- Workshop problem 11a-04

Slide 11

Notes:

Module II-10: PROCESS
Conduct Fire Growth and Propagation

- Select fire modeling tool depending on the characteristics of each scenario
  - Empirical rule sets
  - Hand calculations
  - Zone models
  - Field models
- Analyze fire growth and spread to secondary combustibles
- Estimate resulting environmental conditions
- Estimate time to target set damage
- Workshop problem 11a-05 to 11a-08

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Module III: Task 11a - Detailed Fire Modeling & Single Compartment Fire Scenarios

Slide 11

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Slide 12

Module II-10: PROCESS
Hand Calcs – NUREG 1805

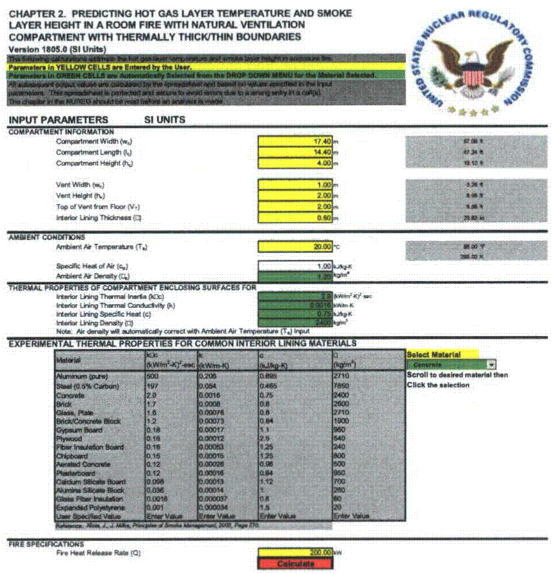
02.1_Temperature_NV.xls
02.2_Temperature_FV.xls
02.3_Temperature_CC.xls
03_HRR_Flame_Height_Burning_Duration_Calculation.xls
04_Flame_Height_Calculations.xls
05.1_Heat_Flux_Calculations_Wind_Free.xls
05.2_Heat_Flux_Calculations_Wind.xls
05.3_Thermal_Radiation_From_Hydrocarbon_Fireballs.xls
06_Ignition_Time_Calculations.xls
07_Cable_HRR_Calculations.xls
08_Burning_Duration_Soild.xls
09_Plume_Temperature_Calculations.xls

09_Plume_Temperature_Calculations.xls
10_Detector_Activation_Time.xls
13_Compartment_ Flashover_Calculations.xls
14_Compartment_Over_Pressure_Calculations.xls
15_Explosion_Claculations.xls
16_Battery_Room_Flammable_Gas_Conc.xls
17.1_FR_Beams_Columns_Substitution_Correlation.xls
17.2_FR_Beams_Columns_Quasi_Steady_State_Spray_Insulated.xls
17.3_FR_Beams_Columns_Quasi_Steady_State_Board_Insulated.xls
17.4_FR_Beams_Columns_Quasi_Steady_State_Uninsulated.xls
18_Visibility_Through_Smoke.xls

Notes:

Slide 13

Module II-10: PROCESS
Hand Calcs – NUREG 1805



CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE AND SMOKE LAYER HEIGHT IN A ROOM FIRE WITH NATURAL VENTILATION COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES
Version 1805.0 (SI Units)

Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.

INPUT PARAMETERS SI UNITS

COMPARTMENT INFORMATION

Compartment Width (w_c) 17.40 m
Compartment Length (l_c) 14.40 m
Compartment Height (h_c) 4.00 m

Vent Width (w_v) 1.00 m
Vent Height (h_v) 2.00 m
Top of Vent from Floor (V_T) 2.00 m
Interior Lining Thickness (δ) 0.60 m

AMBIENT CONDITIONS

Ambient Air Temperature (T_a) 20.00 °C
Specific Heat of Air (c_p) 1.00 kJ/kg-K
Ambient Air Density (ρ_a) 1.20 kg/m³

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

Interior Lining Thermal Inertia (kρc) 2.9 (kW/m²-K)²-sec
Interior Lining Thermal Conductivity (k) 0.0016 kW/m-K
Interior Lining Specific Heat (c) 0.75 kJ/kg-K
Interior Lining Density (ρ) 2400 kg/m³
Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

EXPERIMENTAL THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	kρc (kW/m²-K)²-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m³)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Select Material
Concrete
Scroll to desired material then Click the selection

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 200.00 kW

Calculate

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Slide 13

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Notes:

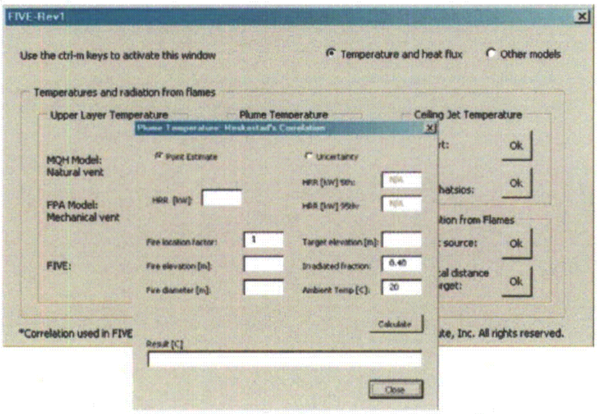
Slide 14

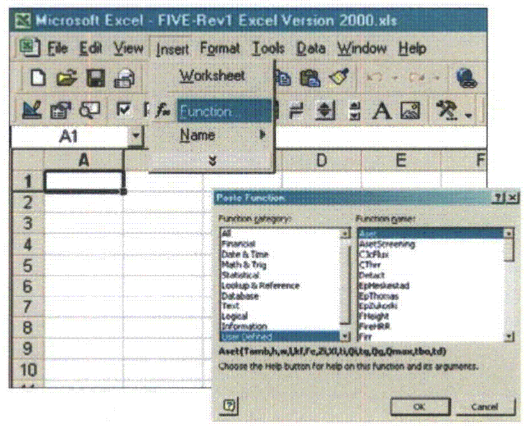
Notes:

Module II-10: PROCESS
Hand Calcs – FIVE-Rev1

- More than ten years after FIVE, most of the equations are still considered "State-of-the-Art"
- A revision of the quantitative fire hazard techniques in FIVE
- Most of the hand calculations in the original EPRI publication and some other models available in the fire protection engineering literature
  - 4 stage heat release rate profile based on t2 growth
  - Heskestad's flame height model
  - A radiation model from a cylindrical flame to targets
  - Models for velocity of plume and ceiling jet flows
  - Model for plume diameter as a function of height
  - MQH model for room temperature
  - Model for visibility through smoke

Module II-10: PROCESS
Hand Calcs – FIVE-Rev1





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Slide 15

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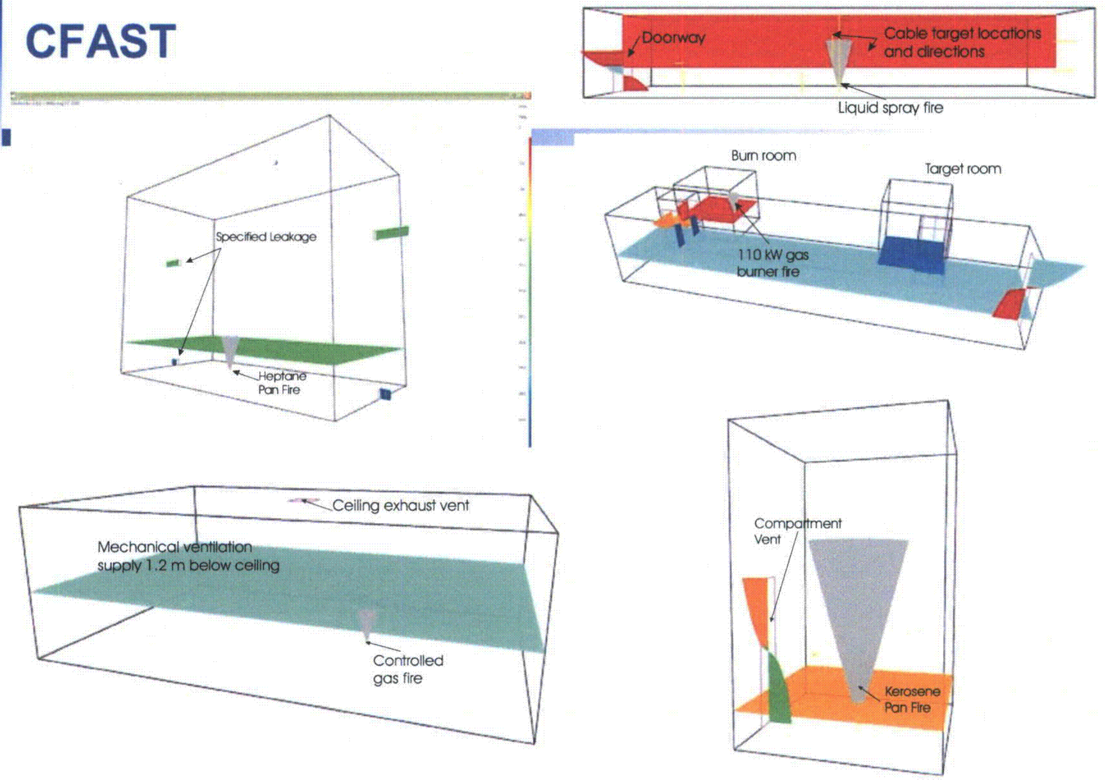
Slide 16

CFAST



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Slide 16

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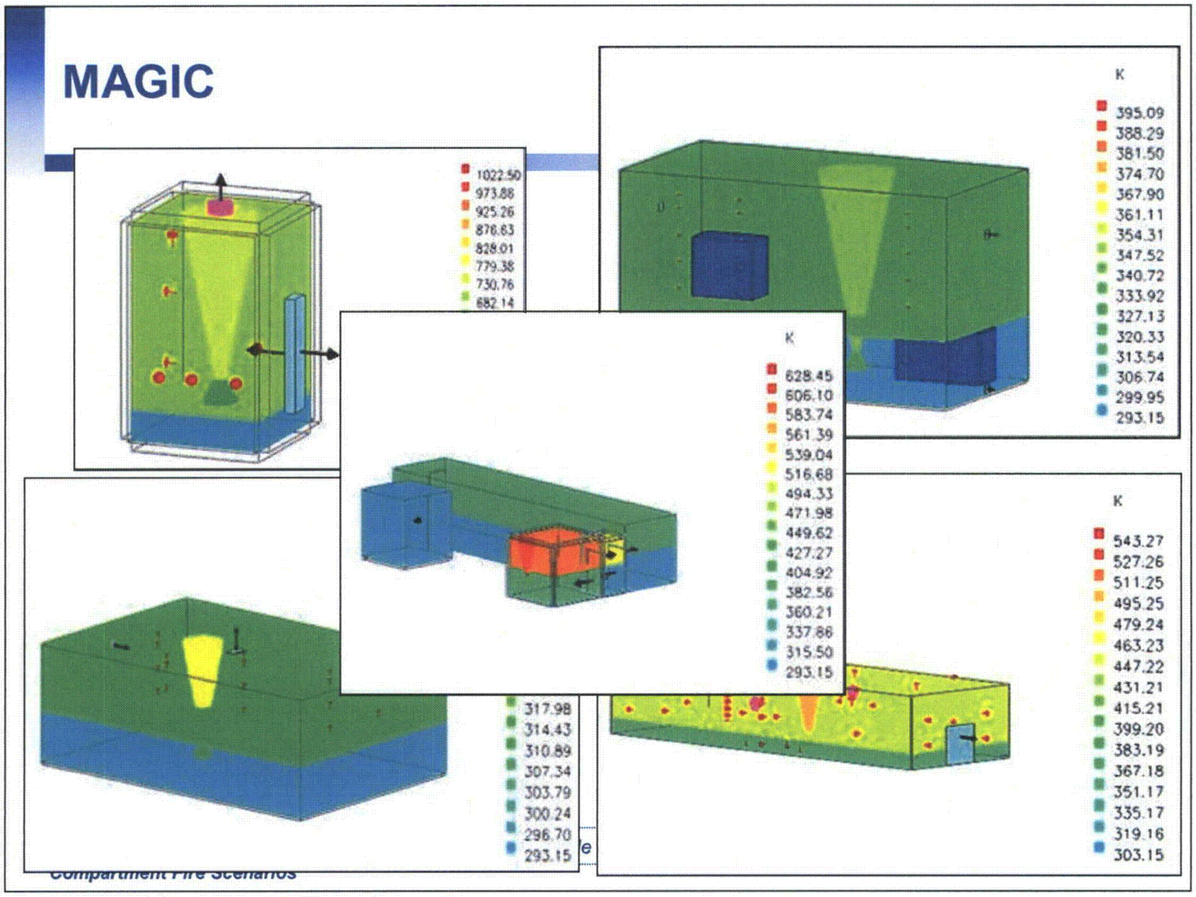
Notes:

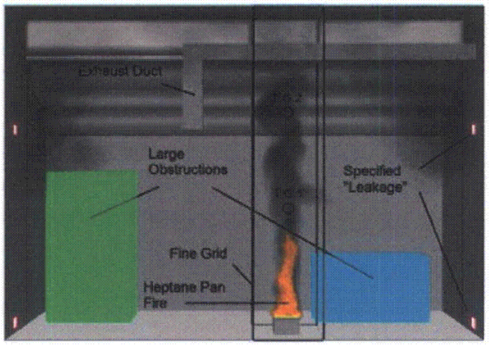
Slide 17

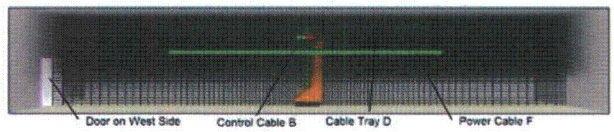


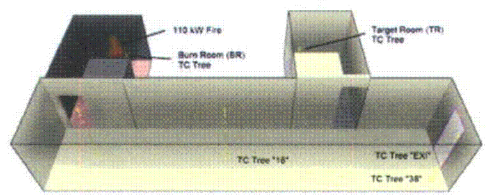
Notes:

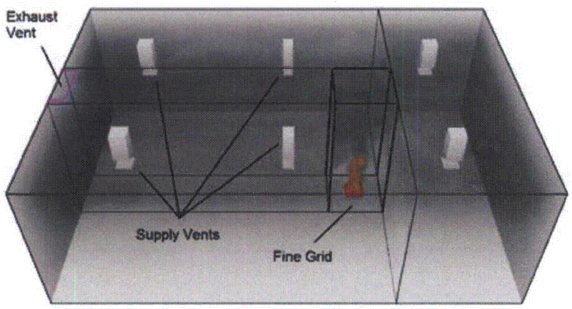
Slide 18

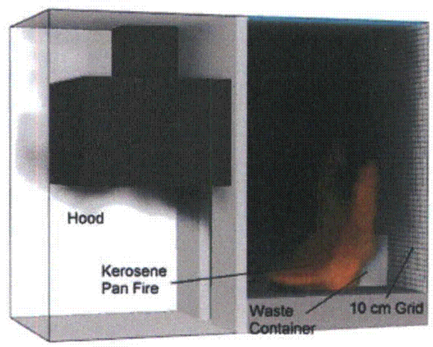
FDS











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Slide 18

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Notes:

Slide 19

Module II-10: PROCESS
Fire Detection/Suppression Analysis

- 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
- Workshop problem 11a-09

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Slide 19

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Notes:

Slide 20

Module II-10: PROCESS
Calculate Severity Factor

- The time to target damage, and as a result the non-suppression probability is a function of the postulated heat release rate
- The severity factor should be calculated in combination with the non-suppression probability
- Workshop problem 11a-10, 11a-11

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Slide 20

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Notes:

Slide 21

Module II-10: PROCESS
Calculate Fire Scenario Frequency

Severity factor for scenario k

$$\lambda_k = \lambda_{i,k} \cdot SF_k \cdot P_{ns,k}$$

Ignition frequency for scenario k

Non-suppression probability for scenario k

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Slide 21

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Notes:

Slide 22

Notes:

Module II-10: PROCESS
Document Analysis Results

- The first tier documentation should be sufficient in detail to allow for an independent reader to understand
  - Scenarios postulated, the basis for their selection and analysis,
  - The tools utilized in the analysis and basis for selection,
  - The final results of the analysis
- The second tier documentation should provide the details of each individual analysis performed including:
  - Details of scenario selection process,
  - The fire modeling analyses performed
- All specific considerations and assumptions should be recorded clearly.

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Slide 22

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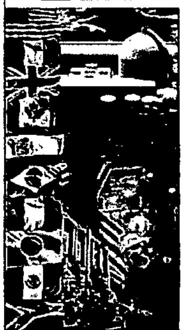
Session 8: Detection and Suppression

Slide 1

Notes:



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III: Detection and Suppression Appendix P

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Slide 2

Notes:

DETECTION & SUPPRESSION
Objectives

The objectives of this module are:

- Describe the process for calculation the non-suppression probability
- Describe the assumptions underlying the recommended approach for determining the non-suppression probability.

Slide 3

DETECTION & SUPPRESSION
Generalities

State of the art fire models do not have the capabilities of modeling the effects of all the different fire detection and suppression strategies available in NPP fire scenarios.

- Time to target damage and non suppression probabilities are independent calculations

- The time to target damage is an input to the detection/suppression analysis

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Slide 4

DETECTION & SUPPRESSION
Crediting a Fire Det or Supp System

Detection and suppression systems can be credited in the fire PRA if they are effective and available

- Effectiveness – Will the system detect/control the fire?
  - Designed, installed and maintained according to the code of record and fire protection engineering judgment
  - Based on the specific characteristics of the postulated fire scenario

- Available – Probability of the system operating upon demand

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Module III: Detection and Suppression Appendix P

Slide 4

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Notes:

Slide 5

Notes:

DETECTION & SUPPRESSION
Fire Detection and Suppression Systems

The following fire detection and suppression systems are considered in the recommended approach:

- Fire Detection
  - Prompt detection
  - Automatic detection
  - Delayed detection
- Fire Suppression
  - Prompt suppression
  - Automatic suppression
  - Manually actuated fixed suppression
  - Manual suppression

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Module III: Detection and Suppression Appendix P

Slide 5

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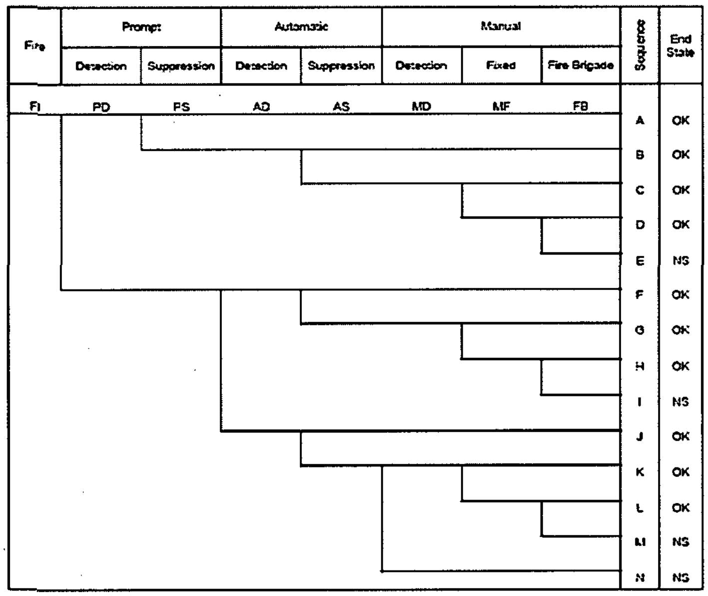
Slide 6

DETECTION & SUPPRESSION
Detection-Suppression Event Tree



$$P_{ns} = E + I + M + N$$

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Slide 7

DETECTION & SUPPRESSION
Detection-Suppression Event Tree

Sequence	Detection	Suppression
A	Prompt detection by	Prompt suppression
B	• Continuous fire watch	Fire suppression by an automatically actuated fixed system
C	• Continuously occupied	Fire suppression by a manually actuated fixed system
D	• High sensitivity detectors	Fire suppression by the fire brigade
E		Fire damage to target items
F	Automatic detection by	Fire suppression by an automatically actuated fixed system
G	• Heat detectors	Fire suppression by a manually actuated fixed system
H	• Smoke detectors	Fire suppression by the fire brigade
I		Fire damage to target items
J	Delayed detection by	Fire suppression by an automatically actuated fixed system
K	• Roving fire watch	Fire suppression by a manually actuated fixed system
L	• Control room verification	Fire suppression by the fire brigade
M		Fire damage to target items
N	Fire damage to target items	

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Module III: Detection and Suppression Appendix P

Slide 7

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Notes:

Slide 8

Notes:

DETECTION & SUPPRESSION
Prompt Detection and Suppression

- Prompt detection
  - Assume 1.0 if a continuous fire watch is credited or in-cabinet detection is available for fires postulated inside cabinets
  - Justify the use of 1.0 if an incipient fire detection system is available
  - Assume 0 if automatic or delayed detection only are credited
- Prompt suppression
  - Credit prompt suppression in hot work fire scenarios
  - Probability is obtained from the welding suppression curve

Slide 9

Notes:

DETECTION & SUPPRESSION
Automatic Detection and Suppression

- Automatic detection
  - Assume a probability of failure no larger than 0.05. This the unreliability for halon systems reported in NSAC 179L.
  - Check for availability!
- Automatic suppression (from NSAC 179L)
  - Halon systems = 0.05
  - CO_2 systems = 0.04
  - Wet pipe sprinklers = 0.02
  - Deluge or pre-action = 0.05
  - Check for availability!

Slide 10

Notes:

DETECTION & SUPPRESSION
Delayed Detection and Suppression

- Delayed detection
  - Assume 1.0 – All fires will eventually be detected
  - Compare time to target damage Vs time to detection and suppression
- Delayed suppression
  - Probability of fire brigade suppression is obtained from the suppression curves
  - Manual actuation of fixed fire suppression systems should include human reliability analysis.

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Slide 10
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Slide 11

Notes:

DETECTION & SUPPRESSION
Detection - Related FAQ

- FAQ 08-0046 Incipient Detection (Status: Open)
  - Issue:
    - Methodology provides no approach for crediting incipient fire detection systems
  - General approach to resolution:
    - Develop an approach that would credit these systems
  - Status:
    - Initial drafts of a proposed approach are under discussion within the RES/EPRI teams
    - Work continues to try to establish a firm technical basis
    - NRC staff and industry review pending

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Module III: Detection and Suppression Appendix P
Slide 11
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Slide 12

DETECTION & SUPPRESSION
Suppression Curves

The suppression curves were developed using FEDB data after 1/1/81

- Developed with the "suppression time" field. If the suppression time was not available, the "duration" field was used.
- Data do not include supervised burn-outs, fires suppressed with automatic systems, and self-extinguished fires.
- Do not include time to detection or fire brigade response.

Notes:

Slide 13

DETECTION & SUPPRESSION
Suppression Curves – Related FAQ

- FAQ 08-0050 Fire Brigade Response (Status: Open)
  - Issue:
    - The fire non-suppression curves as cited as reflecting suppression performance *after* fire brigade response time but a significant fraction of the duration data used in curves includes brigade response time
    - Fire brigade may not be getting adequate credit for suppressing fires prior to damage
  - General approach to resolution:
    - EPRI team has reviewed data and proposed an alternative set of non-suppression curves that would include fire brigade response time
  - Status:
    - Work to date has largely been confined to EPRI team
    - NRC team is currently reviewing proposed resolution
    - Staff and industry reviews pending

Notes:

Slide 14

Notes:

DETECTION & SUPPRESSION
Selection of Suppression Curves

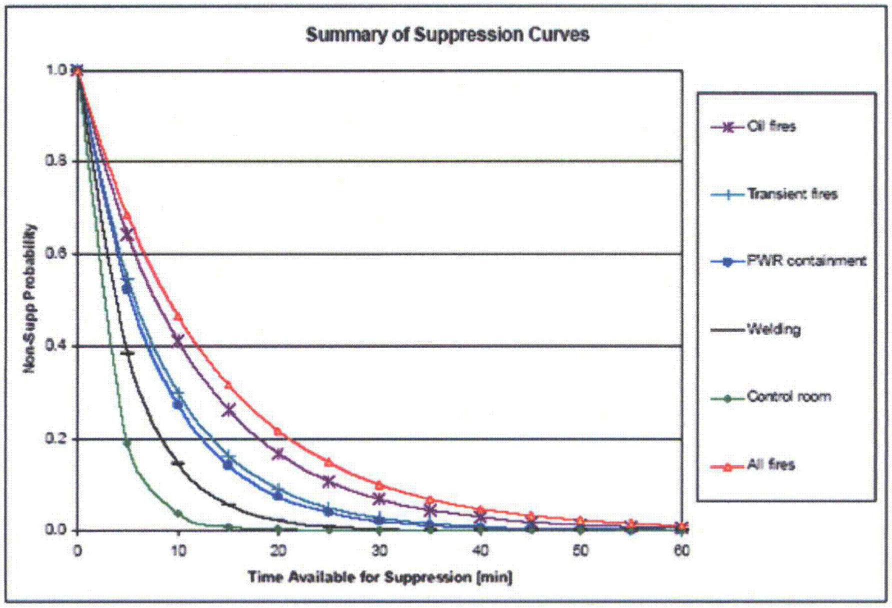
The suppression curve should be selected based on the type of postulated fire.

- For prompt suppression by a welding fire watch, use the welding suppression curve

- If the fire watch is not successful, an appropriate suppression curve should be selected depending on the combustibles ignited due to hot work activities.

Slide 15

DETECTION & SUPPRESSION
Suppression Curves



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Module III: Detection and Suppression Appendix P

Slide 15

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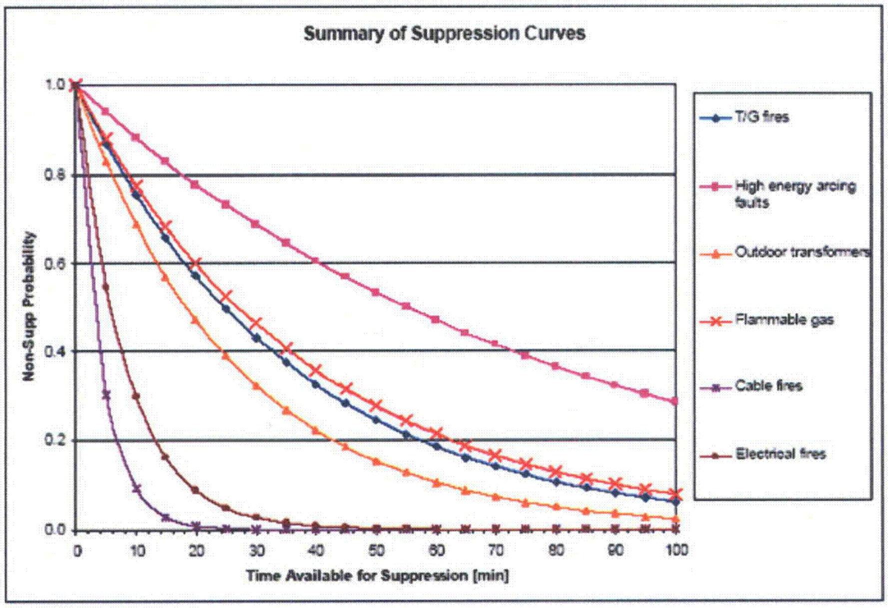
Notes:

Slide 16

DETECTION & SUPPRESSION
Suppression Curves



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Notes:

DETECTION & SUPPRESSION
Suppression Curves

$$P = e^{-\lambda t_{dam}}$$

Suppression curve	n	T	Mean	5th Percentile	50th Percentile	95th Percentile
T/G fires	21	749	0.03	0.02	0.03	0.04
Control room	6	18	0.33	0.15	0.32	0.58
PWR containment	3	23	0.13	0.04	0.12	0.27
Outdoor transformers	14	373	0.04	0.02	0.04	0.06
Flammable gas	5	195	0.03	0.01	0.02	0.05
Oil fires	36	404	0.09	0.07	0.09	0.11
Cable fires	5	21	0.24	0.09	0.22	0.44
Electrical fires	114	942	0.12	0.10	0.12	0.14
Welding fires	19	99	0.19	0.13	0.19	0.27
Transient fires	24	199	0.12	0.08	0.12	0.16
High energy arcing faults	3	239	0.01	0.00	0.01	0.03
All fires	250	3260	0.08	0.07	0.08	0.08

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Slide 17

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Notes:

Slide 18

DETECTION & SUPPRESSION
Dependencies

The following dependencies in suppression analysis could be important:

- Between automatic detection and suppression
  - Example: control panel for a gaseous suppression system
- Between actuated barriers and fire suppression systems
- Between safe shutdown capabilities and automatic suppression
  - Example: crediting fire fighting water for core injection, heat removal or secondary heat removal
- Between manual and automatic suppression

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Slide 18
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Slide 19

DETECTION & SUPPRESSION
Example

The scenario consists of an MCC fire affecting a target in the hot gas layer.

- The room is equipped with a smoke detection system and a manually activated fire suppression system
- Using fire modeling
  - Time to smoke detection = 1 min
  - Time to target damage = 15 min
- From fire drill records and/or plant procedures
  - Brigade response time = 7 min
  - Time to manually actuate the suppression system will not be less than 10 min
  - Time to delayed detection assumed to be 15 min

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Module III: Detection and Suppression Appendix P
Slide 19
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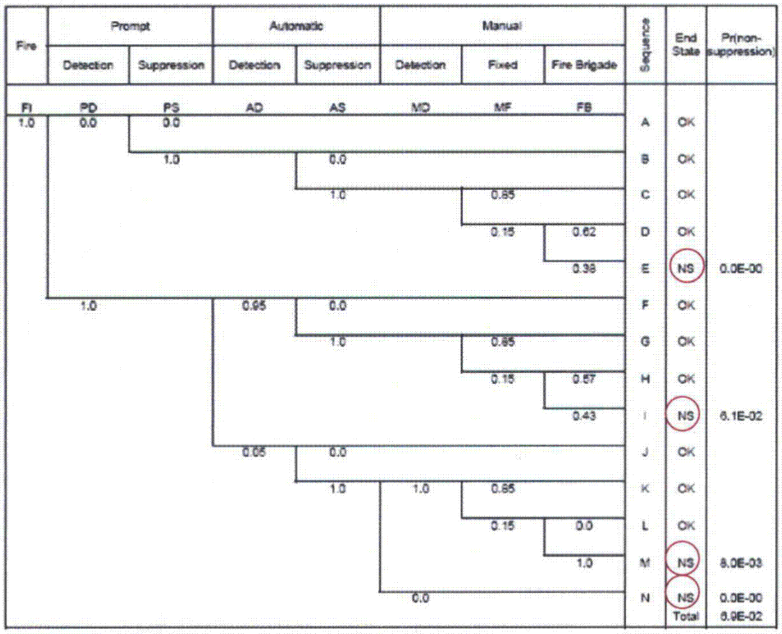
Notes:

Slide 20

DETECTION & SUPPRESSION
Example



- Time available for supp:
  - 15-1-7 = 7 min
- Using the electrical curve
  - P = EXP(-0.12x7)
  - P = 0.43
- Failure of gaseous supp system:
  - P = 0.05 + 0.1

$$P_{ns} = E + I + M + N$$

$$P_{ns} = 6.9E-2$$

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Slide 20

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Notes:

Slide 21

Notes:

DETECTION & SUPPRESSION
Concluding Remarks

The non-suppression probability is credited in Task 11, detailed fire modeling

- Target damage is evaluated assuming no detection/suppression capabilities in the room
- The time to target damage is an input to the detection and suppression analysis.
- The recommended approach includes an event tree capturing prompt, automatic, and delayed detection and suppression capabilities
- The event tree may need to be modified depending on the scenario

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Module III: Detection and Suppression Appendix P

Slide 21

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Session 9: Special Fire Models Part 1

Slide 1

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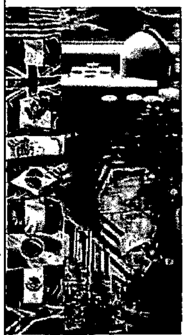
Sandia National Laboratories

SAIC Science Applications International Corporation



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III: Task 11, Special Fire Models Part 1

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September and November 2008
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Notes:

Slide 2

FIRE MODELS

- Generally computational fire models are developed to estimate extent and timing of fire growth
- There are fire scenarios critical to NPP applications that are beyond capability of existing computational fire models
  - Special models are developed for prediction of consequences of such scenarios, based on a combination of:
    - Fire experiments,
    - Operating experience, actual fire events
    - Engineering judgment

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Slide 2

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Notes:

Slide 3

Notes:

SPECIAL MODELS

- Cable fires (modified from IPEEE approaches)
  - Cable spreading room and cable tunnel fire risk
- High energy arcing faults (new)
  - Switchgear room
- Fire propagation to adjacent cabinets (consolidation)
  - Relay room
- Passive fire protection features (consolidation)

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Slide 3

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Slide 4

Notes:

SPECIAL MODELS (Part 2)

- Main control board (new)
- Hydrogen fires (new)
- Turbine generator fires (new)
- Smoke damage (consolidation of research – new risk analysis guidance)

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Slide 5

Notes:

CABLE FIRES (1 of 9)

- No generalized analytical theory is available to accurately model cable fires in all possible configurations in commercial nuclear plants.
- Most of the information compiled for this appendix is in the form of flammability parameters derived from experiments or correlations also developed from experimental data.
- The amount of experimental evidence and analytical tools available to model cable tray fires is relatively small when compared to the vast number of possible fire scenarios that can be postulated for NPPs
- Simplification of these scenarios will be needed

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Module III: Task 11, Special Fire Models Part 1

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Slide 6

Notes:

CABLE FIRES (2 of 9)

Scenarios involving cable fires may start as:

- Self-ignited cable fires
  - Postulate self ignited cable fires in unqualified cables only
  - Self ignited cable fires should be characterized by a cable mass ratio (mass of cables in the room / mass of cables in the plant) representative of the scenario.
  - Cable mass ratio is equivalent to the severity factor
- Or as secondary fires caused by fixed or transient fire sources
  - Cable fires caused by welding & cutting should be postulated in both qualified and unqualified cables.

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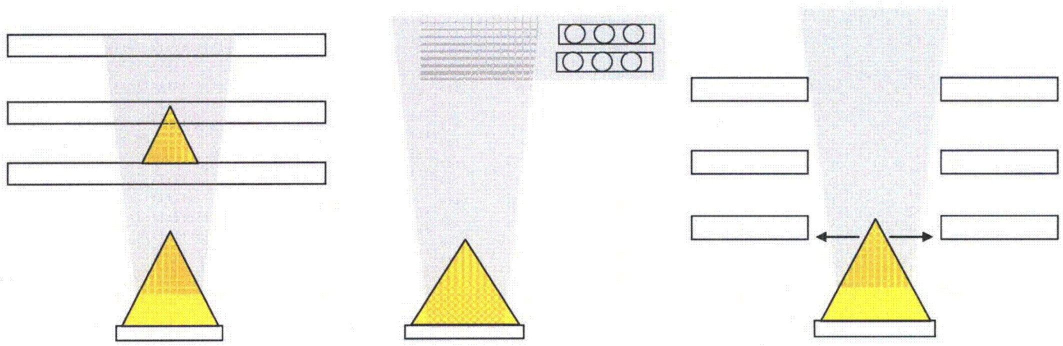
CABLE FIRES (3 of 9)

Cable tray ignition: Simplified cases



Notes:

CABLE FIRES (4 of 9)

Heat release rate from cable fires

$$\dot{Q}_{ct} = 0.45 \cdot \dot{q}_{bs} \cdot A$$

- q_{bs}: bench scale heat release rate per unit area
- A: burning area
  - Length of the ignition source times tray width

Bench Scale HRR Values Under a Heat Flux of 60 kW/m².

