NUREG/CP-0303 **EPRI 3002005205**
Volume 3 of 5

Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES)-2012

Volume 3
Module 3: Fire Analysis

Based on the Joint
NRC-RES/EPRI Training Workshops
Conducted in 2012

Weeks of July 16 and September 24, 2012

Bethesda, MD

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

Electric Power Research Institute
3420 Hillview Avenue
Palo Alto, CA 94304

AVAILABILITY OF REFERENCE MATERIALS IN NRC PUBLICATIONS

NRC Reference Material

As of November 1999, you may electronically access NUREG-series publications and other NRC records at NRC's Library at www.nrc.gov/reading-rm.html. Publicly released records include, to name a few, NUREG-series publications; *Federal Register* notices; applicant, licensee, and vendor documents and correspondence; NRC correspondence and internal memoranda; bulletins and information notices; inspection and investigative reports; licensee event reports; and Commission papers and their attachments.

NRC publications in the NUREG series, NRC regulations, and Title 10, "Energy," in the *Code of Federal Regulations* may also be purchased from one of these two sources.

1. **The Superintendent of Documents**
   U.S. Government Publishing Office
   Mail Stop IDCC
   Washington, DC 20402-0001
   Internet: bookstore.gpo.gov
   Telephone: (202) 512-1800
   Fax: (202) 512-2104

2. **The National Technical Information Service**
   5301 Shawnee Rd., Alexandria, VA 22312-0002
   www.ntis.gov
   1-800-553-6847 or, locally, (703) 605-6000

A single copy of each NRC draft report for comment is available free, to the extent of supply, upon written request as follows:

Address: **U.S. Nuclear Regulatory Commission**
Office of Administration
Publications Branch
Washington, DC 20555-0001
E-mail: distribution.resource@nrc.gov
Facsimile: (301) 415-2289

Some publications in the NUREG series that are posted at NRC's Web site address www.nrc.gov/reading-rm/doc-collections/nuregs are updated periodically and may differ from the last printed version. Although references to material found on a Web site bear the date the material was accessed, the material available on the date cited may subsequently be removed from the site.

Non-NRC Reference Material

Documents available from public and special technical libraries include all open literature items, such as books, journal articles, transactions, *Federal Register* notices, Federal and State legislation, and congressional reports. Such documents as theses, dissertations, foreign reports and translations, and non-NRC conference proceedings may be purchased from their sponsoring organization.

Copies of industry codes and standards used in a substantive manner in the NRC regulatory process are maintained at—

The NRC Technical Library
Two White Flint North
11545 Rockville Pike
Rockville, MD 20852-2738

These standards are available in the library for reference use by the public. Codes and standards are usually copyrighted and may be purchased from the originating organization or, if they are American National Standards, from—

American National Standards Institute
11 West 42nd Street
New York, NY 10036-8002
www.ansi.org
(212) 642-4900

The NUREG series comprises (1) technical and administrative reports and books prepared by the staff (NUREG–XXXX) or agency contractors (NUREG/CR–XXXX), (2) proceedings of conferences (NUREG/CP–XXXX), (3) reports resulting from international agreements (NUREG/IA–XXXX), (4) brochures (NUREG/BR–XXXX), and (5) compilations of legal decisions and orders of the Commission and Atomic and Safety Licensing Boards and of Directors' decisions under Section 2.206 of NRC's regulations (NUREG–0750).

<u>M</u>ethods for <u>A</u>pplying <u>Ri</u>sk <u>A</u>nalysis to <u>Fire</u> <u>S</u>cenarios (MARIAFIRES)-2012

NRC-RES/EPRI Fire PRA Workshop
Volume 3: Module 3: Fire Analysis

NUREG/CP-0303
Volume 3 of 5

EPRI 3002005205

Manuscript Completed: July 2015
Date Published: April 2016

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 94304

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

EPRI Project Manager
A. Lindeman

ORGANIZATION THAT PREPARED THIS DOCUMENT:

U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research

NOTE

For further information about EPRI, call the EPRI Customer Assistance Center at
800.313.3774 or
e-mail askepri@epri.com.

COURSE TRAINING INSTRUCTORS AND PROJECT MANAGERS

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

Susan Cooper – Module 4 HRA

Gabriel Taylor – Module 2 Electrical Analysis

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

Steven Nowlen – Module 3 Fire Analysis

Jeff LaChance – Module 1 PRA

National Institute of Standards and Technology (NIST)
100 Bureau Dr.
Gaithersburg, MD 20899

Kevin McGrattan – Module 5 Adv. Fire Modeling

Electric Power Research Institute (EPRI)
3420 Hillview Avenue
Palo Alto, CA 94304

Stuart Lewis – Module 4 HRA

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

Bijan Najafi

Francisco Joglar-Biloch – Module 3 Fire Analysis

Dan Funk (EDAN Engineering) – Module 2 Electrical

Richard Anoba (Anoba Consulting Services) –Module 1 PRA

Erin Collins –Module 4 HRA

Fred Mowrer (California Polytechnic State University) – Module 5 Adv. Fire Modeling

Kendra Wright /Nicholas Melly
U.S. NRC-RES Project Managers

Ashley Lindeman
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:

F. Gonzalez
K. Hamburger
T. Rivera
P. Smith
D. Stroup
K. Wright

This report describes research sponsored jointly by the U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research 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)-2012, NRC-RES/EPRI Fire PRA Workshop, Volume 1: Overall Course and Module 1: PRA, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC 20555-0001, and Electric Power Research Institute, Palo Alto, CA, NUREG/CP-0303 and EPRI 3002005205.

ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research (RES) and the Electric Power Research Institute (EPRI) working under a memorandum of understanding (MOU) jointly conducted two sessions of the NRC– RES/EPRI Fire Probabilistic Risk Assessment (PRA) Workshop on July 16–20, 2012, and September 24–28, 2012, at the Bethesda Marriott in Bethesda, MD. The purpose of the workshop was to provide detailed, hands-on training on the fire PRA methodology described in the technical document, NUREG/CR-6850 (EPRI 1011989) entitled "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities." This fire PRA methodology document supports implementation of the risk-informed, performance-based rule in Title 10 of the *Code of Federal Regulations* (10 CFR) 50.48(c) endorsing National Fire Protection Association (NFPA) Standard 805, as well as other applications such as exemptions or deviations to the agency's current regulations and fire protection significance determination process (SDP) phase 3 applications.

RES and EPRI provided training in five subject areas related to fire PRA, namely: fire PRA, electrical analysis, fire analysis, fire human reliability analysis (HRA), and advanced fire modeling. Participants selected one of these subject areas and spent the duration of the course in that module. The HRA module reviewed guidance provided in NUREG-1921 (EPRI 1023001), "EPRI/NRC-RES Fire Human Reliability Analysis Guidelines," while the fire modeling module reviewed the fire modeling guidance provided in NUREG-1934 (EPRI 1019195), "Nuclear Power Plant Fire Modeling Application Guide." For each technical area, the workshop also included a 1-day module introducing the fundamentals of the subject. The purpose of the fundamentals modules was to assist students without an extensive background in the technical area in understanding the in-depth training modules that followed. Attendance in the fundamentals modules was optional. The workshop's format allowed for in-depth presentations and practical examples directed toward the participant's area of interest.

This NUREG/CP documents both of the two sessions of the NRC-RES/EPRI Fire PRA Workshop delivered in 2012 and includes the slides and handout materials delivered in each module of the course as well as video recordings of the training that was delivered. This NUREG/CP can be used 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 could also be useful preparatory material for those planning to attend future sessions.

<u>NRC Disclaimer:</u>

This document's text and video content are intended solely for use as training tools. No portions of their content are intended to represent NRC's conclusions or regulatory positions, and they should not be interpreted as such.

CONTENTS

FIGURES

ACKNOWLEDGMENTS

The authors of this report greatly appreciate the contributions made by instructors and students at the 2012 NRC-RES/EPRI Fire PRA Workshop.

In addition, we want to extend our gratitude to Tojuana Fortune-Grasty (NRC's publications specialist) and the NRC's printing specialist's team whose invaluable support and expertise were critical to ensuring the published report's quality. We also extend a special thanks and appreciation to Anita Aikins-Afful (RES/DRA administrative assistant) for providing the technical edit of this report.

ACRONYMS

ACB	Air-cooled Circuit Breaker
ACRS	Advisory Committee on Reactor Safeguards
AEP	Abnormal Event Procedure
AFW	Auxiliary Feedwater
AGS	Assistant General Supervisor
AOP	Abnormal Operating Procedure
AOV	Air Operated Valve
ASEP	Accident Sequence Evaluation Program
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	Cause-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
ECCS	Emergency Core Cooling System
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
ET	Event Tree
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
HCR	Human Cognitive Reliability
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
LP/SD	Low Power and Shutdown
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
ORE	Operator Reliability Experiments
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
SPAR-H	Standardized Plant Analysis Risk HRA
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
T-H	Thermal Hydraulic
THERP	Technique for Human Error Rate Prediction
TGB	Turbine-Generator Building
TSP	Transfer Switch Panel

1
INTRODUCTION AND BACKGROUND

The U.S. Nuclear Regulatory Commission (NRC) approved the risk-informed and performance- based alternative regulation in Title 10 of the *Code of Federal Regulations* (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’s Office of Nuclear Regulatory Research (RES) 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 state-of-the art methods, tools, and data for conducting a fire probabilistic risk assessment (PRA) in a commercial nuclear power plant (NPP) application. This report is intended to serve the needs of a fire risk analysis team by providing a general framework for conducting 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 (IPEEE), 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 the NRC’s participation in the study neither constitutes nor implies regulatory approval of applications based on the analysis contained in that document. The analyses and methods documented in that 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. However, the results from that 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.

However, it is not sufficient to merely develop a potentially useful method, such as NUREG/CR- 6850, and announce its availability. It is also necessary to teach potential users how to properly use the method. To meet this need RES and EPRI have collaboratively conducted the NRC-RES/EPRI Fire PRA Workshops to train interested parties in the application of this methodology since 2005. The course is provided in five parallel modules covering tasks from NUREG/CR-6850.

These five training modules are:

- Module 1: PRA/Systems Analysis – This module covers the technical tasks for development of the system response to a fire including human failure events.

- Specifically, this module covers Tasks/Sections 2, 4, 5, 7, 14, and 15 of Reference [1].

- Module 2: Electrical Analysis – This module covers the technical tasks for analysis of electrical failures as the result of a fire. Specifically, this module covers Tasks/Sections 3, 9, and 10 of Reference [1].

- Module 3: Fire Analysis – This module covers technical tasks involved in development of fire scenarios from initiation to target (e.g., cable) impact. Specifically, this module covers Tasks/Sections 1, 6, 8, 11, and 13 of Reference [1].

- Module 4: Fire Human Reliability Analysis – This module covers the technical tasks associated with identifying and analyzing operator actions and performance during a postulated fire scenario. Specifically, this module covers Task 12 as outlined in Reference [1] based on the application of the approaches documented in Reference [2].