Material	Bench Scale HRR [kW/m²]
XPE/FRXPE	475
XPE/Neoprene	354
XPE/Neoprene	302
XPE/XPE	178
PE/PVC	395
PE/PVC	359
PE/PVC	312
PE/PVC	589
PE, Nylon/PVC, Nylon	231
PE, Nylon/PVC, Nylon	218

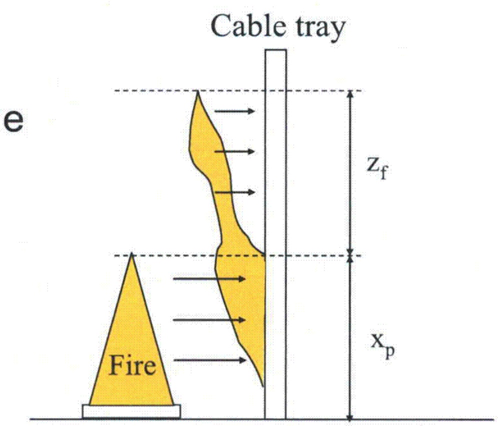
Notes:

CABLE FIRES (5 of 9)

Flame spread

- kf is a constant with a value of 0.01 m²/kW

$$z_f = x_p \cdot \left(k_f \dot{Q}'' - 1\right)$$



Notes:

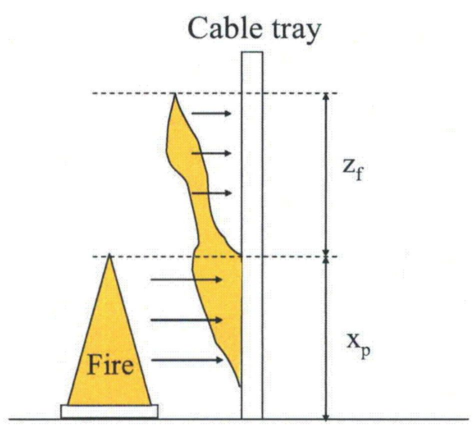
Slide 10

CABLE FIRES (6 of 9)

Flame spread model

$$v = \frac{4\left(\dot{q}_f''\right)^2 \delta_f}{\pi\left(k\rho c\right)\left(T_{ig} - T_{amb}\right)^2}$$

- Vertical trays
  - δ is assumed to be 2 mm
  - q" is assumed as 25 kW/m^2
- Horizontal trays
  - δ is assumed to be z_f
  - q" is assumed as 70 kW/m^2



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Slide 10

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Notes:

Slide 11

CABLE FIRES (7 of 9)

Example

- Material properties

- PVC cables:
  - $K = 0.000192$ kW/m K
  - $\rho = 1380$ kg/m^3
  - $C_p = 1.289$ kJ/kg K
  - $T_{ig} = 218°C$

- XPE cables:
  - $K = 0.000235$ kW/m K
  - $\rho = 1375$ kg/m^3
  - $C_p = 1.390$ kJ/kg K
  - $T_{ig} = 330°C$

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Slide 11

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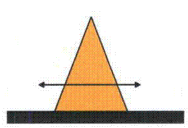
Notes:

Slide 12

CABLE FIRES (8 of 9)

Example

- Horizontal trays
  - Flame spread for XPLE cable = 0.3 mm/sec (~0.05′/min)
  - Flame spread for PVC cable = 0.9 mm/sec (~0.2′/min)



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Slide 12

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Notes:

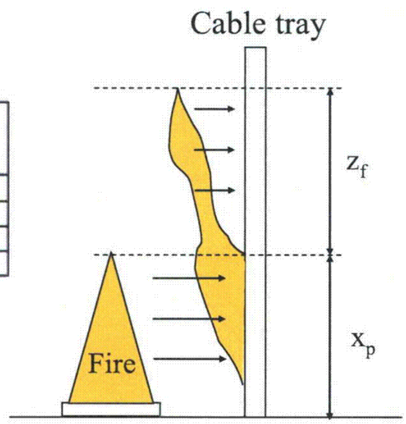
Slide 13

CABLE FIRES (9 of 9)

Example

- Vertical spread in cables
- PE/PVC cables

Material	Bench Scale HRR [kW/m²]	Flame spread rate [mm/s]	Flame spread rate [ft/min]
PE/PVC	395	156	31
PE/PVC	359	137	27
PE/PVC	312	112	22
PE/PVC	589	258	52

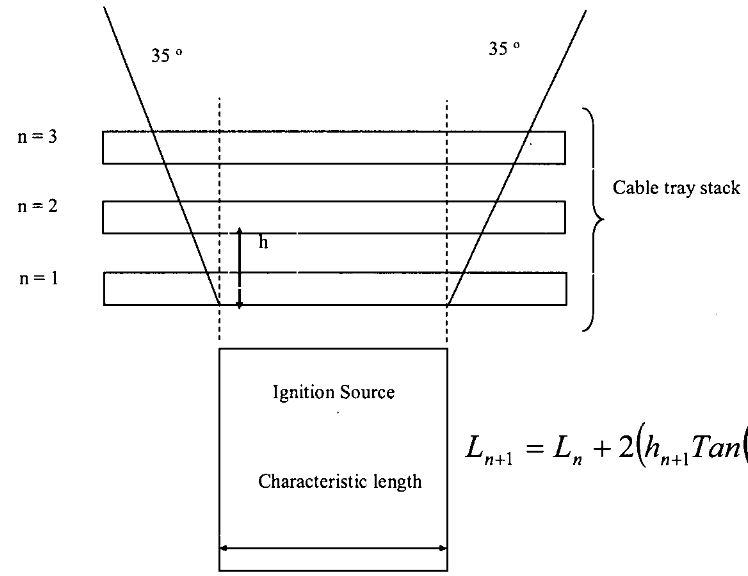


- The heat release rate for XPE cable is 178 kW/m^2. Using these inputs, the estimated flame spread is 11 mm/sec (2 ft/min)

Notes:

Slide 14

FIRE PROPAGATION IN CABLE TRAY STACKS WITH RG 1.75 SEPARATION (1 of 2)



$$L_{n+1} = L_n + 2\left(h_{n+1} Tan\left(35^o\right)\right)$$

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Slide 14

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Notes:

Slide 15

Notes:

FIRE PROPAGATION IN CABLE TRAY STACKS WITH RG 1.75 SEPARATION (2 OF 2)

- First tray to second tray: 4 minutes after ignition of first tray
- Second tray to third tray: 3 minutes after ignition of second first tray
- Third tray to fourth tray: 2 minutes after ignition of third tray
- Fourth tray to fifth tray: 1 minute after ignition of fourth tray
- Balance of trays in stack: 1 minute after ignition of fifth tray

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Slide 15

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Slide 16

Notes:

FIRE PROPAGATION IN CABLE TRAY STACKS WITH RG 1.75 SEPARATION (2 OF 2) (cont'd)

- If there is a second stack of cable trays next to the first stack, spread to the first (lowest) tray in the second stack will be assumed to occur concurrent with spread of fire to the third tray in the original stack .
- Subsequent spread of fire in the second stack will mimic the continued growth of fire in the first stack (e.g., the second tray in the second stack will ignite within 2 minutes of the first tray in the second stack - at the same time as the fourth tray in the first stack.)
- Fire spread will occur at the same rate to stacks on either or both sides of the original stack

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Slide 16

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Slide 17

FIRE PROPAGATION IN CABLE TRAY STACKS Related FAQ

- FAQ 08-0049 (Status: Open)
  - Issue:
    - The cable fire empirical spread model (tray-to-tray, stack-to-stack) has been misapplied in pilot applications
    - Reviewers concluded that misapplication resulted in very conservative fire growth and risk results
  - General approach to resolution:
    - Clarify the bounds of the empirical model to avoid misapplication
  - Status:
    - Proposed resolution has recently completed final review within the RES and EPRI teams
    - Staff and industry final review pending
    - Final revision, as needed, pending
  - Note: as a follow-on, team plans to generate a new FAQ to address broader needs relative to cable fire growth modeling

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Notes:

Slide 18

HIGH ENERGY ARCING FAULTS (1 of 16)

Definition

- Rapid release of electrical energy in the form of heat, vaporized copper, and mechanical force.
- An arc is a very intense discharge of electrons between two electrodes that are carrying an electric current. The arc is created by the flow of electrons through charged particles of gas ions that exist as a result of vaporization of the conductive material.

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Slide 18
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Notes:

Slide 19

Notes:

HIGH ENERGY ARCING FAULTS (2 of 16)

Scope

- Switchgears
- Load centers
- Bus bars

} More than 440 V

- Oil filled outdoor transformers are addressed separately

Slide 20

Notes:

HIGH ENERGY ARCING FAULTS (3 of 16)

General characteristics of HEAF events (from FEDB)

- Indications of heavy smoke in the area, which may delay identification of the fire origin and whether the fire is still burning.
- In nearly all of these events, the HEAF initiates in the feed breaker cubicle. This is because this is where most of the electrical energy in a high-energy cabinet resides.
- HEAFs occurring in 480V switchgears did not report damage beyond the switchgear itself, but some resulted in the cabinet opening.

Slide 21

HIGH ENERGY ARCING FAULTS (4 of 16)

General characteristics of HEAF events (from FEDB)

- Initial use of fire extinguishers may be ineffective in severe HEAF events regardless of the extinguishing agent (CO_2, Halon, or dry chemical). The fires were eventually suppressed with water by the fire brigade.
- No conclusions can be made regarding the effectiveness of fixed fire suppression systems for the ensuing fire. Only one event was successfully suppressed with an automatic Halon system.
- Durations of the fires involving HEAF range from minutes to over an hour. The short durations generally reflect events that do not result in large ensuing fire(s), either in the device itself or external fires.

Notes:

Slide 22

HIGH ENERGY ARCING FAULTS (5 of 16)

General characteristics of HEAF events (from FEDB)

- Sustained fires after the initial HEAF involve combustible materials (cable insulation, for the most part) near the cabinet.
- Damage may extend to cables and cabinets in the vicinity of the high-energy electrical cabinet.
- Damage to cabinet internals and nearby equipment (if observed) appears to occur relatively early in the event.

Notes:

Slide 23

Notes:

HIGH ENERGY ARCING FAULTS (6 of 16)

The arcing or energetic fault scenario in these electrical devices consists of two distinct phases, each with its own damage characteristics and detection/suppression response and effectiveness.

- The first phase is a short, rapid release of electrical energy followed by ensuing fire(s) that may involve the electrical device itself, as well as any external exposed combustibles, such as overhead exposed cable trays or nearby panels, that may be ignited during the energetic phase.

Slide 24

Notes:

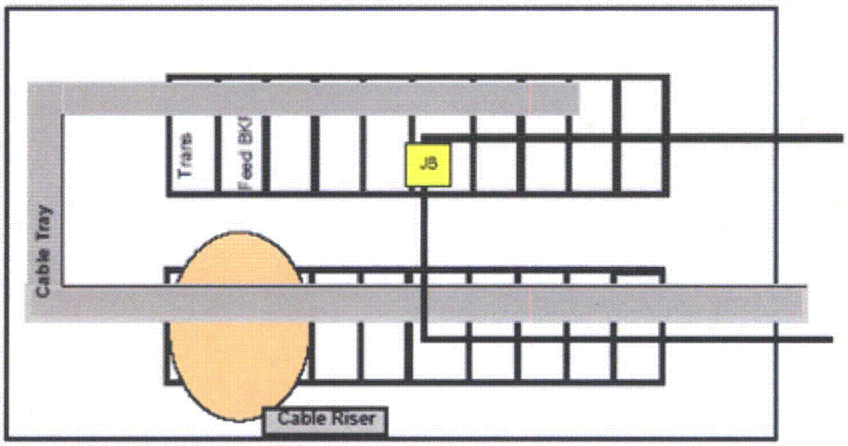
HIGH ENERGY ARCING FAULTS (6 of 16) (cont'd)

- The second phase, i.e., the ensuing fire(s), is treated similar to electrical cabinet fires described else where in this procedure, with one distinction. Any closed electrical cabinet subject to a HEAF is opened to a fully ventilated fire. In dealing with postulated switchgear and load center fires, both phases should be considered.

Slide 25

HIGH ENERGY ARCING FAULTS (7 of 16)

The zone of influence



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Notes:

Slide 26

HIGH ENERGY ARCING FAULTS (8 of 16)

High-Energy Phase: The zone of influence

- The initial arcing fault will cause destructive and unrecoverable failure of the faulting device, e.g., the feeder breaker cubicle, including the control and bus-bar sections.
- The next upstream over-current protection device in the power feed circuit leading to the initially faulting device will trip open, causing the loss of all components fed by that electrical bus. This fault may be recoverable if the initial faulting device can be isolated from the feeder circuit.
- The release of copper plasma and/or mechanical shock will cause the next directly adjoining/adjacent switchgear or load center cubicles within the same cabinet bank and in all directions (above, below, to the sides) to trip open.

Notes:

Slide 27

HIGH ENERGY ARCING FAULTS (9 of 16)

High-Energy Phase: The zone of influence

- Any unprotected cables that drop into the top of the panel in an open air-drop configuration will ignite.
  - Cables in conduit or in a fire wrap are considered protected in this context. In other words, if cables are protected (i.e., not exposed) by conduit or fire wrap, they are assumed damaged, but not ignited, and they do not contribute to the fire load.
  - Armored cables with an exposed plastic covering are considered unprotected in this context.
- Exposed cables, or other exposed flammable or combustible materials or transient fuel materials located within this same region (0.9 m (3') horizontally) will be ignited.

Notes:

Slide 28

Notes:

HIGH ENERGY ARCING FAULTS (10 of 16)

High-Energy Phase: The zone of influence

- Any unprotected cables in the *first* overhead cable tray will be ignited concurrent with the initial arcing fault provided that this first tray is within 1.5 m (5′) vertical distance of the top of the cabinet. The cable tray fire will propagate to additional trays consistent with the approach provided for the treatment of cable tray fires elsewhere in this document, assuming that the time to ignition of the first tray is zero rather than the normal 5 minutes.
  - This applies to any cable tray located directly above the panel.
  - This applies to any cable tray above the aisle way directly in front of, or behind, the faulting cabinet, provided some part of that tray is within 0.3 m (12") horizontally of the cabinet's front or rear face panel.
  - Cables in conduit or in a fire wrap are considered protected in this context.
  - Armored cables with an exposed plastic covering are considered unprotected in this context

Slide 29

Notes:

HIGH ENERGY ARCING FAULTS (11 of 16)

High-Energy Phase: The zone of influence

- Any vulnerable component or movable/operable structural element located within 0.9 m (3′) horizontally of either the front or rear panels/doors, and at or below the top of the faulting cabinet section, will suffer physical damage and functional failure.
  - This will *include* mobile/operable structural elements like fire dampers and fire doors.
  - This will *include* potentially vulnerable electrical or electromechanical components such as cables, transformers, ventilation fans, other cabinets, etc.
  - This will *exclude* fixed structural elements such as walls, floors, ceilings, and intact penetration seals.
  - This will *exclude* large components and purely mechanical components such as large pumps, valves, major piping, fire sprinkler piping, or other large piping (1" diameter or greater).
  - This may *include* small oil feed lines, instrument air piping, or other small piping (less than 1" diameter).

Slide 30

Notes:

HIGH ENERGY ARCING FAULTS (12 of 16)

- In the case of bus ducts, the following equipment should be assumed damaged and/or ignited
  - The entire length of the bus duct.
  - Any cable (damage or ignition) or combustibles (ignition only) immediately adjacent to the bus duct.
  - Equipment connected to the bus duct.
  - If there are fire barriers along the length of the bus duct, these can be credited to limit damage and/or ignition. It may be assumed that the damage and/or ignition from a arcing fault in the bus duct is limited to one side of the fire barrier, except when analyzing multi-compartment fire scenarios that account for failure of the fire barrier(s).

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Module III: Task 11, Special Fire Models Part 1

Slide 30

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Slide 31

Notes:

HIGH ENERGY ARCING FAULTS (13 of 16)

Detection and Suppression

- The amount of smoke from any damaging HEAF event expected to activate any smoke detection system in the area.
- Manual suppression by plant personnel and the fire brigade may be credited to control and prevent damage outside the initial ZOI from ensuing fires.
- Separate suppression curves are developed for these fires documented in Appendix P to the Fire Modeling procedure.

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Slide 31

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Slide 32

HIGH ENERGY ARCING FAULTS (14 of 16)

Modeling HEAF in the Fire PRA

- Identify the equipment in the room where a HEAF can be generated. As indicated earlier, this equipment includes, for the most part, 4160 V to 440 V switchgear cabinets, load centers, and bus bars.
- Two types of initiating events should be postulated for each identified equipment:
  - A HEAF event with an ensuing fire, and
  - A regular equipment fire (no HEAF).

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Notes:

Slide 33

HIGH ENERGY ARCING FAULTS (15 of 16)

Non Suppression Probability and Severity Factors

- Assign a generic frequency for HEAFs listed in Task 6, and apportion it with the location and ignition source weighting factors to the equipment under analysis.
- Assume targets in the ZOI are damaged at time zero.
- The probability of no manual suppression for the targets in the ZOI is 1.0.
- The severity factor for a scenario consisting of targets in the ZOI only is 1.0.
- Probability of no automatic suppression for targets in the ZOI is 1.0
- The probability of no manual suppression for targets outside the ZOI can be calculated using the detection suppression event tree described in Appendix P, with the HEAF manual suppression curve.

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Module III: Task 11, Special Fire Models Part 1 | Slide 33 | A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Notes:

Slide 34

Notes:

HIGH ENERGY ARCING FAULTS (16 of 16)

Example

- Consider a HEAF scenario consisting of a switchgear cabinet affecting two targets. A stack of three cable trays is above the cabinet. The first tray in the stack is 0.9 m (3′) above the cabinet. It has been determined that one of the targets is in the first tray. The other target is in the third tray.
- According to the approach provided in Section M.3, the first target is assumed ignited at the time of the HEAF. The second target is damaged at time 7 minutes (4 minutes for fire propagation from the first to the second tray, and 3 minutes for fire propagation from the second to the third tray).
  - A scenario involving target in the first tray $CDF_i = \lambda_g \cdot W_L \cdot W_{is} \cdot CCDP_i$
  - A scenario involving the two targets $CDF_i = \lambda_g \cdot W_L \cdot W_{is} \cdot P_{ns} \cdot CCDP_i$

Slide 35

Notes:

FIRE PROPAGATION TO ADJACENT ELECTRICAL CABINETS (1 of 3)

Analytical fire models may be used in all types of fire propagation and damage scenarios. .

- This appendix discusses empirical approaches for determining:
  - Fire propagation to adjacent cabinets
  - Fire induced damage in adjacent cabinets
- Empirical approach based on SNL and VTT experiments

Slide 36

Notes:

FIRE PROPAGATION TO ADJACENT ELECTRICAL CABINETS (2 of 3)

The empirical model for fire propagation consists of the following rules:

- Assume no fire spread if either:
  - Cabinets are separated by a double wall with an air gap, or
  - Either the exposed or exposing cabinet has an open top, *and* there is an internal wall, possibly with some openings, *and* there is no diagonal cable run between the exposing and exposed cabinet.
- If fire spread cannot be ruled out, or cabinets are separated by a single metal wall, assume that no significant heat release occurs from the adjacent cabinet for 10 minutes if cables in the adjacent cabinet are in direct contact with the separating wall, and 15 minutes if cables are not in contact with the wall.

Slide 37

Notes:

FIRE PROPAGATION TO ADJACENT ELECTRICAL CABINETS (3 of 3)

The empirical model for fire damage consists of the following rules:

- Assume loss of function in an adjacent cabinet if there is not a double wall with an air gap.
- Assume no damage in the second adjacent cabinet occurs until after the fire propagates to the adjacent cabinet. Assume damage can occur earlier if there are large openings in a wall and plenum areas in which a hot gas layer is likely to form.
- Assume no damage to an adjacent cabinet if:
  - There is a double wall with an air gap, and
  - There are no sensitive electronics in the adjacent cabinet (or the sensitive electronics have been "qualified" above 82°C).
- Assume damage to sensitive electronics occurs at 10 minutes if there is a double wall with an air gap.
- Assume damage to sensitive electronics can be prevented before 10 minutes if the fire is extinguished and the cabinet is cooled, e.g., by CO_2 extinguishers.

Slide 38

PASSIVE FIRE PROTECTION FEATURES (1 of 6)

Most of the fire protection capabilities of passive fire protection features cannot be evaluated using analytical fire modeling tools.

- Empirical approaches
- Limited analytical approaches
- Probabilistic approaches

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Module III: Task 11, Special Fire Models Part 1

Slide 38

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Notes:

Slide 39

PASSIVE FIRE PROTECTION FEATURES (2 of 6)

Passive fire protection refers to fixed features put in place for reducing or preventing fire propagation. Some examples are:

- Coatings
- Cable tray barriers
- Fire stops

} Empirical approach

- Dampers
- Penetration seals

} Probabilistic approach

- Doors
- Walls

} Limited analytical approach

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Module III: Task 11, Special Fire Models Part 1

Slide 39

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Notes:

Slide 40

Notes:

PASSIVE FIRE PROTECTION FEATURES (3 of 6)

The analytical approach for modeling the response of passive fire protection features to fire generated conditions consists of a heat transfer analysis.

- The boundary conditions are the fire generated conditions. In general, these consist of the heat flux exchanges at the surface of the passive feature.
  - Thermo-physical properties of the material are necessary. These properties are readily available for some materials like concrete or steel.
- Models can be used for estimating the temperature profile throughout the thickness of the barrier
- Effects of cracks and gaps in doors or walls can be evaluated only with the objective of analyzing smoke migration.

PASSIVE FIRE PROTECTION FEATURES (4 of 6)

The empirical approaches consist of replicating the thermal response of fire protection features observed in fire tests in the postulated fire scenarios.

- Coatings: SNL tests
  - The cable tray configurations included both a single cable tray and a two-tray stack. Exposure fires included either a gas burner or a diesel fuel pool fire.
- Assume coated, nonqualified cables will not ignite for at least 12 minutes, and coated, nonqualified cables will not be damaged for at least 3 minutes for large exposure fires, and for cable tray fires, more likely about 10 minutes.

Coating	Time to Ignition (min)	Time to Damage (min)
Lower Tray Response		
FlameMaster 71A	13	10
FlameMaster 77	13	6
Vimasco #1A	12	3
Carboline Intumastic 285	No	10
Quelcor 703B	12	11
Upper Tray Response		
FlameMaster 71A	No	11
FlameMaster 77	No	11
Vimasco #1A	12	7
Carboline Intumastic 285	No	19
Quelcor 703B	12	11

Notes:

Slide 42

Notes:

PASSIVE FIRE PROTECTION FEATURES (5 of 6)

The empirical approaches consist of replicating the thermal response of fire protection features observed in fire tests in the postulated fire scenarios.

- Cable tray barriers and fire stops: SNL tests (same configuration as coating tests)
- The following systems were tested:
  - Ceramic wool blanket wrap, solid tray bottom covers, solid tray top cover with no vents, solid tray bottom cover with vented top cover, one-inch insulating barrier between cable trays, and fire stops.
- Propagation of the fire to the second tray was prevented in each case.

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Module III: Task 11, Special Fire Models Part 1

Slide 42

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Slide 43

Notes:

PASSIVE FIRE PROTECTION FEATURES (5 of 6) (cont'd)

- Barriers seem to substantially delay cable damage for qualified cable. The barriers did not delay cable damage for nonqualified cable.
- Results considered most appropriate to exposure fires with smaller HRR and to cable trays in a stack threatened by fires in lower trays.
  - Each barrier prevents cable tray ignition until well after the fire brigade reaches the scene (i.e., greater than 20 minutes),
  - Each barrier prevents damage in *qualified* cable with solid tray bottom covers until well after the fire brigade reaches the scene.

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Module III: Task 11, Special Fire Models Part 1

Slide 43

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Slide 44

Notes:

PASSIVE FIRE PROTECTION FEATURES (6 of 6)

Probabilistic modeling of passive fire suppression systems

- Dampers: Equipment unavailability obtained from inspection results
- Penetration seals: Equipment unavailability obtained from inspection results

Session 10a: Special Fire Models Part 2

Slide 1

Notes:

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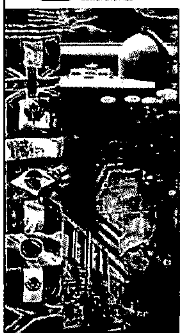
EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III Pt. 2: Special Fire Models Part 2

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Slide 2

Notes:

Module III-11, Pt. 2: Special Models Part 2
Scope of this Module

- Module III-11, Pt. 2 covers the three remaining "Special Models"
  - Main Control Board Fires (Appendix L)
  - Turbine Generator (TG) Set Fires (Appendix O)
  - Hydrogen Fires (Appendix N)

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Module III Pt. 2: Special Fire Models Part 2

Slide 2

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Slide 3

Module III-11, Pt. 2: Special Models Part 2
Main Control Board Damage Likelihood Model

- The main control board (MCB) presents many analysis challenges
  - Design practices vary widely
    - Configuration of the boards themselves
    - Relay rack room versus main control room
    - Separation and partitioning within MCB
  - MCB may be important to risk, but IPEEE vintage approaches were identified as a weakness of those studies
  - Fire models cannot currently predict in-panel fire behavior so an alternative approach is needed
- A method is provided to assess the likelihood that a fire in the MCB will grow large enough to damage a specific target set as defined by a specific physical region of the board

Notes:

Slide 4

Module III-11, Pt. 2: Special Models Part 2
Main Control Board Damage Likelihood Model

- The MCB model is built on several assumptions that are specific to the MCB and the MCR
  - MCB fire frequency partitioning approach
  - Suppression times for MCR fires
  - Fire characteristics of a MCR type control panel (peak HRR and growth profile)
  - Damage limits for control components
- This model applies ONLY to the MCB itself
  - Not intended for other electrical cabinets/panels
  - Not intended for MCR "back-panels"
  - Not intended for the relay rack room or other similar areas

Notes:

Slide 5

Notes:

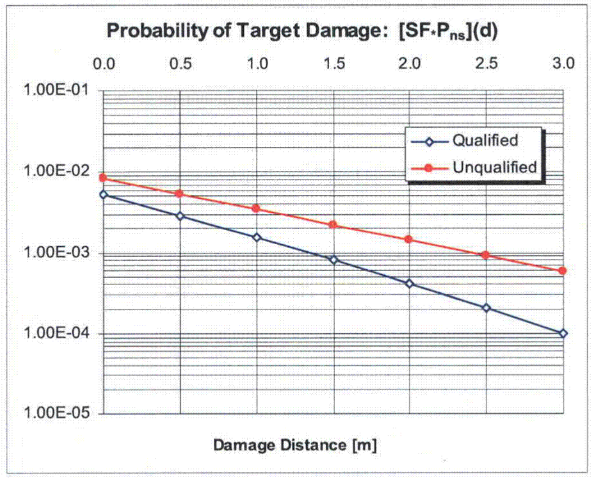
Module II-11, Pt. 2: Special Models Part 2
Main Control Board Damage Likelihood Model

- To use the model you must first identify your target set
  - Example: two control switches on the MCB
- Determine the minimum separation distance between the most remote members of the damage set
  - Consider cable routing within the panel!
- Using this distance, go to the probability curve and estimate the conditional probability that given a fire somewhere in the MCB, the specific zone encompassing the target set will be damaged
- The resulting number includes BOTH the severity factor AND the probability of non-suppression
  - It does not include fire frequency!

Slide 6

Module III-11, Pt. 2: Special Models Part 2
Main Control Board Damage Likelihood Model

- Example:
  - Target set is two switches located 0.5 m apart from each other
  - Inspection shows that the cables leading to each switch are routed in opposite directions such that 2 ft is the minimum separation distance between the switches
  - The MCB contains only IEEE-383 certified low-flame-spread cables
  - The conditional probability that a fire occurring somewhere in the MCB will damage the target set is approximately 3.0E-3



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Module III Pt. 2: Special Fire Models Part 2

Slide 6

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Notes:

Slide 7

Notes:

Module II-11, Pt. 2: Special Models Part 2
Turbine Generator Set Fires

- Four types of fires can occur involving the turbine generator set, and each is treated differently:
  - Electrical fires in the exciter
  - Hydrogen fires:
  - General oil fires
  - Catastrophic failure (e.g., blade ejection)

Slide 8

Notes:

Module III-11, Pt. 2: Special Models Part 2
Turbine Generator Set Fires: Exciter Fires

- Exciter fires do occur, but all evidence indicates fires remain small and non-threatening
  - No evidence of any exciter fire that led to damage to anything other than the exciter itself
  - No attempt was made to estimate likelihood of a severe exciter fire (one that challenges external targets)
- Recommended Practice:
  - Assume exciter fires remain confined to the exciter
  - Verify for your application, but should not represent a significant risk contributor

Slide 9

Module III-11, Pt. 2: Special Models Part 2
Turbine Generator Set Fires: Hydrogen Fires

- Database shows 13 TG set hydrogen fires, two categorized as severe, the rest were small leaks (generally associated with seals) with limited damage range
- For small fires:
  - Assume damage will be limited to within a few feet of the point of release
  - Secondary ignitions should be considered and treated if there are nearby combustibles
  - See more in Hydrogen Fires discussion (Appendix N)

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Module III Pt. 2: Special Fire Models Part 2
Slide 9
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Notes:

Slide 10

Module III-11, Pt. 2: Special Models Part 2
Turbine Generator Set Fires: Hydrogen Fires

- For severe fires, widespread damage may occur due to an explosion or detonation of the hydrogen gas.
  - Assume fire may damage all Fire PRA cables and equipment within the line of site of the generator and its bearings (including above and below)
  - Hydrogen explosion could cause some structural damage as well
  - For further discussion – see Hydrogen Fires

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Slide 10
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Notes:

Slide 11

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Module III-11, Pt. 2: Special Models Part 2
Turbine Generator Set Fires: Catastrophic Failure

- International experience includes a few fires initiated by catastrophic turbine failure that resulted in widespread damage including structural damage
  - Examples: Vandellos (1989), Narora (1993), Chernobyl Unit 2 (1991)
  - Events involve a combination of turbine blade ejection, hydrogen release, and large oil fires.
- Domestically, only one event came close to involving all of these elements (Salem, 1991)
  - Event involved minor damage due to existence of an automatic suppression system and prompt fire brigade response
  - Indicates that both automatic fire suppression systems and fire brigade should be credited to prevent catastrophic consequences observed internationally

Slide 12

Notes:

Module III-11, Pt. 2: Special Models Part 2
Turbine Generator Set Fires: Catastrophic Failure

- Screening approach: assume that the *conditional probability* that given a T/G set fire, the event will involve catastrophic failure (e.g., blade ejection), hydrogen, and oil fires:

  1 over 38 events or 0.025

  - With *successful* suppression, damage would be limited to the T/G system, as was the case at Salem
  - In case of failure of all suppression, automatic and manual, assume loss of all Fire PRA cables and equipment in the Turbine Building
    - Possible failure of exposed structural steel as well
  - Estimate screening CDF contribution, refine as appropriate

Slide 13

Module III-11, Pt. 2: Special Models Part 2
Hydrogen Fires

- This discussion (Appendix N) applies to general hydrogen fires
  - Including TG set fires
  - Also other source of hydrogen leaks and releases (e.g., recombiners, storage tanks, piping, etc.)
- The intent was to provide general discussion of hydrogen fires and their potential effects
- The discussion stops short of recommending modeling approaches, but does provide references to various information resources

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Slide 13

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Notes:

Slide 14

Module III-11, Pt. 2: Special Models Part 2
Hydrogen Fires

- Two general types of fires:
  - Jet fires originating at point of a H2 leak
    - Critical question will be flame length
  - Explosions
    - If there is a mechanism for the release of large quantities of H2 (e.g., a large leak, a prolonged leak that might not be ignited early) then likelihood of a hydrogen explosion is high
    - References provide additional resources for assessing damage potential for an explosion scenario
    - Critical question will be the severity of the overpressure

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Slide 14

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Notes:

Session 10b: Example Problems

Workshop Problems on Task 11a: Detailed Fire Modeling

This handout includes workshop problems on the different steps of Task 11: Detailed Fire Modeling. Problems are grouped according to the steps defined in NUREG/CR-6850. Detailed fire modeling will be conducted in the switchgear access room (Room 9) located in elevation 20 ft of the auxiliary building.

Workshop Problem Set 11a-01

Step 1a: Identify and Characterize Compartments: Review the following information necessary for fire modeling purposes.

- Room size: For the purpose of this exercise, assume the size of the room is 45' by 22' by 20' high.
- Wall boundaries: The surfaces, floor, ceiling, and walls are reinforced concrete. All the surfaces are 2' thick.
- Doors: The room has three doorways: 1) a double door connecting to switchgear room A, 2) a double door connecting to switchgear room B, and 3) a single door connecting to the stairwell. The size of a single door is 6.5' by 3'.
- Mechanical Ventilation: The switchgear access room has a mechanical ventilation system with a balance 5 air changes per hour.

Workshop Problem Set 11a-02

Step 2a: Identify and Characterize fire Detection and Suppression Features and Systems: Review the following information necessary for fire modeling purposes.

- Prompt detection: Prompt detection is not credited since there is no incipient fire detection system in the room and no continuous fire watch.
- Prompt suppression: Prompt suppression is not credited since there is no continuous fire watch in the room.
- Fixed fire detection system/s (type, and sensor location): An automatic fire detection system is credited since the room is equipped with an automatic fire detection system. The location of the relevant detectors is specified in the corresponding scenario descriptions later in this document.
- Fixed fire suppression system/s (type and nozzle location): An automatic CO_2 system is credited since the room is equipped with an automatic CO_2 system. Upon smoke detection alarm, a timer starts providing 60 seconds delay for life safety purposes. The CO_2 is released after the delay time. The soak time is approximately 20 min.
- Fire brigade arrival time: The fire brigade arrival time is assumed to be 15 min.
- Delayed detection: Delayed detection is credited and assumed to be 15 minutes (consistent with the example in page P-14 of NUREG/CR-6850).

Workshop Problem Set 11a-03

Step 3a: Characterize Fire Ignition Sources: From the Task 6 (Fire Ignition Frequencies) calculation package, list the fixed ignition sources located in the switchgear access room (room 9) and assign a heat release rate probability distribution to each of them from Table G-1 of NUREG/CR-6850.

Solution: Table 1 lists the recommended answer to workshop problem 3.

Table 1: Summary of ignition source characteristics in the switchgear access room.

Equipment ID	Equipment Description	Case (Table E-1 of NUREG/CR-6850)	HRR Profile (Page G-6 in NUREG/CR-6850)
MCC-A1			
MCC-B1			
VITAL-A			
VITAL-B			
Transients			

Step 4a: Identify Secondary Combustibles: No workshop problem is associated with this step. The following discussion provides an example of how to identify and characterize secondary combustibles.

<u>Sample Analysis for Step 4a:</u>
For the purpose of this example, let's assume that there is one cable tray stack above each cabinet in the room. Each stack has two trays. The first tray is 1' above each cabinet. The second tray in the stack is 1.5' above the first tray. The trays are ladder-back. A pictorial representation of the secondary combustibles in provided in Figure 1.

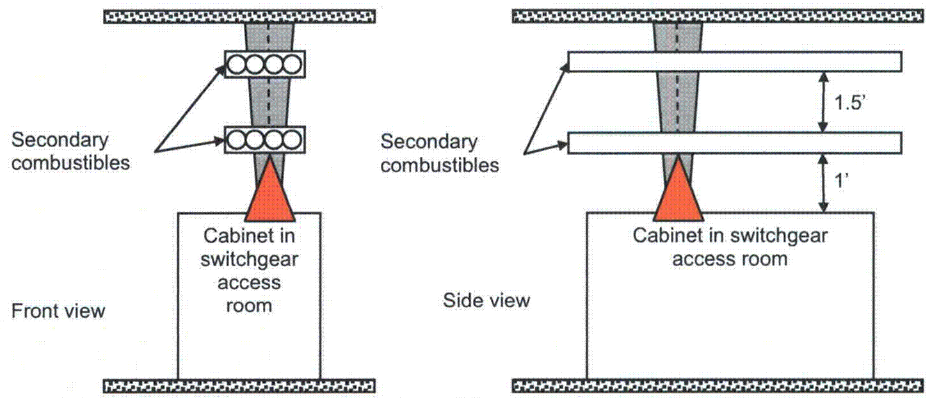

Figure 1: Pictorial representation of the secondary combustibles. Drawing not to scale.

From Table 1, the cabinets in the switchgear access room will have a peak heat release rate of 211 kW. Heskestad's flame height correlation (Chapter 3 of NUREG 1805) suggests a flame height of approximately 4.6' above the ignition source. Therefore, the cable tray stack above the cabinet is expected to ignite and contributing to the fire intensity. Table 2 lists the Heskestad's flame height correlation analysis.

Table 2: Heskestad's flame height correlation analysis.

Heskdestad's Flame Height Correlation	
Inputs	
Fire diameter [m]	0.6
HRR [kW]	211
Results	
Flame height [m]	**1.4**
Flame height [ft]	**4.6**

Step 5a: Identify and Characterize Target Sets: No workshop problem is associated with this step. The following discussion provides an example of how to identify and characterize target sets. In practice, this step requires highlighting of cable tray and conduit targets in room layout drawings based on cable routing analysis and plant walkdowns.

Sample Analysis for Step 5a:
For the purpose of this exercise, let's assume that there are two target sets in the room:
1) HCBT-35A and HCBT-35B, and 2) VCBT-20A, and VCBT-20B. These trays are identified in Figure 2. The trays have both thermo-set and thermo-plastic cables. Specifically, a fire damaging either the two horizontal trays or the two vertical trays will generate the postulated plant condition.

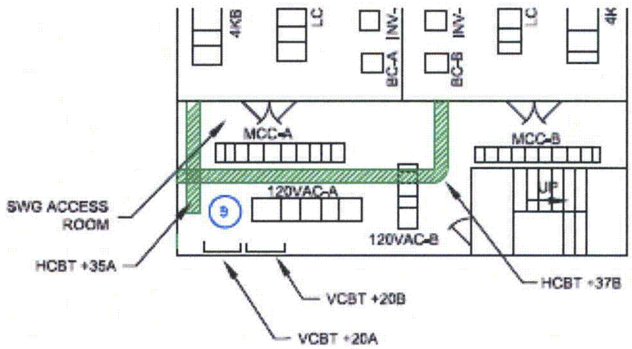

Figure 2: Cable tray locations in the switchgear access room

Tray locations:

- HCBT 35A: This horizontal tray comes into the switchgear access room from switchgear room A. The tray is the second tray in an elevated stack. The lowest tray in the stack is at elevation 33' (13' from the floor). The target tray, HCBT 35A, is at elevation 35' (15' ft from the floor and 2' above the lowest tray in the stack).

- HCBT 37B: This horizontal tray comes in the south direction into the switchgear access room from switchgear room B and turns west. The tray is the first tray in an elevated stack. It is located at elevation 37' (17' from the floor). At the point the cable tray crosses HCBT 35A, it is the third tray in the stack.

- VCBT 20A: This is a vertical cable tray in the south west corner of the room. The tray comes into the room through a floor penetration at elevation 20' and runs up to the ceiling.

- VCBT 20B: This is a vertical cable tray in the south west corner of the room. The tray comes into the room through a floor penetration at elevation 20' and runs up to the ceiling.

Workshop Problem 11a-04

Step 6a: Define the Fire Scenarios to be Analyzed: Define the fire scenarios to be analyzed in the switchgear access room using the information provided or collected in the first five steps.

- Fixed ignition source fire scenarios:

Solution:

- Transient ignition source fire scenarios:

Solution:

Step 7a: Conduct Fire Growth and Propagation Analysis: For the purpose of this workshop, only two of the fire scenarios listed in the previous section are analyzed in detail: Scenario 1, and Scenario 4.

Workshop Problem 11a-05:

Determine if a fire in the ignition sources associate with scenarios 1 and 4 can produce room wide damage in the switchgear access room. If the ignition sources alone are not expected to generate room wide damage, determine the amount of secondary combustibles necessary to achieve it.

Solution:

Workshop Problem 11a-06

Determine the time to target damage, time to smoke detection, time to automatic suppression and the fire brigade arrival time for scenario 1.

Solution:

Workshop Problem 11a-07

Determine the time to target damage, time to smoke detection, time to automatic suppression and the fire brigade arrival time for scenario 4.

Solution:

Workshop Problem 11a-08

Let's assume that MCC-A1, which is the ignition source in scenario 1 it's a 4160V switchgear. In this case, a high energy arcing fault event should be also postulated and evaluated. Determine if the cable tray targets will be within the zone of influence of a high energy arcing fault.

Solution:

Step 8a: Conduct Fire Detection and Suppression Analysis*:* The detection and suppression is reflected in the risk analysis with the non-suppression probability, which is calculated using a Detection/Suppression event tree approach discussed in Appendix P of NUREG/CR-6850, Detection and Suppression Analysis. Recall that the switchgear access room is equipped with a smoke detection system, and an automatic CO_2 system. The CO_2 system has a 60 second warning alarm delay. In addition to these fixed systems, the fire brigade can also provide manual suppression activities.