- Module 5: Advanced Fire Modeling – This module was added to the training in 2011. It covers the fundamentals of fire science and provides practical implementation guidance for the application of fire modeling in support of a fire PRA. Module 5 covers fire modeling applications for Tasks 8 and 11 as outlined in Reference [1] based on the material presented in Reference [3].

The first three modules are based directly on the "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities," EPRI 1011989, and NUREG/CR-6850 [1]. However, that document did not cover fire human reliability analysis (HRA) methods in detail. In 2010, the training materials were enhanced to include a fourth module based on a more recent EPRI/RES collaboration and the then draft guidance document, EPRI 1019196, NUREG-1921 [2] published in late 2009. The training materials are based on this draft document including the consideration of public comments received on the draft report and the team's responses to those comments. In 2011 a fifth training module on Advanced Fire Modeling techniques and concepts was added to the course. This module is based on another joint RES/EPRI collaboration and a draft guidance published in January 2010, NUREG-1934 EPRI 1019195 [3].

In 2012 an additional first day of training was included in the NRC-RES/EPRI Fire PRA Workshop to cover principal elements of each technical area covered in the Fire PRA course, i.e., PRA, HRA, Electrical Analysis, and Fire Analysis. This introductory module was intended to assist in preparing the students to understand the in-depth fire PRA training modules that followed. The introductory modules were not intended to be a substitute for education and/or training in the subject matter. The intent was that they would serve as a primer for those individuals who lacked such training or those who were cross-training in an area other than their primary area of expertise.

The four introductory modules listed below (referred to as Module 0) were offered in parallel on the first day of the workshop.

Module 0a: Principles of PRA
Module 0b: Principles of Electrical Analysis

Module 0c: Principles of Fire Science and Modeling
Module 0d: Principles of HRA

These sub-modules are included in the text and on the accompanying DVDs as a part of their related module.

1.1 About this text

"Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES) – 2012", is a collection of the materials that were presented at the two sessions of the NRC-RES/EPRI Fire PRA conducted July 16–20, 2012, and September 24-28, 2012.

The 2012 workshop was video recorded and adapted as an alternative training method for those who were unable to physically attend the training sessions. This NUREG/CP is comprised of the materials supporting those videos and includes the five volumes below (the videos are enclosed on DVD in the published paper copies of this NUREG/CP). This material can also serve as a refresher for those who attended one or more of the training sessions, and would be useful preparatory material for those planning to attend a session.

MARIAFIRES is comprised of 5 volumes.

Volume 1 – Module 0a Principles of PRA and Module 1: PRA/Systems Analysis
Volume 2 – Module 0b Principles of Electrical Analysis and Module 2: Electrical Analysis
Volume 3 – Module 0c Principles of Fire Science and Modeling and Module 3: Fire Analysis
Volume 4 – Module 0d Principles of HRA and Module 4: Fire Human Reliability Analysis
Volume 5 – Module 5: Advanced Fire Modeling

Integral to Modules 1, 2 and 3 is a set of hands-on problems based on a conceptual generic nuclear power plant (NPP) developed for training purposes. This generic plant is referred to in this text and in classroom examples as SNPP (Simplified Nuclear Power Plant). The same generic NPP is used in all three modules. Chapter 2 of this document provides the background information for the problem sets of each module, including a general description of the sample power plant and the internal events PRA needed as input to the fire PRA. The generic NPP defined for this training is an extremely simplified one that in many cases does not meet any regulatory requirements or good engineering practices. For training purposes, the design features presented highlight the various aspects of the fire PRA methodology.

For Module 4 and 5, independent sets of examples are used to illustrate key points of the analysis procedures. The examples for these two modules are not tied to the simplified plant. Module 4 uses examples that were derived largely from pilot applications of the proposed fire HRA methods and on independent work of the EPRI and RES HRA teams. The examples for Module 5 were taken directly from Reference [3] and represent a range of typical NPP fire scenarios across a range of complexity and that highlight some of the computation challenges associated with the NPP fire PRA fire modeling applications.

A short description of the Fire PRA technical tasks is provided below. For further details, refer to the individual task descriptions in EPRI 1011989, NUREG/CR-6850, Volume 2. The figure presented at the end of this chapter provides a simplified flow chart for the analysis process and indicates which training module covers each of the analysis tasks.

Plant Boundary Definition and Partitioning (Task 1). The first step in applying the fire PRA methodology is to define the physical boundary of the analysis and to divide the area within that boundary into analysis compartments.

Fire PRA Component Selection (Task 2). The selection of components that are to be credited for plant shutdown following a fire is a critical step in any fire PRA. Components selected would generally include many, but not necessarily all, components credited in the 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," Appendix R, "Fire Protection Program for Nuclear Power Facilities Operating prior to January 1, 1979," post-fire safe shutdown (SSD) analysis. Additional components will likely be selected, potentially including most, but not all, components credited in the plant's internal events PRA. Also, the proposed methodology would likely introduce components beyond either the 10 CFR 50 Appendix R list or the internal events PRA model. Such components are often of interest because of concern for multiple spurious actuations that may threaten the credited functions and components, as well as from concerns about fire effects on instrumentation used by the plant crew to respond to the event.

Fire PRA Cable Selection (Task 3). This task provides instructions and technical considerations associated with identifying cables supporting those components selected in Task 2 above. In previous fire PRA methods (such as EPRI Fire-Induced Vulnerability Evaluation (FIVE) and Fire PRA Implementation Guide), this task was relegated to the SSD analysis and its associated databases. NUREG/CR-6850 (EPRI 1011989) offers a more structured set of rules for selection of cables.

Qualitative Screening (Task 4). This task identifies fire analysis compartments that can be shown, without quantitative analysis, to have little or no risk significance. Fire compartments may be screened out if they contain no components or cables identified in Tasks 2 and 3 and if they cannot lead to a plant trip because of either plant procedures, an automatic trip signal, or technical specification requirements.

Plant Fire-Induced Risk Model (Task 5). This task discusses steps for the development of a logic model that reflects plant response following a fire. Specific instructions have been provided for treatment of fire-specific procedures or plans. These procedures may impact availability of functions and components or include fire-specific operator actions (e.g., self- induced station blackout).

Fire Ignition Frequency (Task 6). This task describes the approach to develop frequency estimates for fire compartments and scenarios. Significant changes from the EPRI FIVE method have been made in this task. The changes generally relate to the use of challenging events, considerations associated with data quality, and increased use of a fully component-based ignition frequency model (as opposed to the location/component-based model used, for example, in FIVE).

Quantitative Screening (Task 7). A fire PRA allows the screening of fire compartments and scenarios based on their contribution to fire risk. This approach considers the cumulative risk associated with the screened compartments (i.e., the ones not retained for detailed analysis) to ensure that a true estimate of fire risk profile (as opposed to vulnerability) is obtained.

Scoping Fire Modeling (Task 8). This step provides simple rules to define and screen fire ignition sources (and therefore fire scenarios) in an unscreened fire compartment.

Detailed Circuit Failure Analysis (Task 9). This task provides an approach and technical considerations for identifying how the failure of specific cables will impact the components included in the fire PRA SSD plant response model.

Circuit Failure Mode Likelihood Analysis (Task 10). This task considers the relative likelihood of various circuit failure modes. This added level of resolution may be a desired option for those fire scenarios that are significant contributors to the risk. The methodology provided in NUREG/CR-6850 (EPRI 1011989) benefits from the knowledge gained from the tests performed in response to the circuit failure issue.

Detailed Fire Modeling (Task 11). This task describes the method to examine the consequences of a fire. This includes consideration of scenarios involving single compartments, multiple fire compartments, and the main control room. Factors considered include initial fire characteristics; fire growth in a fire compartment or across fire compartments; detection and suppression; electrical raceway fire barrier systems, and damage from heat and smoke. Special consideration is given to turbine generator (T/G) fires, hydrogen fires, high-energy arcing faults (HEAF), cable fires, and main control board (MCB) fires. Considerable improvements can be found in the method for this task over the EPRI FIVE and Fire PRA Implementation Guide in nearly all technical areas.

Post-Fire Human Reliability Analysis (Task 12). This task considers operator actions for manipulation of plant components. The analysis task procedure provides structured instructions for identification and inclusion of these actions in the fire PRA. The procedure also provides instructions for estimating screening human error probabilities (HEPs) before detailed fire modeling results (e.g., fire growth and damage behaviors) have necessarily been developed or detailed circuit analyses (e.g., can the circuit spuriously actuate as opposed to simply assuming it can actuate) have been completed. In a fire PRA, the estimation of HEP values with high confidence is critical to the effectiveness of screening. This report does not develop a detailed fire HRA methodology. A number of HRA methods can be adopted for fire with appropriate additional instructions that superimpose fire effects on any of the existing HRA methods such as the Technique for Human Error Rate Prediction (THERP), Causal Based Decision Tree (CBDT), A Technique for Human Event Analysis (ATHEANA), etc. This would improve consistency across analyses (i.e., fire and internal events PRA).

Seismic Fire Interactions (Task 13). This task is a qualitative approach to help identify the risk from any potential interactions between an earthquake and a fire.

Fire Risk Quantification (Task 14). The task summarizes what is to be done for quantification of the fire risk results.

Uncertainty and Sensitivity Analyses (Task 15). This task describes the approach to follow for identifying and treating uncertainties throughout the fire PRA process. The treatment may vary from quantitative estimation and propagation of uncertainties where possible (e.g., in fire frequency and non-suppression probability) to identification of sources without quantitative estimation. The treatment may also include one-at-a-time variation of individual parameter values or modeling approaches to determine the effect on the overall fire risk (i.e., sensitivity analysis).

Fire PRA Documentation (Task 16). This task describes the approach to follow for documenting the Fire PRA process and its results. Figure 1 shows the relationship between the above 16 technical tasks from EPRI 1011989, NUREG/CR-6850, Volume 2.