Considering the above fire protection features, the suppression strategy in the switchgear access room can be summarized as:

1. Indication of smoke detection in control room
2. Control room sends an operator to the switchgear access room to confirm the fire
3. If fire is confirmed, the operator first if the automatic CO_2 system operated.
4. If further suppression activities are warranted after any of the automatic systems, manual suppression by the fire brigade may be used.

Workshop Problem Set 11a-09

Develop a detection suppression event tree for the fire protection strategy defined above.

Solution:

Workshop Problem 11a-10

Step 9a: Calculate Conditional Non-Suppression Probability and Severity Factor:
Determine the severity factor and the non-suppression probability for scenario 1.

Solution:

Workshop Problem 11a-11

***Step 10a: Calculate Scenario Frequency*:** Using the ignition frequency calculated in Task 6 for the ignition sources in the switchgear access room, and the severity factor and non-suppression probability calculated in the previous step for scenario 1, determine the frequency for fire scenario 1.

Solution:

Session 11a: Main Control Room Fire Analysis

Slide 1

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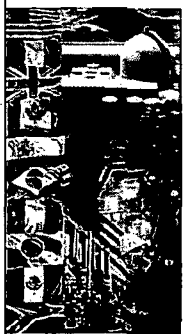

EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 11b - Main Control Room Fire Analysis

Joint RES/EPRI Fire PRA Workshop
September 2008
Washington DC

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Notes:

Slide 2

Main Control Room Fire Analysis
Objectives

The objective of this module is:

- Describe the recommended approach for detailed fire modeling in the main control room. Specifically:
  - Differences between the main control room and other compartments
  - Criteria for abandonment due to fire generated environmental conditions
  - Description of how to calculate:
    - Forced control room abandonment time
    - Conditional probability of damage to a target set

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Task 11b - Main Control Room Fire Analysis

Slide 2

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Notes:

Slide 3

Notes:

Main Control Room Fire Analysis
What is Different in the MCR?

- The control and instrumentation circuits of all redundant trains for almost all plant systems are present in the control room.
  - Redundant train controls may be installed within a short distance
  - Small fires within control panels may be risk-significant.
- The room is continuously occupied, which provides the capability of "prompt detection and suppression."
- Evaluating control room abandonment conditions is necessary.
  - Abandonment refers to situations in which control room operators are forced to leave due to untenable fire generated conditions (temperature, toxicity, and visibility).

Slide 4

Notes:

Main Control Room Fire Analysis
Recommended Steps

- Step 1: Identify and characterize main control room features
- **Step 2: Estimate control room fire frequency**
- Step 3: Identify and characterize fire detection and suppression features and systems
- **Step 4: Characterize alternate shutdown features**
- Step 5: Identify and characterize target sets
- Step 6: Identify and characterize ignition sources
- **Step 7: Define fire scenarios**
- **Step 8: Conduct fire growth and propagation analysis**
- **Step 9: Fire detection and suppression analysis and severity factor**
- **Step 10: Estimate failure probability of using alternate shutdown features**
- **Step 11: Estimate probability of control room abandonment**
- Step 12: Calculate scenario frequencies
- Step 13: Document analysis results

Slide 5

Notes:

Main Control Room Fire Analysis
Step 1: Identify and Characterize MCR Features

The specific features of the control room and the control board are identified.

- Control room dimensions
- Other adjacent compartments included in the MCR proper
- Location, shape, dimensions and special features of the control panels and other electrical panels
- Main control board layout and location of various controls and displays
- Cable penetration into the control room and into the control panels
- Ventilation system characteristics
- Wall construction type and thickness;
- False ceiling features and the ceiling above it
- False floor and cable channels under the floor
- Openings in the false ceiling should be specifically noted as potential pathway for hot gases entering the area between the two ceilings.
- *Problem Set 11b-01 (Example)*

Slide 6

Main Control Room Fire Analysis
Step 2: Control Room Fire Frequency

The MCR fire frequency includes contributions from the Main Control Board (bin #4), PWC - Electrical cabinets (bin #15), PWC- Self Ignited Cable Fires (bin #12), Control/Aux/Reactor Bldg. - general transient fires (bin #7), transient fires caused by welding and cutting (bin #6) and cable fires caused by welding and cutting (bins #5) as follows:

$$\lambda_{MCR} = W_{L,MCR}(\lambda_{MCB} + W_{PWC,Elec.Cab,MCR}\,\lambda_{PWC,Elec.Cab.}$$

$$+ W_{PWC,SICF}\,\lambda_{PWC,SICF} + W_{CAR,trans,MCR}\lambda_{transient}$$

$$+ W_{CAR,weld,MCR}\lambda_{CAR,welding} + W_{CAR,weld\text{-}cables,MCR}\,\lambda_{CAR,\ weld\text{-}cables})$$

Problem Set 11.b-02

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Task 11b - Main Control Room Fire Analysis

Slide 6

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Notes:

Slide 7

Notes:

Main Control Room Fire Analysis
Step 3: Fire Detection and Suppression Features

The detection and suppression features that may be credited when analyzing the fire scenarios are identified in this step.

- Smoke detectors (false and main ceilings and control panels)
- Detectors in the ventilation ducts and their function
- Fixed fire suppression systems inside and outside the control panels,
- Location and characteristics of portable fire extinguishers
- Location and characteristics of hose reels.
- *Problem Set 11b-03 (Example)*

Slide 8

Notes:

Main Control Room Fire Analysis
Step 4: Characterize Alternate Shutdown Features

The features of alternate shutdown capability vary widely among NPP's

- In general, a control panel is installed at a location away from the control room where the operators can control and monitor key core cooling functions and parameters independent of the MCR.
- In other plants, alternate shutdown capability is achieved through a set of control points and control panels located at various points of the plant requiring coordinated actions of several operators.
- It is necessary for the fire risk analysts to understand the alternate shutdown capability of the plant.
  - For example, the analyst may select safety-related target sets on the panel that are not backed up by an alternate shutdown control or instrumentation circuit.
- *Problem Set 11b-04 (Example)*

Slide 9

Notes:

Main Control Room Fire Analysis
Step 5: Identify and Characterize Target Sets

The target sets can be identified by systematically examining combinations of control and instrumentation items found on the control panels, electrical cabinets, wireways, and cable raceways inside the MCR.

- Examine the control panels from one end to the other
- Groups of adjacent controls and instrumentation
- Cursory and conservative estimation of the CCDP/CLERP as the basis
- Elements of a set are located within the reach of a potential fire
- Exposure fire affecting multiple cabinets
- *Problem Set 11.b-05*

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Task 11b - Main Control Room Fire Analysis | Slide 9 | A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Slide 10

Notes:

Main Control Room Fire Analysis
Step 6: Identify and Characterize Ignition Sources

The final product of this step is a list of ignition sources, their relevant characteristics, and fire ignition frequencies associated with each source

- Similar to Step 3.a of single compartment analysis
- Type, quantity, dimensions and heat release rate profile of each source
- Main control board as ignition source
- Assume fire might occur at any point on a control panel
- Other control panels, electrical cabinets, wireways, and cable raceways
- Kitchen appliances and other electrical devices?
- Transient combustible fires
- Frequency of fire ignition based on Step 2b analysis
- *Problem Set 11.b-06*

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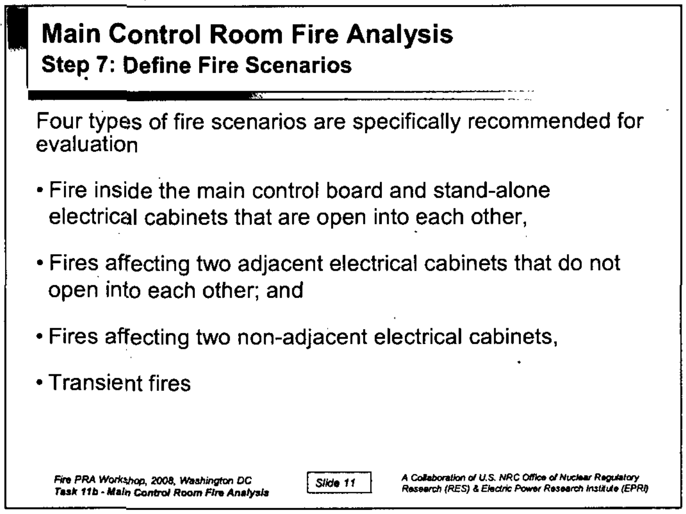
Task 11b - Main Control Room Fire Analysis | Slide 10 | A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Slide 11



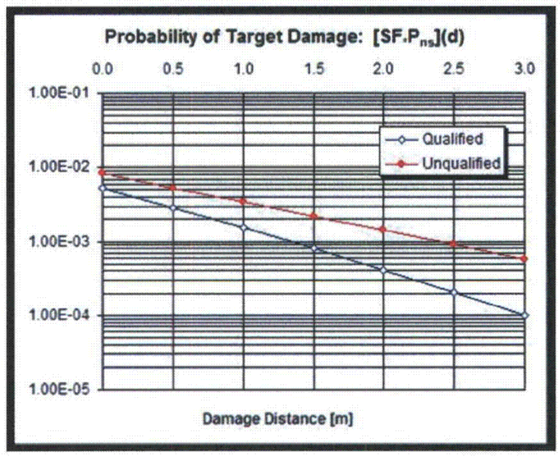
Notes:

Slide 12

Main Control Room Fire Analysis
Step 8: Fire Growth and Propagation Analysis

The methodology suggests the following specific approach for conducting fire growth and propagation analysis:

- Fire inside the main control board
  - Use Appendix L



Notes:

Slide 13

Main Control Room Fire Analysis

Step 8: Fire Growth . . . (cont'd)

A probabilistic model of the main control board fire spread estimates the likelihood that a set of targets separated by a predetermined distance would be affected by a fire.

- Difficult to model fire spread within a cabinet using current state-of-the-art analytical tools.
- Probabilistic model based on EPRI's Fire Events Database and cabinet fire experiments reported in NUREG/CR-4527.
- The likelihood is a combination of severity factors and non-suppression probabilities

$$\lambda(d) = \lambda_{MCB}\,[SF \cdot P_{ns}](d)$$

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Task 11b - Main Control Room Fire Analysis

Slide 13

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Notes:

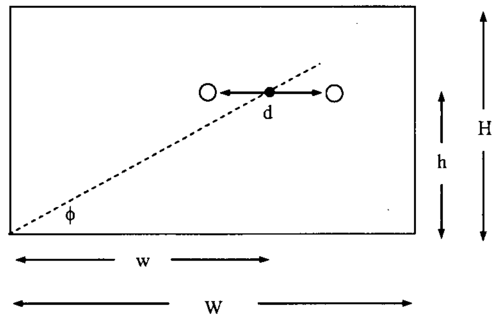
Slide 14

Main Control Room Fire Analysis

Step 8: Fire Growth . . . (cont'd)

The likelihood is a combination of severity factors and non-suppression probabilities integrated over all possible fire events inside the panel that may damage the postulated target set.

- All possible fire origin locations



$$\lambda(d) = \lambda_{MCB}\,[SF \cdot P_{ns}](d)$$

$$[SF \cdot P_{ns}](d) = \frac{1}{H \cdot W} \int_0^H \int_0^W SF(d,w,h) \cdot P_{ns}(d,w,h)\,dw\,dh$$

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Task 11b - Main Control Room Fire Analysis

Slide 14

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Notes:

Slide 15

Main Control Room Fire Analysis

Step 8: Fire Growth . . . (cont'd)

- Two adjacent but separated control cabinets
  - No propagation if panels are separated by a double wall with an air gap (Appendix S)
  - If separated by a single wall,
  - If open back panels, check for direct radiation or other damaging fire generated conditions
- Non-Adjacent cabinets

$$\lambda_{Adjacent\,Cabinets}(d_a) = \lambda_{MCB}[SF \cdot P_{ns}](d_a) P_{ns}(15\,\text{min})$$

  - Very small likelihood of damage among non-adjacent cabinets
  - Check for transient fires between cabinets
  - Assume time to target damage of 15 min if there is direct exposure from the fire to the panel walls
- *Problem Set 11.b-07*

Notes:

Slide 16

Main Control Room Fire Analysis
Step 9: Non-Supp Prob & Severity Factor

The non-suppression probability and severity factors are calculated as recommended in the approach for single compartment fires

- For fires inside a control panel, use the method described in Appendix L

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Task 11b - Main Control Room Fire Analysis

Slide 16

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Notes:

Slide 17

Main Control Room Fire Analysis
Step 10: Estimate Failure Prob Using ASP

Two approaches may be followed:

- An overall failure probability is estimated representing the failure of the alternate shutdown means.
- The alternate shutdown procedure is integrated in the plant response model (i.e., the fault trees and event trees). The core damage sequences are adjusted to include failures associated with alternate shutdown means, and the human error probabilities are reevaluated based on the alternate shutdown procedures.

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Task 11b - Main Control Room Fire Analysis

Slide 17

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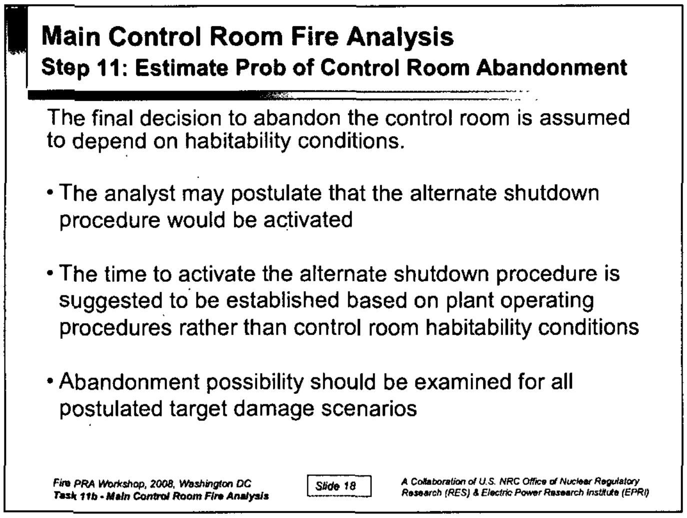
Notes:

Slide 18



Notes:

Slide 19

Main Control Room Fire Analysis

Step 11: Estimate Prob of Control Room Abandonment

Abandonment criteria based on habitability conditions

- Temperature, or heat flux
  - The heat flux at 6′ above the floor exceeds 1 kW/m2. This can be considered as the minimum heat flux for pain to skin. A smoke layer of approximately 95°C (200°F) could generate such heat flux.

$$\dot{q}'' = \sigma \cdot T_{sl}^4 \approx 1.0 \quad kW/m^2$$

- The smoke or hot gas layer descends below 6′ from the floor
- Visibility
  - Optical density of the smoke is less than 3.0 m-1. With such optical density, a light-reflecting object would not be seen if its more than 0.4m away. A light-emitting object will not be seen if it is more than 1m away.
- A panel fire affects two target items 2.13 m (7′) apart.

Notes:

Slide 20

Notes:

Main Control Room Fire Analysis
Step 11: Estimate Prob of Control Room Abandonment

The conditional probability of abandonment can be estimated based on the calculated evacuation time.

- Determine the heat release rate generating abandonment conditions
- Calculate the severity factor for fires of this size
- Determine the time for abandonment
  - Time to reach untenable conditions such as 200°F hot gas layer or smoke density conditions of 3.0 m-1
- Calculate non-suppression probability
- Multiply the severity factor and non-suppression probability to determine conditional abandonment probability.

Main Control Room Fire Analysis
Example

- Credit prompt detection
- Suppression by fire brigade
  - Pns from CR suppression curve
- SF from probability distribution for vertical cabinets with unqualified cable and fire propagating to more than one bundle.

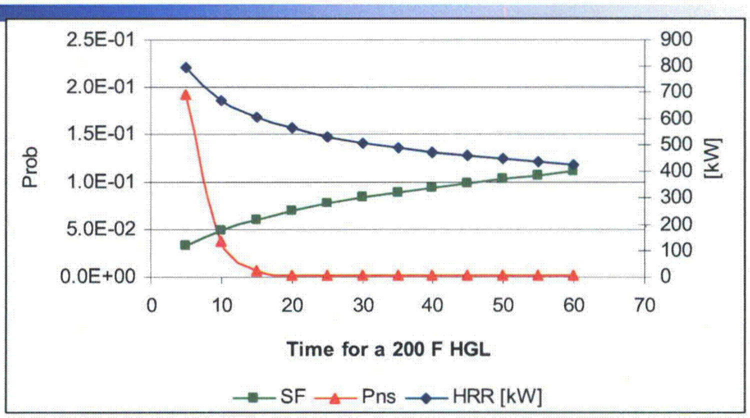
Inputs	
Ambient temperature [C]	20
Duration [sec]	
Opening area [m2]	4
Height of opening [m]	2
Room length [m]	20
Room width [m]	15
Room height [m]	6
Thermal conductivity [kW/mK]	0.0014
Density [kg/m3]	2000
Specific heat [kJ/kg]	0.88
Wall thickness [m]	0.15
Temperature for abandonment [C]	93

- *Problem Set 11.b-08 (Example)*

Notes:

Slide 22

Main Control Room Fire Analysis
Example (cont'd)



Duration [Min]	Required HRR [kW]	SF	Pns	SF*Pns
5	**794**	3.2E-02	1.9E-01	6.1E-03
10	**668**	4.8E-02	3.7E-02	1.8E-03
15	**603**	6.0E-02	7.1E-03	4.2E-04
20	**561**	6.9E-02	1.4E-03	9.4E-05
25	**531**	7.7E-02	2.6E-04	2.0E-05

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Task 11b - Main Control Room Fire Analysis

Slide 22

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Notes:

Slide 23

Notes:

Session 11b: Example Problems

Workshop Problems for Task 11b: Detailed Fire Modeling in the Main Control Room

Workshop Problem Set 11b-01 (Example)

Step 1.b: Identify and Characterize Main Control Room Features: The following list summarizes the key features of the Main Control Room (MCR):

- The MCR is located at Elevation 55ft of the Auxiliary Building. See Drawings A-01 and A-07 for details.
- In this analysis, the kitchen and shift supervisor's office are included as part of Main Control Room proper.
- The dimensions of the MCR proper are as follows:
  - 15'ft high
  - 50 ft long
  - 30 ft wide
- Access to the kitchen and shift supervisor's office are solely from the control room
- The kitchen includes an electric water heater and a microwave oven, a refrigerator, a sink, kitchen cabinets and a small dining table and chairs.
- The shift supervisor's office includes a desk, a computer and printer, chairs and large quantity of reports, engineering documents and other paper documents.
- The Main Control Room includes the following:
  - A horse shoe shaped main control board (MCB) (see Drawing A-09 for details)
  - One free standing electrical panel where fire protection system display and controls are mounted
  - Two desks, assortment of chairs, book cases containing paper documents
  - Two printers with continuous feed paper roll.
- The main control board (MCB) is 22 feet long and 9 feet tall
- The fire protection panel has only one segment (there are no divisional walls within the panel). The panel is 8 feet tall, 3feet deep and 6 feet wide.
- The walls of the MCR are made of reinforced concrete with no penetrations in the ceiling and the walls except for a ventilation opening in the east wall. There are sealed control cable penetrations under the MCB and fire protection panel.
- Ventilation (heating, cooling and fresh air supply) is provided by a dedicated unit that provides fresh air from outside and can be shut closed by the MCR operators and put on a recirculation mode.
- There is a false ceiling 3 feet below the control ceiling of the MCR. The false ceiling is composed of light non-combustible boards held by an aluminum structure.

The following list summarizes the key features of the Main Control Board (MCB):

- The Main Control Board is composed of 7 segments (CB-1 through Cb-7). See Drawings A-01 and A-07 for details.
- Each Main Control Board segment is separated from the adjacent segments by a partial wall that extends halfway inside the panel.
- All cables enter the panel from below through sealed penetrations.
- The insulation of the cable and wires is a mixture of thermoset and thermoplastic insulation.
- The back and top of the control panel is closed. There are doors on the side walls that are normally closed.
- Instrumentation technicians enter the Main Control Board for various tasks no more than once per week.
- There are no power cables in the Main Control Board.

Workshop Problem Set 11b-02

Step 2.b: Estimate Control Room Fire Frequency: For the overall MCR fire frequency the equation provided on pages 11-33 and 11-34 of NUREG/CR-6850 has been updated to read as follows:

$$\lambda_{MCR} = W_{L,MCR}(\lambda_{MCB} + W_{PWC,Elec.Cab,MCR.}\lambda_{PWC,Elec.Cab.} + W_{transients,MCR}\lambda_{transient} + W_{welding,MCR}\lambda_{welding} + W_{Cable,MCR}\lambda_{cable})$$

where:

λ_{MCR} :	Main Control Room fire frequency
$W_{L, MCR}$:	Location weighting factor for the MCR
λ_{MCB} :	Main Control Board fire frequency (Table 6-1, bin 4)
$W_{PWC, Elec. Cab, MCR.}$:	Ignition source weighting factor of Plant Wide Electrical Cabinets found in the Main Control Room.
$\lambda_{PWC, Elec. Cab.}$:	Fire frequency of Plant Wide Electrical Cabinets (applies to all electrical cabinets in the plant including those panels in the MCR that were not labeled as MCB.) (Table 6-1, bin 15)
$W_{transients, MCR}$:	Ignition source weighting factor of Control/Aux/Rx Bldg Transient Fire events that may occur in the MCR. This fraction should be computed using the same method as for transients for other parts of the location using the following influencing factors: - Maintenance – Low - Occupancy – High - Storage – High (reflecting large quantity of paper materials)
$\lambda_{transient}$:	Control/Aux/Rx Bldg Transient fire frequency (Table 6-1, bin 7).
$W_{welding, MCR}$:	If welding is allowed in the MCR during power operation, this ignition source weighting factor should be evaluated in the same way as that for transient fire using the following influencing factors: - Maintenance – Low
$\lambda_{welding}$:	Control/Aux/Rx Bldg, transient fires caused by welding frequency (Table 6-1, bin 6).
$W_{Cable,MCR}$:	Ignition source weighting factor of Control/Aux/Rx Bldg Cable Fires Caused by Welding and Cutting that may occur in the MCR. This fraction should be computed using the same method as for transients for other parts of the location using the following influencing factors: - Maintenance – Low
λ_{cable} :	Control/Aux/Rx Bldg, cable fires caused by welding frequency (Table 6-1, bin 5).

Workshop Problem Set 11b-02 (continued)

Step 2.b: Estimate Control Room Fire Frequency: Using the information provided in this Sample Package, and the above formula copied from NUREG/CR 6850, estimate the frequency of fire for the SNPP MCR.

$W_{L,\ MCR}$ =	per ________
λ_{MCB} =	per ________
$W_{PWC,\ Elec.\ Cab,\ MCR.}$ =	per ________
$\lambda_{PWC,\ Elec.\ Cab.}$ =	per ________
$W_{transients,\ MCR}$ =	per ________
$\lambda_{transient}$ =	per ________
$W_{welding,\ MCR}$ =	per ________
$\lambda_{welding}$ =	per ________
$W_{Cable,MCR:}$ =	per ________
λ_{cable} =	per ________

λ_{MCR} =

Workshop Problem Set 11b-03 (Example)

Step 3.B: Identify and Characterize Fire Detection and Suppression Features and Systems: The following list summarizes the key features of the fire detection and suppression systems of the Main Control Room (MCR):

- At least two qualified operators are present in the MCR at all times.
- There are smoke detectors under the false ceiling
- There are smoke detectors above the false ceiling
- There are portable fire extinguishers inside the kitchen and inside the Control Room area
- There is a wet hose reel in the Control Room Access area that can reach anywhere within the control room
- The ventilation system can be switched to smoke purge mode to exhaust the air from the control room to the outside.

Workshop Problem Set 11b-04 (Example)

Step 4.B: Characterize Alternate Shutdown Features: The following list summarizes the key features of the Alternate Shutdown Panel:

- The Alternate Shutdown Panel is located at El. +20ft, in the SWG Access Room. The panel is located at the North wall between the two switchgear room doors.
- The following list of components can be controlled from the Alternate Shutdown Panel.

Equipment ID	Equipment Description	Power Supply	Control Room Panel
HPI-A	High pressure safety injection pump A	4.16kV Bus A	CB-5
HPI-B	High pressure safety injection pump B	4.16kV Bus B	CB-5
AFW-A	Motor driven AFW pump A	4.16kV Bus A	CB-3
AFW-C	Motor driven AFW pump C	4.16 kV Bus 2	CB-3
AOV-2 (SOV-2)	Letdown isolation valve	125 VDC Bus B	CB-5
MOV-1	HPI valve	480V MCC A1	CB-5
MOV-2	VCT isolation valve	480V MCC B1	CB-5
MOV-9	HPI valve	480V MCC B1	CB-5
MOV-10	AFW discharge valve	480V MCC A1	CB-3
MOV-11	AFW discharge valve	125 VDC Bus B	CB-3
MOV-14	AFW turbine steam line isolation valve	125 VDC Bus B	CB-3
MOV-15	AFW steam inlet throttle valve	125 VDC Bus B	CB-3
MOV-18	AFW C Pump Discharge	480 V MCC-2	CB-3
MOV-19	AFW test line isolation valve	480 V MCC-2	CB-3
LI-1	RWST level	120VAC Bus A	CB-5
LI-2	RWST level	120VAC Bus B	CB-5
A-1	AFW motor high temp	120VAC Bus A	CB-3
EDG-A	Train A Emergency Diesel Generator	PNL-A	CB-6
EDG-B	Train B Emergency Diesel Generator	PNL-B	CB-6

- To activate the alternate shutdown panel, the operators have to enter each switchgear room separately and transfer the controls of the desired components from the Main Control Board to the Alternate Shutdown Panel.
- A separate set of procedures exists for taking control at the Alternate Shutdown Panel.

Workshop Problem Set 11b-05

Step 5.b: Identify and characterize target sets: Identify at least five target sets for the Main Control Room by inspecting drawings DWG A-07 and A-09 and other information provided in this Sample Package.

Target Set ID	Items in the target set	Basis for selecting target set

Workshop Problem Set 11b-06

Steps 6.b: Identify and Characterize Ignition Sources:

Steps 7.b: Define Fire Scenarios: For the target sets provided in the solution of the preceding problem set, identify the corresponding ignition sources and fire scenarios.

Target Set ID	Ignition Sources	Fire Scenarios
MCR-01		
MCR-02		
MCR-03		
MCR-04		
MCR-05		

Workshop Problem Set 11b-07

Step 8b: Conduct Fire Growth and Propagation Analysis

Step 9b: Detection and Suppression Analysis and Severity Factor: Using the information provided in the solution to Problem Set 11b-03 and Figure L-1, conduct fire propagation, detection and suppression analysis for the following fire scenarios and calculate scenario frequency:

<u>MCR-03.1</u>

SFxPNS =

$\lambda_{MCR-03.1}$ =

<u>MCR-04.1</u>

SFxPNS =

$\lambda_{MCR-04.1}$ =

Workshop Problem Set 11b-08 (Example)

Step 11.B: Estimate Probability of Control Room Abandonment: The following is an example case presented here as an illustration on how the probability of abandonment can be estimated

The probability of abandonment represents the likelihood of a fire generating adverse environmental conditions meeting the criteria for control room evacuation described in Task 11 of NUREG/CR-6850. The abandonment criteria suggests that analysts must assume operators will leave the control room if:

- The room or hot gas layer temperature reaches 200 °F (93 °C).
- The heat flux to the control room floor is above 1 kW/m^2,
- The hot gas layer is 6 ft or lower above the floor and has and optical density of 3.0 1/m. Such optical density will prevent operators to see through smoke.

Considering these criteria, the abandonment probability was calculated as follows:

1. From Task 6, the ignition sources in the main control room are:
   - the main control board,
   - vertical electrical cabinets and
   - transients.

2. The probability distribution for heat release rate Case 5 in Table E-1 of NUREG/CR-6850 has been assigned to the main control board and other electrical cabinets. This distribution applies to cabinets with un-qualified cables and fire spreading to more than one cable bundle.
3. The time to abandonment was calculated deterministically for the range of heat release rate values defined by the probability distributions listed in item 1 above. The zone model MAGIC was used for these calculations. Relevant inputs to MAGIC include the geometry of the main control room complex, and the mechanical ventilation system. The time to abandonment is the shortest time when one of the three defined above criteria is met.
4. Each MAGIC result (i.e., the time to abandonment resulting from a specific heat release rate input) is associated with a severity factor from the corresponding probability distribution for heat release rate. Similarly, there is a corresponding non-suppression probability for each MAGIC result. The non-suppression probability captures the likelihood that the fire will not be suppressed before the calculated abandonment time.
5. The resulting abandonment probability and average abandonment times are a weighted average of all the probabilities of fire sizes and corresponding non-suppression probabilities.

Table 3 summarizes the calculation of abandonment probabilities and average abandonment times for electrical cabinets. The first column in Table 3 refers to the heat release rate value used in MAGIC for determining the time to abandonment. The column labeled SF lists the severity factor associated with the heat release rate value (taken from Appendix E of NUREG/CR-6850). The Time column lists the resulting time to abandonment calculated with MAGIC. The column labeled P_{ns} lists the non-suppression probabilities. In general, $P_{ns} = \exp(-\lambda t)$ where λ for the control room is 0.33 (see Appendix P of NUREG/CR-6850), and t is the time listed in the "Time" column.

The average abandonment time is calculated as

$$\hat{t}_{ab} = \frac{\sum t_i \cdot SF_i \cdot P_{ns-i}}{\sum SF_i \cdot P_{ns-i}}$$

which is the weighted average of the abandonment times calculated with MAGIC. The abandonment probability is calculated as

$$P_{ab} = \sum SF_i \cdot P_{ns-i}$$

which can also be interpreted as an average non-suppression probability since the SF_i's for all possible heat release rates add to one. The following results are obtained using the two equations above:

- Electrical cabinets: Average abandonment time is approximately 8 minutes and the probability of abandonment is approximately 1.3E-2.
- Transient fires: For the purpose of this study, the time to abandonment and the abandonment probability calculated for electrical cabinet fires is assumed to be the same as for transient fires. This is a conservative assumption since the heat release rate profiles for the electrical cabinet fire suggests higher fire intensities with faster profiles that are expected to result in faster abandonment times.

Table 3: Time to abandonment and abandonment probability analysis for electrical cabinet fires. Calculations assume no mechanical ventilation system in the room.

HRR [kW]	SF	Time to Abb (min)	Pns	SF·Pns
1	0.0E+00	60	2.5E-09	0.0E+00
42	6.4E-01	60	2.5E-09	1.6E-09
197	1.6E-01	16	5.1E-03	7.9E-04
337	8.1E-02	11	3.1E-02	2.5E-03
475	4.7E-02	9	4.9E-02	2.3E-03
612	2.9E-02	8	6.4E-02	1.9E-03
749	1.8E-02	8	8.0E-02	1.4E-03
886	1.1E-02	7	9.4E-02	1.0E-03
1024	7.0E-03	7	1.1E-01	7.7E-04
1162	5.0E-03	6	1.2E-01	6.2E-04
1299	3.0E-03	6	1.4E-01	4.1E-04
1436	2.0E-03	6	1.5E-01	2.9E-04
1573	1.0E-03	6	1.5E-01	1.5E-04
1710	1.0E-03	6	1.6E-01	1.6E-04
1847	1.0E-03	5	1.7E-01	1.7E-04
2276	1.0E-03	5	2.0E-01	2.0E-04

Simulations with MAGIC Software Package

As mentioned earlier, time to abandonment calculations were conducted using the zone model MAGIC. MAGIC is a fire two-zone model, which provides the capability of simulating the development of a hot gas layer in rooms with and without mechanical ventilation systems. Key inputs to MAGIC includes: 1) room geometry, 2) wall thickness and construction, 3) specifications of the mechanical ventilation system, 4) fire size and 5) fuel properties.

The control room was modeled in MAGIC as a single room. The fire was located in the center of the common control room area. Figure 3 illustrates the geometry as modeled in MAGIC. Notice that the control room area was modeled as having a rectangular floor base with equivalent floor area. Simulation times were 20 minutes.

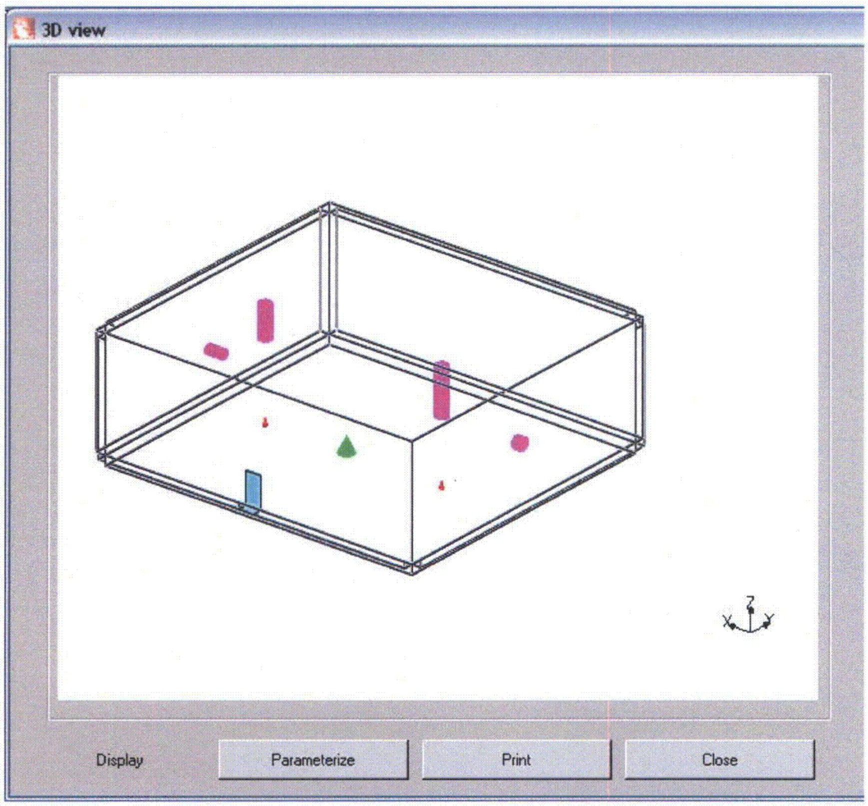

Figure 3: Control room geometry as modeled in MAGIC

The following were considered when running MAGIC:

- Room size and construction: The control room area was modeled with an effective floor area of 67' x 60' and a ceiling height of 23'.
- All wall materials were modeled as 2' thick concrete.
- Horizontal openings: As illustrated in Figure 3 above, the control room was modeled as having one 3' x 6' open door.
- Mechanical ventilation: The mechanical ventilation system is modeled as a balanced supply/exhaust system with a flow rate of 2.73 m^3/s. The room also has a smoke extraction system with two vents, each extracting 3.7 m^3/s. This system is manually activated by the fire brigade.
- For the purpose of the simulation, it is assumed that the smoke extraction system operates 10 minutes after the fire starts. At this point, the normal system is turned off.

- Heat release rate profiles: The heat release rate profiles follow the guidance provided in Appendices E & G of NUREG/CR-6850. That is, the peak heat release rates listed in Tables E-6 and E-9 in NUREG/CR-6850 for electrical cabinets and transients respectively were used. It was assumed that the growth profile is t^2 growing to a peak in approximately 12 minutes.
- Fuel Properties: Fuel was assumed to have a soot yield of 0.18.

Relevant outputs/Abandonment criteria

MAGIC creates one output file for each simulation. The output files contain the information necessary for determining the time to abandonment. Specifically, the following outputs were evaluated:
- hot gas layer temperature in the MCR area,
- hot gas layer height in the MCR area,
- Total heat flux to Target 1, and
- optical density in the MCR area.

Specific MAGIC inputs are included in the MAGIC input files. Figure 4 illustrates a snapshot of a MAGIC simulation with and without mechanical ventilation. Notice that the simulation with no mechanical ventilation suggests the development of a hot gas layer and flows moving out through the open doors.

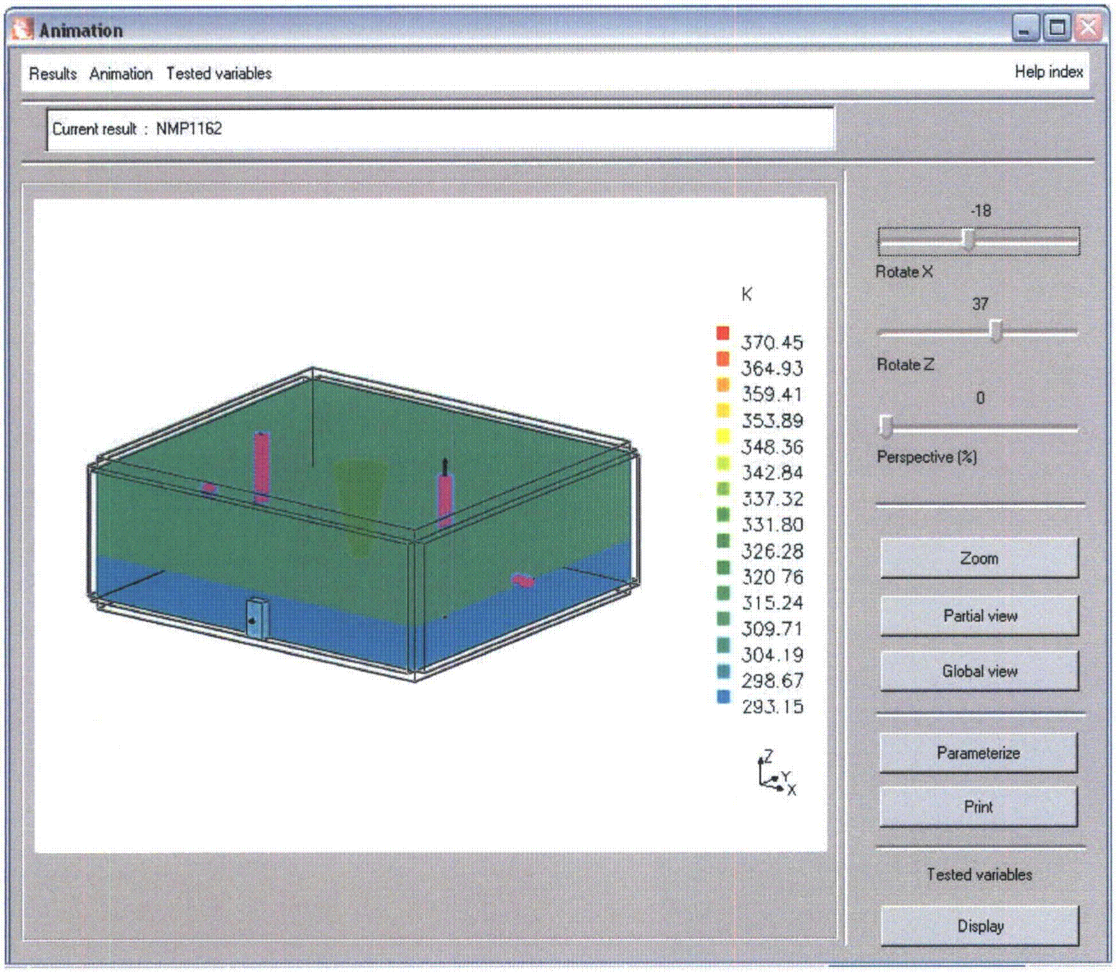

Figure 4: Pictorial representation of a MAGIC simulation of the control room fire

Session 12: Multi-Compartment Fire Analysis

Slide 1

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EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 11c - Multi-Compartment Fire Analysis

Joint RES/EPRI Fire PRA Workshop
September 2008
Washington DC

A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

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Slide 2

MULTI-COMPARTMENT FIRES
Objective

Fire scenarios involving multiple, interconnected or adjacent fire compartments are analyzed in this part of Task 11.

- Fire propagation
- Smoke propagation
- A rare event in U.S. NPP fire experience
- Screening process

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Task 11c - Multi-Compartment Fire Analysis

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Notes:

MULTI-COMPARTMENT FIRES
Overall Approach

Multi-compartment analysis is focused on screening of potential scenarios before any detailed analysis is attempted.

- Single compartment analysis to be conducted before this step
- Reduce number of multi-compartment combinations
- Same analytical approach as in Detailed Fire Modeling

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Notes:

MULTI-COMPARTMENT FIRES
Definitions

The following two terms are specifically defined for this part of the analysis:

- *Exposing Compartment*: The compartment where fire ignition occurs
- *Exposed Compartment*: The compartments where fire from the exposing compartment propagates to

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Notes:

MULTI-COMPARTMENT FIRES
Analysis Steps

The following steps define one possible approach for multi-compartment fire risk analysis:

- Step 1.c: Exposing and Exposed Compartments Matrix
- Step 2.c: First Screening–Qualitative
- Step 3.c: Second Screening–Low Fire Load Exposing Compartments
- Step 4.c: Third Screening–Frequency of Occurrence
- Step 5.c: Fourth Screening–CDF Based
- Step 6.c: Detailed Analysis
- Step 7.c: Document the Analysis

Slide 6

Notes:

MULTI-COMPARTMENT FIRES
Step 1.c: Exposing and Exposed Compartments Matrix

Develop a matrix to identify all potential multi-compartment fire scenarios that start with an *exposing* compartment and propagate into a set of *exposed* compartments.

- Well defined pathways
- Means of propagation (i.e., hot gas, smoke, etc.)
- Special characteristics to be noted (e.g., self closing doors, fire dampers and vents near the ceiling)
- More than one exposed compartment
- Supported by a walk-down

Slide 7

MULTI-COMPARTMENT FIRES
Step 1.c: Exposing and Exposed Matrix (cont'd)

The following rules are suggested to identify multi-compartment scenarios:

- Postulate only one barrier failure (e.g., door left open)
  - Unless there is a clear reason to assume common cause failure of multiple barriers
- Assume minimal smoke damage
- Hot gas can travel to all physically possible exposed compartments
  - For a large number of compartments open into each other, detailed analysis may be warranted

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MULTI-COMPARTMENT FIRES

Step 1.c: Exposing and Exposed Matrix (cont'd)

Example:

#	Exposing Compartment		#	Exposed Compartment		#	Path	Comments
	ID	Name		ID	Name			
1	9	SWG Access Room	1.1	10	Swtich Gear Room A	1.1.1	Door	The door is 3-hr rated and normally closed
						1.1.2	Opening	Ventilation opening between rooms with fusible link activated fire dampers.
			1.2	11	Swtich Gear Room B	1.2.1	Door	The door is 3-hr rated and normally closed
						1.2.2	Opening	Ventilation opening between rooms with fusible link activated fire dampers.
			1.3	--	Stairway	1.3.1	Door	The door is 3-hr rated and normally closed
2	4A	RHR Room	2.1	4B	AFW Pump Room	2.1.1	Door	The door is 3-hr rated and normally closed
						2.1.2	HVAC Duct	There are two HVAC ducts with opening in both compartments providing intake and discharge
			2.2	--	Stairway	2.2.1	Door	The door is 3-hr rated and normally closed
3	4B	AFW Pump Room	3.1	4A	RHR Room	3.1.1	Door	The door is 3-hr rated and normally closed
						3.1.2	HVAC Duct	There are two HVAC ducts with opening in both compartments providing intake and discharge

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Slide 9

MULTI-COMPARTMENT FIRES
Step 2.c: First Screening – Qualitative

The first screening of the scenarios can be based on the contents of the exposed compartments.

The following criteria may be used:

- The exposed compartment(s) do not contain any Fire PRA components or cables, or
- The Fire PRA components and cables of the exposed compartment(s) are identical to those in the exposing compartment.

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Slide 10

MULTI-COMPARTMENT FIRES
Step 3.c: Second Screening–Low Fire Load

Exposing compartments that do not include combustible loading sufficient for generating a hot gas layer in any of the exposed compartments can be screened out.

- Conservative HRR values
  - Ignition sources with highest 98% HRR
  - Add HRR of intervening combustibles
- Determine damaging HRR values
  - Hand calculations
  - Hot gas layer damage in exposed compartment
- Compare HRRs

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Task 11c - Multi-Compartment Fire Analysis
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Slide 11

Notes:

MULTI-COMPARTMENT FIRES
Step 4.c: Third Screening–Occurrence Frequency

Scenario likelihood is established from the following three parameters:

- Ignition frequency
- Combined severity factor and non-suppression probability
  - HRR comparison (preceding step) can give the severity factor
  - May assume $P_{NS} = 1.0$
- Barrier failure probability

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Slide 11

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Slide 12

Notes:

MULTI-COMPARTMENT FIRES
Step 4.c: Third Screening / *Barrier Failure*

Generally, data on barrier failure probability is sparse, and what is available is subject to many limitations.

- Initial attempt may be based on a screening value
  - May use Pr(barrier failure) = 0.1 for screening
- For scenarios that do not screen out, may use the following:
  - For water curtain, use detection and suppression approach
  - Verify that there are no plant-specific barrier failure problems
  - Use the following *generic* barrier failure probabilities
    - Type 1 – fire, security, and water tight doors – 7.4E-03
    - Type 2 - fire and ventilation dampers – 2.7E-03
    - Type 3 - penetration seals, fire walls – 1.2E-03

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Slide 12

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Slide 13

Notes:

MULTI-COMPARTMENT FIRES
Step 5.c: Fourth Screening–CDF Based

Those scenarios that survive the preceding screening steps may be screened based on their CDF.

- Assume all PRA components and cables of exposing and exposed compartments are failed
- Estimate CCDP
- Use scenario frequency of preceding step

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Slide 13

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Slide 14

Notes:

MULTI-COMPARTMENT FIRES
Step 6.c: Detailed Analysis

Those scenarios that do not screen out in the preceding steps may be analyzed using the same methods as for single compartments.

- Same set of steps as in single compartment analysis
- Include target sets from exposed compartment(s)

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Slide 14

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Slide 15

Notes:

MULTI-COMPARTMENT FIRES
Concluding Remarks

Multi-compartment fire analysis should be performed to ensure completeness of the Fire PRA.

- Compartment partitioning process (Task 1) has a direct impact on this task
- Develop a matrix of exposing and exposed compartments to ensure completeness
- Screening analysis is necessary to limit the level of effort
- Barrier failure probabilities should be treated conservatively
- May have to revisit some of the partitioning definitions

Session 13: Seismic Fire Interaction

Slide 1

Notes:

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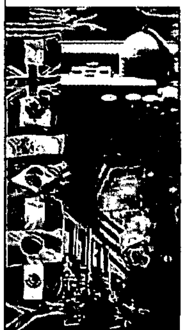

EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 13: Seismic Fire Interactions

Joint RES/EPRI Public Workshop
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Notes:

Task 13 - Seismic Fire Interactions

Scope of this Task

- Task 13 covers the Seismic Fire Interactions review
  - You will find that little has changed compared to the guidance available in the IPEEE days
  - The review remains a qualitative, walk-down based approach to identify and address potential vulnerabilities or weaknesses
  - The procedure does not recommend any quantitative work in this area

The main goal of the outlined methodology is to verify that the the risk associated with seismically induced fires is low.

Slide 3

Notes:

Task 13: Seismic Fire Interactions
Seismically Induced Fires

A severe seismic event may cause fires inside or outside an NPP by damaging . . .

- Pipes and storage tanks containing flammable liquids or gases
- Electrical equipment

An EPRI study and NPPs experiencing earthquakes have demonstrated that these events are rare.

Slide 4

Notes:

Task 13: Seismic Fire Interactions
Background

- Seismic Fire Interactions originated with the Fire Risk Scoping Study (NUREG/CR-5088, 1989)
- The conclusion of that study was:

  "It would appear that this is an issue which is more easily corrected than quantified. A series of simple steps was outlined which if implemented on a plant specific basis would significantly reduce the potential impact of such considerations."

  This conclusion remains valid today.

Slide 5

Notes:

Task 13: Seismic Fire Interactions
Key Compartments

- The review should focus on those compartments that house equipment and cables needed to support post-seismic safe shutdown
  - Review your seismic-related procedures and identify key equipment (components and cables) and any required manual actions
  - To the extent possible, map equipment to compartments
  - Identify the associated compartments and focus efforts on these compartments
    - Areas/compartments housing the key equipment (components and cables)
    - Areas where a manual action takes place
    - Access paths for manual actions

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Task 13: Seismic Fire Interactions

Slide 5

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Notes:

Task 13: Seismic Fire Interactions
Seismically-Induced Fires

- Potential sources:
  - Unanchored electrical equipment such as where motion during seismic event might cause a fire
  - Unanchored gas cylinders
  - Flammable gas piping
  - Flammable liquid piping or storage tanks
- If any *significant* sources are identified, consider potential plant modifications to minimize potential hazard.

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Task 13: Seismic Fire Interactions

Slide 6

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Notes:

Task 13: Seismic Fire Interactions
Degradation of FP Systems and Features

- Review:
  - General plant practice related to seismic restraints for fire protection systems and features
  - Installed systems and features and assess potential for seismic-induced failure
- Assess potential significance of system or feature failure to post-seismic event operations.
- If any potential vulnerabilities are identified, consider fixes to reduce likelihood of failure.

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Task 13: Seismic Fire Interactions

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Slide 8

Notes:

Task 13: Seismic Fire Interactions
Spurious Detection Signals

- A seismic event will likely trigger activation of various fire detection systems – especially smoke detectors
- Consider how the operators will respond to multiple fire detection signals
  - You can't ignore them even though many may be false
  - Have you identified the issue in your response procedures?
  - Have you (can you) prioritize your response based on the important compartments?
- Consider potential procedural enhancements to recognize and deal with this issue

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Task 13: Seismic Fire Interactions

Slide 8

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Slide 9

Notes:

Task 13: Seismic Fire Interactions
Spurious Suppression Actuation/Release

- Review the fixed fire protection systems in key areas for the potential that they might spuriously operate
  - Got any of those mercury switches left?
  - How about a non-seismic deluge valve?
  - What happens if a sprinkler head is damaged or a pipe breaks?
  - Are storage tanks for gaseous suppressants seismically robust?
- If any potential vulnerabilities are identified, consider fixes to reduce likelihood of spurious suppressant release.

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Task 13: Seismic Fire Interactions
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Slide 10

Notes:

Task 13: Seismic Fire Interactions
Manual Fire Fighting

- Access pathways to key areas – could something block the path and are there alternative paths?
- Required fire fighting assets – will assets remain available after an earthquake
  - Especially fire water system and fire hoses
- Do post-seismic response procedures allow for manual fire fighting needs and responsibilities
- If any potential vulnerabilities are identified, consider fixes

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Task 13: Seismic Fire Interactions
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Slide 11

Notes:

Task 13: Seismic Fire Interactions
Summary

- Seismic fire interaction is considered a low risk phenomena
- NPP and other industry experiences partly verify this premise
- A qualitative approach is suggested for verifying that plant specific conditions confirm low risk notion
- Systemic or procedural upgrades are recommended for identified potential vulnerabilities

Conclusion

Part 1: Integration

Slide 1

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EPRI/NRC-RES FIRE PRA METHODOLOGY

Integration, Lessons Learned and Insights

Bijan Najafi, SAIC
Steve Nowlen, SNL
Joint RES/EPRI Fire PRA Course
Sept. 29 – Oct. 2, and Nov. 17-20, 2008
Bethesda, MD

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Slide 2

PART I

Integration

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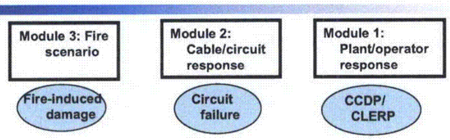
Slide 3

Integration
Modules



- Module 1: PRA/HRA
  - Post-fire plant response model, including systems, components and operator manual actions (CCDP, CLERP)
- Module 2: Cable selection, circuit failure mode analysis
  - Electrical response, embedded in the Post-fire plant response model (P_{cf})
- Module 3: Fire analysis
  - Fire hazard; ignition frequency, fire severity, fire growth, detection/suppression ($IF * SF * P_{ns}$)

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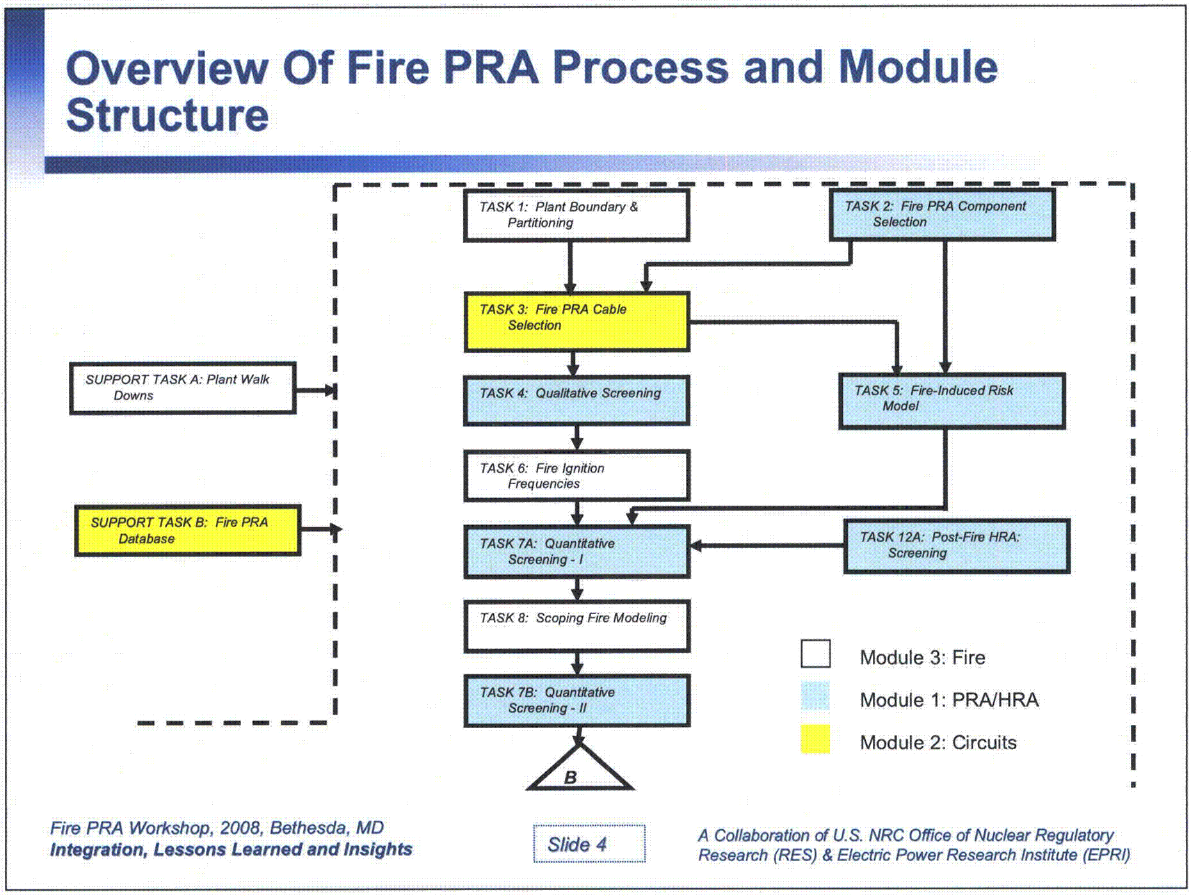

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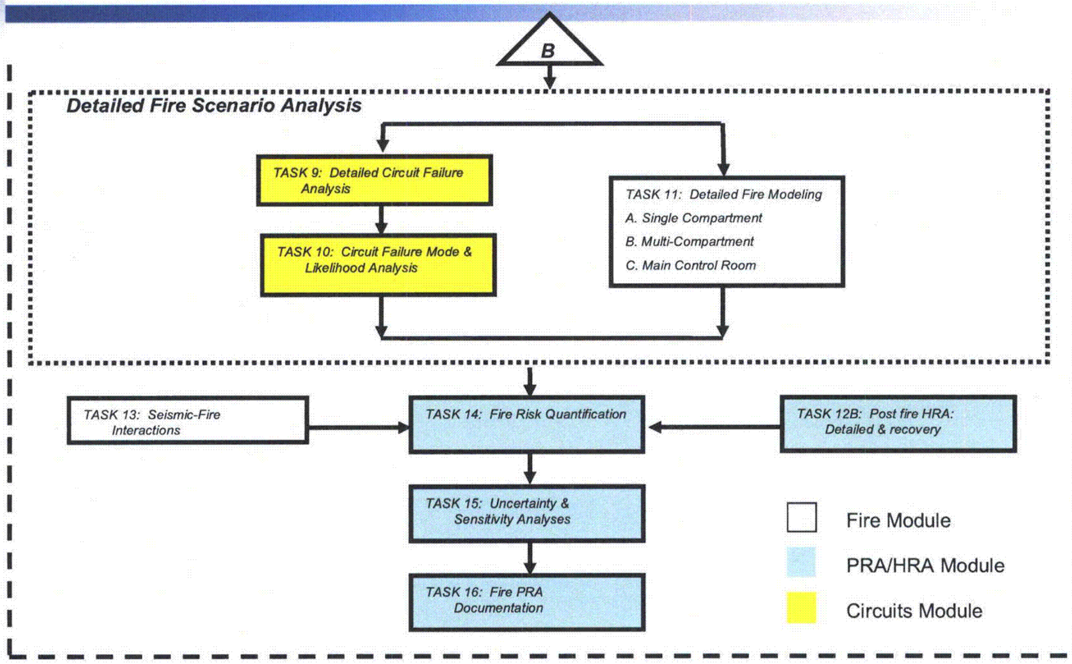
Slide 5

Overview Of Fire PRA Process and Module Structure (2)



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Part 2: Lessons Learned and Insights

Slide 6

PART II

Lessons Learned and Insights to-date

on Use of

EPRI 1011989, NUREG/CR-6850

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Integration, Lessons Learned and Insights

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Lessons Learned and Insights
Scope of this Module

- Demonstration studies / Pilots
  - *Focus today is on NFPA-805 pilot plants and other "early adopters"*
- FAQ process and methods-related topics
- General insights; Programmatic & Technical
- Path forward with EPRI 1011989 , NUREG/CR-6850

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Slide 7

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Lessons Learned and Insights
Demonstration /Pilot Studies

- The procedures were individually tested during development
- All the procedures worked, and seemed to be of reasonable depth, scope, and clarity to make implementation practical
- First top-to-bottom testing as a full, consolidated, and complete set ongoing by 805 pilots and other early adopters

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Integration, Lessons Learned and Insights

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Lessons Learned and Insights
Demonstration /Pilot Studies (continued)

- Numerical results are being developed, but remain preliminary
- The potential for "hidden surprises" was acknowledged from the outset, and there have been some…
  - Others likely remain to be discovered, and ***you*** may find them
- *The NFPA-805 FAQ process is the primary mechanism currently available to address application issues*
  - As a user, you should monitor the FAQ process
  - FAQ resolutions may resolve your questions as well
- We continue to seek user feedback and experience – the procedures are intended to be "living documents" to at least some extent

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Integration, Lessons Learned and Insights

Slide 9

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Slide 10

Notes:

Lessons Learned and Insights

Pilot Studies – Our Early Experience Showed and Pilots Confirm that...

- It's Easy to get distracted, e.g.:
  - If you want to re-baseline Appendix R, do that first, then do your fire PRA – the objectives are *NOT* the same although the Fire PRA would benefit
  - Work together with the Appendix R re-baseline to ensure the final product is useful for Fire PRA purposes
- Get a team of the right people with the right knowledge to do the job, e.g.:
  - The PRA gurus may think they know circuits, but you really need those with true electrical expertise
  - You *NEED* your team to include expertise in fire, systems, PRA, plant operations, HRA, and electrical circuits/analysis

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Notes:

Lessons Learned and Insights

Frequently Asked Questions (FAQ)

- The NPFA-805 FAQ process is the primary vehicle for feedback to EPRI TR 1011989, NUREG/CR-6850
  - Managed by the NEI/NRC NFPA-805 task force and NRC/NRR NFPA-805 team
- FAQs cover a range of topics and not all are related to the fire PRA methodology
- FAQs come from various sources including the RES/EPRI team, the 805 pilot plants, and other early adopters

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Lessons Learned and Insights
Frequently Asked Questions (FAQ) (continued)

- To date 52 FAQs have been initiated
- Of these 52, 16 are related to implementation of EPRI TR-1011989, NUREG/CR-6850
- Of these 16:
  - 4 are closed (i.e., resolution complete and docketed)
  - 12 are pending (i.e., resolution is not yet final)
    - Various stages from near complete to in the initial "problem statement" stage
- Caveat:
  - Although a resolution may be complete and docketed, a FAQ still remains "unofficial" until endorsed in a revision of Regulatory Guide 1.205 (either directly, or by endorsing a NEI-04-02 revision that incorporates the FAQ)

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Slide 12
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Notes:

Slide 13

Lessons Learned and Insights
Frequently Asked Questions (FAQ) (cont)

- Fire PRA "Methodology" FAQs include
  - Clarifications to existing guidance
  - Filling in methodology "gaps"
  - Refinements to existing approaches
  - Revised guidance for specific aspects of the analysis
- 14 of the 16 methodology FAQs are "fire" questions
  - These FAQs cover a range of topics
- The other two are "electrical" questions
  - Spurious actuation dependency given multiple cables with HS potential impacted by the same fire
  - Hot short duration

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Integration, Lessons Learned and Insights
Slide 13
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Notes:

Slide 14

Lessons Learned and Insights
Closed FAQs

- FAQ 06-0016: Electrical cabinet counting guidance
  - Provides clarifying examples of "vertical section" counting guidance
- FAQ 06-0017: High Energy Arc Faults in electrical cabinets
  - Provides clarifying guidance for counting cabinets in the context of HEAF ignition frequency
  - Provides a frequency split between low and medium voltage cabinets
  - Clarifies treatment of HEAF in MCCs
- FAQ 06-018: Main control board (MCB) fires
  - Clarifies definition of MCB (what to include, what to exclude)
  - Clarifies direct link between model in Appendix L and the as-defined MCB

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Slide 14

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Notes:

Slide 15

Lessons Learned and Insights
Closed FAQs (continued)

- FAQ 06-0031: Ignition source counting guidance clarifications and extensions
  - **Bin 14 – Electric motors**: clarifies guidance, provides for excluding small motors of 5hp or less and totally enclosed motors.
  - **Bin 21 – Pumps**: provides for excluding small sampling pumps, and other pumps of 5hp or less
  - **Bin 23 – Transformers**: provides for excluding dry transformers of 45KVA or less
  - **Bin 26 – Ventilation subsystems**: clarifies that intent is to exclude small subsystems powered by motors of 5hp or less (consistent with electric motors bin 14)

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Integration, Lessons Learned and Insights

Slide 15

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Notes:

Slide 16

Notes:

Lessons Learned and Insights
In-process FAQs

- FAQ 07-0035: High energy arc faults in bus ducts
  - Issue:
    - Guidance document is silent on topic
  - General approach to resolution:
    - Acknowledge potential for such events (e.g., Diablo Canyon 5/2000)
    - Provide plant wide frequency and counting/partitioning guidance
    - Provide zone of influence and scenario development guidance
  - Status:
    - FAQ resolution has been drafted and reviewed
    - Final revisions in process

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Integration, Lessons Learned and Insights

Slide 16

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Slide 17

Notes:

Lessons Learned and Insights
In-process FAQs (continued)

- FAQ 08-0042
  - Issue:
    - Guidance provides conflicting language regarding propagation of fire from cabinets (Chapter 6 versus Appendix G)
  - General approach to resolution:
    - Clarify and expand definition of "well-sealed and robustly secured cabinets" (which will not propagate fires)
  - Status:
    - FAQ resolution has been drafted and reviewed by RES/EPRI team
    - Industry and NRC staff reviews pending

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Slide 17

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Slide 18

Notes:

Lessons Learned and Insights
In-process FAQs (continued)

- FAQ 08-0043
  - Issue:
    - Guidance for placement of a cabinet fire (the source location) suggests inspecting cabinet contents and placing fire at fuel location
    - Applicants would prefer a "one size" approach less conservative than placing on top of cabinet that would not require internal inspection
  - General approach to resolution:
    - RES/EPRI teams are debating merits of general application of fire protection SDP approach – place fire 1 foot below cabinet top (unless top is unsealed or vented)
  - Status:
    - Team position has been drafted and is under review
    - Staff final review pending

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Slide 18

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Slide 19

Notes:

Lessons Learned and Insights
In-process FAQs (continued)

- FAQ 08-0044
  - Issue:
    - Guidance for large oil spill and fire is generating conservative results especially in the case of MFW pump fires (high frequency of large release compared to experience base)
  - General approach to resolution:
    - Provide an alternative approach and revised fire frequencies for leaks and spills from higher volume circulating oil/lubrication systems
  - Status:
    - General consensus that a revised treatment is appropriate and needed
    - RES/EPRI team discussion of the specific resolution approach continues, reviews ongoing
    - NRC 805 team and industry 805 task force reviews pending

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Integration, Lessons Learned and Insights

Slide 19

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Slide 20

Lessons Learned and Insights
In-process FAQs (continued)

- FAQ 08-0045
  - Issue:
    - Fire growth recommendations for electrical cabinets does not include consideration of an incipient stage (e.g., pre-ignition heating and generation of un-burned pyrolysates which might be detected)
  - General approach to resolution:
    - No clear resolution approach has yet been developed
  - Status:
    - A problem statement has been generated
    - FAQ may be withdrawn - not amenable to short-term solution

Notes:

Slide 21

Lessons Learned and Insights
In-process FAQs (continued)

- FAQ 08-0046
  - Issue:
    - Methodology provides no approach for crediting incipient fire detection systems
  - General approach to resolution:
    - Develop an approach that would credit these systems
  - Status:
    - Initial drafts of a proposed approach are under discussion within the RES/EPRI teams
    - Work continues to try to establish a firm technical basis
    - NRC staff and industry review pending

Notes:

Slide 22

Notes:

Lessons Learned and Insights
In-process FAQs (continued)

- FAQ 08-0047
  - Issue:
    - Guidance states that when more than one cable can cause the same spurious actuation you combine probabilities using "exclusive or"
    - This assumes faults/effects are independent
  - General approach to resolution:
    - Consensus reached that "exclusive or" is not appropriate if faults are dependent (e.g., a common power supply for both cables)
    - Clarify treatment to determine and address dependency
  - Status:
    - Team draft has been completed
    - Staff and final industry review pending.

Slide 23

Notes:

Lessons Learned and Insights
In-process FAQs (continued)

- FAQ 08-0048
  - Issue:
    - Fire frequency analysis may not reflect industry trends (i.e., towards reduced fire frequencies
  - General approach to resolution:
    - Work is under way within EPRI team to determine if statistically significant fire frequency trends can be demonstrated
    - Fire frequencies for one or more ignition source bins may be modified (up or down depending on trends)
  - Status:
    - Work to date remains largely within the EPRI team
    - Review/input by RES team pending

Slide 24

Notes:

Lessons Learned and Insights
In-process FAQs (continued)

- FAQ 08-0049
  - Issue:
    - The cable fire empirical spread model (tray-to-tray, stack-to-stack) has been misapplied in pilot applications
    - Reviewers concluded that misapplication resulted in very conservative fire growth and risk results
  - General approach to resolution:
    - Clarify the bounds of the empirical model to avoid misapplication
  - Status:
    - Proposed resolution has recently completed final review within the RES and EPRI teams
    - Staff and industry final review pending
    - Final revision, as needed, pending
  - Note: as a follow-on, team plans to generate a new FAQ to address broader needs relative to cable fire growth modeling

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Integration, Lessons Learned and Insights

Slide 24

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Slide 25

Notes:

Lessons Learned and Insights
In-process FAQs (continued)

- FAQ 08-0050
  - Issue:
    - The fire non-suppression curves as cited as reflecting suppression performance *after* fire brigade response time but a significant fraction of the duration data used in curves includes brigade response time
    - Fire brigade may not be getting adequate credit for suppressing fires prior to damage
  - General approach to resolution:
    - EPRI team has reviewed data and proposed an alternative set of non-suppression curves that would include fire brigade response time
  - Status:
    - Work to date has largely been confined to EPRI team
    - NRC team is currently reviewing proposed resolution
    - Staff and industry reviews pending

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Integration, Lessons Learned and Insights

Slide 25

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Slide 26

Notes:

Lessons Learned and Insights
In-process FAQs (continued)

- FAQ 08-0051
  - Issue:
    - The guidance does not provide a method for estimating the duration of a hot short once formed
    - This could be a significant factor for certain types of plant equipment that will return to a "fail safe" position if the hot short is removed
  - General approach to resolution:
    - Analyze the existing cable failure modes and effects test data to determine if an adequate basis exists to establish hot short duration distributions
  - Status:
    - Initial data analysis has been completed and results are under team review
    - NRC staff and industry review pending

Slide 27

Notes:

Lessons Learned and Insights
In-process FAQs (continued)

- FAQ 08-0052
  - Issue:
    - No guidance on fire growth times for transient fires
    - Guidance not clear as to which non-suppression curve would apply to transient fires in the MCR (i.e., transient curve or MCR curve)
  - General approach to resolution:
    - Review existing test data and develop guidance for transient fire growth times
    - Clarify non-suppression curve application for this case
  - Status:
    - Initial team position drafted and undergoing review within the teams
    - Staff and industry reviews pending

Slide 28

Lessons Learned and Insights
Component Selection

- Resource intensive and critical, for the most part due to consideration of multiple spurious operation (MSO)
  - ANS Fire PRA Standard is identifying requirements on MSOs
- Defines the scope of the Fire PRA as it relates to post-fire plant (system and operator) response
  - Ongoing discussions re: instrumentation in NFPA 805 pilot program
- Fire PRA component list will be larger than your Appendix R and PRA component list
  - New components whose omission will be non-conservative
    - For MSO considerations
    - For fire-specific operator manual actions (OMAs)
  - Expect that you *will* want/need to consider others to get a realistic risk result
- NMP-1 pilot follows the EPRI/NRC-RES method on MSO consideration

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Integration, Lessons Learned and Insights

Slide 28

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Notes:

Slide 29

Lessons Learned and Insights
Cable Selection

- Cable selection is probably the single biggest factor that will drive your resource requirements
  - The burden comes largely with the need to trace selected cables
  - You also need an *accessible* cable database, and constructing such a database from your existing system may not be so easy
  - This is going to depend a lot on the depth of your cable tracing and the nature of your current tracking system
- Exercise judgment
  - You may initially want to trace *all* your cables, but that may not be the best choice – you are taking on quite a job at most plants
  - Take advantage of the iterative approaches to cable tracing

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Integration, Lessons Learned and Insights

Slide 29

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Notes:

Slide 30

Notes:

Lessons Learned and Insights
Circuit Analysis

- Circuit analysis need not be a huge burden
- Compared to cable tracing, circuit analysis should be far less resource intensive – although it does require participation of key personnel (the electrical guru)
- The procedure provides various approaches that have been drawn from past practice and experience
  - Make use of those options!
  - Go after the "bang for the buck" circuits and "take the hit" when it is not risk important

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Slide 30

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Slide 31

Notes:

Lessons Learned and Insights
Fire Ignition Frequency and Fire Modeling

- Understand the scope of work of Tasks 1, 6, 8 and 11
  - One walkdown effort for collecting information for all the tasks
  - Use of a relational database for organizing and analyzing data is recommended
  - It is recommended that Task 8, Scoping Fire Modeling be conducted with Task 6, Fire Ignition Frequencies or Task 11, Detailed Fire Modeling
- Fire modeling in single compartments
  - Hand calculations will suffice for many cases, but more sophisticated modeling (e.g., compartment fire models) also has a place
  - Create fire modeling drawing packages. These are room layout drawings with ignition sources and Fire PRA targets highlighted.
- Fire modeling in the main control room
  - Fire zone or field models are necessary
  - Will require detailed system analysis and HRA
  - Smoke removal system can significantly impact abandonment and risk

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Integration, Lessons Learned and Insights

Slide 31

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Part 3: Perspective

Slide 1

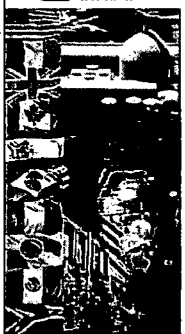
Notes:

U.S.NRC

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III-2: Perspective

Ken Canavan - EPRI
J.S. Hyslop - RES
Joint EPRI/RES Fire PRA Course
September 29 – October 2, & November 17-20, 2008
Bethesda, MD

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Slide 2

Notes:

On The Requantification Project

- A consensus methodology for Fire PRA that is facilitating implementation of risk-informed fire protection
- Remains the best available method to estimate fire risk & obtain insights
- Guidance is producing greater agreement among technical experts
- Much activity ongoing in NFPA 805 FAQ program due to fire PRAs being performed during transition

Slide 3

Continued Cooperation

- We established a framework for future research cooperation
  - Quality of work and positive technical reviews pave the way for continued cooperation
- The cooperation under the MOU is continuing
  - Fire Model User's Guide
  - Fire Human Reliability Analysis (HRA)
  - Fire Low Power and Shutdown
  - Others....

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Module III-2: Perspective

Slide 3

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Notes:

Appendices

Appendix A: Questions Asked in Module 3 Sessions

<u>NRC Disclaimer</u>: Appendix A is intended solely for use as part of a training tool. No portion represents NRC conclusions or Regulatory Positions, and should not be interpreted as such.

Session 1: Plant Partitioning

QUESTION

Slide 21: Who conducts these plant walkdowns? Are they done in-house or by contractors, for example?

RESPONSE

All of the people you mentioned are part of this effort. Contractors, utility people, co-ops, recent graduates, everyone. The level of experience and knowledge needed to do this must not be taken for granted.

Session 2: Fire Ignition Frequency

QUESTION

Presentation b, page 6: I still don't get how to consider W_L.

RESPONSE

I basically try to start fresh and say how I'm going to count the equipment, and once you make that decision, this becomes simpler. For example, if it's very easy for you to assign equipment to one unit or another, which is not always the case, then you just count them by unit and forget about this stuff. It's all 1. The reason I'm saying that it's not all that easy is because if we're trying to count equipment by unit, where one panel is assigned to unit 1 and another to unit 2. Then, you go to a room and there is a panel with no label. You don't know what it is, so your ideal situation breaks down. So, this helps you count things. Then, you bring into the picture the question of whether or not the equipment is shared. At this point, you can do what Marty said, like counting half of a pump. Usually, in the control room, it can be discerned what corresponds to unit 1 or unit 2, and either you can split them in half or assign the board to one unit. If there is the case of a problem that is swinging, it may be better just to count it as half. If you are clear on how you are counting, then this does not pose a problem; either count it as half if it's shared, or count it as one.

If, on the other hand, you have a shared control room and you counted only one unit, without even considering the other unit, then the ignition sources for that room are twice what you have counted. So the contribution for the fire source is twice the ignition frequency. If you have a generic frequency for a single unit but have twice the units, then you have to double it. My advice, therefore, is to consider how and what you are counting in the interest of being systematic. If you're just doing a localized analysis for the control room, you can just count something as one unit, but if you have a shared room, you need to add that multiplier because you are not counting the rest otherwise. (The answer to B is 2.)

The key to this is that the frequency in 6-1 applies to the cabinet in the unit that you are analyzing. That is the count on which Francisco is focusing. That frequency is the total frequency of fire ignition for a specific type of component. If you count that accurately as best you can, then in a room where the other unit is in there also, you can do what I suggested and you will be fine. The point is that this whole thing is unit based and that any new components must have units that match the existing components.

QUESTION

Page 6: Would this be equivalent to saying that a fire that starts in unit 2's control board is guaranteed to spread to unit 1's board?

RESPONSE

No. It is not necessarily guaranteed, but it is a possible contributor. You're establishing the frequency of fire within that room. Any fire. Actually, we're trying *not* to count it twice. That's what we need to be careful with, double-counting. This is equivalent to counting the two units, such that where you have 400 panels instead of 800, to simply double all the frequencies. When you do that, you will get the right weighting factors. Whatever you do, prevent that double counting, because the frequencies are per unit, and you have two units. Make sure you don't double-count.

QUESTION

Page 6: I think you hit the nail on the head that if you're doing the per-component count for the entire space, that you wouldn't need the sign there, a WL of 2, if you count every source in there. If you know what's in unit 1 but are unsure of what's in unit 2, but you know that it has a similar configuration, then you could assume a WL of 2 for that space, that time in your analysis, right?

RESPONSE

If you count everything, and you counted it well, you will get the weighting factors correctly.

QUESTION

Presentation A, slide 22: Suppose they're done horizontally?