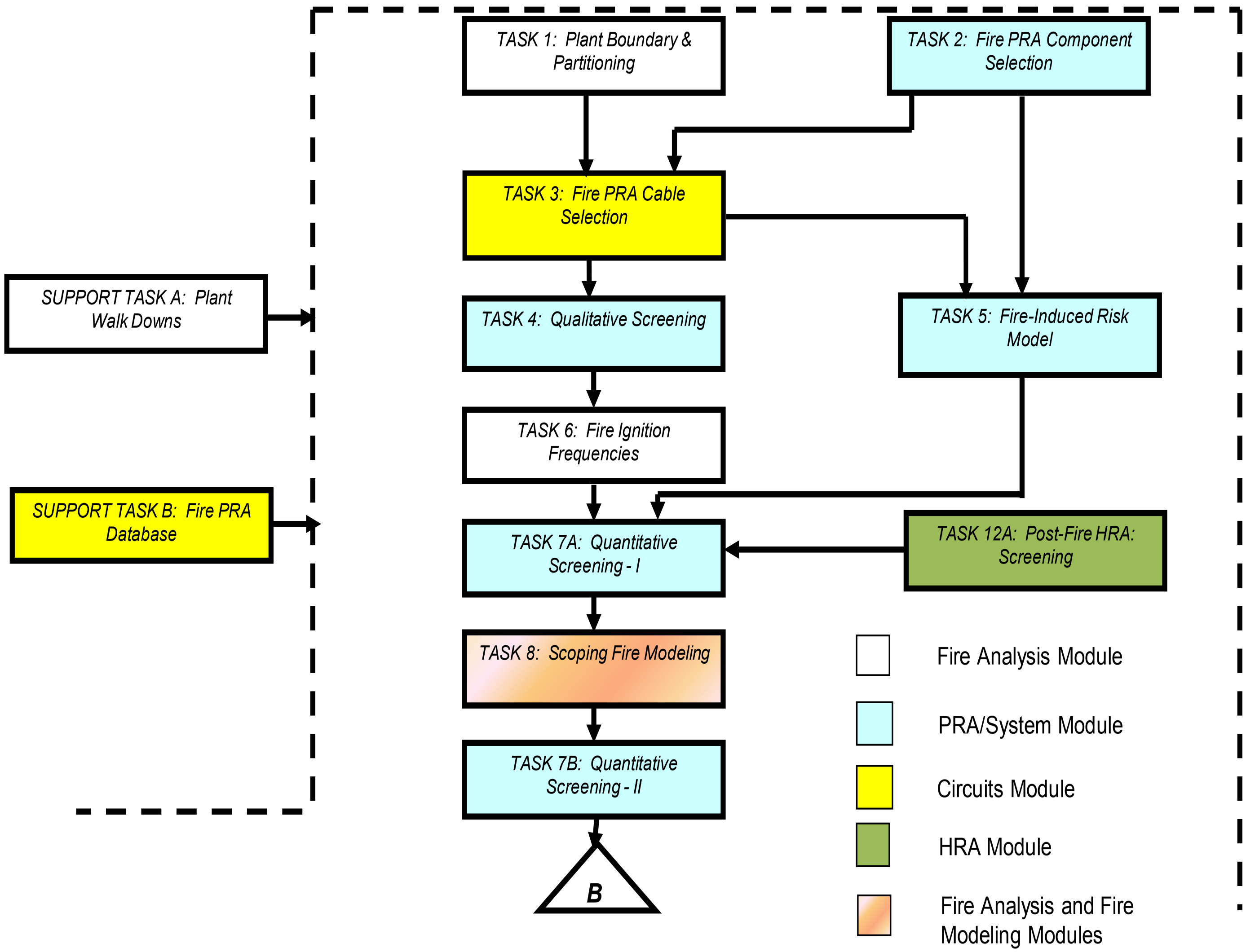


Figure 1-1 Relationship of Technical Tasks in NUREG/CR 6850 Volume 2

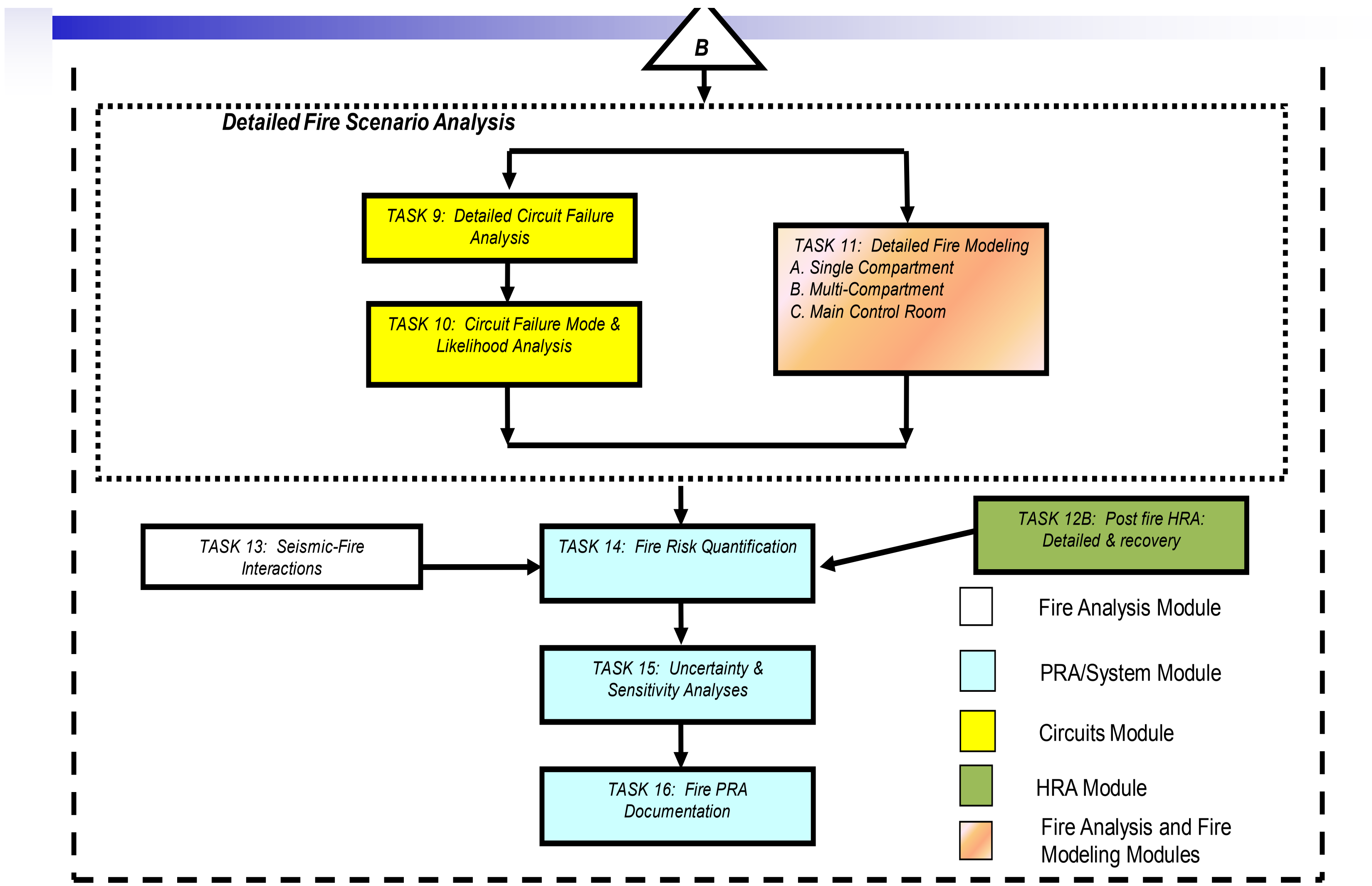


Figure 1-2 Note: "B" is from Task 7B (Previous Page)

1.2 **References**

1. NUREG/CR-6850, EPRI 1011989, *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities*, September 2005.

2. NUREG-1921, EPRI 1023001, *EPRI/NRC-RES Fire Human Reliability Analysis Guidelines*, May 2012.

3. NUREG-1934, EPRI 1023259, *Nuclear Power Plant Fire Modeling Application Guide,* November 2012[1].

[1] At the time of the 2012 NRC-RES/EPRI Fire PRA Workshop, this final report had not yet been published. A draft for public comment was used to conduct the training.

2

EXAMPLE CASE PLANT-GENERAL INFORMATION

2.1 Overall Plant Description

This chapter provides background information about the generic plant used in the hands-on problem sets of Modules 1, 2 and 3. Note that the examples used in Module 4 (HRA) are not based on the example case plant. The following notes generally describe the example case plant, including its layout:

1. The plant is a pressurized water reactor (PWR) consisting of one primary coolant loop, which consists of one steam generator, one reactor coolant pump and the pressurizer. A chemical volume control system and multiple train High Pressure Injection system, as well as a single train residual heat removal system interface with the primary system

2. The secondary side of the plant contains a main steam and feedwater loop associated with the single steam generator, and a multiple train auxiliary feedwater system to provide decay heat removal.

3. The operating conditions and parameters of this plant are similar to that of a typical PWR. For example, the primary side runs at about 2,200 psi pressure. The steam generator can reject the decay heat after a reactor trip. There is a possibility for feed and bleed.

4. It is assumed that the reactor is initially at 100% power.

5. The plant is laid out in accordance with Figures 1 through 9. The plant consists of a containment building, auxiliary building, turbine building, diesel generator building and the yard. All other buildings and plant areas are shown but no details are provided.

2.2 Systems Description

This section provides a more detailed description of the various systems within the plant and addressed in the case studies. Each system is described separately.

2.2.1 Primary Coolant System

The following notes and Figure 10 define the primary coolant system:

1. The primary coolant loop consists of the reactor vessel, one reactor coolant pump, and one steam generator and the pressurizer, along with associated piping.

2. The pressurizer is equipped with a normally closed power operated relief valve (PORV), which is an air operated valve (AOV-1) with its pilot solenoid operated valve (SOV-1). There is also a normally open motor operated block valve (MOV-13) upstream of the PORV.

3. The pressure transmitter (PT-1) on the pressurizer provides the pressure indication for the primary coolant system and is used to signal a switch from chemical volume control system (CVCS) to high pressure injection (HPI) configuration. That is, PT-1 provides the automatic signal for high pressure injection on low RCS pressure. It also provides the automatic signal to open the PORV on high RCS pressure.

4. A nitrogen bottle provides the necessary pressurized gas to operate the PORV in case of loss of plant air but does not have sufficient capacity to support long-term operation.

2.2.2 Chemical Volume Control and High Pressure Injection Systems

The following notes and Figure 10 define the shared CVCS and HPI System:

1. The CVCS normally operates during power generation.

2. Valve type and position information include:

Table 2-1 Chemical volume control and high pressure injection systems valve type and position information

Valve	Type	Status on Loss of Power (Or Air as applicable)	Position During Normal Operation	Motor Power (hp)
AOV-2	Air Operated Valve	Fail Closed	Open	N/A
AOV-3	Air Operated Valve	Fail Open	Open	N/A
MOV-1	Motor Operated Valve	Fail As Is	Closed	>5
MOV-2	Motor Operated Valve	Fail As Is	Open	<5
MOV-3	Motor Operated Valve	Fail As Is	Closed	<5
MOV-4	Motor Operated Valve	Fail As Is	Closed	<5
MOV-5	Motor Operated Valve	Fail As Is	Closed	<5
MOV-6	Motor Operated Valve	Fail As Is	Closed	>5
MOV-9	Motor Operated Valve	Fail As Is	Closed	>5

3. One of the two HPI pumps runs when the CVCS is operating.

4. One of the two HPI pumps is sufficient to provide all injection needs after a reactor trip and all postulated accident conditions.

5. HPI and CVCS use the same set of pumps.

6. On a need for safety injection, the following lineup takes place automatically:

- AOV-3 closes.
- MOV-5 and MOV-6 open.
- MOV-2 closes.
- Both HPI pumps receive start signal, the stand-by pump starts and the operating pump continues operating.
- MOV-1 and MOV-9 open.

7. HPI supports feed and bleed cooling when all secondary heat removal is unavailable. When there is a low level indication on the steam generator, the operator will initiate feed and bleed cooling by starting the HPI pumps and opening the PORV.