RESPONSE

Again, you need to define your own reference cabinet and compare that against the reference cabinet. Define vertical segments of some kind and count it that way. You see, what it comes down to is that that specific cabinet vs. the rest of the cabinets in the plant that are within that group; all of the frequencies from 6-1 will be assigned to all of them. You must ask yourself how much of the frequency you will assign to this cabinet from another cabinet. If you come up with an internally consistent scheme, this will give you the best approach for use. All of your cabinets are horizontally divided, right? All of them are. Each horizontal division will be assigned one count. It comes down to pro-rating your total frequency to each item.

Session 3: Scoping Fire Modeling

A BRIEF REVIEW

Reviewing the risk equation.

Points to lambda sub G; This is the generic frequency. Where does it come from? *Inaudible answer. Points to W sub is-1.* What is this? Where is it coming from? Walkdowns, and counts of ignition sources. This is a split fraction of ignition sources. What is this? *Points to severity factor.* Where is it coming from? Heat release rate. Somebody can tell me how we come up with the severity factor? Where does it come from? HRR that would damage your target. We assign a distribution to each ignition source, right? We found the HRR that would damage the target, found that value in the distribution, and the area under the curve to the right is, what Dean said, 2% or less, then you can screen it. We say that it is unlikely that the fire will get that big.

QUESTION

Slide 13: So we screen ignition SOURCES if the critical value is higher than the 98^{th} percentile?

RESPONSE

Yes. The only cautionary note is that the critical value should come only from the ignition source. If you have trays above the ignition source, the HRR may not come only from the ignition source. That may be one you have to further analyze to see what the cable trays would do. Only an isolated ignition source, incapable of propagating, would be able to be screened. This admittedly limits its applicability, given some of the complex geometries that we have, but that's the way to use it.

QUESTION

Slide 13: How do you determine whether or not an ignition source will screen?

RESPONSE

Let's do two cases. If, above your cabinet, you have a stack of cable trays, and you start a fire; if the only cable you care about is in a tray remote from the ignition source, then you can screen the source. If, however, you have the ability to propagate a fire up, you can not simply screen the fire, even if the actual target is remote from the fire.

QUESTION

Slide 7: How would you organize your list of design fires?

RESPONSE

I would strongly suggest a section, when you are dealing with either scoping fire modeling or detailed fire modeling, that clearly says "these are the types of fires I have, and I'm going to use this generic values, or I have these plant-specific values," and you just get it over with in a clear section that you can reference, writing justifications for what your damage criteria are. Keep the HRRs in a centralized place where you know where your justifications are. That should work fine.

QUESTION

Slide 7: What conduit do you use in this fire modeling?

RESPONSE

The conduit is the same as the type of cable that you have inside. That was thermoset cable in a conduit, so we used 625.

QUESTION

Slide 13: Do you treat transient fires in the same probabilistic manner as other ignition sources, by saying where they are most likely to be located?

RESPONSE

What Walt is telling me is that this FAQ will need to be more detailed in addressing types of panels and transient fires. It is also silent on when to put a transient fire. People love to talk about trash bags. Where do you place a trash can fire? All of these are questions that are not addressed in 6850. Hopefully this FAQ will address it.

QUESTION

Slide 13: What I'm hearing is that one thing being accounted for in the FAQ is that these correlations have not been developed for use in multi-dimensional cabinet fires. It seems that this is not an appropriate application for this model. A fire inside of an enclosure has an obstructed plume, resulting in a three-dimensional fire, rather than a two-dimensional fire. Now, there are ways to get around that. When I'm putting on my peer review pack, or I'm doing the analysis myself, what, when you're talking about justification, has been done in the way of discussion about whether these are really applicable to these cables and, if you recognize that they aren't, what documentation do you need to provide to be able to say "we handled this in a manner that deals conservatively with the answer to that question"?

RESPONSE

You're right in all your points. For fires inside cabinets, you're right, these are not applicable, and I think our treatment has been "forget about the cabinet, we just put our fire there." Hopefully the effects of the cabinet walls will be to the benefit of those targets, so not having it adds that conservative approach.

QUESTION

You could say that we measured the heat release rates and determined how much energy is being released there, and that the distribution of this release is unimportant because the plumes have different amounts of energy. You can postulate a single plume coming out. Like you said, I'm not saying that this is a show-stopper, but what I would do is go back to the FAQ and say "what's the bounding analysis where I can locate my fire?" The answer to your analysis may not *be favorable, and that's what I'm reading in this FAQ; that this answer is too conservative, and that we want something a little better, but we don't have the means to really do that. At this point, I don't think there are enough test data or analysis calculations.*

RESPONSE

In a way, that's why 6850 was silent, because this task is somewhat beyond the state of the art. That was the task of these documents, state of the art. I agree with that argument. I'm telling you that so far, once you assume this fire, the guidance is to use an unobstructed plume up to where you encounter this obstruction. In my example, I intentionally included intervening trays that are not targets and advised you to screen them if you have obstructions.

QUESTION

Looking at some of these analyses, though, if you just plug and chug this, I will have to flag it and ask you to show me why this limitation is valid. There may be a valid reason, though, if you take that HRR and situate it atop the cabinet. You may not have a decent argument if it is situated on the floor. It is by no means a showstopper, but have there been discussions about this issue? When you get to the end of this, it could be a showstopper.

RESPONSE

There is either limited guidance or questions being raised on the FAQ. The only point I want to make about the FAQ is that its focus is very narrow, and is not intended to expand into a research-wide paper. Another point to be made is that some of the arguments used in this may come on risk terms, rather than on fire modeling terms. They may choose to be very conservative, rather than using the best inputs, because they can accept the more conservative plant impacts.

QUESTION

So then these equations are justified by guesses about conservatism?

RESPONSE

I'm not saying that that's the justification. I am saying that the equations we have are what we have, not something new developed for the nuclear industry or something, and that there are documents and training describing its use and limitations. Analysts are using them within the limitations. I suggested that not all of the justifications will be on a fire modeling basis. There are other issues that provide these checks, not just because of the use of the model. In a risk analysis, the justification will not simply be the use of this model. By the time you know what the impact is, you must also know the cables involved, what the impact is, how the circuit behaves, and many other things involved in it.

Are you suggesting that the models we have are not conservative? Because the models can be quite conservative, we hope. Are you suggesting that we are guiding people in the wrong direction?

QUESTION

I don't think that there's sufficient guidance to tell people how to take correlations developed from two-dimensional pool fires and three-dimensional wood grids and apply them to an electrical cabinet. What you're saying with the lack of guidance here is that it's okay to do that. I don't see anything here that says "electrical cabinets: beware, because this is how these empirical correlations have been developed." They're outliers.

RESPONSE

I don't see that when we suggest "view the fire and forget about these cabinet walls" we are misapplying the correlation.

QUESTION

I don't think that you are. I think that one solution would be to do a bounding analysis where you find the HRR and find a reasonable representation of the area of the fire, and that will be all I've got. What I see in the FAQ is that this tends to be the most conservative approach, and we're asking for a less conservative approach. I don't think we're there yet, I don't think that we have the fundamentals to put forth this less conservative approach. That is guidance that could be provided to people, by saying "look, we understand this stuff doesn't work, but here's how you get around it."

RESPONSE

It's not that it doesn't work, it just yields a very conservative answer.

QUESTION

We don't know if it yields a conservative answer.

RESPONSE

That's the impression I'm getting, is that they're getting very short time periods, and that's giving them headaches.

QUESTION

We never validated the cabinet fires with the correlations. That's never been done. It's just been in applications.

RESPONSE

Then what you're suggesting is that what we have in the guidance is not conservative. That's the key here. What we have here is the important element that we have to fault on the side of the conservative.

QUESTION

The bounding analysis places the fire on the exterior of the cabinet, and thus far, I fail to see this addressed in the FAQ.

RESPONSE

Any reading that you're doing on this FAQ is not final yet. The FAQ is still in process, and these concerns that you raised are being considered. FAQ is a misleading term; it's actually only one question. This is currently under analysis. I am the first one to agree with you; from an experimental, analytical perspective, we may not have the tools to address it with math. That's not the only place in risk analysis where this is an issue.

QUESTION

But it has to be addressed, I think. There is a workaround, and it just needs to be put forth so that everybody knows exactly how we're getting around the limitation. All of these correlations were verified, right?

RESPONSE

Well, verified by experiment. That's how it's done.

QUESTION

But in the DMD study, if I remember correctly, you screened those out because they weren't the correct equipment. You can't use that in your correlation because it was essentially the junk data from another experiment. You did it for other well-known, well-characterized fires.

RESPONSE

We have to be careful here. I agree with you in that these correlations are applicable if you have a fire inside a panel and you want to consider this panel, walls, and the effect that the cabinet will have. Do we have a correlation for that? Do we have guidance on how to do that? No. People report a heat release rate and assume there is no cabinet. In this case, if there are no obstructions, we have said "yes, use this plume correlation". Would I want to see further research and a model to account for that? Probably yes. Do we have it? No, that's why it's not here.

QUESTION

But then specifically, how do you justify the use of the correlations this case?

RESPONSE

By assuming no cabinet. Is there an argument that yes, you actually have a cabinet and aren't accounting for it? Of course.

QUESTION

So that's an assumption and the engineering validates these assumptions, and so, to me, the best guidance would be to take the equipment fire and measure that heat release rate, and then place it at the top of the cabinet as the bounding analysis.

RESPONSE

That's fine. That's what Walt says that his inspectors are doing, and I know plants are doing that in some cases.

RESPONSE

I think that people who are doing these analyses need to understand that this is merely a workaround to do this.

QUESTION

Why isn't fire modeling used every time? Wouldn't that help to evaluate each scenario in context?

RESPONSE

The general approach in PRA is that you start with several failures. Rather than postulating no damage, you start with fires that damage everything. From there, you make reductions. When you apply fire modeling, you do so with the goal of proving that the target is undamaged, because this disproves the initial assumption. You start assuming all these failures. If you have high-risk, sharpen your pencils and see what you can get. It is in this reduction that you start being less conservative because you're not killing everything, but within the application, your conservatism is built in, and hopefully, the way you use these models is on the conservative end, given that they are not the exact geometries present in each nuclear power plant scenario. When we were doing the validation work, this is a point we raised. To get validation for every single nuclear power plant scenario is probably impractical in the near future, due to all of the geometries that can be observed in different plants. This is part of the state of the audience.

Session 6: Damage Criteria

QUESTION

Slide 3: How were the cables tested? Did they short and that caused the ignition?

RESPONSE

Well, it's just cables under a big flame. Those tests were trying to figure out the probabilities and how this circuit behaves. So, yes, the cable is exposed to either a plume or flames.

QUESTION

Was there a documented pilot, a point where the cable ignited each time?

RESPONSE

Once the experimenters observed a short, the cable shortly thereafter ignited and this was the pilot you were talking about.

Session 7: Detailed Fire Modeling and Single Compartment Fire Scenarios

QUESTION

Slide 10: Can you set boundaries for ignition by saying "this is the closest ignition source, therefore since it doesn't catch, all of the others won't ignite also"?

RESPONSE

Why, yes. With the right tools like a well-organized database that can talk to the PRA, you can play games like failing all of the conduits and see if you can use that approach to screen the cable trays for something. That sounds easier than what it is if you don't have the right tools, because when it's not hooked up, this becomes a manual process. But once it is, and you understand your ID systems of how trays and conduits are labeled, then you can do cable database events on a larger scale in order to screen things. I have seen databases where the cable and raceways would have so-called "rooms" within compartments, based on column lines, because the cable and raceway database was based on these column lines. So we defined these rooms within the fire compartments. Since everything was so well-labeled, we could go and say "fail a room" in that compartment. That would be a portion of it defined by column lines where all the conduits and trays there could be set with trays associated to them. This would allow us to see where we really needed to go and sharpen our pencils. I stress that this sounds simpler than what it is, because it requires a well-structured database with good data. In plants that have that, it is straightforward by postulating fires once you have your ignition sources. But if it takes some building to do and some data cleanup, then so be it.

QUESTION

If you use CFAST, you don't have to verify and validate your model, do you?

RESPONSE

That's our intent. We want it to be such that if you use CFAST within reasonable bounds of what was V&Ved, then that's your V&V. But a V&V has its own limitations, a set of extrema that were set for it, so not every single feature in CFAST was V&Ved. The sprinkler feature, for example, lacks the verification process applied to the cable fire modeling within CFAST. The way it works is that we classify the results, and say "this kind of overestimates", or says that one part is right on target. Our intent, to the best extent possible, is that if you use CFAST, you don't have to write an appendix explaining your validation. I agree with you, that before the V&V, we would have to write an explanation of the model we were choosing, which is why we have this suggestion now: it is very convenient.

QUESTION

If you use CFAST, do you need to have it V&Ved on each computer? Is it workstation-specific, like in DOE?

RESPONSE

I will let higher pay grades answer that question. I don't know.

Session 8: Detection and Suppresion

QUESTION

Slide 15: Where is the data for the BWR containment? Four of them are not directed. Wouldn't we then use the PWR containment?

RESPONSE

I would say so. We didn't have data for the BWR containment to develop this. We knew that there were a few that were not. There are four in this country, but we only thought there was one. I guess we were off.

QUESTION

Does this assume a standpipe with a hose is available, or a fire extinguisher, or perhaps a mix?

RESPONSE

This is the deal with these curves. We have the data from the fire events database, and some of that data lists time (fire duration), or time to suppression, or both. So a subset of the data that we use for the frequency has that kind of information. In addition, we only use data after 1980, which is when appendix R kicked in. That's the data we use for these curves. Admittedly, not all of the data has this information. When available, we use the time to suppression, but if the duration was available and not suppression we will use the duration. This is part of the FAQ, saying "well, those duration times are longer than the actual time to suppression". By the way, the Browns Ferry fire was listed in order of minutes that they finally decided to use water after hours of trying to use extinguishers. You have to be careful with those numbers. The bottom line is that if the suppression was available, we picked that number. If not, then if the duration was available, we picked that number. That may be a limitation of this. I'm talking now about a subset of the data, post-1980, and data that had either suppression or duration available, and then we started excluding events that were suppressed by fixed systems, or self-extinguished. So all of this is basically someone with an extinguisher or the fire brigade coming. These are the events that made it to these curves, and with those events we developed this thing.

QUESTION

So for anything other than a brigade we don't use this time as a factor in the previous chart?

RESPONSE

Wrong. Like I was telling him, even for the activation of the sprinkler system, you need to calculate the time for that activation.

QUESTION

The suppression probability you gave on slide 9: this is the probability of non-suppression?

RESPONSE

No, this is the probability of failure of the system. If you go back to the event tree, the PNS is the sum of the non-suppression branches. When I'm crediting a smoke detection system, I would put here the probability of failure (the split fraction) for the smoke detection system. These are just probabilities of failure to put in these branches, but it is not the aggregate probability of non-suppression. Those numbers in slide 9 are inputs to the event tree.

QUESTION

The curve shown here is only manual?

RESPONSE

Yes, only for the suppression probability for the fire brigade. There are more curves, and one of the longest ones is the high-energy arcing faults. In this one, the quickest one to suppress was the cable fire, which took only about ten minutes. You see that you very quickly go to very low probabilities of the system.

QUESTION

Is there a curve for automatic suppression as well?

RESPONSE

No. The automatic suppression numbers will come out of the event tree when you do the same thing. This is the same in table format, and this is the curve, so if you have a lambda, that would be this mean here, and you stick it in and get this probability as a function of time.

QUESTION

Slide 20: Is your fire brigade response time just the time it takes them to get there?

RESPONSE

Well, it should be the time to start suppression activities. We usually go through the real records of things within the plant, through all of your fire compartments in task 1, but places close to it, and average drill records, and come up with numbers.

QUESTION

So if I have a damage time of 15 minutes and a brigade response time of 15 minutes,...

RESPONSE

The brigade fails. I was doing work in one international plant, and asked for the brigade drill records, and they were all very good (~5 minutes), but then I tried to find out what was going on, and the drill was always to the same place, and they knew where the fire was. They would say "oh, gosh. We have a fire in that room. Perhaps, you know, if you want, you can go and fight it or something." If every week you go to the same place, they start becoming very, very good. They don't have an addressable fire detection system, so when the alarm sounds they don't know where it is, so for the drill they tell them where to go. This doesn't really represent the real story. I have been in plants here, not to draw comparisons, but when I go through them, some of them are very detailed, with times for everything on reports for each drill, and we pick out of that the time to start the suppression activities. I put that as input data in my rooms tables, where I have time to brigade response, and this becomes the time input to the event tree.

QUESTION

To take it a step further, if the damage time is longer than the response time, is there a suppression time you add on top of the response time?

RESPONSE

No. If you can start suppression activities in 13 minutes and the damage time is 15, then you go to your curve for 2 minutes and see numbers very close to failure. That assumes, of course, that the fire brigade immediately begins doing the correct thing, rather than just wandering around.

Session 9: Special Fire Models Part 1

QUESTION

Slide 8: Why are the units for the bench scale HRR given as flux?

RESPONSE

The bench scale is a small piece of material that you subject to heat flux and measure its HRR. They express that HRR per unit area, and then we multiply it by total area to get the total answer in kW. In this case, it is the area of the cable that is burning.

QUESTION

I know you mentioned qualified and non-qualified, what makes a cable qualified?

RESPONSE

It's just that 383 flame spread rate, whether or not it can propagate. It's not exactly the same, but there are two conditions: qualified and non-qualified, just like thermoset and thermoplastic materials. The best description of a thermoset cable vs a thermoplastic cable, as I heard from MARK SALLEY, is that a thermoplastic just melts and drips, and the insulation falls. The thermoset is like a hot dog that you leave on the grill on the 4th of July, in that it just chars around and the insulation doesn't fall, it just remains there. Unqualified and qualified comes from the IEEE test, where we pass or fail that test. We kind of use thermoset / thermoplastic to mean qualified / unqualified, even though that's not really what it means. But this PVC is clearly thermoplastic. Some of the others are thermoset. You would need to decide on a number, and this is all we have. There is a NIST report on this, and the NIST report has the most guidance. The SFPE handbook has a condensed version, which is essentially the same thing as what is shown in the slides, and 1805 has somewhere in the middle a discussion of where this is coming from.

QUESTION

Slide 14: How far apart were the trays when you saw the fires jump between them?

RESPONSE

1 to 2 feet apart. Definitely not 10 feet.

QUESTION

Slide 15: If a plant uses some computational fluid dynamics and fire models, do they match this model? If I built a model of that room and ran the calculations that you suggested here, would it realistically match the expected results and propagate?

RESPONSE

Permit me to answer your inquiry in two parts.

Will it do some propagation? Absolutely.

The other part of your answer, a rather political topic, is that these models have not been experimentally verified, and we don't have input parameters for the model, to V&V it. Even if we take the experiments that were used for it and put it in a model, we would not have the properties of the cables and other inputs that a fire modeler would need to say "this is V&V". That's why we have it this way, and we say "go put it in a CFD code and see what it does", because we don't have properties.

QUESTION

Why do you expect a disconnect between the model and the experiment?

RESPONSE

Obviously, some of the variables are not valid for it. But I have seen simulations of fires like this, and there is no question that the fire jumps all over the place. My own opinion, by looking at those simulations and these experiments, is that definitely this happens, and until we have more data or better properties, we are not ready to go into those calculations, but at the same time, I am not ready to say that propagation will not happen. I mean, models show that, for whatever properties you put in, and experiments show it, for whatever experimental conditions you have. I am being careful in my answer, because that is the discussion we have been having.

QUESTION

Is there a stated limitation in how far, when you get outside of the test parameters, that you can apply this model?

RESPONSE

The configuration of the test is described there.

QUESTION

Slide 19: When you say "segmented", you're talking about bus bars that are bolted together, rather than what we call bus ducts, which essentially consist of concrete holes with cables running through them.

RESPONSE

Actually, you can screen those, because it's only one piece of a cable that goes from one side to the other with no junction points, right? FAQ allows you to screen it.

QUESTION

Wouldn't it be much better if you abandon the control room and go to the backup where your probability of success is much higher?

RESPONSE

Yeah.

QUESTION

Why would you even try and stay in a place even if the temp of 85 degrees? Isn't the probability of making a mistake 50% or higher?

RESPONSE

I am finding the probability that at these temperatures the operator cannot even be there, risk analysis says that if there is a fire big enough, the operator should leave because this might be their only chance, it is going to raise the risk if you stay under these conditions that are slightly less than this limit, It is going to raise the risk than if you abandon the control room and shut the plan down from elsewhere. You are penalizing yourself.

QUESTION

Are they just giving you a limit where you can't stay in the control room from the fire analysis side? You got to take what they are doing and reintegrate it back into the model. One must establish the appropriate abandonment criteria on when you are going to leave versus when you going to stay. I am just saying that you start weighing how well are you're weighing your leave the room methodology versus staying in the control room.

RESPONSE

I believe that people will want to learn how to improve their smoke purge techniques among other things before they would want to worry about shutdown methodology. Fuel will burn fast, and the creation of smoke will be rapid. But to be completely honest, most of these control room monitors have to act on instinct because there is nobody in the background that tells you exactly what to do in fires such as these.

QUESTION

Should we expect any procedures that are below the levels than the ones that were included in this presentation, such as ones below the ultimate shutdown methodology? What we are learning as of now is the steps that we should take in these situations and what is the allowable time a operator should stay in the control room, From that information, it seems that we can determine the realistic criteria for abandoning a control room and we can also consider the shape factor and likelihood of making special actions.

RESPONSE

Not usually based on specific fire conditions they are more specific on what Walter was talking about, I lose some of her ability and I usually take positions and waiting for judgments from the operators you went and that might mean that people can stay and some in the control and others do their own things. If you get to this stage, forget about the control, you are out of it.

Session 10: Special Fire Models Part 2

QUESTION

Slide 8: In the case of these fires, should you postulate a plant trip?

RESPONSE

What else is failing besides the trip? An extreme example is an RHR pump room fire. If you're testing the RHR pump and the motor catches fire, will the plant trip? Most likely not. Of course, the shift super may panic and say "shut down the plant", but there's no reason for them to lower the power level and start a shutdown. You could argue that some of these events are a part of the internal event, something that other people have already modeled, because a plant trip can happen for many causes, including this one. You need to be careful how you do this, in order to ensure that anything else that could be affected is not. If you can convince yourself that nothing else is being affected by it, then you can say that it is a part of the failure probability that the internal events people already considered.

QUESTION

Slide 8: When you look at the nature of these analyses, does it make sense that they would not be a non-threatening fire? The data tells you something, but when you actually look at the component, does it make sense that there's something about the way that the exciters are put together that your fires are always hot and bright, because there's nothing to burn around them?

RESPONSE

That's exactly what I'm suggesting. Don't take this word and say "because evidence is confined every time, therefore there's no need to worry"; you should look into the exciter and see if there's anything nearby that is on the fire PRA component list. If it's on that list, you should look at it carefully and see if it can be affected or not. This will come up again when we discuss the catastrophic failures.

QUESTION

Slide 14: How do you resolve the fire size of the hydrogen formulas? I don't see a formula here.

RESPONSE

We didn't provide you a formula there. We have references. If you need the flame length, there are formulas to find it, found in appendix N. I would suggest that you assume everything in that room is destroyed, and if you can't screen that, then you should use these formulas. If the room is huge, then use a smaller zone, but if it's a small room (which is typically where I find the hydrogen piping), then assume everything is gone. If you can't screen that, then use the appendix N formulas.

QUESTION

Slide 14: For battery fires, did fires result in structural damage to the buildings?

RESPONSE

The pictures I've seen have been in non-nuclear environments. In a nuclear plant, typical battery rooms are inside buildings and they're well-established. They're in isolated rooms with rated fire walls and ceilings. But the ones I'm familiar with were on the outside of another building with a regular frame-type construction.

QUESTION

Slide 14: Have you ever encountered any catastrophic hydrogen deflagrations?

RESPONSE

I think the majority of the events in nuclear plants have been deflagrations. I don't remember any detonations in the nuclear events, because the quantity generally is small. The large quantity releases have been outside, where the relief valve has vented and created a hydrogen fire on top of the hydrogen storage tank and created a large fire. In this case, the fire brigade has correctly said "okay, we're not going to put it out, just let it burn itself out". By the way, hydrogen flame (I think) is not visible.

Session 11: Main Control Room Fire Analysis

QUESTION

Why would analyze the fire impact on the farthest element from the postulated ignition source? Wouldn't it screen more efficiently if you addressed the closest element?

RESPONSE

I wouldn't pick the farthest one, I'd pick the closest. That's exactly what I'm saying. You need to be careful to see what set you're selecting. You will select the minimal selection that does your damage.

QUESTION

Are you trying to say that you want to find the scenarios that could take out all aux feedwater pumps? Or is there an exercise up front that will select those components you think you can seek, so if I was going in looking at aux feedwater pumps, will I look for those things that will take out all aux feed and measure those?

RESPONSE

In principle, you should look at every possible combination of these controls and instrumentation. Obviously, that's an impossible task, so minimal cutsets is one idea, albeit imperfect, because often times you don't have a perfect minimal cutest. You may have a partial minimal cutset, so you basically need to pass judgment to see which areas are the most important. Actually, it's a spatial exercise. You're basically going through the panel and imagining a glob of fire of different dimensions moving about and around and affecting things.

QUESTION

As per the chart, I will take auxiliary feedwater and measure the distance to main feedwater, with the assumption of no intervening barriers. Do we retroactively account for that?

RESPONSE

Not unless there is a very clear separation, a perfect wall. Cabinet walls can be considered perfect walls, so long as there is no air gap. Imagine two cabinets put next to one another: a perfect wall. Then, we give you a fifteen-minute credit in the methodology. Follow the associated guidelines where they are listed. The main control board is no exception, although it is generally open in the back. That opening has associated options with it, like half-walls, or channels coming in, where things are put through. Some of them are completely open, with spaghetti of wiring in the back well within sight.

QUESTION

If you postulate this type of fire, you discount the possibility that some of these elements with potentially massive ramifications (very large CCDP) will be affected by the postulated fires.

RESPONSE

In this case, you can not say "I don't care", because you need to be very specific which pump you will pick. You need to measure that distance. It may be difficult to establish the very fine resolution, saying that one will be affected and not another. I would not recommend it. If things are so close to one another, it is unrealistic to say that the fire will hit one element and not the one next to it. The best thing to do is to form your list of possible fire events and then examine all of those for which you think the CCDP will be significant. Significant CCDP in this world is probably anything above .01. Anything above this number probably has some contribution.

QUESTION

What about a fire in the back of the control board? Something that affects the wiring?

RESPONSE

This method includes damage to the wiring. I have seen cases where people have chosen to be so thorough as to walk it down and note where things cross from one part to another. That raises another important point. If you have two elements separated by a certain large distance, but whose wiring comes together in a small area of the control board, then a fire necessary to take out both elements is not the large fire that affects the distance of separation, but rather a fire only large enough to damage the control board at the point of contact, large enough only to affect the distance that the wires are separated. The presumption is that the fire happens in the back of the control board, or underneath.

QUESTION

What are some possible fire scenarios in this case? Where could the fire come from?

RESPONSE

Shorts, relays, smoking; there are some events inside panels that start with circuit guards. Some start in the wires. I think it has happened internally within wires, although usually this stems from a short somewhere else in the plant with a side effect of overheating within the panel.

Let me recap. By doing this exercise, you effectively are also analyzing everything in the immediate back of the panel that serves the front panel. Now if you have another back panel with its own instruments and devices back there, you treat it as an electrical cabinet. This does not change the exercise, though, in that you still walk the cabinet down and say "I care about this part because it has a high CCDP".

QUESTION

Is there an indication that they're relying on their damage temperature for MCR abandonment higher than 200 F?

RESPONSE

In the control room, usually some cables and sensitive electronics will be damaged below this temperature. That can happen even with a fire that requires abandonment. This does not assume that the entire room reaches a temperature of 200 F, just the gas layer at the top. If the board is at a lower temperature, the room can still be tenable. When I have done these analyses, I have seen that the HVAC in the MCR becomes a very significant factor that should be included in your fire model. You may not even develop a hot gas layer, because the rate of smoke removed from the room may be higher than the rate of smoke produced. Of course, the HVAC systems are also subject to failure, which can be represented in the same way as any other component, with a probability of failure. I have seen plants with detailed procedures for smoke purge. It is a mode, clearly defined, with operator guidance on usage. Push a button, and a certain fan starts the smoke purge. There are others that do not have such specific requirements; the only options are normal operation and emergency mode, which is designed to contend with such things as radiation as well as fire. If smoke purge is not clearly defined, then it is more of a challenge. I have seen others that it is there, but for some reason, it is behind a plate that makes it completely inaccessible during emergency conditions. They knew the procedure, and there was certainly a way to make it automatic, but it was completely counterintuitive.

Session 12: Multi-Compartment Fire Analysis

QUESTION

Slide 2: Spreading that you speak of here is just the gas and not the flame?

RESPONSE

Unless you have a direct line of sight for the radiation effects of the flame, you should take the gas into consideration, but generally what we have in mind is that a very hot gas forms under the ceiling, and it moves out. There are situations where there is a complete opening between rooms, and this task is to do a screening analysis in a stepwise way to arrive at specific scenarios that merit a more detailed analysis. You can appreciate that we could easily have a very large combination of compartments that are adjacent to one another, and would communicate with one another. Effectively, you must consider all combinations of rooms and screen them out.

QUESTION

Slide 10: In this case, will you include all of the fuel in the room, not just the burning cabinet?

RESPONSE

Yes. Add the intervening combustibles when considering your multi-compartment fire.
QUESTION

Slide 11: When calculating all of the combustibles in the room, how do you add the transient combustibles?

RESPONSE

We have a distribution for the transients, there is a 98 percentile HRR for the transients. We recommend you use the worst-case fire you have in the room, and see if you can do damage next door. In this step, something less than the worst case could do the damage, so this gives you a severity factor, and also in this step, you must consider the probability of failure of a certain fire barrier if it is required as a means of egress.

QUESTION

Slide 14: Do I need to subtract (1 – the barrier probability) from the other analysis that I did? In the other analysis, we examined the potential for damage to the walls of the compartment during a fire, so do I need to examine this scenario when assessing the probability that the flame will spread?

RESPONSE

In principle, yes. But I think the impact will probably be insignificant.

QUESTION

If you can not screen out a fire spreading to a second compartment, do you then use that second compartment as a source for the third compartment?

RESPONSE

Yes, you follow the same procedure that you followed for a single compartment analysis, but then in this case the new target set is based on the elements in the new room. At this point, do the same analysis that was done for a single analysis.

QUESTION

Could this lead to a domino effect, where rooms concatenate to form an extreme fire? In practice, how does the fire brigade play into all of this?

RESPONSE

The detailed analysis addresses this. In this task, the multi-compartment analysis is only screening-level analysis. This merely eliminates some scenarios and arrives at some others that can not be eliminated, and then applies the detailed analysis for only that subset.

QUESTION

In your experience, how readily do you see individual rooms that fail to screen?

RESPONSE

Very many of these rooms will screen, making multi-compartment fires rather unlikely. You need to consider barrier failure probabilities. The key is that the most important discriminator will be the things that are failing in the second room. In other words, the CCDP will play a very significant role in all of this. This is one area that requires a great deal of judgment. Over the years, some plants involve fire zones, and some have no walls. Some have 20 feet on the floor and say "this is my separation", with cable databases and documents all identifying this distinction. They find it very difficult to redefine everything and remap all the cables in the database. What I have commented on is that if you put fires in those boundaries and figure out very quickly what your targets there are, and in those areas, place fires and check the ramifications. One noteworthy exclusion is addressing what to do with oil. You could make such a big fire that it is difficult to screen. You then need to decide which oil fire size you will use, something that is not clearly defined in 6850. This is one thing that requires documentation.

Session 13: Seismic Fire Interactions

QUESTION

Can you stay in a room that is on fire with temperatures rising to 90 degrees Celsius?

RESPONSE

If it gets to that temperature, that best course of action is just to abandon the room.

QUESTION

Would you be able to do anything within the control room once temperatures reaches these extreme conditions?

RESPONSE

Yeah, you will be able to do things at these temperatures. But it is known that smoke that is coming from the fire will affect your sight as well as your ability to breathe, so it will be assumed when the first signs of a fire are witnessed, you are geared up and you have your breathing equipment on.

QUESTION

A limitation of a 0.4 meter radius to see what is around you during an intense fire gives very low visibility to do anything. Usually, control room operators are about 6-8ft away from the actual control board. What should operators do in these situations?

RESPONSE

I mean, even with breathing equipment and everything I am not suggesting that you will have all the crew doing everything that they suppose to do. I am talking about a fire accident and we are just trying to find out where definitely they really have can't really do anything else in that room. Everyone who is in this vicinity should be equipped with equipment in order to protect themselves for the short time to evacuate the premises or do their specified duties.

QUESTION

At 95 degrees Celsius, aren't those temperatures where most people will gain 2nd degree burns in a matter of 10 min?

RESPONSE

Yes they are, but we aspect our staff to be fully and properly geared up.

QUESTION

Do operator success probabilities change with room tenability? Obviously, they can not effect changes within the control room after it has been abandoned, but does performance change over time while the room is burning?

RESPONSE

One of the things that I think wasn't fully translated is if you assume that this operator stay in this control room at these conditions, there are significant changes on the performance shaping factor on the success of the operator. We are assuming that they are suited up as well as other things to keep them safe during a fire. Those operators are sweating and their success rates are low. I mean you got a high probability at play here for their actions within the main control room.

QUESTION

Do you know the location of the switches that transfer the controls are?

RESPONSE

The switches are always located outside of the control room.

A Brief Review: by Mardy Kazarians

Here is my version of it. If you have an incident at all plants to the tune of about once every ten years, your CDF is to the tune of a serious incident at one plant about once every 500000 years. So to go from an incident every decade to a CDF of about 1 in 500,000 is a large step. I am not saying that the basis for a CDF is weak, but merely that it requires a very solid basis.

In order to achieve this, we had to develop a frequency for ignition sources. We multiplied this ignition frequency by a whole bunch of parameters, which became the fire scenario frequency. We then multiplied this by a CCDP, something that came from the PRA model.

There is something wedged in between, which is the circuit analysis. This is not a trivial part! The circuit analysis wedges between the fire scenario frequency and the CCDP because it may identify events that are probabilistic. If we ignore the probabilities on that one, it affects the CCDP, but sometimes we look at circuits and say "it probably won't happen, but here's the likelihood that it will." That is wedged in between the scenario frequency and the CCDP. The circuit analysis is a very important part of fire risk analysis for several reasons. The weakness of a NPP is really in the cables that run from one place to another, because they are bunched together. Common cause failure happens because they are bunched together and one fire can affect many elements. Cables are part of a circuit, so understanding how circuits work is important because the control circuit can cause failures that are not part of the risk model, like a spurious actuation. Not all circuit failures can do that, so an understanding of how it can happen is very important.

Our focus was completely on the fire frequency. We established the ignition frequency based on component type. We also said that fire is a localized phenomenon, so we will focus on compartments, a convenient way of looking at it. Ultimately, we will look at fire scenarios. Thus, the way we should think about this is by starting with a very specific item or device, and propagate that fire and its effects onto other items. This is the fire scenario, but it is too much work at the beginning. In order to have a complete analysis without doing an excessive amount of work, we use fire compartments and base our analysis on the compartments. We then take this component type as an identifier for our ignition frequency and say that it is the same for all components in the plant of that type.

We then need to multiply this by a factor that will correct it, to make it specific to either a certain device, or to all possible ignition sources within a compartment. This is the ignition source weighting factor. I don't want to talk about location factors, because this is the multi-unit factor, but that is something you may wish to consider if you want to do a multi-unit analysis. This establishes the initial fire. Now we must say that this fire must be strong enough, because not all fires are strong enough to damage each item. Smaller fires can damage these components, but they will take a very long time. A very strong fire is also possible from here, that can damage these components quickly, so the discrimination between fires that can damage these components quickly is the non-suppression probability. I can have a spectrum of severities of the fire, and if it is medium strength, there is more time to suppress the fire than if I have an extremely strong fire. It is an integral of all possible severities. We showed you how to do this, and that there is a range of HRRs based on a gamma distribution. Based on the gamma distribution, we showed you how to calculate the propagation rate to the targets, to establish the time to damage, and then we also talked about how to establish the probability of non-suppression based on location-specific features. If this event is a welding and cutting related event, then we have a prompt detection and probability of prompt suppression. If it is a component fire, then will the automatic systems come on? How long will it take the fire brigade to show up? With this, we have established a scenario frequency, and this entire thing will be multiplied with the CCDP and other things.

This is a summary of the parts we have discussed. Obviously, some of the parts are pretty complicated, and the methodology behind it is very, very complicated. Effectively, we will use relatively simplistic models to model what happens in nature. That basically gives you an overview of what we tried to cover in the past few days.

Appendix B: Reference Tables and Figures

Table 1
Fire Frequency Bins and Generic Frequencies

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
					Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
1	Battery Room	Batteries	All	7.5E-04	1.0	0	0	0	0	0
2	Containment (PWR)	Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
3	Containment (PWR)	Transients and Hotwork	Power	2.0E-03	0	0	0.44	0.56	0	0
4	Control Room	Main Control Board	All	2.5E-03	1.0	0	0	0	0	0
5	Control/Aux/Reactor Building	Cable fires caused by welding and cutting	Power	1.6E-03	0	0	0	1.0	0	0
6	Control/Aux/Reactor Building	Transient fires caused by welding and cutting	Power	9.7E-03	0	0	0	1.0	0	0
7	Control/Aux/Reactor Building	Transients	Power	3.9E-03	0	0	1.0	0	0	0
8	Diesel Generator Room	Diesel Generators	All	2.1E-02	0.16	0.84	0	0	0	0
9	Plant-Wide Components	Air Compressors	All	2.4E-03	0.83	0.17	0	0	0	0
10	Plant-Wide Components	Battery Chargers	All	1.8E-03	1.0	0	0	0	0	0
11	Plant-Wide Components	Cable fires caused by welding and cutting	Power	2.0E-03	0	0	0	1.0	0	0
12	Plant-Wide Components	Cable Run (Self-ignited cable fires)	All	4.4E-03	1.0	0	0	0	0	0
13	Plant-Wide Components	Dryers	All	2.6E-03	0	0	1.0	0	0	0
14	Plant-Wide Components	Electric Motors	All	4.6E-03	1.0	0	0	0	0	0

Table 6-1
Fire Frequency Bins and Generic Frequencies (Continued)

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
					Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
15	Plant-Wide Components	Electrical Cabinets	All	4.5E-02	1.0	0	0	0	0	0
16	Plant-Wide Components	High Energy Arcing Faults[1]	All	1.5E-03	0	0	0	0	0	1.0
17	Plant-Wide Components	Hydrogen Tanks	All	1.7E-03	0	0	0	0	1.0	0
18	Plant-Wide Components	Junction Boxes	All	1.9E-03	1.0	0	0	0	0	0
19	Plant-Wide Components	Misc. Hydrogen Fires	All	2.5E-03	0	0	0	0	1.0	0
20	Plant-Wide Components	Off-gas/H2 Recombiner (BWR)	Power	4.4E-02	0	0	0	0	1.0	0
21	Plant-Wide Components	Pumps	All	2.1E-02	0.54	0.46	0	0	0	0
22	Plant-Wide Components	RPS MG Sets	Power	1.6E-03	1.0	0	0	0	0	0
23a	Plant-Wide Components	Transformers (Oil filled)	All	9.9E-03	0	1.0	0	0	0	0
23b	Plant-Wide Components	Transformers (Dry)			1.0	0	0	0	0	0
24	Plant-Wide Components	Transient fires caused by welding and cutting	Power	4.9E-03	0	0	0	1.0	0	0

Table 6-1
Fire Frequency Bins and Generic Frequencies (Continued)

ID	Location	Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type					
					Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
25	Plant-Wide Components	Transients	Power	9.9E-03	0	0	1.0	0	0	0
26	Plant-Wide Components	Ventilation Subsystems	All	7.4E-03	0.95	0.05	0	0	0	0
27	Transformer Yard	Transformer – Catastrophic[2]	Power	6.0E-03	1.0[3]		0	0	0	0
28	Transformer Yard	Transformer - Non Catastrophic[2]	Power	1.2E-02	1.0[3]		0	0	0	0
29	Transformer Yard	Yard transformers (Others)	Power	2.2E-03	1.0	0	0	0	0	0
30	Turbine Building	Boiler	All	1.1E-03	0	1.0	0	0	0	0
31	Turbine Building	Cable fires caused by welding and cutting	Power	1.6E-03	0	0	0	1.0	0	0
32	Turbine Building	Main Feedwater Pumps	Power	1.3E-02	0.11	0.89	0	0	0	0
33	Turbine Building	Turbine Generator Excitor	Power	3.9E-03	1.0	0	0	0	0	0
34	Turbine Building	Turbine Generator Hydrogen	Power	6.5E-03	0	0	0	0	1.0	0
35	Turbine Building	Turbine Generator Oil	Power	9.5E-03	0	1.0	0	0	0	0
36	Turbine Building	Transient fires caused by welding and cutting	Power	8.2E-03	0	0	0	1.0	0	0
37	Turbine Building	Transients	Power	8.5E-03	0	0	1.0	0	0	0

1. See Appendix M for a description of high-energy arcing fault (HEAF) fires.

2. See Section 6.5.6 below for a definition.

3. The event should be considered either as an electrical or oil fire, whichever yields the worst consequences.

Table 2
Description of Transient Fire Influencing Factors

Influencing Factor	No (0)	Low (1)	Medium (3)	High (10)	Very High (50)
Maintenance	Maintenance activities during power operation are precluded by design.	Small number of PM/CM work orders compared to the average number of work orders for a typical compartment.	Average number of PM/CM work orders.	Large number of (PM)/(CM) work orders compared to the average number of work orders for a typical compartment.	Should be assigned to plant areas that may experience significantly more (PM)/(CM) work orders compared to the average number of work orders for a typical compartment.
Occupancy	Entrance to the compartment is not possible during plant operation.	Compartment with low foot traffic or out of general traffic path.	Compartments not continuously occupied, but with regular foot traffic.	Continuously occupied compartment.	Not applicable
Storage	Entrance to the compartment is not possible during plant operation.	Compartment where no combustible/ flammable materials are stored.	Compartments where all combustible/ flammable material is stored in closed containers placed in dedicated fire-safe cabinets.	Compartments where combustible/ flammable materials may sometimes be brought in and left in either open containers for a short time or in a closed container, but outside a dedicated fire-safe cabinet for an extended time.	Not applicable

From Page 6-24 of NUREG/CR-6850

For *general transients* (i.e., Bins 3, 7, 25, and 37), the following equation should be used to establish the ignition source weighting factor:

$$W_{GT,J,L} = (n_{m,J,L} + n_{o,J,L} + n_{s,J,L})/N_{GT,L}$$

$$N_{GT,L} = \Sigma\ (n_{m,i,L} + n_{o,\ i,L} + n_{s,\ i,L})$$

(summed over i, all compartments of location L).

where:

$n_{m,J,L}$ = Maintenance influence factor rating of compartment J of location L,

$n_{o,J,L}$ = Occupancy influence factor rating of compartment J of location L, and

$n_{s,J,L}$ = Storage influence factor rating of compartment J of location L.

In the case of *transient fires caused by welding and cutting* (i.e., Bins 6, 24, and 36), the following equation should be used:

$$W_{WC,J,L} = n_{m,J}/N_{WC}$$

$$N_{WC} = \Sigma\ n_{m,i,L}$$

(summed over i, all the compartments of location L).

For *cable fires caused by welding and cutting* (i.e., Bins 5, 11, and 31), the following equation should be used:

$$W_{CF,J} = n_{m,J}\ W_{Cable,J}\ /N_{CF}$$

$$N_{CF} = \Sigma\ n_{m,i,L}\ W_{Cable,i}$$

(summed over i, all compartments of location L),

where:

$W_{Cable,i}$ = Cable load of compartment i, based on the ratio of quantity of cables in compartment i over the total quantity of cables in the location.

Table 3
List of Heat Release Rate Distributions

Case	Ignition Source	HRR kW (Btu/s)		Gamma Distribution		Reference
		75th	98th	α	β	
1	Vertical cabinets with qualified cable, fire limited to one cable bundle	69 (65)	211 (200)	0.84 (0.83)	59.3 (56.6)	Table G-1
2	Vertical cabinets with qualified cable, fire in more than one cable bundle	211 (200)	702 (665)	0.7 (0.7)	216 (204)	Table G-1
3	Vertical cabinets with unqualified cable, fire limited to one cable bundle	90 (85)	211 (200)	1.6 (1.6)	41.5 (39.5)	Table G-1
4	Vertical cabinets with unqualified cable, fire in more than one cable bundle closed doors	232 (220)	464 (440)	2.6 (2.6)	67.8 (64.3)	Table G-1
5	Vertical cabinets with unqualified cable, fire in more than one cable bundle open doors	232 (220)	1002 (950)	0.46 (0.45)	386 (366)	Table G-1
6	Pumps (electrical fires)	69 (65)	211 (200)	0.84 (0.83)	59.3 (56.6)	Table G-1
7	Motors	32 (30)	69 (65)	2.0 (2.0)	11.7 (11.1)	Table G-1
8	Transient Combustibles	142 (135)	317 (300)	1.8 (1.9)	57.4 (53.7)	Section G-4

Table 4
Discretized Distribution for Case 1 Heat Release Rate (Vertical Cabinets with Qualified Cable, Fire Limited to One Cable Bundle)

Bin	Heat Release Rate – kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	26 (25)	11 (10.5)	0.446
2	26 (25)	53 (50)	38 (36)	0.219
3	53 (50)	79 (75)	64 (61)	0.129
4	79 (75)	106 (100)	92 (87)	0.078
5	106 (100)	132 (125)	118 (112)	0.048
6	132 (125)	158 (150)	145 (137)	0.030
7	158 (150)	185 (175)	171 (162)	0.019
8	185 (175)	211 (200)	197 (187)	0.012
9	211 (200)	237 (225)	224 (212)	0.007
10	237 (225)	264 (250)	250 (237)	0.005
11	264 (250)	290 (275)	276 (262)	0.003
12	290 (275)	317 (300)	303 (287)	0.002
13	317 (300)	343 (325)	329 (312)	0.001
14	343 (325)	369 (350)	356 (337)	0.001
15	369 (350)	Infinity	427 (405)	0.001

Table 5
Discretized Distribution for Case 2 Heat Release Rate (Vertical Cabinets with Qualified Cable, Fire in more than One Cable Bundle)

Bin	Heat Release Rate – kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	90 (85)	34 (32.7)	0.506
2	90 (85)	179 (170)	130 (123)	0.202
3	179 (170)	269 (255)	221 (209)	0.113
4	269 (255)	359 (340)	310 (294)	0.067
5	359 (340)	448 (425)	400 (379)	0.041
6	448 (425)	538 (510)	490 (464)	0.026
7	538 (510)	628 (595)	579 (549)	0.016
8	628 (595)	717 (680)	669 (634)	0.010
9	717 (680)	807 (765)	759 (719)	0.006
10	807 (765)	897 (850)	848 (804)	0.004
11	897 (850)	986 (935)	938 (889)	0.003
12	986 (935)	1076 (1020)	1028 (974)	0.002
13	1076 (1020)	1166 (1105)	1118 (1060)	0.001
14	1166 (1105)	1255 (1190)	1208 (1145)	0.001
15	1255 (1190)	Infinity	1462 (1386)	0.001

Table 6
Discretized Distribution for Case 3 Heat Release Rate (Vertical Cabinets with Unqualified Cable, Fire Limited to One Cable Bundle)

Bin	Heat Release Rate - kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	26 (25)	15 (14.2)	0.227
2	26 (25)	53 (50)	39 (37)	0.261
3	53 (50)	79 (75)	65 (62)	0.192
4	79 (75)	106 (100)	92 (87)	0.126
5	106 (100)	132 (125)	118 (112)	0.079
6	132 (125)	158 (150)	143 (136)	0.048
7	158 (150)	185 (175)	170 (161)	0.028
8	185 (175)	211 (200)	196 (186)	0.016
9	211 (200)	237 (225)	223 (211)	0.010
10	237 (225)	264 (250)	249 (236)	0.005
11	264 (250)	290 (275)	275 (261)	0.003
12	290 (275)	317 (300)	302 (286)	0.002
13	317 (300)	343 (325)	328 (311)	0.001
14	343 (325)	369 (350)	354 (336)	0.001
15	369 (350)	Infinity	414 (392)	0.001

Table 7
Discretized Distribution for Case 4 Heat Release Rate (Vertical Cabinets with Unqualified Cable, Fire in more than One Cable Bundle Closed Doors)

Bin	Heat Release Rate - kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	53 (50)	36 (34)	0.082
2	53 (50)	106 (100)	80 (76)	0.213
3	106 (100)	158 (150)	131 (124)	0.224
4	158 (150)	211 (200)	184 (174)	0.177
5	211 (200)	264 (250)	235 (223)	0.122
6	264 (250)	317 (300)	288 (273)	0.077
7	317 (300)	369 (350)	341 (323)	0.046
8	369 (350)	422 (400)	394 (373)	0.027
9	422 (400)	475 (450)	446 (423)	0.015
10	475 (450)	528 (500)	499 (473)	0.008
11	528 (500)	580 (550)	552 (523)	0.004
12	580 (550)	633 (600)	603 (572)	0.002
13	633 (600)	686 (650)	656 (622)	0.001
14	686 (650)	739 (700)	709 (672)	0.001
15	739 (700)	Infinity	816 (773)	0.001

Table 8
Discretized Distribution for Case 5 Heat Release Rate (Vertical Cabinets with Unqualified Cable, Fire in more than One Cable Bundle Open Doors)

Bin	Heat Release Rate - kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	137 (130)	42 (39.5)	0.638
2	137 (130)	274 (260)	197 (187)	0.155
3	274 (260)	411 (390)	337 (319)	0.081
4	411 (390)	549 (520)	475 (450)	0.047
5	549 (520)	686 (650)	612 (580)	0.029
6	686 (650)	823 (780)	749 (710)	0.018
7	823 (780)	960 (910)	886 (840)	0.011
8	960 (910)	1097 (1040)	1024 (971)	0.007
9	1097 (1040)	1234 (1170)	1162 (1101)	0.005
10	1234 (1170)	1372 (1300)	1299 (1231)	0.003
11	1372 (1300)	1509 (1430)	1436 (1361)	0.002
12	1509 (1430)	1646 (1560)	1573 (1491)	0.001
13	1646 (1560)	1783 (1690)	1710 (1621)	0.001
14	1783 (1690)	1920 (1820)	1847 (1751)	0.001
15	1920 (1820)	Infinity	2276 (2157)	0.001

Table 9
Discretized Distribution for Case 6 Heat Release Rate (Pumps – Electrical Fires)

Bin	Heat Release Rate – kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	26 (25)	11 (10.5)	0.446
2	26 (25)	53 (50)	38 (36)	0.219
3	53 (50)	79 (75)	64 (61)	0.129
4	79 (75)	106 (100)	92 (87)	0.078
5	106 (100)	132 (125)	118 (112)	0.048
6	132 (125)	158 (150)	145 (137)	0.030
7	158 (150)	185 (175)	171 (162)	0.019
8	185 (175)	211 (200)	197 (187)	0.012
9	211 (200)	237 (225)	224 (212)	0.007
10	237 (225)	264 (250)	250 (237)	0.005
11	264 (250)	290 (275)	276 (262)	0.003
12	290 (275)	317 (300)	303 (287)	0.002
13	317 (300)	343 (325)	329 (312)	0.001
14	343 (325)	369 (350)	356 (337)	0.001
15	369 (350)	Infinity	427 (405)	0.001

Table 10
Discretized Distribution for Case 7 Heat Release Rate (Motors)

Bin	Heat Release Rate – kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	7 (7)	5 (4.4)	0.132
2	7 (7)	15 (14)	12 (11)	0.227
3	15 (14)	22 (21)	18 (17)	0.205
4	22 (21)	30 (28)	25 (24)	0.153
5	30 (28)	37 (35)	33 (31)	0.105
6	37 (35)	44 (42)	40 (38)	0.069
7	44 (42)	52 (49)	47 (45)	0.043
8	52 (49)	59 (56)	55 (52)	0.027
9	59 (56)	66 (63)	62 (59)	0.016
10	66 (63)	74 (70)	70 (66)	0.010
11	74 (70)	81 (77)	77 (73)	0.006
12	81 (77)	89 (84)	84 (80)	0.003
13	89 (84)	96 (91)	92 (87)	0.002
14	96 (91)	103 (98)	99 (94)	0.001
15	103 (98)	Infinity	116 (110)	0.001

Table 11
Discretized Distribution for Case 8 Heat Release Rate (Transients[1])

Bin	Heat Release Rate – kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	37 (35)	22 (21.2)	0.169
2	37 (35)	74 (70)	55 (52)	0.249
3	74 (70)	111 (105)	92 (87)	0.205
4	111 (105)	148 (140)	128 (121)	0.143
5	148 (140)	185 (175)	165 (156)	0.093
6	185 (175)	222 (210)	202 (191)	0.058
7	222 (210)	258 (245)	238 (226)	0.035
8	258 (245)	295 (280)	275 (261)	0.020
9	295 (280)	332 (315)	312 (296)	0.012
10	332 (315)	369 (350)	349 (331)	0.007
11	369 (350)	406 (385)	386 (366)	0.004
12	406 (385)	443 (420)	423 (401)	0.002
13	443 (420)	480 (455)	460 (436)	0.001
14	480 (455)	517 (490)	497 (471)	0.001
15	517 (490)	Infinity	578 (548)	0.001

Table 12
Damage Criteria for Electrical Cables – Generic Screening Criteria for the Assessment of the Ignition and Damage Potential of Electrical Cables [See Ref 8-1]

Cable Type	Radiant Heating Criteria	Temperature Criteria
Thermoplastic	6 kW/m^2 (0.5 BTU/ft2s)	205°C (400°F)
Thermoset	11 kW/m^2 (1.0 BTU/ft2s)	330°C (625°F)

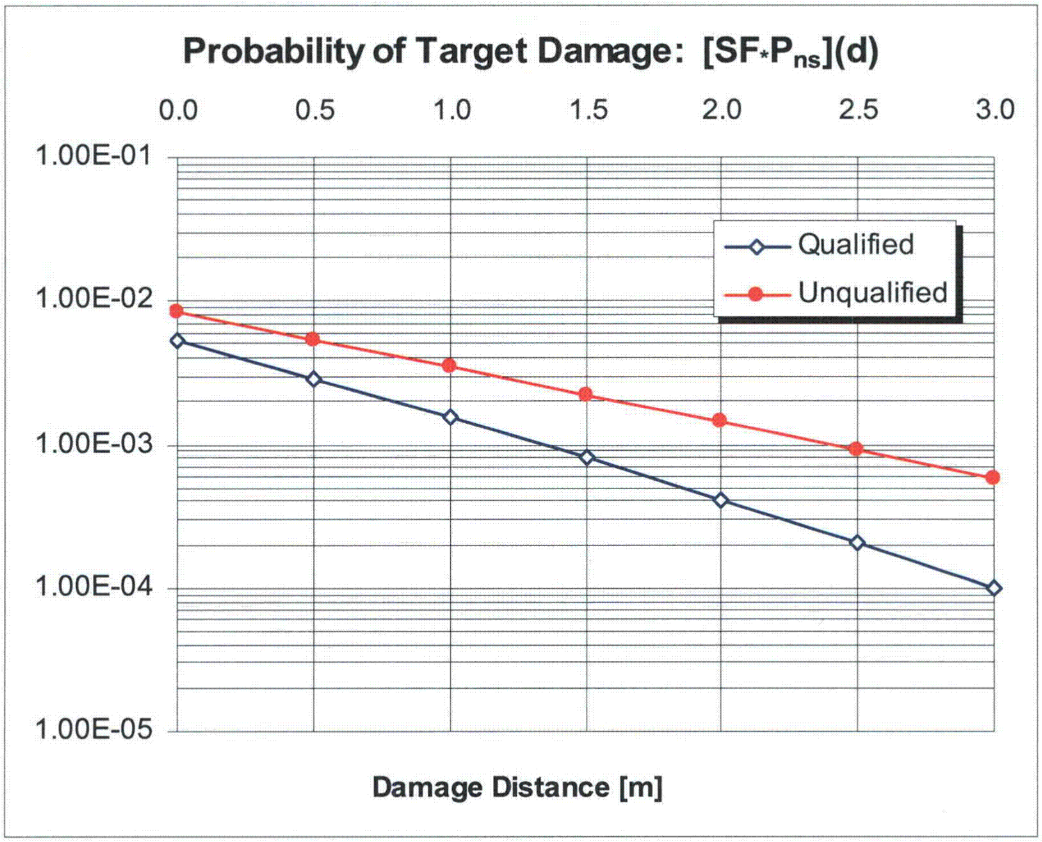


Figure 1
Likelihood of Target Damage Calculated as the Severity Factor Times the Probability of Non-suppression for MCB Fires

Table 13
Probability Distribution for Rate of Fires Suppressed per Unit Time, λ

Suppression Curve	Number of Events in Curve	Total Duration	λ Mean	5th Per	50th Per	95th Per
T/G fires	21	749	0.03	0.02	0.03	0.04
Control room	6	18	0.33	0.15	0.32	0.58
PWR containment	3	23	0.13	0.04	0.12	0.27
Outdoor transformers	14	373	0.04	0.02	0.04	0.06
Flammable gas	5	195	0.03	0.01	0.02	0.05
Oil fires	36	404	0.09	0.07	0.09	0.11
Cable fires	4	11	0.24	0.12	0.33	0.70
Electrical fires	112	937	0.12	0.10	0.12	0.14
Welding fires	19	99	0.19	0.13	0.19	0.27
Transient fires	24	199	0.12	0.08	0.12	0.16
High energy arcing faults	5	118	0.01	0.02	0.04	0.08
All fires	250	3260	0.08	0.07	0.08	0.08

Table 14
Numerical Results for Suppression Curves

Time (min)	T/G fires	High energy arcing faults	Outdoor transformers	Flammable gas	Oil fires	Electrical fires	Transient fires	PWR containment	Welding	Control room	Cable fires	All fires
0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
5	0.87	0.94	0.83	0.88	0.64	0.55	0.55	0.52	0.38	0.19	0.30	0.68
10	0.76	0.88	0.69	0.77	0.41	0.30	0.30	0.27	0.15	0.04	0.09	0.46
15	0.66	0.83	0.57	0.68	0.26	0.16	0.16	0.14	0.06	0.01	0.03	0.32
20	0.57	0.78	0.47	0.60	0.17	0.09	0.09	0.07	0.02	0.00	0.01	0.22
25	0.50	0.73	0.39	0.53	0.11	0.05	0.05	0.04	0.01	*	0.00	0.15
30	0.43	0.69	0.32	0.46	0.07	0.03	0.03	0.02	0.00	*	*	0.10
35	0.37	0.64	0.27	0.41	0.04	0.01	0.01	0.01	0.00	*	*	0.07
40	0.33	0.61	0.22	0.36	0.03	0.01	0.01	0.01	*	*	*	0.05
45	0.28	0.57	0.18	0.32	0.02	0.00	0.00	0.00	*	*	*	0.03
50	0.25	0.53	0.15	0.28	0.01	0.00	0.00	0.00	*	*	*	0.02
55	0.21	0.50	0.13	0.24	0.01	0.00	0.00	*	*	*	*	0.01
60	0.19	0.47	0.11	0.21	0.00	*	*	*	*	*	*	0.01
65	0.16	0.44	0.09	0.19	0.00	*	*	*	*	*	*	0.01
70	0.14	0.42	0.07	0.17	0.00	*	*	*	*	*	*	0.00
75	0.12	0.39	0.06	0.15	0.00	*	*	*	*	*	*	0.00
80	0.11	0.37	0.05	0.13	*	*	*	*	*	*	*	0.00
85	0.09	0.34	0.04	0.11	*	*	*	*	*	*	*	0.00
90	0.08	0.32	0.03	0.10	*	*	*	*	*	*	*	0.00
95	0.07	0.30	0.03	0.09	*	*	*	*	*	*	*	*
100	0.06	0.29	0.02	0.08	*	*	*	*	*	*	*	*

* A value of 1E-3 should be used

Appendix C: Exercise Set Solutions

Session 1b: Example Problems (Plant Partitioning)

Workshop Problems for Task 1: Plant Boundary Definition and Partitioning

Workshop Problem Set 01-01

Step 1 - Selection of Global Plant Analysis Boundary: Using Drawing # 01 in the Sample Package and the information provided in other drawings, identify the Global Plant Analysis Boundaries in terms of plant areas. Make a complete list of plant areas shown on Drawing #01 in the matrix provided below. Specify whether or not the area shall be included within the Global Plant Analysis Boundaries and then provide the basis of your decision.

Plant Area	Included?	Basis
Auxiliary Building	Yes	Contains equipment and cables that may be included in the fire PRA analysis
Containment	Yes	Contains equipment and cables that may be included in the fire PRA analysis
Diesel Generator Building	Yes	Contains equipment and cables that may be included in the fire PRA analysis
Turbine Building	Yes	Contains equipment and cables that may be included in the fire PRA analysis
Yard	Yes	Contains equipment and cables that may be included in the fire PRA analysis
Security Building	No	There are no equipment or cables in this building needed for safe shutdown
Switchyard	No	Offsite power is impacted from equipment or cable failure in the Switchyard. However, the impact of a fire event in the switchyard would be limited to loss of offsite power and no other safe shutdown related functions. Therefore, switchyard fires are considered a part of loss of offsite
Intake Structure	Yes	Contains equipment and cables that may be included in the fire PRA analysis

Workshop Problem Set 01-02

Step 2: Plant Partitioning: Using the drawings provided in the Sample Package, identify the set of fire compartments that you will consider for the fire PRA. In the following matrix (1) list selected compartments, (2) give each an identification number, (3) identify the associated plant area for each compartment from the Solution Statement for Problem Set 01-01. Provide comments where warranted.

Fire Comp. ID #	Fire Compartment Descriptor	Plant Area	Comments
1	Main Control Room	Auxiliary Building	Includes the kitchen and Shift Supervisor's Office
2	Aux Bldg El. 0 Ft	Auxiliary Building	
3	Cable Spreading Room	Auxiliary Building	
4A	Aux Bldg. El. -20 Ft, RHR Room	Auxiliary Building	
4B	Aux Bldg. El. -20 Ft, AFW Room	Auxiliary Building	
5	Battery Room A	Auxiliary Building	1 hour rated walls and 2 hour rated ceiling within the Switchgear rooms
6	Battery Room B	Auxiliary Building	1 hour rated walls and 2 hour rated ceiling within the Switchgear rooms
7	Containment	Containment	
8A	DG-A Room	Diesel Generator Building	

Fire Comp. ID #	Fire Compartment Descriptor	Plant Area	Comments
8B	DG-B Room	Diesel Generator Building	
9	SWG Access Room	Auxiliary Building	
10	Switchgear Room A	Auxiliary Building	
11	Switchgear Room B	Auxiliary Building	
12	Turbine Bldg El. 0 Ft	Turbine Building	
13	Yard	Yard	Includes the Transformers next to the Diesel Generator Building and the two safety related tanks.
14	Intake Structure	Intake Structure	A long building with some divisions with large openings among them with no doors isolating each compartment from other compartments.
15	Battery Room 1	Turbine Building	1 hour rated walls and 2 hour rated ceiling within the Switchgear rooms
16	Stairway	Auxiliary Building	All doors are 1 hour rated
17	Control Room Access	Auxiliary Building	

Workshop Example

Step 3: Compartment Information Gathering and Characterization: The following tabulation provides an example of the information about fire compartments that may be used in a fire PRA project.

Item	**Resolution**
Fire Compartment ID #	9
Fire Compartment	Switchgear Access Room
Building	Auxiliary Building
Boundary Characteristics	The compartment is bounded by 3-hr rated fire walls, ceiling and floor.
Ventilation Features	The ventilation is provided by the Auxiliary Building HVAC system (1). The equipment housed in this compartment can function properly and perform their safe shutdown duties in case of total loss of the HVAC system.
Fire Protection Features	The fire protection features of this compartment includes: 1. Handheld extinguishers inside the compartment (2 units) (1) 2. Wet hose reel outside the door inside the stairwell(1) 3. Smoke detectors attached to the ceiling (6 units) (1) 4. Automatic CO_2 system
Fire Sources	The following ignition sources were identified in this compartment. 1. MCC-A 2. MCC-B 3. 125VAC-A 4. 125VAC-B 5. ATS 6. Lighting Fixtures (10 units)(1) Additionally the following combustibles are present: 1. Cable trays containing thermoset control cables 2. Wooden desk used by the electrical department(1)
Adjacent Compartments	The following compartments share a wall, ceiling or floor with this compartment: 1. Switchgear Room A 2. Switchgear Room B 3. Stairwell 4. Charging pump room 5. Cable spreading room
Access Routes	1. This room can be accessed from outside through the stairwell 2. Switchgear Rooms A and B are accessed through this room
Components /Systems / Cables Present	See the component and cable lists provided in Tasks 2 and 3.
SSD Human Actions Credited in this Compartment	To be completed after Task 12 is completed.

(1) Provided here to demonstrate how this part of the step may be addressed. These features are not intended to be included in the Fire PRA of this Sample Package.

Session 2b: Example Problems (Fire Ignition Frequency)

Workshop Problems for Task 6: Fire Ignition Frequency

Workshop Problem Set 06-01

Step 1: Mapping plant ignition sources to generic sources: Using the information provided in this Sample Package, map the items listed in the following table to generic sources.

Equipment ID	Equipment Description	Equipment Type	Bin #	Bin Description / Comment\
HPI-B	High pressure safety injection pump B	Pump	21	Pumps
MOV-1	HPI valve	MOV	14	Electric Motors
MOV-5	RWST isolation valve	MOV	--	Less than 5hp motor
BAT-B	Train B Battery	Battery	1	Batteries
RCP-1	Reactor coolant pump 1	Pump	2	Reactor Coolant Pump
AOV-1 / (SOV-1)	Pressure operated relief valve	AOV	--	Assumed as insignificant ignition source.
PT-1	RCS pressure	Instrument	--	Assumed as insignificant ignition source.
EDG-A	Train A Emergency Diesel Generator	Diesel Generator	8	Diesel Generators
MCC-B1	Train B 480 V Motor Control Center	Motor Control Center	15	Electrical Cabinets
ATS-1	Automatic Transfer Switch	ATS	15	Electrical Cabinets
VITAL-A	Train A 120 VAC Vital Bus	120VAC Bus	15	Electrical Cabinets
SWGR-A	Train A 4160 V Bus	Switchgear	15/16	Electrical Cabinets/HEAF
LC-A	Train A 480 V Load Center	Load Center	15/16	Electrical Cabinets/HEAF
SST-A	Train A Station Service Transformer	Transformer	23a	Transformers (Dry)
BC-A	Train A Battery Charger	Battery Charger	10	Battery Chargers
DC BUS-A	Train A 125 VDC Bus	DC Bus	15	Electrical Cabinets
PNL-A	Train A 125 VDC Panel	Panelboard	15	Electrical Cabinets
INV-A	Train A Inverter	Inverter	15	Electrical Cabinets
AFW-A	Motor driven AFW pump A	Pump	21	Pumps
AFW-B	Steam driven AFW Pump B	Pump	21	Pumps
SUT-1	Startup Transformer	Transformer	29	Yard transformers (Others)

The following table provides the components specifically addressed in the Fire PRA of this Sample Package.

Equipment ID	Equipment Description	Equipment Type	Bin #	Bin Description / Comment\
TI-1	Letdown heat exchanger outlet temp	Instrument	--	Comment 1 (below)
HPI-A	High pressure safety injection pump A	Pump	21	Pumps
HPI-B	High pressure safety injection pump B	Pump	21	Pumps
AOV-2 / (SOV-2)	Letdown isolation valve	AOV	--	Comment 1
AOV-3 / (SOV-3)	Charging pump injection valve	AOV	--	Comment 1
MOV-1	HPI valve	MOV	14	Electric Motors
MOV-2	VCT isolation valve	MOV	14	Electric Motors
MOV-5	RWST isolation valve	MOV	--	Less than 5hp motor
MOV-6	RWST isolation valve	MOV	--	Less than 5hp motor
MOV-9	HPI valve	MOV	14	Electric Motors
RHR-B	RHR pump B	Pump	21	Pumps
MOV-3	Cont. sump recirc valve	MOV	14	Electric Motors
MOV-4	Cont. sump recirc valve	MOV	14	Electric Motors
MOV-8	RHR outboard suction valve	MOV	14	Electric Motors
BAT-A	Train A Battery	Battery	1	Batteries
BAT-B	Train B Battery	Battery	1	Batteries
RCP-1	Reactor coolant pump 1	Pump	2	Reactor Coolant Pump
AOV-1 / (SOV-1)	Pressure operated relief valve	AOV	--	Comment 1
MOV-7	RHR inboard suction valve	MOV	14	Electric Motors
MOV-13	PORV block valve	MOV	--	Comment 2
LI-3	Containment sump level	Instrument	--	Comment 1
LI-4	Containment sump level	Instrument	--	Comment 1
PT-1	RCS pressure	Instrument	--	Comment 1
EDG-A	Train A Emergency Diesel Generator	Diesel Generator	8	Diesel Generators
EDG-B	Train B Emergency Diesel Generator	Diesel Generator	8	Diesel Generators
ANN-1	AFW motor high temp	Annunciator	--	Comment 1
MCC-A1	Train A 480 V Motor Control Center	Motor Control Center	15	Electrical Cabinets
MCC-B1	Train B 480 V Motor Control Center	Motor Control Center	15	Electrical Cabinets
ATS-1	Automatic Transfer Switch	ATS	15	Electrical Cabinets
VITAL-A	Train A 120 VAC Vital Bus	120VAC Bus	15	Electrical Cabinets
VITAL-B	Train B 120 VAC Vital Bus	120VAC Bus	15	Electrical Cabinets
SWGR-A	Train A 4160 V Bus	Switchgear	15/16	Electrical Cabinets/HEAF
LC-A	Train A 480 V Load Center	Load Center	15/16	Electrical Cabinets/HEAF
SST-A	Train A Station Service Transformer	Transformer	23a	Transformers (Dry)
BC-A	Train A Battery Charger	Battery Charger	10	Battery Chargers
DC BUS-A	Train A 125 VDC Bus	DC Bus	15	Electrical Cabinets
PNL-A	Train A 125 VDC Panel	Panelboard	15	Electrical Cabinets
INV-A	Train A Inverter	Inverter	15	Electrical Cabinets
SWGR-B	Train B 4160 V Bus	Switchgear	15/16	Electrical Cabinets/HEAF
LC-B	Train B 480 V Load Center	Load Center	15/16	Electrical Cabinets/HEAF
SST-B	Train B Station Service Transformer	Transformer	23a	Transformers (Dry)

The following table provides the components specifically addressed in the Fire PRA of this Sample Package.

Equipment ID	Equipment Description	Equipment Type	Bin #	Bin Description / Comment\
BC-B	Train B Battery Charger	Battery Charger	10	Battery Chargers
DC BUS-B	Train B 125 VDC Bus	DC Bus	15	Electrical Cabinets
PNL-B	Train B 125 VDC Panel	Panelboard	15	Electrical Cabinets
INV-B	Train B Inverter	Inverter	15	Electrical Cabinets
LC-1	Non-Safety 480 V Load Center	Load Center	15/16	Electrical Cabinets/HEAF
LC-2	Non-Safety 480 V Load Center	Load Center	15/16	Electrical Cabinets/HEAF
SWGR-1	Non-Safety 4160 V Bus	Switchgear	15/16	Electrical Cabinets/HEAF
SWGR-2	Non-Safety 4160 V Bus	Switchgear	15/16	Electrical Cabinets/HEAF
COMP-1	Instrument air compressor	Compressor	9	Air Compressors
MOV-10	AFW discharge valve	MOV	--	Comment 2
MOV-11	AFW discharge valve	MOV	--	Comment 2
MOV-18	AFW C Pump Discharge	MOV	--	Comment 2
SST-1	Non-Safety Station Service Transformer	Transformer	23b	Transformers (Oil filled)
SST-2	Non-Safety Station Service Transformer	Transformer	23b	Transformers (Oil filled)
MCC-1	Non-Safety 480 V Motor Control Center	Motor Control Center	15	Electrical Cabinets
MCC-2	Non-Safety 480 V Motor Control Center	Motor Control Center	15	Electrical Cabinets
BC-1	Non-Safety Swing Battery Charger	Battery Charger	10	Battery Chargers
BAT-1	Non-Safety Battery	Battery	1	Batteries
DC BUS-1	Non-Safety 250 VDC Bus	DC Bus	15	Electrical Cabinets
AFW-A	Motor driven AFW pump A	Pump	21	Pumps
AFW-B	Steam driven AFW Pump B	Pump	21	Pumps
AFW-C	AFW pump C	Pump	21	Pumps
MOV-14	AFW turbine steam line isolation valve	MOV	--	Comment 2
MOV-15	AFW steam inlet throttle valve	MOV	--	Comment 2
MOV-16	AFW test line isolation valve	MOV	--	Comment 2
MOV-17	AFW test line isolation valve	MOV	--	Comment 2
MOV-19	AFW test line isolation valve	MOV	--	Comment 2
V-12	CST isolation valve	MOV	--	Comment 2
LI-1	RWST level	Instrument	--	Comment 1
LI-2	RWST level	Instrument	--	Comment 1
SUT-1	Startup Transformer	Transformer	27/28	Yard transformers (Others)

Comment 1: Assumed as insignificant ignition source.
Comment 2: Less than 5hp motor

Workshop Problem Set 06-04

Step 4: Mapping Plant-Specific Locations to Generic Locations: Using the information provided in this Sample Package, map the items listed in the following table to the applicable generic locations provided in NUREG/CR 6850. Note that some of the compartments may map to more than one Generic Location.

Step 5: Location Weighting Factors: Assign the location weighting factors of the Fire Compartments in the following table.

Fire Comp. #	Plant Fire Compartment	Plant Area	Generic Location	W_L
1	Main Control Room	Auxiliary Building	See Note 1	1.0
2	Aux Bldg El. 0 Ft	Auxiliary Building	See Note 2	1.0
3	Cable Spreading Room	Auxiliary Building	See Note 2	1.0
4A	RHR Pump Room	Auxiliary Building	See Note 2	1.0
4B	AFW Pump Room	Auxiliary Building	See Note 2	1.0
5	Battery Room A	Auxiliary Building	See Note 3	1.0
6	Battery Room B	Auxiliary Building	See Note 3	1.0
9	SWG Access Room	Auxiliary Building	See Note 2	1.0
10	Switchgear Room A	Auxiliary Building	See Note 2	1.0
11	Switchgear Room B	Auxiliary Building	See Note 2	1.0
14	Stairway	Auxiliary Building	See Note 2	1.0
7	Containment	Containment	Containment	1.0
8A	DG-A Room	DG Bldg.	See Note 4	1.0
8B	DG-B Room	DG Bldg.	See Note 4	1.0
12	Turbine Bldg El. 0 Ft	Turbine Building	See Note 5	1.0
15	Battery Room 1	Turbine Building	See Note 6	1.0
13	Yard	Yard	See Note 7	1.0
14	Intake Structure	Intake Structure	Plant-Wide Components	1.0

Note 1: Control Room (for the Main Control Board) and Control/Aux/Reactor Building (for cable and transient fires)

Note 2: Control/Aux/Reactor Building (for cable and transient fires) and Plant-Wide Components for all other items

Note 3: Battery Room (for the batteries) and Control/Aux/Reactor Building (for cable and transient fires)

Note 4: Diesel Generator Room (for the Diesel Generators), Control/Aux/Reactor Building (for cable and transient fires), and Plant-Wide Components for all other items

Note 5: Turbine and Plant-Wide Components (for all items not specifically assigned to the Turbine Building)

Note 6: Battery Room (for the batteries) and Turbine Building (for cable and transient fires)

Note 7: Transformer Yard and Plant-Wide Components for all other items

Workshop Problem Set 06-05

Step 5: Location Weighting Factors: At a two-unit nuclear power plant, the Main Control Room is shared between the two units. The control room consists of two separate Main Control Boards that do not share any controls and are dedicated to one unit each. There are 5 electrical cabinets in the control room in addition to the Main Control Boards that are shared between the two units.

a. For Unit 1, establish the Location Weighting Factor of the Main Control Board

$W_{L,\ MCR,\ Main\ Control\ Board} = 2.0$

b. For Unit 1, establish the Location Weighting Factor of the electrical cabinets.