8. HPI is used for re-circulating sump water after successful injection in response to a loss-of-coolant accident (LOCA) or successful initiation of feed and bleed cooling. For recirculation, upon proper indication of low refueling water storage tank (RWST) level and sufficient sump level, the operator manually opens MOV-3 and MOV-4, closes MOV-5 and MOV-6, starts the RHR pump, and aligns component cooling water (CCW) to the RHR heat exchanger.

9. RWST provides the necessary cooling water for the HPI pumps during injection. During the recirculation mode, HPI pump cooling is provided by the recirculation water.

10. There are level indications of the RWST and containment sump levels that are used by the operator to know when to switch from high pressure injection to recirculation cooling mode.

11. The air compressor provides the motive power for the air-operated valves but the detailed connections to the various valves are not shown.

2.2.3 Residual Heat Removal System

The following notes and Figure 10 define the residual heat removal (RHR) system:

1. The design pressure of the RHR system downstream of MOV-8 is low.

2. Valve type and position information include the following:

Table 2-2 Residual heat removal system valve type and position information

Valve	Type	Status on Loss of Power	Position During Normal Operation	Motor Power (hp)
MOV-7	Motor Operated Valve	Fail As Is	Closed (breaker racked out)	>5
MOV-8	Motor Operated Valve	Fail As Is	Closed	>5
MOV-20	Motor Operated Valve	Fail As Is	Closed	>5

3. Operators have to align the system for shutdown cooling, after reactor vessel depressurization from the control room by opening MOV-7 and MOV-8, turn the RHR pump on and establish cooling in the RHR heat exchanger.

2.2.4 Auxiliary Feedwater System

The following notes and Figure 11 define the Auxiliary Feedwater (AFW) System:

1. One of three pumps of the AFW system can provide the necessary secondary side cooling for reactor heat removal after a reactor trip.

2. Pump AFW-A is motor-driven, AFW-B is steam turbine-driven, and AFW-C is diesel-driven.

3. Valve type and position information include the following:

Table 2-3 Auxiliary feedwater system valve type and position information

Valve	Type	Status on Loss of Power	Position During Normal Operation	Motor Power (hp)
MOV-10	Motor Operated Valve	Fail As Is	Closed	>5
MOV-11	Motor Operated Valve	Fail As Is	Closed	>5
MOV-14	Motor Operated Valve	Fail As Is	Closed	<5
MOV-15	Motor Operated Valve	Fail As Is	Closed	<5
MOV-16	Motor Operated Valve	Fail As Is	Closed	<5
MOV-17	Motor Operated Valve	Fail As Is	Closed	<5
MOV-18	Motor Operated Valve	Fail As Is	Closed	>5
MOV-19	Motor Operated Valve	Fail As Is	Closed	<5

4. Upon a plant trip, main feedwater isolates and AFW automatically initiates by starting AFW-A and AFW-C pumps, opening the steam valves MOV-14 and MOV-15 to operate the AFW-B steam-driven pump, and opening valves MOV-10, MOV-11, and MOV-18.

5. The condensate storage tank (CST) has sufficient capacity to provide core cooling until cold shutdown is achieved.

6. The test return paths through MOVs-16, 17, and 19 are low-flow lines and do not represent significant diversions of AFW flow even if the valves are open.

7. There is a high motor-temperature alarm on AFW pump A. Upon indication in the control room, the operator is to stop the pump immediately and have the condition subsequently checked by dispatching a local operator.

8. The atmospheric relief valve opens, as needed, automatically to remove decay heat if the main condenser path should be unavailable.

9. The connections to the main turbine and main feedwater are shown in terms of one main steam isolation valve (MSIV) and a check valve. Portions of the plant beyond these interfacing components will not be addressed in the course.

10. Atmospheric dump valve AOV-4 is used to depressurize the steam generator in case of a tube rupture.

2.2.5 Electrical System

Figure 12 is a one-line diagram of the Electrical Distribution System (EDS). Safety-related buses are identified by the use of alphabetic letters (e.g., SWGR-A, MCC-B1, etc.) while the non-safety buses use numbers as part of their designations (e.g., SWGR-1 and MCC-2).

The safety-related portions of the EDS include 4,160-volt (V) switchgear buses SWGR-A and SWGR-B, which are normally powered from the startup transformer SUT-1. In the event that offsite power is lost, these switchgear buses receive power from emergency diesel generators EDG-A and EDG-B. The 480-V safety-related load centers (LC-A and LC-B) receive power from the switchgear buses via station service transformers SST-A and SST-B. The motor control centers (MCC-A1 and MCC-B1) are powered directly from the load centers. The MCCs provide motive power to several safety-related motor-operated valves (MOVs) and to dc buses DC BUS-A and DC BUS-B via battery chargers BC-A and BC-B. The two 125-V dc batteries, BAT-A and BAT-B, supply power to the dc buses in the event that all ac power is lost. DC control power for the 4,160-V, safety-related switchgear is provided through distribution panels PNL-A and PNLB. The 120 V ac vital loads are powered from buses VITAL-A and VITAL-B, which in turn receive their power from the dc buses through inverters INV-A and INV-B.

The non-safety portions of the EDS reflect a similar hierarchy of power flow. There are important differences, however. For example, 4,160-V SWGR-1 and SWGR-2 are normally energized from the unit auxiliary transformer (UAT-1) with backup power available from SUT-1. A cross-tie breaker allows one non-safety switchgear bus to provide power to the other. Non-safety load centers LC-1 and LC-2 are powered at 480 V from the 4,160-V switchgear via SST-1 and SST-2. These load centers provide power directly to the non-safety MCCs. The non-vital dc bus (DC BUS-1) can be powered from either MCC via an automatic transfer switch (ATS-1) and battery charger BC-1 or directly from the 125-V dc battery, BAT-1.

2.2.6 Other Systems

The following systems and equipment are mentioned in the plant description but not explicitly included in the fire PRA:

- Component Cooling Water (CCW) – provides cooling to letdown heat exchanger and the RHR heat exchanger– assumed to be available at all times.

- It is assumed that the control rods can successfully insert and shutdown the reactor under all conditions.

- It is assumed that the emergency core cooling system (ECCS) and other AFW related instrumentation and control circuits (other than those specifically noted in the diagrams) exist and are perfect such that in all cases, they would sense the presence of a LOCA or other need to trip the plant and provide safety injection and auxiliary feedwater by sending the proper signals to the affected components (i.e., close valves and start pumps, insert control rods, etc.).

- Instrument air is required for operation of AOV-1, AOV-2, AOV-3, and AOV-4.

2.3 <u>**Plant Layout**</u>

The following notes augment the information provided in Figures 1 through 9 (Drawings A-01 through A09):

- The main structures of the plant are as follows:
  - containment
  - auxiliary building
  - turbine building
  - diesel generator building
  - intake structure
  - security building

- In Figure 1 (Drawing A-01), the dashed lines represent the fence that separates two major parts: the yard and switchyard.

- Switchyard is located outside the yard with a separate security access.

- CST, RWST, UAT, main transformer and SUT are located in the open in the yard.

- All walls shown in Figures 1 through 8 (Drawings A-01 through A-08) should be assumed to be fire rated.

- All doors shown in Figures 1 through 8 (Drawings A-01 through A-08) should be assumed as fire rated and normally closed.

- Battery rooms A and B are located inside the respective switchgear rooms with 1-hour rated walls, ceilings and doors.

- All cable trays are open type. Vertical cable trays are designated as VCBT and horizontal cable trays as HCBT. For horizontal cable trays, the number following the letters indicates the elevation of the cable tray. For example, HCBT+35A denotes a horizontal cable tray at elevation +35 ft (11 meters).

- The stairwell in the auxiliary building provides access to all the floors of the building. The doors and walls are fire rated and doors are normally closed.

2.4 **SNPP Drawings**

The following 12 pages provide schematic drawings of the generic NPP, SNPP. Drawings A-01 through A-09 are general physical layout drawings providing plan and elevation views of the plant. These drawings also identify the location of important plant equipment. Drawing A-10 provides a piping and instrumentation diagram (P&ID) for the primary coolant system, and drawing A-11 provides a P&ID for the secondary systems. Drawing A-12 is a simplified one-line diagram of the plant power distribution system.

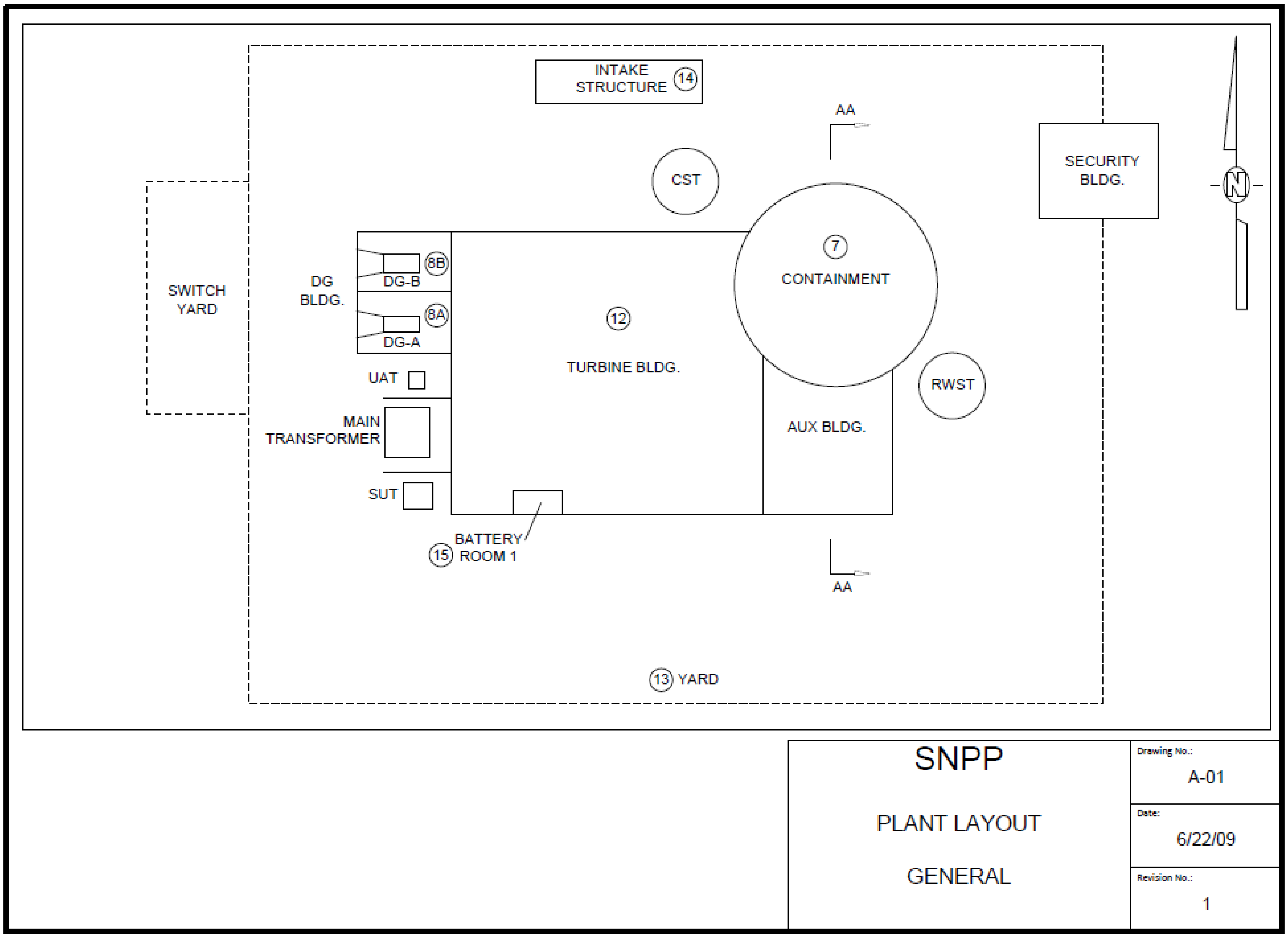


Figure 2-1 General Plant Layout

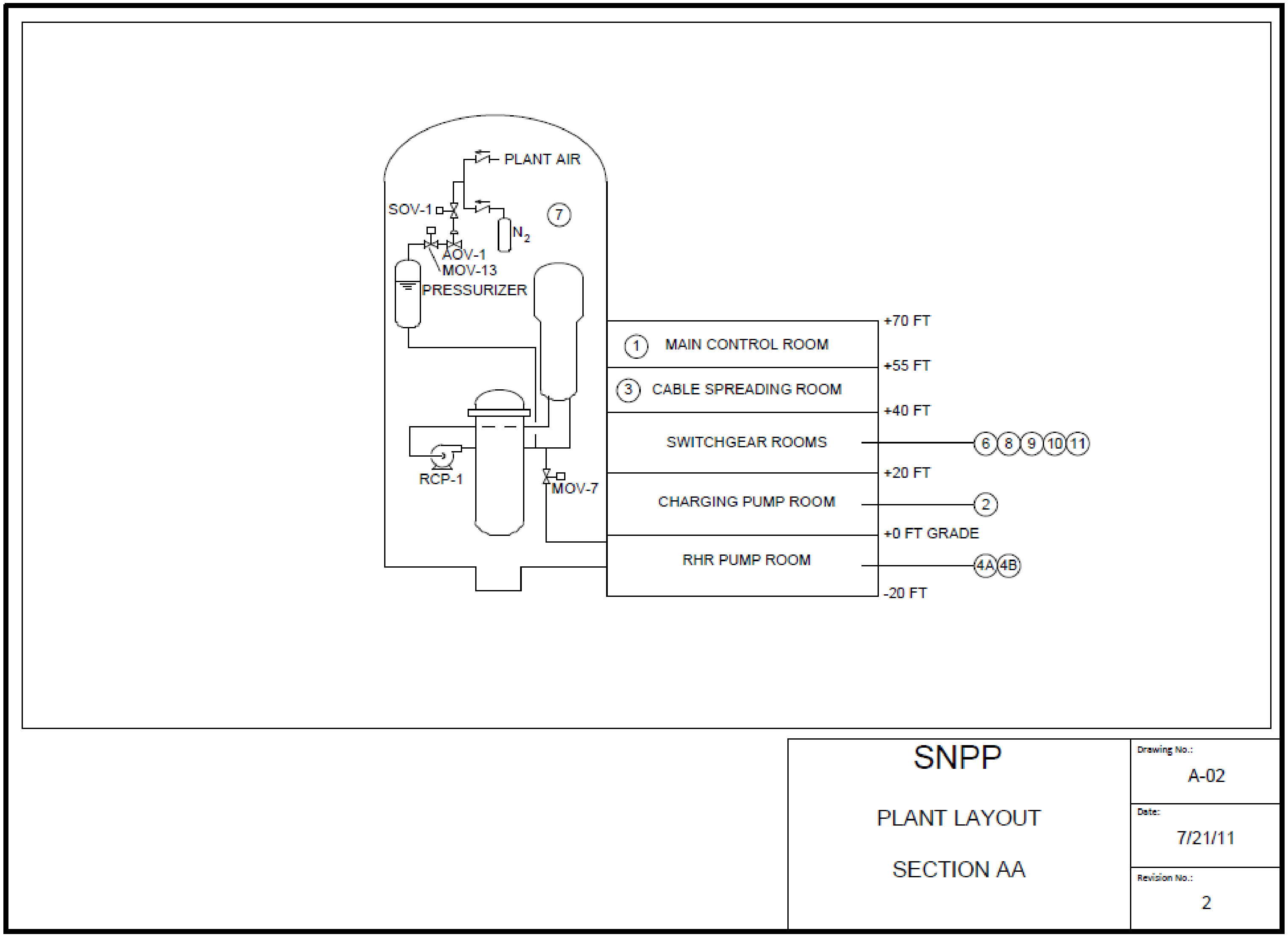


Figure 2-2 Plant Layout Section AA

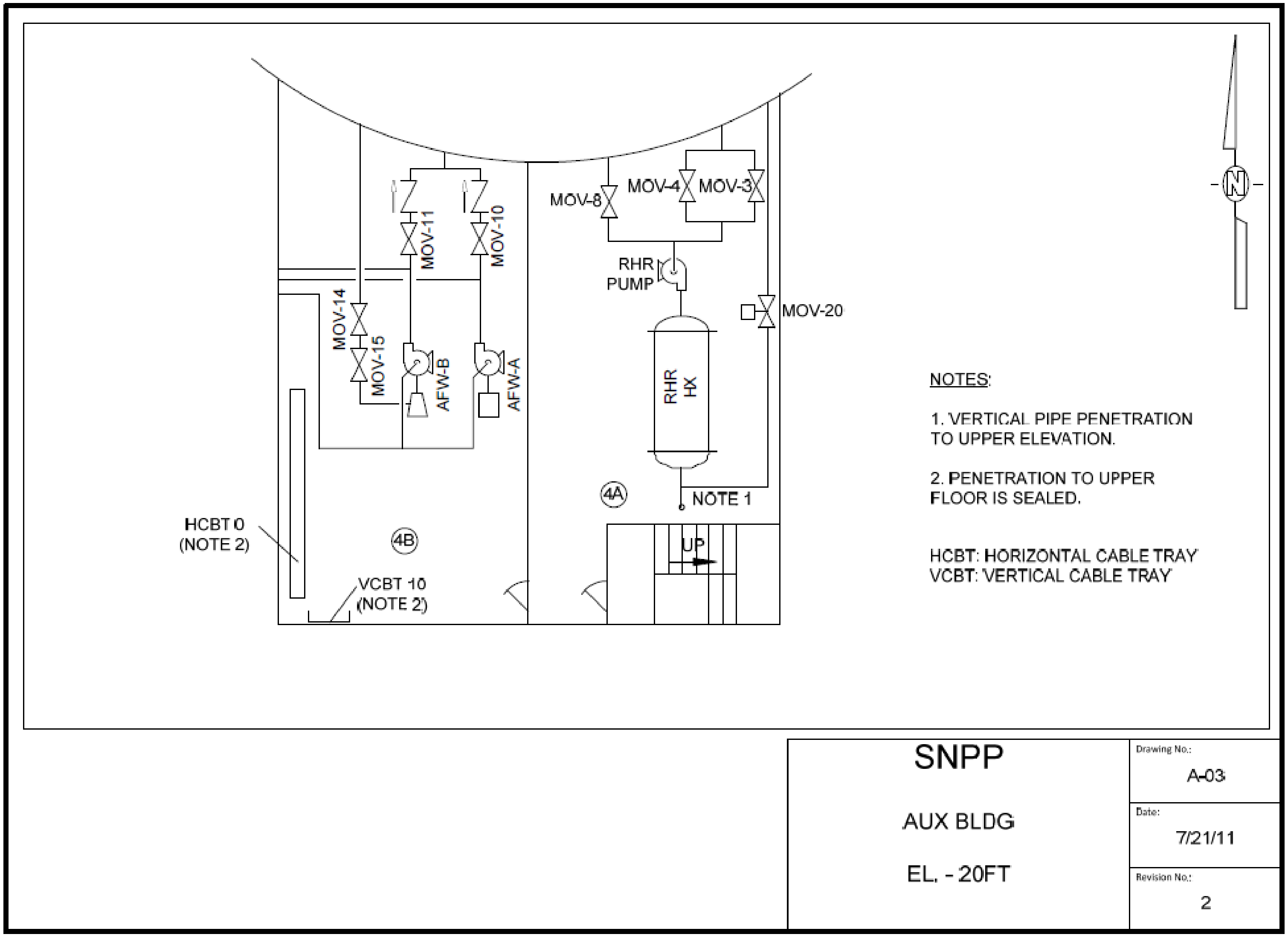


Figure 2-3 Auxiliary Building - Elevation 20 Ft.