$W_{L,\ MCR,\ Electrical\ Cabinets} = 2.0$

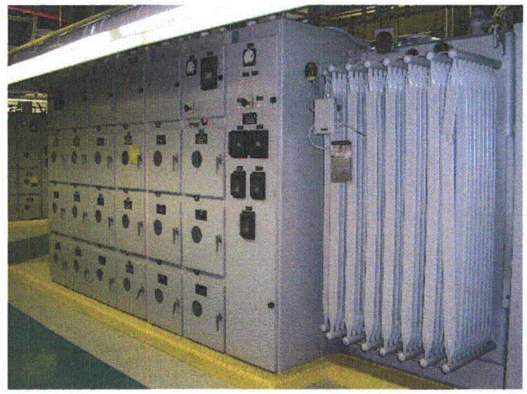
c. For Unit 1, establish the Location Weighting Factor of transient fires in the Main Control Room

$W_{L,\ MCR,\ Transients} = 2.0$

Workshop Problem Set 06-06

Step 6: Fixed Fire Ignition Source Counts: Estimate the ignition source counts for only those items that are noted under each picture and are visible in the foreground of the picture:

Electrical Panels: 8 vertical sections



Electrical Panels: 7 vertical sections

Transformers: 1

Transformers: 1

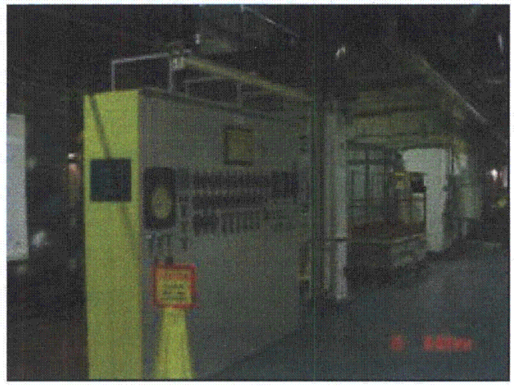
Electrical Panels: 5 vertical sections

Transformers: 2

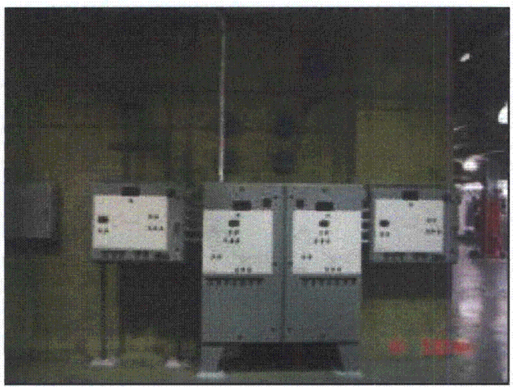
Electrical Panels: 2 vertical sections

Electrical Panels: 3 vertical sections

Electrical Panels: <u>2 vertical sections</u>



Electrical Panels: <u>1vertical sections</u>



Electrical Panels: <u>No count –Sealed with low voltage circuits</u>

Workshop Problem Set 06-07

Step 6: Fixed Fire Ignition Source Counts: Estimate the ignition source counts for the components identified in Step 1 above.

			Bin # and Description (per Table 6-1)												
			1	2	8	4	9	10	14	15	16	21	23a	23b	29
			Batteries	Reactor Coolant Pump	Diesel Generators	Main Control Board	Air Compressors	Battery Chargers	Electric Motors	Electrical Cabinets	High Energy Arcing Faults	Pumps	Transformers (Dry)	Transformers (Oil filled)	Yard transformers (Others)
#	Compartment	Plant Area	BAT	RCP	DG	MCB	AC	BC	EM	EC	HEAF	PMP	XFMR-Dry	XFMR-Oil	XFMR-Yard
1	Main Control Room	Control/Aux/Reactor Building	0	0	0	1	0	0	0	1	0	0	0	0	0
2	Aux Bldg El. 0 Ft	Control/Aux/Reactor Building	0	0	0	0	0	0	3	0	0	2	0	0	0
3	Cable Spreading Room	Control/Aux/Reactor Building	0	0	0	0	0	0	0	0	0	0	0	0	0
4A	RHR Pump Room	Control/Aux/Reactor Building	0	0	0	0	0	0	3	0	0	1	0	0	0
4B	AFW Pump Room	Control/Aux/Reactor Building	0	0	0	0	0	0	0	0	0	2	0	0	0
5	Battery Room A	Plant Wide Components	1	0	0	0	0	0	0	0	0	0	0	0	0
6	Battery Room B	Plant Wide Components	1	0	0	0	0	0	0	0	0	0	0	0	0
9	SWG Access Room	Plant Wide Components	0	0	0	0	0	0	0	31	0	0	0	0	0
10	Switchgear Room A	Plant Wide Components	0	0	0	0	0	1	0	25	14	0	1	0	0
11	Switchgear Room B	Plant Wide Components	0	0	0	0	0	1	0	24	14	0	1	0	0
14	Stairway	Plant Wide Components	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Containment	Containment	0	1	0	0	0	0	1	0	0	0	0	0	0
8A	DG-A Room	Plant Wide Components	0	0	1	0	0	0	0	0	0	0	0	0	0
8B	DG-B Room	Plant Wide Components	0	0	1	0	0	0	0	0	0	0	0	0	0
12	Turbine Bldg El. 0 Ft	Plant Wide Components		0	0	0	2	1	0	57	28	1	0	2	0
15	Battery Room 1	Plant Wide Components	1	0	0	0	0	0	0	0	0	0	0	0	0
13	Yard	Plant Wide Components	0	0	0	0	0	0	0	0	0	0	0	0	3
14	Intake Structure	Plant Wide Components	0	0	0	0	0	0	0	0	0	0	0	0	0
		Total	**3**	**0**	**2**	**1**	**2**	**3**	**7**	**136**	**56**	**6**	**2**	**2**	**3**

Workshop Problem Set 06-08

Step 7: Ignition Source Weighting Factors: For an NPP, the fire PRA analysts have counted 23 pumps within the Plant Analysis Boundary.

- For RHR Pump RHRP-C located in RHR Pump room (FZ-03A), which in turn is located in the Reactor Building, establish the IS, J and L subscripts of:

$W_{IS,J,L} = W_{\text{RHRP-C,FZ-03A,AUX BLDG}}$

- For the same RHR Pump, RHRP-C, calculate the Ignition Source Weighting Factor

W = 1/23 = 0.043

- RHR Pump room FZ-03A contains three pumps. Calculate the ignition source weighting factor for the pumps in this compartment.

W = 3/23 = 0.13

Workshop Problem Set 06-09

Step 7: Ignition Source Weighting Factors: For an NPP, the fire PRA analysts have counted 351 electrical cabinet vertical sections within the Plant Analysis Boundary.

- 480VAC MCC-A is composed of 32 breakers arranged in 8 vertical segments. Calculate the ignition source weighting factor for this MCC.

  W_{MCC-A} = 8/351 = 0.023

- 4kV non-1E Switchgear 1 is composed of 8 breakers. Each breaker takes up one vertical segment of the switchgear. Calculate the ignition source weighting factor for this electrical panel.

  W_{SWG-1} = 8/351 = 0.023

- The local control panel, CP-1, for the chemicals addition system located in the Reactor Building has the following dimensions: 2' Deep, 12'Long, 8'High. There are no partitions within the panel. Calculate the ignition source weighting factor for this electrical panel.

  W_{CP-1} = 1/351 = 0.0028

Workshop Problem Set 06-10

Step 7: Ignition Source Weighting Factors: Using the information provided in the solution for Problem Set 06-07, calculate the component weighting factors for the components listed below.

			Bin # and Description (per Table 6-1)												
			1	2	8	4	9	10	14	15	16	21	23a	23b	29
			Batteries	Reactor Coolant Pump	Diesel Generators	Main Control Board	Air Compressors	Battery Chargers	Electric Motors	Electrical Cabinets	High Energy Arcing Faults	Pumps	Transformers (Dry)	Transformers (Oil filled)	Yard transformers (Others)
#	Compartment	Plant Area	BAT	RCP	DG	MCB	AC	BC	EM	EC	HEAF	PMP	XFMR-Dry	XFMR-Oil	XFMR-Yard
1	Main Control Room	Control/Aux/Reactor Building				1.0E+00				7.4E-03					
2	Aux Bldg El. 0 Ft	Control/Aux/Reactor Building							4.3E-01			3.3E-01			
3	Cable Spreading Room	Control/Aux/Reactor Building													
4A	RHR Pump Room	Control/Aux/Reactor Building							4.3E-01			1.7E-01			
4B	AFW Pump Room	Control/Aux/Reactor Building										3.3E-01			
5	Battery Room A	Plant Wide Components	3.3E-01												
6	Battery Room B	Plant Wide Components	3.3E-01												
9	SWG Access Room	Plant Wide Components								2.2E-01					
10	Switchgear Room A	Plant Wide Components						3.3E-01		1.8E-01	2.5E-01		5.0E-01		
11	Switchgear Room B	Plant Wide Components						3.3E-01		1.8E-01	2.5E-01		5.0E-01		
14	Stairway	Plant Wide Components													
7	Containment	Containment		1.0E+00					1.4E-01						
8A	DG-A Room	Plant Wide Components			5.0E-01										
8B	DG-B Room	Plant Wide Components			5.0E-01										
12	Turbine Bldg El. 0 Ft	Plant Wide Components	3.3E-01				1.0E+00	3.3E-01		4.2E-01	5.0E-01	1.7E-01		1.0E+00	
15	Battery Room 1	Plant Wide Components													
13	Yard	Plant Wide Components													1.0E+00
14	Intake Structure	Plant Wide Components													

Workshop Problem Set 06-11

Transient Ignition Source Weighting Factors: An NPP is composed of three compartments with the following characteristics:

A. Enter the influencing factors for each compartment and category:

	Influencing Factor			Cable Run (self-ignited cable fires)
Compartment	Maintenance	Occupancy	Storage	
Compartment 1	10	1	10	1,000
Compartment 2	3	1	3	--
Compartment 3	1	10	10	10,000
Total	14	12	23	11,000

B. Calculate the ignition source weighting factors for each compartment

Compartment	General Transients	Transients fires caused by welding and cutting	Cable fires caused by welding and cutting	Cable Run (self-ignited cable fires)
Compartment 1	43%	10/14	50%	9.1%
Compartment 2	14%	3/14	--	--
Compartment 3	43%	1/14	50%	90.9%
Total	100.0%	100.0%	100.0%	100.0%

C. Calculate the ignition frequencies for each compartment

	General Transients	Transients fires caused by welding and cutting	Cable fires caused by welding and cutting	Cable Run (self-ignited cable fires)
Total Location Frequency (/ry)	*3.90E-03*	*9.70E-03*	*1.60E-03*	*4.40E-03*
Compartment 1	1.67E-03	6.93E-03	8.0E-04	4.00E-04
Compartment 2	5.57E-04	2.08E-03	--	--
Compartment 3	1.67E-03	6.93E-04	8.0E-04	4.00E-03

Session 6b: Example Problems (Scoping Fire Modeling)

Workshop Problems on Task 8: Scoping Fire Modeling
This handout includes workshop problems on the different steps of Task 8: Scoping Fire Modeling. Problems are grouped by steps.

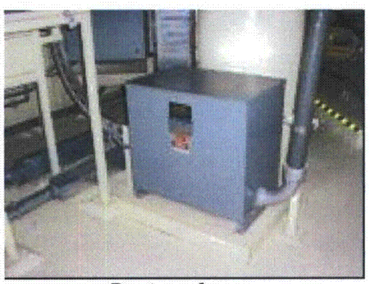
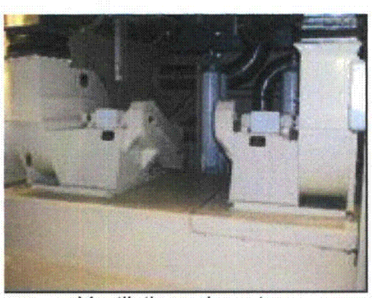
Step 1: Preparation for Walkdown

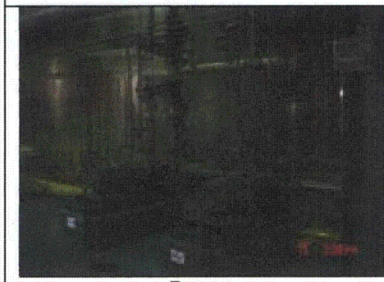
Step 1 has three sub-steps: 1) Estimate heat release rate for fixed ignition source screening, 2) Target and intervening combustibles damage or ignition criteria, and 3) Develop a zone of influence.

Workshop problem 08-01:

Step 1.1: Estimate heat release rate for fixed ignition source screening: Assign a heat release rate to the ignition sources depicted in the pictures of the following Table 08-01. For this exercise, assume that the plant has a mix of qualified and unqualified cables. The heat release rates are listed in Table E-1 of NUREG/CR-6850.

Table 08-01: Inputs for Workshop problems 1

Ignition Source	Table E-1 Case	98th Percentile HRR	Justification
 Dry transformer	*7*	*69 kW*	*Table 8-1 in NUREG/CR-6850 suggests the use of the "Electric Motors" heat release rate probability distribution for dry transformers*
 Fire protection panel	*4*	*464 kW*	*Fire protection panels have usually moderate to high combustible loading (including relays circuit cards etc.). It is therefore assumed that the fire may be able to propagate to more than one cable bundle.*
 Ventilation sub-system	*7*	*69 kW*	*Table 8-1 in NUREG/CR-6850 suggests the use of the "Electric Motors" heat release rate probability distribution for ventilation sub-systems*
fc	*6*	*211 kW*	*Table 8-1 in NUREG/CR-6850*

Ignition Source	Table E-1 Case	98th Percentile HRR	Justification
 Pumps			*suggests not to screen pumps due to the need of evaluating oil fires. Table E-1 suggests a heat release rate of 211 kW for electrical fires only.*

Workshop Problem Set 08-02:

Step 1.2: Target and intervening combustible damage and ignition criteria: Assign damage criteria to the ignition sources depicted in Table 08-01. For this exercise, assume that the plant has a mix of thermoset and thermoplastic cable. Generic damage criteria are listed in Table H-1 of NUREG/CR-6850.

Table 08-02: Inputs for workshop problem 2

Target/Intervening Combustible	Damage Criteria	Justification
Cables in a ladder back tray	*6 kW/m^2 (0.5 BTU/ft2s) or 205°C (400°F)*	*From Table H-1 in NUREG/CR-6850. Page H-2 of NUREG/CR-6850 suggests using the "weakest link" for determining damage criteria. Therefore the damage criteria for thermoplastic cable were selected.*
Cables in a solid tray	*6 kW/m^2 (0.5 BTU/ft2s) or 205°C (400°F)*	*Page H-2 of NUREG/CR-6850 suggests using the "weakest link" for determining damage criteria. Therefore the damage criteria for thermoplastic cable were selected. Solid trays are treated as conduits in this task. See second bullet in page H-1 of NUREG/CR-6850.*
Theromset cable in a conduit	*11 kW/m2 (1.0 BTU/ft2s) or 330°C (625°F)*	*From Table H-1 in NUREG/CR-6850. See second bullet in page H-1 of NUREG/CR-6850.*
Motor operated valve (MOV).	*6 kW/m^2 (0.5 BTU/ft2s) or 205°C (400°F)*	*See section H.2 in NUREG/CR-6850. Cables connecting the MOV are assumed thermoplastic in this example.*
Cabinet with a solid state device	*3 kW/m^2 (0.25 BTU/ft2s) or 65°C (150°F)*	*See section H.2 in NUREG/CR-6850.*

Workshop Problem Set 08-03

Step 1.3: Develop zone of influence: Calculate the heat release rate required for generating target damage for the following ignition source/target combination and determine if the ignition source can be screened. Use the engineering calculations described in NUREG-1805 for determining the heat release rate value.

- Target in the hot gas layer:
  - A cable tray target is located near the ceiling in a room approximately 21' by 7' and has a normally closed door on each end. The room is approximately 20' high. The inside walls of the MCC room are reinforced concrete. There is one MCC cabinet in the room. The MCC cabinet has unqualified cable.

The MQH room temperature correlation described in Section 2.6 of NUREG-1805 was selected for calculating the hot gas layer temperature in the room. Input values for the MQH model are listed in Table 08-03. Notice that a heat release rate of 600 kW generates room temperatures of approximately 205 °C. This calculation assumes a 20-min fire duration and one open door in the room.

Table 08-03: MQH room temperature correlation analysis

MCC Room	
Length [ft]:	*21*
Width [ft]:	*7*
Height [ft]:	*20*
MQH Temperature Correlation	
Inputs	
Ambient temperature [C]	*20*
Duration [sec]	*1200*
Opening area [m2]	*2*
Height of opening [m]	*2*
Room length [m]	*6*
Room width [m]	*2*
Room height [m]	*6*
Thermal conductivity [kW/mK]	*0.0014*
Density [kg/m3]	*2000*
Specific heat [kJ/kg]	*0.88*
Wall thickness [m]	*0.6*
HRR [kW]	*600*
Results	
Room Temp [C]	***205***

- Target subjected to flame impingement or fire plume temperatures:
  - A vertical cable tray is located 5' ft from a floor based ventilation subsystem.

The Heskestad' flame height and plume temperature correlations described in Chapter 3 and 9 of NUREG-1805 respectively were selected for calculating flame height and room temperature. Input values for the models are listed in Table 08-04 and Table 08-05. Notice that a heat release rate of 250 kW generates a flame height of 5'. In the case of the plume temperature correlation, a heat release rate of 165 kW generates damage temperatures of approximately 205 °C at the location of the target.

Table 08-04: Heskestad flame height correlation

Heskdestad's Flame Height Correlation		
Inputs		
Fire diameter [m]	*0.6*	
HRR [kW]	*250*	
Results	*[m]*	*[ft]*
Flame height [m]	***1.5***	***5.0***

Table 08-05: Heskestad plume temperature correlation

Heskestad Plume Temperature Correlation	
Inputs	
Ambient temperature [C]	*20*
Fire location factor	*1*
HRR [kW]	*165*
Fire elevation [m]	*0*
Target Elevation [m]	*1.5*
Radiation Fraction	*0.40*
Fire Diameter [m]	*1*
Results	
Plume Temp [C]	***202***

- Target subjected to flame radiation:
  - A conduit is located 3 ft from a battery charger with qualified cable.

The point source flame radiation model described in section 5.3 of NUREG-1805 was selected for calculating the incident heat flux at the location of the target. Input values for the point source model are listed in
Table 08-06. Notice that a heat release rate of 160 kW generates incident heat fluxes of 5 kW/m^2.

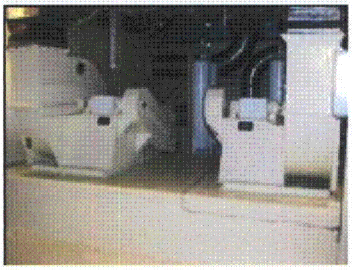
Table 08-06: Point source flame radiation model

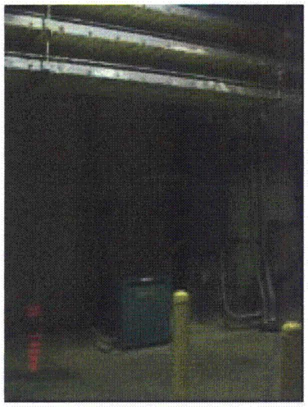
Point Source Flame Radiation Model	
Inputs	
Fire heat release rate [kW]	*160*
Radiation fraction	*0.40*
Distance from flames [m]	*1*
Results	
Heat flux [kW/m2]	***5.1***

Workshop Problem Set 08-04

Step 2: Plant Walkdown: Inspect the ignition source and target combination in the pictures included in Table 08-07 and determine the appropriate zone of influence calculation necessary.

Table 08-07: Inputs for Workshop problems 1

Ignition Source	Ignition Source/Target	Zone of Influence	Distance
	*Fire protection panel/Conduits above*	*Targets in the conduits will be affected by flame or plume conditions. Depending on the fire size and the characteristics of the room, the target may also be affected by hot gas layer temperatures.*	*~4'*
	*Electrical cabinets/Conduit*	*Targets in the conduits will be affected by flame or plume conditions. Depending on the fire size and the characteristics of the room, the target may also be affected by hot gas layer temperatures.*	*~3'*
	*Ventilation Subsystem/Ventilation Subsystem*	*Adjacent ventilation subsystem will be affected by flame radiation. Depending on the fire size and the characteristics of the room, the target may also be affected by hot gas layer temperatures.*	*~2'*

Ignition Source	Ignition Source/Target	Zone of Influence	Distance
	*Ventilation Subsystem/MOV's*	*MOV's and associated cables will be affected by flame radiation from a fire in the ventilation subsystem. Depending on the fire size and the characteristics of the room, the target may also be affected by hot gas layer temperatures.*	*~3'*
	*Electrical cabinet/Cable tray*	*Targets in the cable tray will be affected by flame or plume conditions. Depending on the fire size and the characteristics of the room, the target may also be affected by hot gas layer temperatures.*	*~4'*
	*Transformer/Cable tray*	*Targets in the cable tray will be affected by flame or plume conditions. Depending on the fire size and the characteristics of the room, the target may also be affected by hot gas layer temperatures.*	*~5'*
	*Pump/Pump*	*Adjacent pump will be affected by flame radiation. Depending on the fire size and the characteristics of the room, the target may also be affected by hot gas layer temperatures.*	*~4'*

Step 3: Verification of Screened Ignition Sources

No workshop problem for Step 3.

Workshop Problem Set 08-05

Step 4: Calculation of Severity Factors: Calculate the severity factors for the ignition source and target combinations listed in Workshop Problem 08-03. Use the results of Workshop Problem Set 08-03 as inputs to this exercise.

- Target in the hot gas layer
  - *Ignition source: MCC cabinet with unqualified cable*
  - *Heat release rate probability distribution: Case 4, Gamma distribution with* $\alpha = 2.6$ & $\beta = 67.8$.
  - *Critical heat release rate: 600 kW*
  - *Severity factor: Using a Microsoft Excel function,*
    SF = 1-GAMMADIST(600,2.6,67.8,TRUE) ≈ 0.004

- Target subjected to flame impingement or plume temperatures
  - *Ignition source: Ventilation subsystem*
  - *Heat release rate probability distribution: Case 7, Gamma distribution with* $\alpha = 2.0$ & $\beta = 11.7$.
  - *Critical heat release rate: 250 kW or 165 kW*
  - *Severity factor: Using a Microsoft Excel function,*
    SF = 1-GAMMADIST(250,2,11.7,TRUE) ≈ 1.2E-8 or
    SF =1-GAMMADIST(165,2,11.7,TRUE) ≈ 1.1E-5

- Target subjected to flame radiation
  - *Ignition source: Battery charger with qualified cable*
  - *Heat release rate probability distribution: Case 2, Gamma distribution with* $\alpha = 0.7$ & $\beta = 216$.
  - *Critical heat release rate: 160 kW*
  - *Severity factor: Using a Microsoft Excel function,*
    SF =1-GAMMADIST(160,0.7,216,TRUE) ≈ 0.83

It should be noted that this problem can also be solved using the discretized Gamma distribution tables in Appendix E of NUREG/CR-6850. Consider the target subjected to flame radiation, which was assigned the following Case 2 gamma distribution for heat release rate:

Bin	Heat Release Rate – kW (Btu/s)			Severity Factor (P_i)
	Lower	Upper	Point Value	
1	0 (0)	90 (85)	34 (32.7)	0.506
2	90 (85)	179 (170)	130 (123)	0.202
3	179 (170)	269 (255)	221 (209)	0.113
4	269 (255)	359 (340)	310 (294)	0.067
5	359 (340)	448 (425)	400 (379)	0.041
6	448 (425)	538 (510)	490 (464)	0.026
7	538 (510)	628 (595)	579 (549)	0.016
8	628 (595)	717 (680)	669 (634)	0.010
9	717 (680)	807 (765)	759 (719)	0.006
10	807 (765)	897 (850)	848 (804)	0.004
11	897 (850)	986 (935)	938 (889)	0.003
12	986 (935)	1076 (1020)	1028 (974)	0.002
13	1076 (1020)	1166 (1105)	1118 (1060)	0.001
14	1166 (1105)	1255 (1190)	1208 (1145)	0.001
15	1255 (1190)	Infinity	1462 (1386)	0.001

Figure 1: Table E-3 from NUREG/CR-6850

The severity factor is the sum of the severity factor column after the "Point Value" 160 kW (highlighted values in Figure 1).

Workshop Problem Set 08-06

Step 5: Calculation of Revised Compartment Fire Frequency: Determine a revised compartment ignition frequency for switchgear room A assuming the walkdown results listed in Table 08-08.

Table 08-08: Summary of Task 8 calculations

Equipment Description	Count	Fire Condition	Measured Distance (ft)	Table E-1 Case	Critical HRR (Table E-1)	Room Area (ft2)	Room Height (ft)	Calculated HRR (kW)	Room Temp (F)	Screened	Severity Factor	Count Task 8
Train A 4160 V Bus	8	flame or plume	1.7	9	Do Not Screen	1350	20	7	N/A	No	**1.00**	**8.00**
Train A 480 V Load Center	6	flame radiation	4.9	9	Do Not Screen	1350	20	401	N/A	No	**1.00**	**6.00**
Train A Station Service Transformer	1	flame radiation	4.5	9	Do Not Screen	1350	20	336	N/A	No	**1.00**	**1.00**
Train A Battery Charger	1	flame or plume	2.9	4	464	1350	20	25	264	No	**0.98**	**0.98**
Train A 125 VDC Bus	8	flame or plume	0.7	4	464	1350	20	1	264	No	**1.00**	**8.00**
Train A 125 VDC Panel	1	flame radiation	2.8	4	464	1350	20	129	264	No	**0.60**	**0.60**
Train A Inverter	1	flame radiation	2.0	4	464	1350	20	64	264	No	**0.88**	**0.88**

Table 08-09: Comparison of switchgear room A ignition frequency

Task 6	Switchgear Room A	**≈ 1.5E-02**
Task 8	Switchgear Room A	**≈ 1.5E-02**

Session 10b: Example Problems (Detailed Fire Modeling)

WORKSHOP PROBLEMS ON TASK 11A: DETAILED FIRE MODELING

This handout includes workshop problems on the different steps of Task 11: Detailed Fire Modeling. Problems are grouped according to the steps defined in NUREG/CR-6850. Detailed fire modeling will be conducted in the switchgear access room (Room 9) located in elevation 20 ft of the auxiliary building.

Workshop Problem Set 11a-01

***Step 1a: Identify and Characterize Compartments*:** Review the following information necessary for fire modeling purposes.

- Room size: For the purpose of this exercise, assume the size of the room is 45' by 22' by 20' high.
- Wall boundaries: The surfaces, floor, ceiling, and walls are reinforced concrete. All the surfaces are 2' thick.
- Doors: The room has three doorways: 1) a double door connecting to switchgear room A, 2) a double door connecting to switchgear room B, and 3) a single door connecting to the stairwell. The size of a single door is 6.5' by 3'.
- Mechanical Ventilation: The switchgear access room has a mechanical ventilation system with a balance 5 air changes per hour.

Workshop Problem Set 11a-02

Step 2a: Identify and Characterize fire Detection and Suppression Features and Systems: Review the following information necessary for fire modeling purposes.

- Prompt detection: Prompt detection is not credited since there is no incipient fire detection system in the room and no continuous fire watch.
- Prompt suppression: Prompt suppression is not credited since there is no continuous fire watch in the room.
- Fixed fire detection system/s (type, and sensor location): An automatic fire detection system is credited since the room is equipped with an automatic fire detection system. The location of the relevant detectors is specified in the corresponding scenario descriptions later in this document.
- Fixed fire suppression system/s (type and nozzle location): An automatic CO_2 system is credited since the room is equipped with an automatic CO_2 system. Upon smoke detection alarm, a timer starts providing 60 seconds delay for life safety purposes. The CO_2 is released after the delay time. The soak time is approximately 20 min.
- Fire brigade arrival time: The fire brigade arrival time is assumed to be 15 min.
- Delayed detection: Delayed detection is credited and assumed to be 15 minutes (consistent with the example in page P-14 of NUREG/CR-6850).

Workshop Problem Set 11a-03

Step 3a: Characterize Fire Ignition Sources: From the Task 6 (Fire Ignition Frequencies) calculation package, list the fixed ignition sources located in the switchgear access room (room 9) and assign a heat release rate probability distribution to each of them from Table G-1 of NUREG/CR-6850.

Solution: Table 10 lists the recommended answer to workshop problem 3.

Table 10: Summary of ignition source characteristics in the switchgear access room.

Equipment ID	Equipment Description	Case (Table E-1 of NUREG/CR-6850)	HRR Profile (Page G-6 in NUREG/CR-6850)
MCC-A1	Train A 480 V Motor Control Center	Case 3	t^2 grow to a peak of 211 kW in 12 min followed by steady burning for 8 additional minutes
MCC-B1	Train B 480 V Motor Control Center	Case 3	t^2 grow to a peak of 211 kW in 12 min followed by steady burning for 8 additional minutes
VITAL-A	Train A 120 VAC Vital Bus	Case 3	t^2 grow to a peak of 211 kW in 12 min followed by steady burning for 8 additional minutes
VITAL-B	Train B 120 VAC Vital Bus	Case 3	t^2 grow to a peak of 211 kW in 12 min followed by steady burning for 8 additional minutes
Transients	Regular solid transient ignition sources.	Case 8	t^2 grow to a peak of 317 kW in 12 min followed by steady burning for 8 additional minutes

Step 4a: Identify Secondary Combustibles: No workshop problem is associated with this step. The following discussion provides an example of how to identify and characterize secondary combustibles.

Sample Analysis for Step 4a:
For the purpose of this example, let's assume that there is one cable tray stack above each cabinet in the room. Each stack has two trays. The first tray is 1' above each cabinet. The second tray in the stack is 1.5' above the first tray. The trays are ladder-back. A pictorial representation of the secondary combustibles in provided in Figure 2.

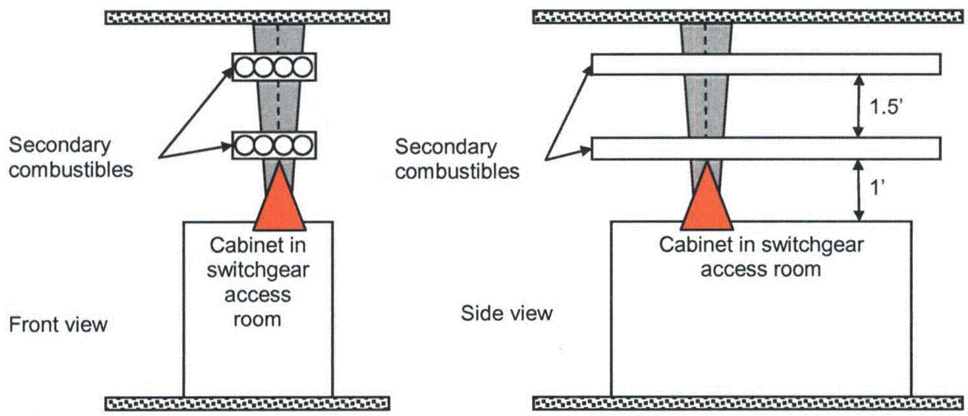


Figure 2: Pictorial representation of the secondary combustibles. Drawing not to scale.

From Table 10, the cabinets in the switchgear access room will have a peak heat release rate of 211 kW. Heskestad's flame height correlation (Chapter 3 of NUREG 1805) suggests a flame height of approximately 4.6' above the ignition source. Therefore, the cable tray stack above the cabinet is expected to ignite and contributing to the fire intensity. Table 11 lists the Heskestad's flame height correlation analysis.

Table 11: Heskestad's flame height correlation analysis.

Heskdestad's Flame Height Correlation	
Inputs	
Fire diameter [m]	0.6
HRR [kW]	211
Results	
Flame height [m]	**1.4**
Flame height [ft]	**4.6**

Step 5a: Identify and Characterize Target Sets: No workshop problem is associated with this step. The following discussion provides an example of how to identify and characterize target sets. In practice, this step requires highlighting of cable tray and conduit targets in room layout drawings based on cable routing analysis and plant walkdowns.

Sample Analysis for Step 5a:
For the purpose of this exercise, let's assume that there are two target sets in the room: 1) HCBT-35A and HCBT-37B, and 2) VCBT-20A, and VCBT-20B. These trays are identified in Figure 3. The trays have both thermo-set and thermo-plastic cables. Specifically, a fire damaging either the two horizontal trays or the two vertical trays will generate the postulated plant condition.

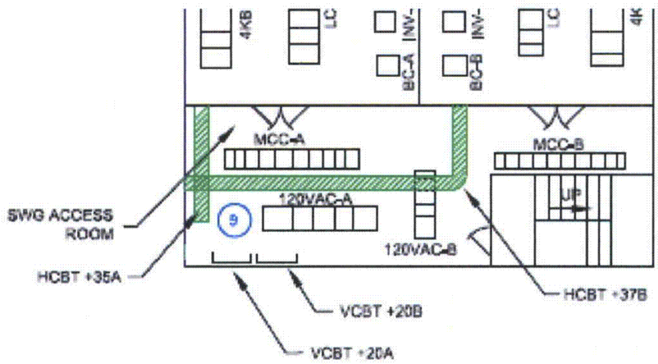


Figure 3: Cable tray locations in the switchgear access room

Tray locations:

- HCBT 35A: This horizontal tray comes into the switchgear access room from switchgear room A. The tray is the second tray in an elevated stack. The lowest tray in the stack is at elevation 33' (13' from the floor). The target tray, HCBT 35A, is at elevation 35' (15' ft from the floor and 2' above the lowest tray in the stack).

- HCBT 37B: This horizontal tray comes in the south direction into the switchgear access room from switchgear room B and turns west. The tray is the first tray in an elevated stack. It is located at elevation 37' (17' from the floor). At the point the cable tray crosses HCBT 35A, it is the third tray in the stack.

- VCBT 20A: This is a vertical cable tray in the south west corner of the room. The tray comes into the room through a floor penetration at elevation 20' and runs up to the ceiling.

- VCBT 20B: This is a vertical cable tray in the south west corner of the room. The tray comes into the room through a floor penetration at elevation 20' and runs up to the ceiling.

Workshop Problem 11a-04

Step 6a: Define the Fire Scenarios to be Analyzed: Define the fire scenarios to be analyzed in the switchgear access room using the information provided or collected in the first five steps.

Solution: The following tables and figures describe the fire scenarios defined for analysis. For the purpose of this exercise, only the scenarios that will be analyzed in detail in upcoming workshop problems have been defined in detail.

- Fixed ignition source fire scenarios: Fixed ignition source fire scenarios are postulated in the two closest cabinets to the target trays.

Table 12: Summary of scenario 1.

Scenario 1: A fire in the MCC-A cabinet affecting the two horizontal cable tray targets. The targets could be affected by hot gas layer temperatures, flame radiation or horizontal flame spread.	
Ignition Source	MCC-A cabinet. The fire is postulated 1' below the top of the cabinet. The cabinet is 7' high.
Secondary combustibles	Cable tray stack above the electrical cabinet.
Target	HCBT-35A, HCBT-37B. The pinch point is located 2' horizontally from the cabinet (closest distance from fire to pinch point).
Credited detection	Automatic fire detection system
Credited suppression	Automatic CO_2 system and fire brigade

Figure 4 provides a pictorial representation of this scenario.

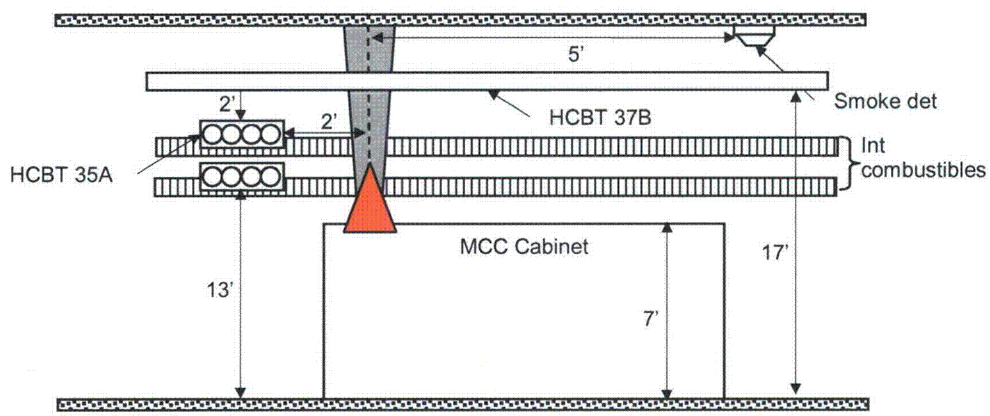


Figure 4: Pictorial representation of fire scenario 1. Drawing not to scale.

Table 13: Summary of scenario 2.

Scenario 2: A fire in the 120VAC-A cabinet affecting the two horizontal cable tray targets. The targets could be affected by hot gas layer temperatures, direct flame radiation, or horizontal flame spread.	
Ignition Source	120VAC-A cabinet
Secondary combustibles	Cable tray stack above the electrical cabinet.
Target	HCBT-35A, HCBT-37B
Credited detection	Automatic fire detection system
Credited suppression	Automatic CO_2 system and fire brigade

Table 14: Summary of scenario 3.

Scenario 3: A fire in the 120VAC-A cabinet affecting the vertical cable tray targets. The targets could be affected by hot gas layer temperatures, direct flame radiation, or horizontal flame spread..	
Ignition Source	120VAC-A cabinet
Secondary combustibles	
Target	HCBT-35A, HCBT-37B
Credited detection	Automatic fire detection system
Credited suppression	Automatic CO2 system and fire brigade

Finally, Figure 4 illustrates the location of the postulated fires.

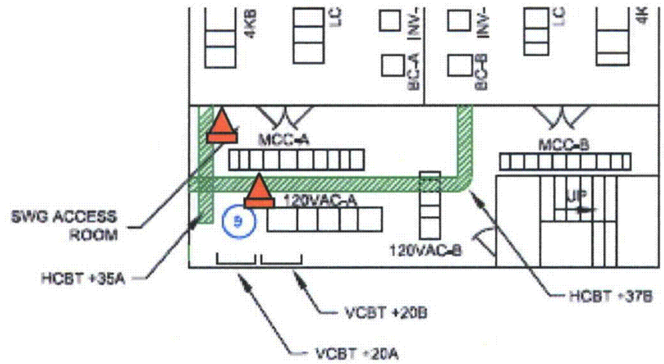


Figure 5: Pictorial representation of the location of the postulated fire scenarios.

- Transient ignition source fire scenarios: Only regular solid transient fire scenarios at floor level are postulated in this room. Since the room does not contain any mechanical equipment requiring lubrication or oil, fires resulting from combustible liquid spills are not postulated.

Table 15: Summary of scenario 4.

Scenario 4: A transient fire at floor level affecting the two horizontal cable tray targets. The targets could be affected by hot gas layer temperatures, flame impingement or fire plume temperatures.	
Ignition Source	Floor based transient fire
Secondary combustibles	
Target	VCBT-20A, VCBT-20B
Credited detection	Automatic fire detection system
Credited suppression	Automatic CO2 system and fire brigade

Figure 6 provides a pictorial representation of this scenario.

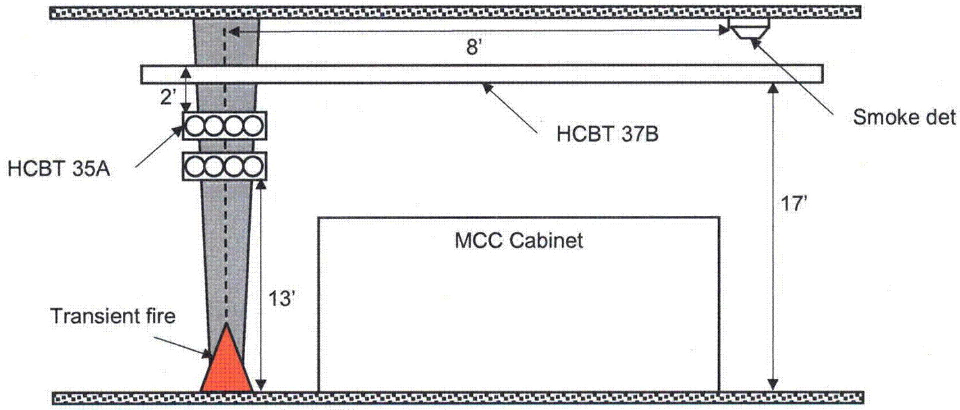


Figure 6: Pictorial representation of fire scenario 4. Drawing not to scale.

Table 16: Summary of scenario 5.

Scenario 5: A transient fire at floor level affecting the two vertical cable tray targets. The targets could be affected by hot gas layer temperatures, flame impingement or direct flame radiation.	
Ignition Source	Floor based transient fire
Secondary combustibles	
Target	VCBT-20A, VCBT-20B
Credited detection	Automatic fire detection system
Credited suppression	Automatic CO2 system and fire brigade

Figure 7 illustrate the location of the postulated transient fires.

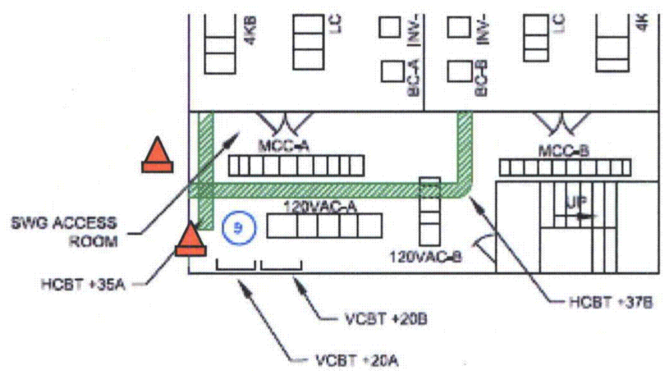


Figure 7: Pictorial representation of the location of the postulated fire scenarios.

- Additional scenarios that should be considered include self-ignited cable fires and junction box fires since this room has unqualified cable.

Step 7a: Conduct Fire Growth and Propagation Analysis: For the purpose of this workshop, only two of the fire scenarios listed in the previous section are analyzed in detail: Scenario 1, and Scenario 4.

Workshop Problem 11a-05:

Determine if a fire in the ignition sources associate with scenarios 1 and 4 can produce room wide damage in the switchgear access room. If the ignition sources alone are not expected to generate room wide damage, determine the amount of secondary combustibles necessary to achieve it.

Solution:
A 1.1 MW fire is necessary for generating room wide damage in the aux switchgear access room. Using the MQH Room Temperature correlation (NUREG 1805), a 1.1 MW fire may generate a room temperature of 205 °C, which is the assumed damage temperature (Appendix H of NUREG/CR-6850) for thermoplastic cables in the aux control room. The aux control room has approximately 1000 ft^2 floor and 20 ft high ceiling. All room surfaces are concrete. The calculation assumes one single open door and a 20 min fire duration. Table 17 lists the inputs and output of the MQH room temperature analysis.

Table 17: Summary of room temperature analyses using the MQH model.

MQH Temperature Correlation			MQH Temperature Correlation			MQH Temperature Correlation	
Single cabinet cubicle fire			Transient fire			Limiting fire size	
Inputs			**Inputs**			**Inputs**	
Ambient temperature [C]	20		Ambient temperature [C]	20		Ambient temperature [C]	20
Duration [sec]	1200		Duration [sec]	1200		Duration [sec]	1200
Opening area [m2]	2		Opening area [m2]	2		Opening area [m2]	2
Height of opening [m]	2		Height of opening [m]	2		Height of opening [m]	2
Room length [m]	14		Room length [m]	14		Room length [m]	14
Room width [m]	7		Room width [m]	7		Room width [m]	7
Room height [m]	6		Room height [m]	6		Room height [m]	6
Thermal cond [kW/mK]	0.0014		Thermal cond [kW/mK]	0.0014		Thermal cond [kW/mK]	0.0014
Density [kg/m3]	2000		Density [kg/m3]	2000		Density [kg/m3]	2000
Specific heat [kJ/kg]	0.88		Specific heat [kJ/kg]	0.88		Specific heat [kJ/kg]	0.88
Wall thickness [m]	0.6		Wall thickness [m]	0.6		Wall thickness [m]	0.6
HRR [kW]	211		HRR [kW]	317		HRR [kW]	1100
Results			**Results**			**Results**	
Room Temp [C]	**82**		Room Temp [C]	**102**		Room Temp [C]	**205**

Both an electrical cabinet and a transient fire are postulated at floor level in the switchgear access room. Appendix G of NUREG/CR-6850 suggests that the 98^{th} percentile heat release rates for these fires are 211 kW and 317 kW (see also Table 10). These fire intensities are lower than the critical value of 1.1 MW calculated earlier required for room wide damage. Consequently, fire propagation to nearby cable trays or secondary combustibles (if available) is necessary to reach the critical fire intensity.

The cable tray heat release rate model described in Chapter 7 of NUREG-1805 suggests a heat release rate of 265 kW for a 1 m^2 for a bench scale HRR of 589 kW/m^2 (PE/PVC material). With this approximation:

- If the fire starts in an electrical cabinet, approximately 5 trays will need to burn to produce a 1.9 MW fire assuming a 1 m^2 of tray on fire: $(1100 - 211)/265 \approx 4$ (assuming a tray length of approximately 3').

- If the fire starts as a transient fire, approximately 6 trays will need to burn to produce a 1.9 MW fire assuming a 1 m^2 of tray on fire: $(1100 - 317)/265 \approx 3$ (assuming a tray length of approximately 3').

In the case of self ignited or junction box fires, a total of $1100/265 \approx 5$ trays will need to be on fire in order to generate room wide damage.

This analysis will serve as basis for decision making in selecting and analyzing fire scenarios in the aux control room. In this particular room, it appears that there are not enough trays above the cabinets or transients where the fire is postulated to generate room wide damage without significant horizontal flame spread and if suppression activities fail before fire propagates upward to at least five or six trays.

Workshop Problem 11a-06

Determine the time to target damage, time to smoke detection, time to automatic suppression and the fire brigade arrival time for scenario 1.

Solution:

- Time to target damage: Time to target damage is assumed to be: 1) the time required for the fire to heat up the cable trays to its damage temperature by direct flame radiation, or 2) the time to room heat up to cable damage temperature. In either case, the fire growth profile will be an important factor in this analysis.

  Heat release rate profile for the ignition source: Table 10, the heat release rate profile for this ignition source is t^2 grow to a peak of 211 kW in 12 min followed by steady burning for 8 additional minutes. This is the profile recommended in NUREG/CR-6850 for this electrical cabinet, page G-6.

  Heat release rate from secondary combustibles: Recall that the secondary combustibles (cable tray stack above the panel) is expected to contribute to the fire intensity. Consequently, the heat release rate profile should include such contribution. Appendix R of NUREG/CR-6850 describes the following model for fire propagation in cable trays: the first tray above the ignition source will ignited at the calculated time using fire modeling tools. The second tray will ignite 4 minutes after the first one. Evaluating the flame height and plume temperature using the corresponding correlations from Heskestad (Chapters 3 & 9 in NUREG 1805), both models suggest ignition of the first tray in approximately 3 to 5 min. Therefore, ignition of the second tray is expected in approximately 9 min after ignition. Table 18 lists the solution of the correlations as a function of time. Notice that between times 4 and 5 min, the flame height reaches 1' (the location of the first tray above the cabinet). At this time however, the plume temperature has exceeded the cable damage temperature.

Table 18: Summary of Heskestad's flame height and plume temperature analysis as a function of time.

Time (min)	HRR (kW)	Flame height (ft)	Plume Temp (F)
0	0	0.0	68
1	1	0.0	123
2	6	0.0	226
3	13	0.2	380
4	23	0.7	596
5	37	1.2	895
6	53	1.8	1305
7	72	2.3	1871
8	94	2.7	2663
9	119	3.2	3794
10	147	3.7	5458
12	211	4.6	12138
14	211	4.6	12138
16	211	4.6	12138

Considering that the cables above the cabinet are expected to ignite, the contribution from the cable tray fire should be included in the analysis. The heat release rate profile listed in Table 19 is obtained using the cable tray heat release rate model described in Chapter 7 of NUREG-1805 with a bench scale HRR of 589 kW/m^2 (PE/PVC material). Notice that the total heat release rate profile includes the contribution from both, the cabinet fire and the cable tray fire. .

Table 19: Summary of heat release rate profile and room temperature analysis as a function of time.

Tray width [m]:	0.6					
Tray sep [m]:	0.46					
Bench Scale HRR [kW/m²]	589					
Ignition Source	**Length [m]**	**Fire Duration [min]**	**HRR [kW] for cable trays**	**HRR for electrical cab [kW]**	**Total HRR [kW]**	**Room Temp [F]**
Electrical cabinet		0		0	0	Ambient
Tray 1	0.6	5	95	37	132	134
Tray 2	1.03	9	164	119	283	187
		10		147	311	197
		12		211	375	219
		14		211	375	223
		16		211	375	226
		18		211	375	229
		20		211	375	232

In the case of room heat up, Table 19 suggests that the fire will not generate hot gas layer temperatures capable of producing room wide damage. These temperatures were calculated using the MQH model for room temperature. The results are also consistent with the analysis in workshop problem 5.

In the case of direct flame radiation, the pinch point is located approximately 2' from the fire. The point source flame radiation model (see Chapter 5 of NUREG 1805), suggest a damaging incident heat flux 2' from the ignition source from a fire intensity of 60 kW. This intensity is lower than the peak calculated earlier and listed in Table 19. A 60 kW fire is expected somewhere in between 5 and 9 min due to the fire quickly propagating to cable trays above. The point source flame radiation analysis is documented in Table 20. This heat flux result bounds the flame spread analysis since the fire at the ignition source location is capable of impacting the target.

Table 20: Summary of point source flame radiation model analysis

Point Source Flame Radiation Model	
Inputs	
Fire heat release rate [kW]	60
Radiation fraction	0.40
Distance from flames [m]	0.6

Results	
Heat flux [kW/m2]	5.3

- Time to smoke detection:

  The time to smoke detection is assumed to be 1 min. The technical basis for this assumption is as follows: The time to smoke detection listed in Table 21 below are calculated using the model described in Chapter 11 of NUREG 1805. Notice that for vertical and horizontal distances from the ignition source in the order of 6 meters, calculated times to detection are in the order of seconds, which suggests that the 1 min assumption is conservative. The time to detection calculations were conducted conservatively assuming a low heat release rate of 25 kW. It should be noted that these activation times are not considering any incipient stage of the fire development, e.g., smoldering.

Table 21: Time to detector activation

Seconds		Horizontal Radial Distance (m)					
		1	**2**	**3**	**4**	**5**	**6**
Vertical Height Above Fire (m)	**1**	0.5	1.3	2.4	3.9	5.7	7.9
	2	0.8	1.3	2.1	3.2	4.5	6.0
	3	1.2	1.6	2.2	3.1	4.2	5.4
	4	1.6	2.0	2.5	3.3	4.2	5.3
	5	2.1	2.4	2.9	3.6	4.4	5.4
	6	2.6	2.9	3.4	4.0	4.7	5.6

- Time to automatic suppression: Assuming a smoke detection signal in 1 min, and considering the delay time of 60 for the automatic CO_2 system, the time for automatic suppression is estimated as 2 min.

- Time to fire brigade arrival: The time to fire brigade arrival at the room is estimated as 15 min from brigade drill records.

Workshop Problem 11a-07

Determine the time to target damage, time to smoke detection, time to automatic suppression and the fire brigade arrival time for scenario 4.

Solution:

- Time to target damage: Time to target damage is assumed to be: 1) the time required for the fire to heat up the cable trays to its damage temperature from fire plume exposure, or 2) the time to room heat up to cable damage temperature, whichever is less. In either case, the fire growth profile will be an important factor in this analysis.

Heat release rate profile for the ignition source: From Table 10, the heat release rate profile for this ignition source is t^2 growth to a peak of 317 kW in 12 min followed by steady burning for 8 additional minutes. This is the profile recommended in page G-6 of NUREG/CR-6850 for this electrical cabinet. Similar to the flame height and plume temperature analysis in workshop problem 6, Table 22 lists the corresponding results for the transient fire. The results suggest that the fire will not affect cable trays located 13' above the floor since the plume temperature does not reach 405 °F.

Table 22: Summary of Heskestad's flame height and plume temperature analysis as a function of time.

Time (min)	HRR (kW)	Flame height (ft)	Plume Temp (F) (at 13' above the floor)
0	0	0.0	68
1	2	0.0	72
2	9	0.0	79
3	20	0.5	88
4	35	1.2	98
5	55	1.8	110
6	79	2.4	123
7	108	3.0	137
8	141	3.6	152
9	178	4.1	168
10	220	4.7	186
12	317	5.7	226
14	317	5.7	226
16	317	5.7	226

- Time to smoke detection: Time to smoke detection is assumed to be 1 min based on the results presented in Table 21.

- Time to automatic suppression: Assuming a smoke detection signal in 1 min, and considering the delay time of 60 for the automatic CO_2 system, the time for automatic suppression is estimated as 2 min.

- Time to fire brigade arrival: The time to fire brigade arrival at the room is estimated as 15 min from brigade drill records.

Workshop Problem 11a-08

Let's assume that MCC-A1, which is the ignition source in scenario 1 it's a 4160V switchgear. In this case, a high energy arcing fault event should be also postulated and evaluated. Determine if the cable tray targets will be within the zone of influence of a high energy arcing fault.

Solution: The two horizontal trays, HCBT-35A and HCBT-37B are located 6' vertically and 2' horizontally from the cabinet. According to the criteria listed in pages M-13 and M-14 or NUREG-CR/6850, the target trays will be outside the zone of influence. However, the stack of cable trays above the cabinet (the secondary combustibles) will be within the zone of influence, and therefore, will ignite at time zero. The time to target damage calculated in workshop problem 6 will be affected due to different ignition time of secondary combustibles.

Step 8a: Conduct Fire Detection and Suppression Analysis*:* The detection and suppression is reflected in the risk analysis with the non-suppression probability, which is calculated using a Detection/Suppression event tree approach discussed in Appendix P of NUREG/CR-6850, Detection and Suppression Analysis. Recall that the switchgear access room is equipped with a smoke detection system, and an automatic CO_2 system. The CO_2 system has a 60 second warning alarm delay. In addition to these fixed systems, the fire brigade can also provide manual suppression activities.

Considering the above fire protection features, the suppression strategy in the switchgear access room can be summarized as:

1. Indication of smoke detection in control room
2. Control room sends an operator to the switchgear access room to confirm the fire
3. If fire is confirmed, the operator first determines if the automatic CO_2 system operated.
4. If further suppression activities are warranted after any of the automatic systems, manual suppression by the fire brigade may be used.

Workshop Problem Set 11a-09

Develop a detection suppression event tree for the fire protection strategy defined above.

Solution:

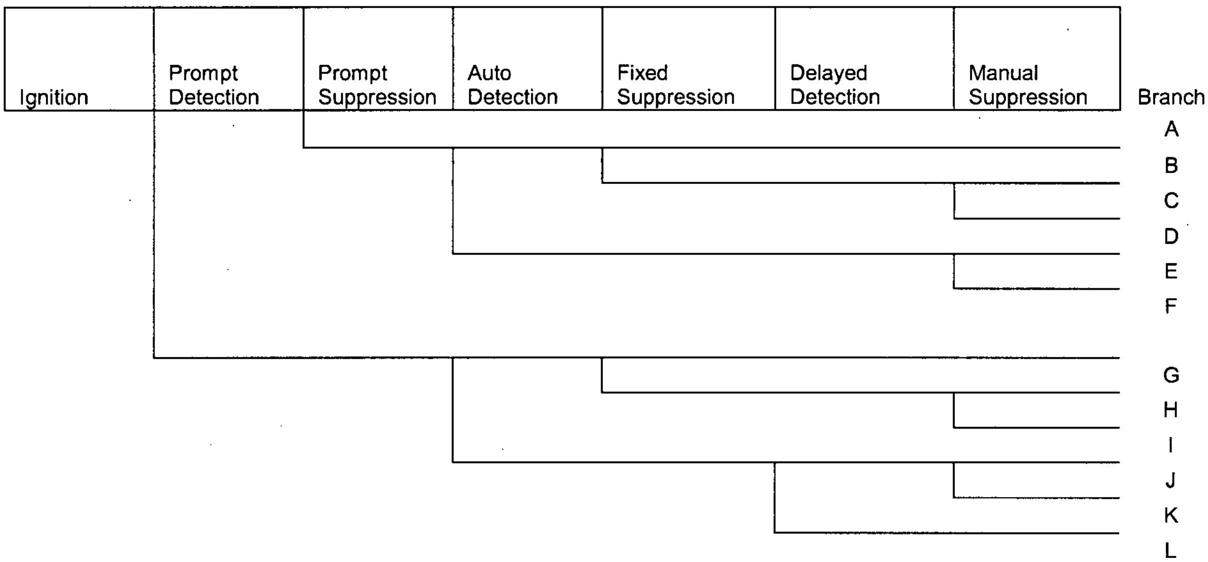
The above strategy is reflected in the event tree depicted in Figure 8 (similar to the one described in Appendix P of NUREG/CR-6850). The event tree is then applied to each of the fire scenarios producing a non-suppression probability for each. The non-suppression probability results from the summation of the failure to suppress branches in the event tree. The event tree includes the events listed in Table 23:

Table 23:Events included in the detection suppression event tree

Sequence	Detection	Suppression
A	Prompt detection	Prompt suppression
B	Prompt detection	Automatic suppression
C	Prompt detection	Fire brigade
D	Prompt detection	Fire brigade failure
E	Prompt detection	Fire brigade
F	Prompt detection	Fire brigade failure
G	Automatic detection	Automatic suppression
H	Automatic detection	Fire brigade
I	Automatic detection	Fire brigade failure
J	Delayed detection	Fire brigade
K	Delayed detection	Fire brigade failure
L	Delayed detection failure	

Prompt detection and prompt suppression are not credited in the analysis since the switchgear access room has no continuous fire watch or is equipped with an incipient fire detection system. Automatic detection is credited since the room has a fire detection system. Fixed automatic suppression is also credited since the room has an automatic CO_2 system. Delayed detection is not credited since time to ignition of the first tray occurs in approximately 7 to 10 min, which is less than the recommended 15 min for delayed detection in NUREG/CR-6850. Finally, manual suppression by the fire brigade could be credited but will not have any impact since the CO_2 release is expected to occur first and the room must remain close during the CO_2 soak time.

Figure 8: Detection/suppression event tree for the switchgear access room



Workshop Problem 11a-10

Step 9a: Calculate Conditional Non-Suppression Probability and Severity Factor:
Determine the severity factor and the non-suppression probability for scenario 1.

Solution:
This scenario consists of a fire propagating to cable trays above. From Table 9, a heat release rate of approximately 13 to 23 kW (based on plume results) is necessary for a fire to affect the cables above. For the purpose of this example, a value of 15 kW is selected. Per Table 1, the ignition source is assigned a Case 3 probability distribution for heat release rate from Table E-1 in NUREG/CR-6850. This is a Gamma distribution with $\alpha = 1.6$ and $\beta = 41.5$. The severity factor values for heat release rates greater than 15 kW is (using the gamma distribution function in Microsoft Excel):

SF = 1-GAMMADIST(15,1.6,41.5,TRUE) = 0.89

This is interpreted as the probability of a fire spreading to the cable trays above.

Solving the event tree depicted in Figure 8 for a damage time of 5 min, the non suppression probability is ≈ 0.1. The solution of the event tree is presented in Figure 9. The general inputs to the event tree are listed in Table 24. Additional inputs to the event tree, developed from the fire modeling analysis described in the previous step are listed in

Table 25.

Table 24: General inputs to detection/suppression event tree

Prompt Detection:	FALSE
Auto Det:	TRUE
Prompt Suppression:	FALSE
Fixed Suppression:	TRUE
Fixed Supp Type:	Automatic
Supp Agent:	CO2
Delay time (Min):	1
Brigade Arrival (min):	15
Target Damage (min):	5
Det reliability:	0.95
Supp system reliability:	0.95
Traditional Sprinklers:	FALSE
HEP:	1
Supp Curve (Table P-3):	Electrical Fires

Table 25: Fire modeling inputs to detection/suppression event tree

Time to (Min)	
Ignition:	0
Prompt Det:	0
Prompt Supp:	0
Auto Det:	1
Fixed Supp:	2
Delayed Det:	15
Target Damage (min):	5

Figure 9: Solution of the detection/suppression event tree

Ignition	Prompt Detection	Prompt Suppression	Auto Detection	Fixed Suppression	Delayed Detection	Manual Suppression	Branch	Branch Probability
	0	0.00					A	--
		1.00	0.95	0.95			B	--
				0.05		0.00	C	0.0E+00
						1.00	D	--
			0.05			0.00	E	--
						1.00	F	0.0E+00
	1		0.95	0.95			G	--
				0.05		0.00	H	--
						1.00	I	4.8E-02
			0.05		0	0.00	J	--
						1.00	K	0.0E+00
					1		L	5.0E-02
							P_{NS}	0.098

Workshop Problem 11a-11

***Step 10a: Calculate Scenario Frequency*:** Using the ignition frequency calculated in Task 6 for the ignition sources in the switchgear access room, and the severity factor and non-suppression probability calculated in the previous step for scenario 1, determine the frequency for fire scenario 1.

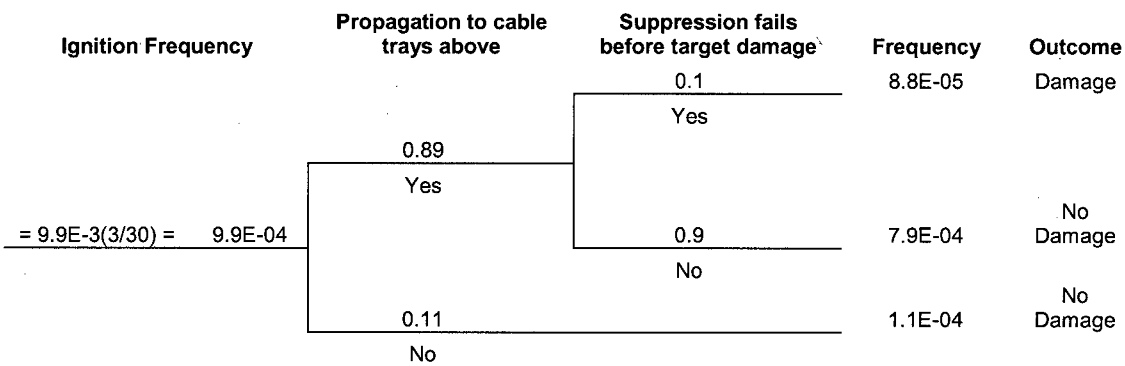
Solution:

Recall that this scenario consists of a fire propagating to a cable tray stack above and generating target damage due to direct flame radiation. This sequence of events is captured in the event tree depicted in Figure 10.

- The first event is the ignition frequency calculated in Task 6 of the Fire PRA as documented in NUREG/CR-6850.
- The second event refers to the fire propagating to the cable tray stack above. The probability of propagating is given by the severity factor calculated in Step 9.
- The third event is defined by the probability of suppressing the fire before target damage, as calculated earlier in Step 9.

Only one outcome in the event tree refers to cable damage before suppression. The frequency of this outcome is 8.8E-5.

Figure 10: Event tree depicting the sequence of events leading to target damage



Session 11b: Example Problems (Main Control Room Fire Analysis)

Workshop Problems for Task 11b: Detailed Fire Modeling in the Main Control Room

Workshop Problem Set 11b-02 (Solution)

Step 2.b: Estimate Control Room Fire Frequency: Using the information provided in this Sample Package, and the above formula copied from NUREG/CR 6850, estimate the frequency of fire for the SNPP MCR.

$W_{L, MCR}$ = 1 per N/A
There is only one unit and one MCR for the unit.

λ_{MCB} = 2.5E-03 per reactor year
From Table 6-1 of NUREG/CR 6850, bin # 4

$W_{PWC, Elec. Cab, MCR.}$ = 7.4E-03 per N/A
From Results of Task 6 Problem Set 06-09

$\lambda_{PWC, Elec. Cab.}$ = 4.5E-02 per reactor year
From Table 6-1 of NUREG/CR 6850, bin # 15

$W_{transients, MCR}$ = 0.64 per N/A
From Task 6 Calculations

$\lambda_{transient}$ = 3.9E-03 per reactor year
From Table 6-1 of NUREG/CR 6850, bin # 7

$W_{welding, MCR}$ = 0.2 per N/A
From Task 6 Calculations

$\lambda_{welding}$ = 9.7E-03 per reactor year
From Table 6-1 of NUREG/CR 6850, bin # 6

$W_{Cable,MCR:}$ = 0.35 per N/A
From Task 6 Calculations

λ_{cable} = 1.6E-03 per reactor year
From Table 6-1 of NUREG/CR 6850, bin # 5

λ_{MCR} = 1 x (2.5E-03 + 7.4E-03 x 4.5E-02 + 0.64 x 3.9E-03 + 0.2 x 9.7E-03 + 0.35 x 1.6E-03 =

= 2.5E-03 + 3.3E-04 + 2.5E-03 + 1.9E-03 + 5.6E-04 = 7.79E-03 per reactor year

Workshop Problem Set 11b-05 (Solution)

Step 5.b: Identify and characterize target sets: Identify at least five target sets for the Main Control Room by inspecting drawings DWG A-07 and A-09 and other information provided in this Sample Package.

Target Set ID	Items in the target set	Basis for selecting target set
MCR-01	Control room habitability	Of potential scenarios involving control room abandonment without any damage to the Main Control Board, a fire in the kitchen could be severe enough forcing the operators out.
MCR-02	Service water controls CCW Controls	Service water and CCW are controlled from a small part of the Main Control Board. A fire within CB-7 may fail both systems. Loss of Service Water alone, may have a significant CCDP.
MCR-03	HPI-A High pressure safety injection pump A HPI-B High pressure safety injection pump B RHR-B RHR pump AOV-2 (SOV-2) Letdown isolation valve AOV-3 (SOV-3) Charging pump injection valve MOV-1 HPI valve MOV-2 VCT isolation valve MOV-3 Cont. sump recirc valve MOV-4 Cont. sump recirc valve MOV-5 RWST isolation valve MOV-6 RWST isolation valve MOV-7 RHR inboard suction valve MOV-8 RHR outboard suction valve MOV-9 HPI valve LI-1 RWST level LI-2 RWST level LI-3 Cont. sump level LI-4 Cont. sump level TI-1 Letdown heat exchanger outlet temp	CB-5 contains a large number of safety related component controls. A fire limited to this part of the panel, affecting the equipment controlled from this panel may have a significant CCDP.

Target Set ID	Items in the target set	Basis for selecting target set
MCR-04	AFW-A Motor driven AFW pump A AFW-C Motor driven AFW pump C MOV-10 AFW discharge valve MOV-11 AFW discharge valve MOV-14 AFW turbine steam line isolation valve MOV-15 AFW steam inlet throttle valve MOV-16 AFW test line isolation valve MOV-17 AFW test line isolation valve MOV-18 AFW C Pump Discharge MOV-19 AFW test line isolation valve A-1 AFW motor high temp	CB-3 contains all post shutdown secondary cooling equipment controls. A fire limited to this part of the panel, affecting the equipment controlled from this panel may have a significant CCDP.
MCR-05	HPI-A High pressure safety injection pump A HPI-B High pressure safety injection pump B AOV-2 (SOV-2) Letdown isolation valve MOV-2 VCT isolation valve LI-3 Cont. sump level LI-4 Cont. sump level AFW-A Motor driven AFW pump A AFW-C Motor driven AFW pump C MOV-14 AFW turbine steam line isolation valve MOV-15 AFW steam inlet throttle valve	The shortest distance between the controls of the HPI and AFW systems that can render the pumps from both system inoperable is the distance from MOV-15 control switch to HPI-A control switch. Loss of both systems may have a significant CCDP.

Workshop Problem Set 11b-06 (Solution)

Steps 6.b: Identify and Characterize Ignition Sources:

Steps 7.b: Define Fire Scenarios: For the target sets provided in the solution of the preceding problem set, identify the corresponding ignition sources and fire scenarios.

Target Set ID	Ignition Sources	Fire Scenarios
MCR-01	1. Water heater in the kitchen	MCR-01.1. An electrical short in the water heater leads to a fire in the kitchen that becomes severe enough to lead to control room abandonment.
	2. Microwave oven in the kitchen	MCR-01.2. An electrical short in the microwave oven or a food item fire inside the oven leads to a fire in the kitchen that becomes severe enough to lead to control room abandonment.
MCR-02	1. Main Control Board – Fire in CB-7	MCR-02.1. A fire inside Main Control Board due to internal causes. The fire initiates inside CB-7. Operator response in putting the fire is not fast enough to prevent damage to CB-7 contents. But the fire is controlled before it propagates to other parts of the panel.
	2. Transient fire	MCR-02.2 A transient fire inside Main Control Room, but outside the Main Control Board, occurs near CB-7 such that only CB-7 is affected either because of the location of the fire or fire fighting efforts.
	3. Transient fire due welding and cutting	MCR-02.3. A transient fire due to welding and cutting inside Main Control Room, but outside the Main Control Board, occurs near CB-7 such that only CB-7 is affected either because of the location of the fire or fire fighting efforts.
	4. Cable fire due welding and cutting.	MCR-02.4. A cable fire occurs due to welding and cutting inside Main Control Board occurs near CB-7 such that only CB-7 is affected because fire fighting efforts limit the reach of the fire.
MCR-03	1. Main Control Board – Fire in CB-5	MCR-03.1. A fire inside Main Control Board due to internal causes. The fire initiates inside CB-5. Operator response in putting out the fire is not fast enough to prevent damage to CB-5 contents. But the fire is controlled before it propagates to other parts of the panel.
	2. Transient fire	MCR-03.2. A transient fire inside Main Control Room, but outside the Main Control Board, occurs near CB-5 such that only CB-5 is affected either because of the location of the fire or fire fighting efforts.
	3. Transient fire due welding and cutting	MCR-03.3. A transient fire due to welding and cutting inside Main Control Room, but outside the Main Control Board, occurs near CB-5 such that only CB-5 is affected either because of the location of the fire or fire fighting efforts.

Target Set ID	Ignition Sources	Fire Scenarios
	4. Cable fire due welding and cutting.	MCR-03.4. A cable fire occurs due to welding and cutting inside Main Control Board occurs in CB-5 such that only CB-5 is affected because fire fighting efforts limit the reach of the fire.
MCR-04	1. Main Control Board – Fire in CB-3	MCR-04.1. A fire inside Main Control Board due to internal causes. The fire initiates inside CB-3. Operator response in putting the fire is not fast enough to prevent damage to CB-3 contents. But the fire is controlled before it propagates to other parts of the panel.
	2. Transient fire	MCR-04.2. A transient fire inside Main Control Room, but outside the Main Control Board, occurs near CB-3 such that only CB-3 is affected either because of the location of the fire or fire fighting efforts.
	3. Transient fire due welding and cutting	MCR-04.3. A transient fire due to welding and cutting inside Main Control Room, but outside the Main Control Board, occurs near CB-3 such that only CB-3 is affected either because of the location of the fire or fire fighting efforts.
	4. Cable fire due welding and cutting.	MCR-04.4. A cable fire occurs due to welding and cutting inside Main Control Board occurs in CB-3 such that only CB-3 is affected because fire fighting efforts limit the reach of the fire.
MCR-05	1. Main Control Board – Fire starting either in CB-3 or in CB-5	MCR-05.1. A fire inside Main Control Board due to internal causes. The fire initiates inside CB-3 or CB-5. Operator response in putting the fire is not fast enough to prevent damage to the postulated target set. But the fire is controlled before it propagates to other parts of the panel.
	2. Transient fire	MCR-05.2. A transient fire inside Main Control Room, but outside the Main Control Board, occurs near CB-3 and CB-5 such that only the postulated target set is affected either because of the location of the fire or fire fighting efforts.
	3. Transient fire due welding and cutting	MCR-05.3. A transient fire due to welding and cutting inside Main Control Room, but outside the Main Control Board, occurs near CB-3 and CB-5 such that only the postulated target set is affected either because of the location of the fire or fire fighting efforts.
	4. Cable fire due welding and cutting.	MCR-05.4. A cable fire occurs due to welding and cutting inside Main Control Board occurs in CB-3 or CB-5 such that only the postulated target set is affected because fire fighting efforts limit the reach of the fire.

Workshop Problem Set 11b-07 (Solution)

Step 8b: Conduct Fire Growth and Propagation Analyiss

Step 9b: Detection and Suppression Analysis and Severity Factor: Using the information provided in the solution to Problem Sets 11b-05 and 06 and Figure L-1, conduct fire propagation, detection and suppression analysis for the following fire scenarios and calculate scenario frequency:

<u>MCR-03.1</u>

The farthest distance between the postulated control devices on the board is 4 ft.

d = 4 ft = 1.2 m

Assumed non-qualified cables since a portion of the cables are non-qualified. From Figure L-1 it is concluded:

$[SFxP_{NS}]_{MCR-03.1}$ = 3.0E-03

$\lambda_{MCR-03.1}$ = 2.5E-03 x 3.0E-03 = 7.5E-06 per reactor year

<u>MCR-04.1</u>

The farthest distance between the postulated control devices on the board is 2 ft.

d = 2 ft = 0.6 m

Assumed non-qualified cables since a portion of the cables are not qualified. From Figure L-1 it is concluded:

$[SFxP_{NS}]_{MCR-04.1}$ = 5.0E-03

$\lambda_{MCR-04.1}$ = 2.5E-03 x 5.0E-03 = 1.25E-05 per reactor year

NRC FORM 335 (9-2004) NRCMD 3.7 — U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)
NUREG/CP-0194 Volume 3

2. TITLE AND SUBTITLE
Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES) - 2008, NRC-RES/EPRI Fire PRA Workshop, Volume 3 - Module 3: Fire Analysis

3. DATE REPORT PUBLISHED

MONTH	YEAR
July	2010

4. FIN OR GRANT NUMBER

5. AUTHOR(S)
Compiled and edited by D. Stroup, F. Gonzalez, and H. Woods (NRC)

6. TYPE OF REPORT
Conference Proceedings

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*
U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research (RES), Washington, DC 20555-0001
Electric Power Research Institute (EPRI), 3420 Hillview Avenue, Palo Alto, CA 94303

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*
U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research (RES), Washington, DC 20555-0001
Electric Power Research Institute (EPRI), 3420 Hillview Avenue, Palo Alto, CA 94303

10. SUPPLEMENTARY NOTES
NRC-RES/EPRI Fire PRA Workshops conducted Sept. 28 - Oct. 2, 2008 and Nov. 17-20, 2008 in Bethesda, MD

11. ABSTRACT *(200 words or less)*
The U.S. Nuclear Regulatory Commission (NRC) approved the risk-informed and performance-based alternative regulation 10 CFR 50.48(c) in July 2004, which allows licensees the option of using fire protection requirements contained in the National Fire Protection Association (NFPA) Standard 805, "Performance Based Standard for Fire protection for Light-Water Reactor Electric Generating Plants, 2001 Edition," with certain exceptions. To support licensees' use of that option, the NRC and the Electric Power Research Institute (EPRI) jointly issued NUREG/CR-6850 (EPRI 1011989) "Fire PRA Methodology for Nuclear Power Facilities," in September 2005. That report documents the state-of-the-art methods, tools, and data for conducting a fire Probabilistic Risk Assessment (PRA) in a commercial nuclear power plant (NPP) application. Since the release of NUREG/CR-6850 in 2005, the NRC-RES and EPRI have conducted a number of joint public workshops to provide training in the use of the methodologies and tools contained in the document. The workshops have attracted both domestic and international. The material in this NUREG/CP was recorded during two workshops conducted in 2008. It was adapted by NRC-RES Fire Research Branch (FRB) members for use as an alternative training method for those who were unable to physically attend the training sessions. This report can also serve as a refresher for those who attended one or more training sessions, and would be useful preparatory material for those planning to attend a session.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*
fire, performance-based, risk-Informed regulation, fire hazard analysis (FHA), fire safety, fire protection, nuclear power plant, probabilistic risk assessment (PRA), fire modeling, circuit analysis

13. AVAILABILITY STATEMENT
unlimited

14. SECURITY CLASSIFICATION
(This Page) unclassified
(This Report) unclassified

15. NUMBER OF PAGES

16. PRICE

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EPRI 1020621

United States Nuclear Regulatory Commission
Washington, D.C.

NUREG/CP-0194

ELECTRIC POWER RESEARCH INSTITUTE

3420 Hillview Avenue, Palo Alto, California 94304-1395 • PO Box 10412, Palo Alto, California 94303-0813 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com