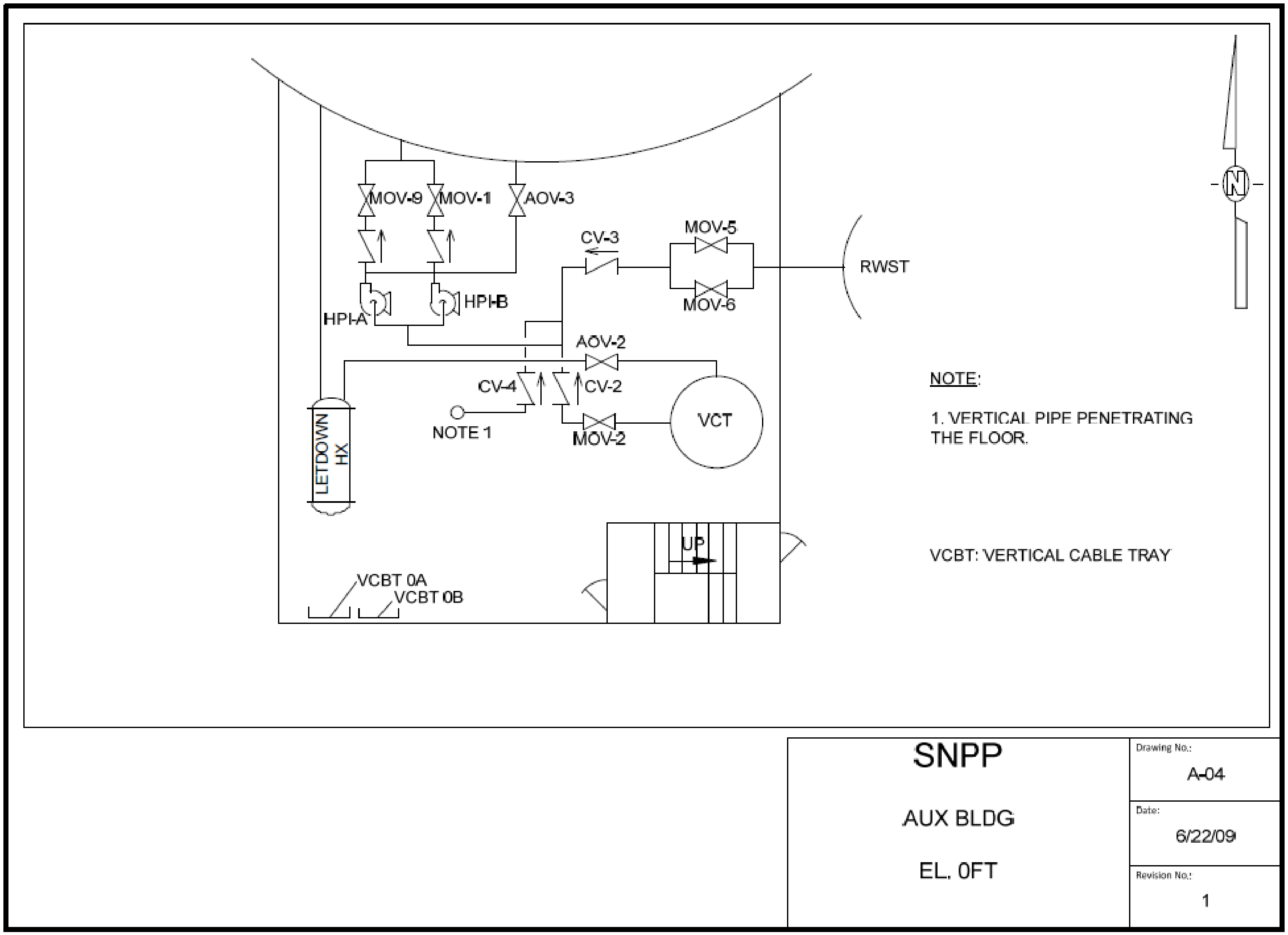


Figure 2-4 Auxiliary Building – Elevation 0 Ft

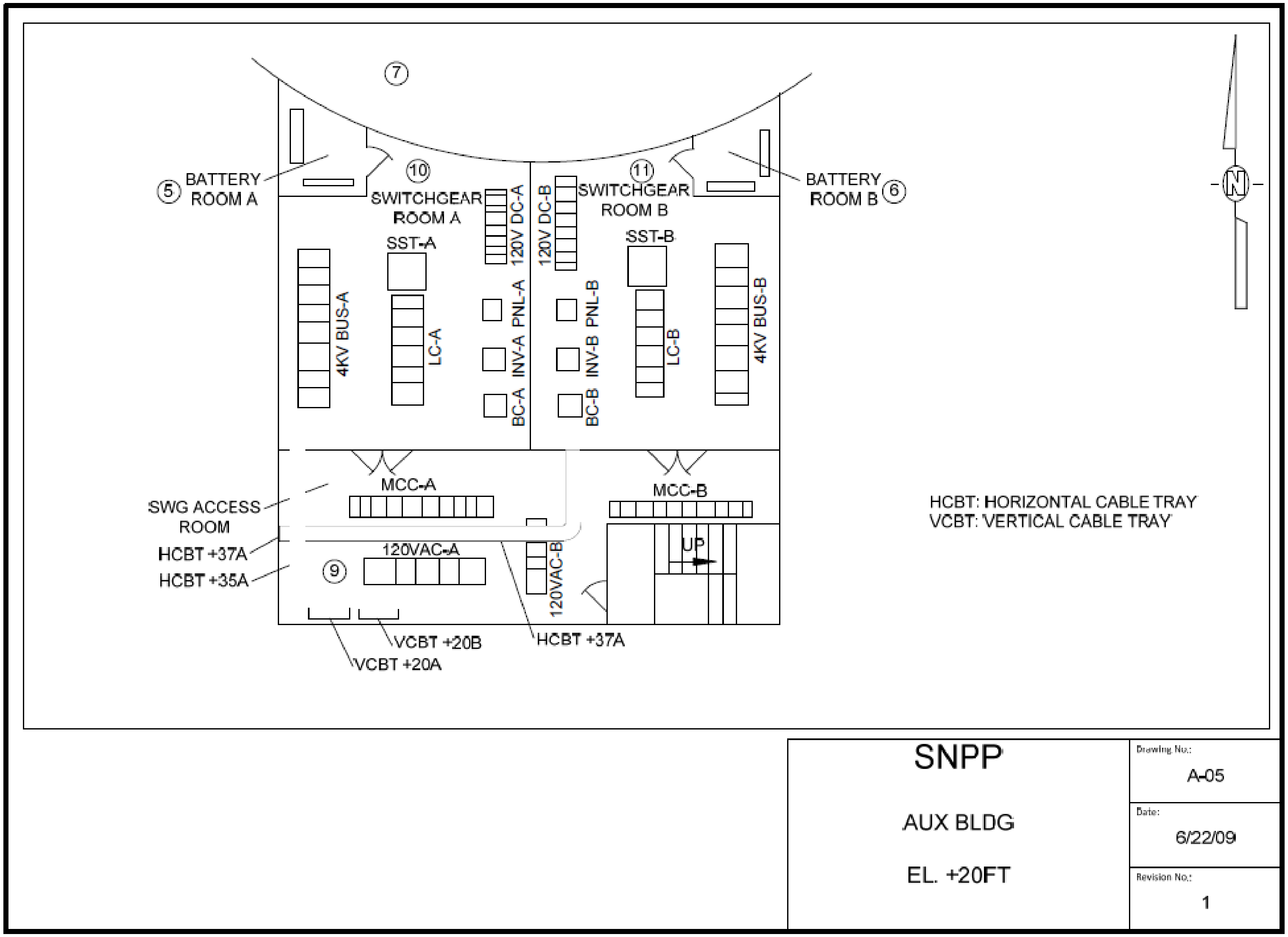


Figure 2-5 Auxiliary Building – Elevation +20 Ft.

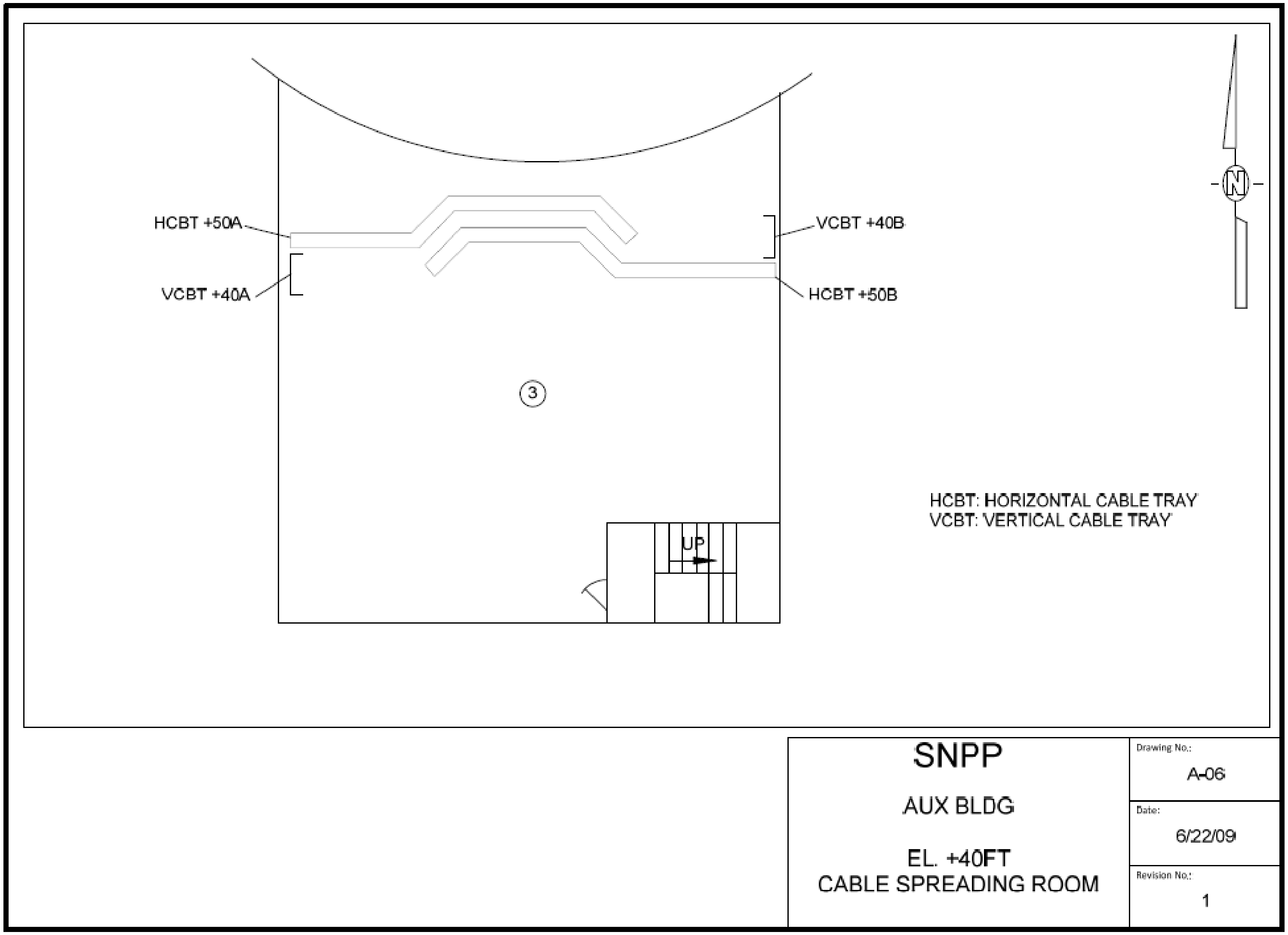


Figure 2-6 Auxiliary Building – Elevation +40 Ft.

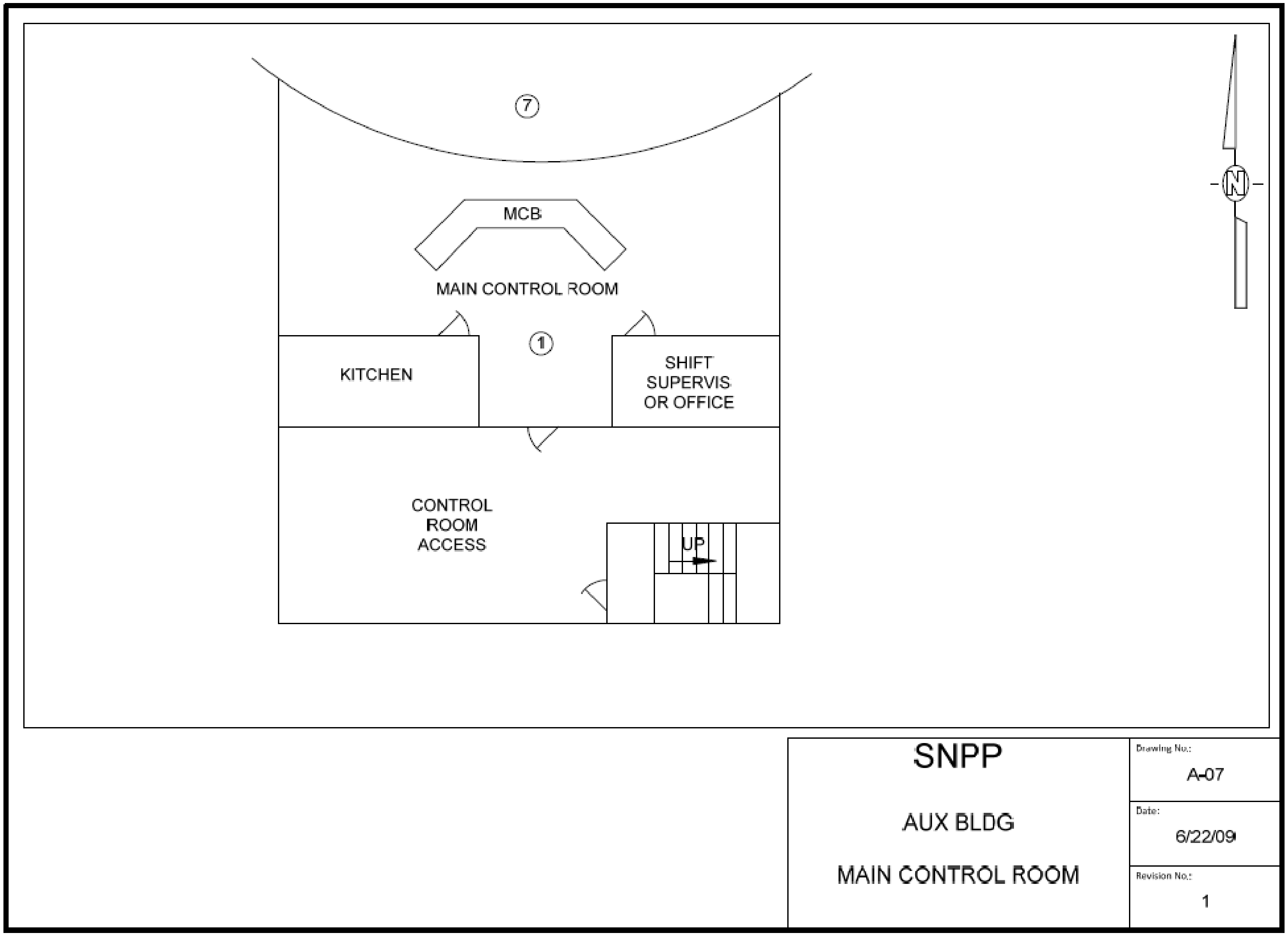


Figure 2-7 Auxiliary Building Main Control Room

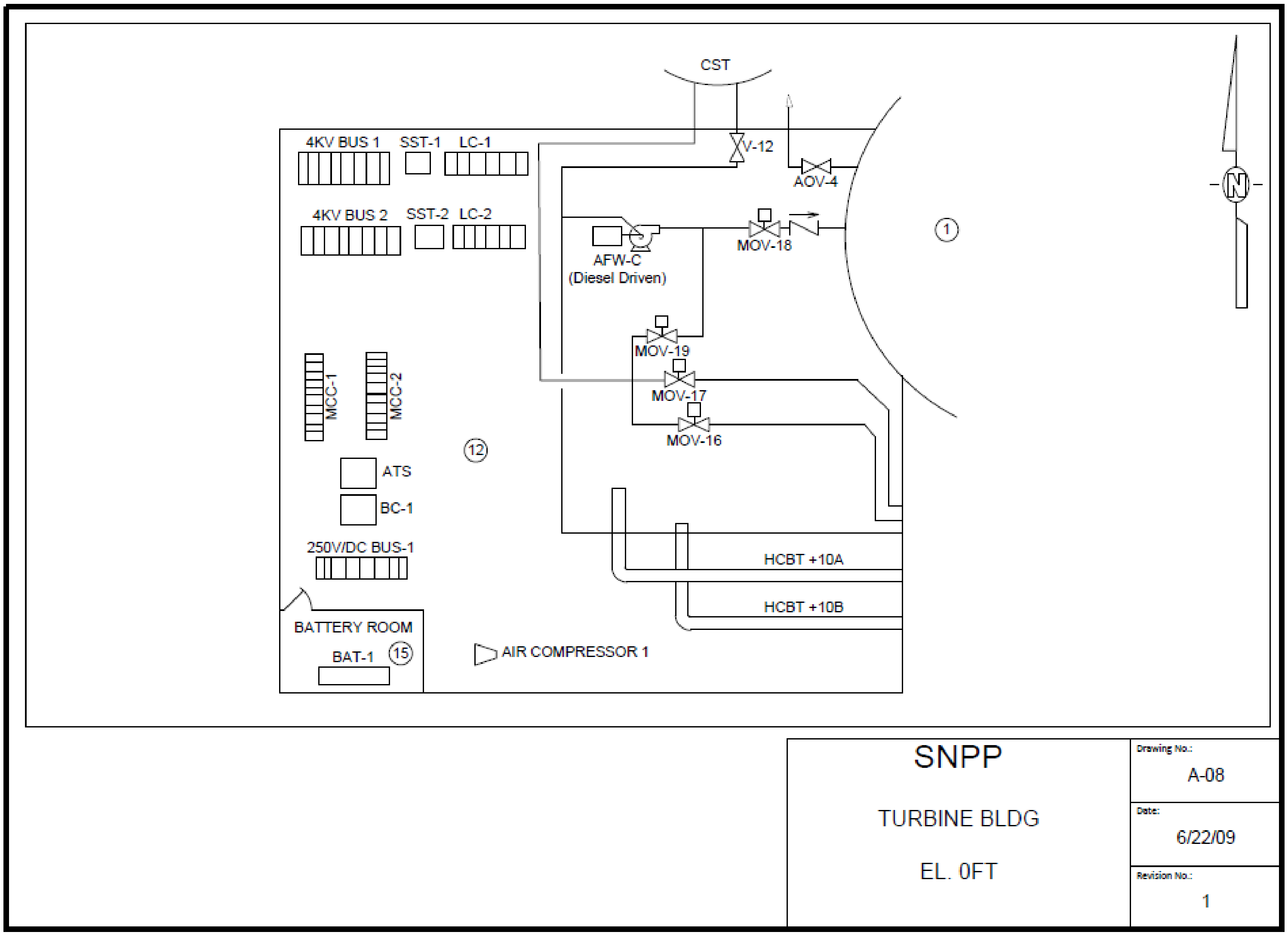


Figure 2-8 Turbine Building – Elevation 0 Ft.

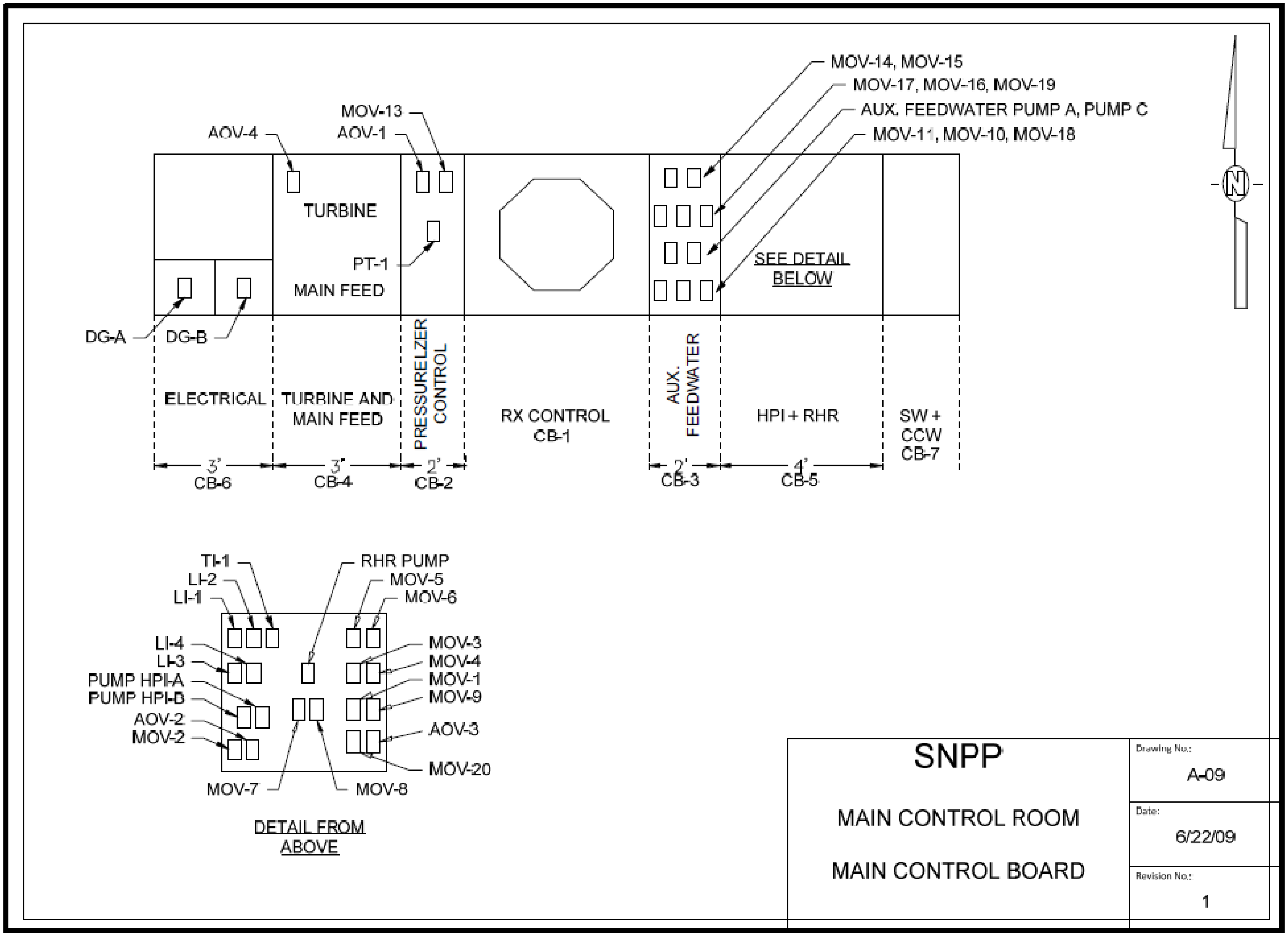


Figure 2-9 Main Control Board

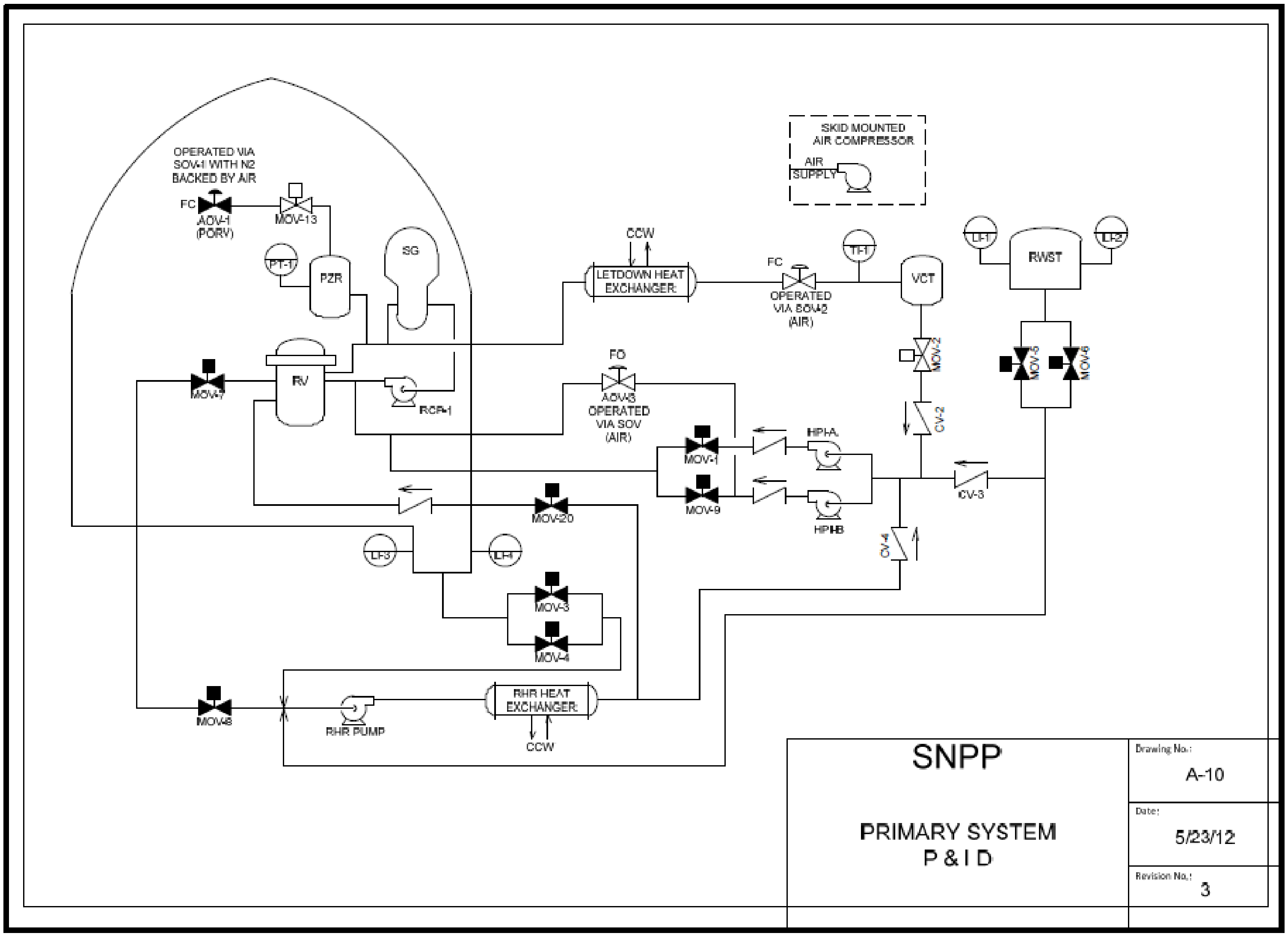


Figure 2-10 Primary System P&ID

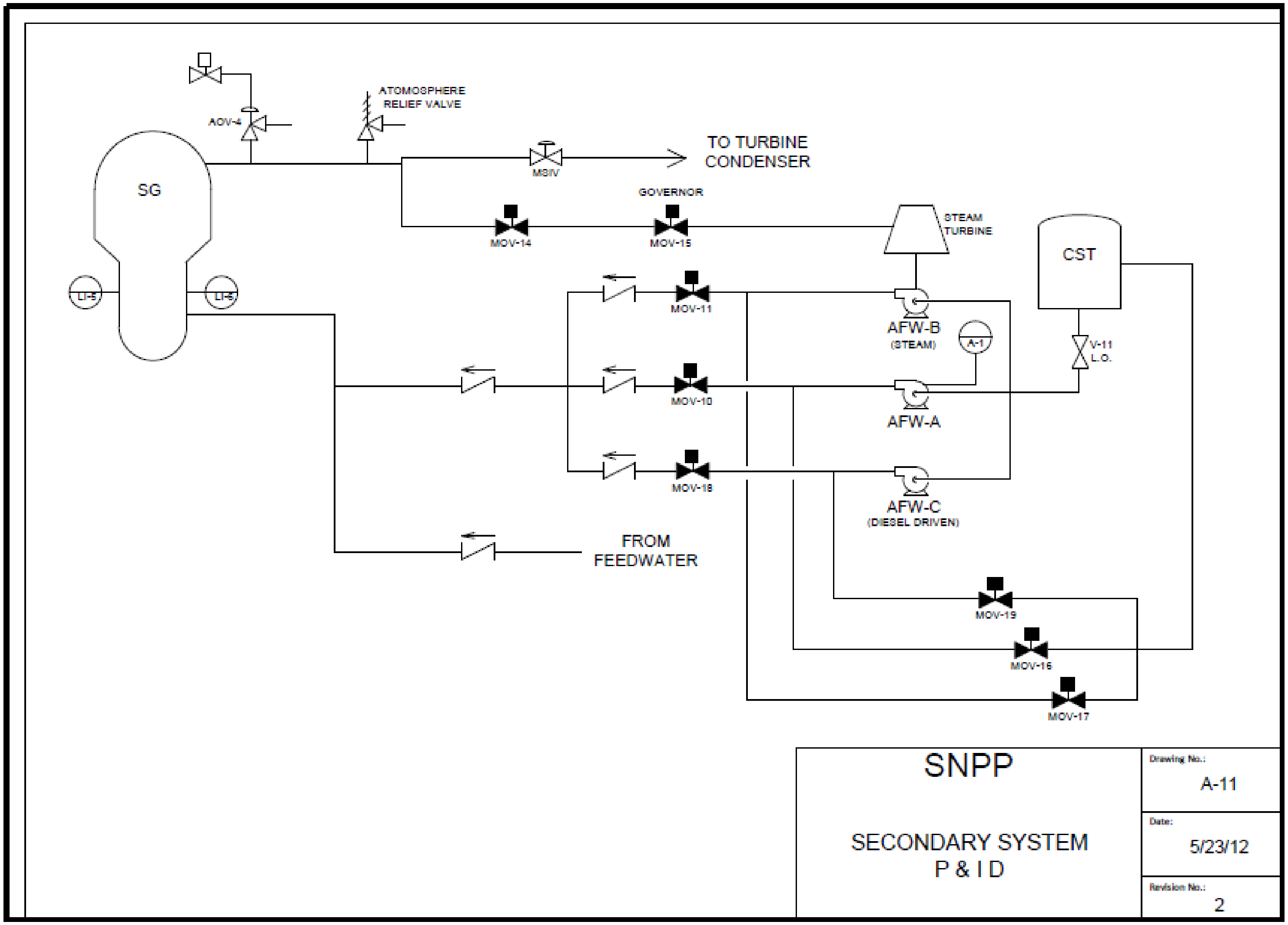


Figure 2-11 Secondary System P&ID

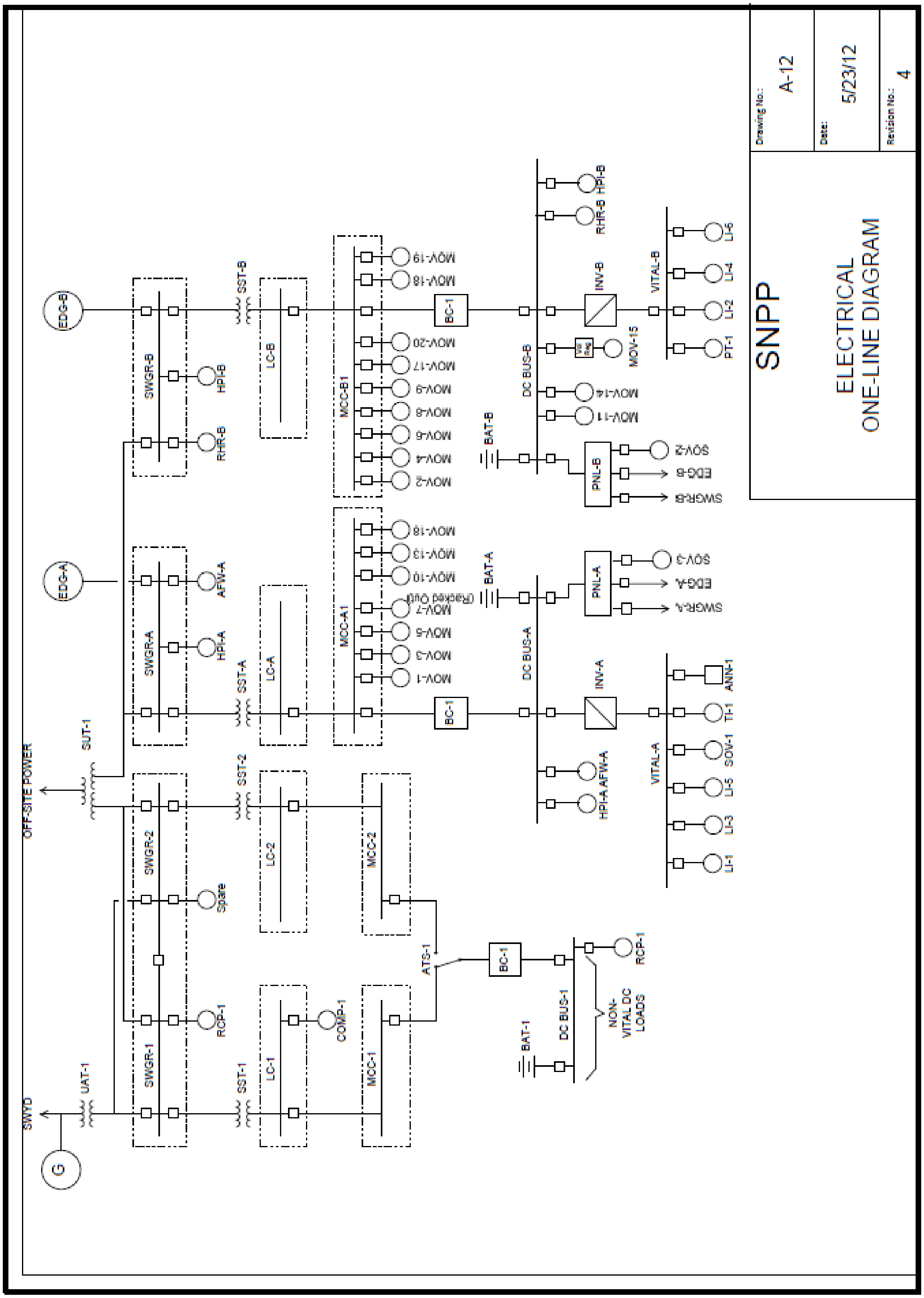


Figure 2-12 Electrical One-Line Diagram

3
FUNDAMENTALS OF FIRE ANALYSIS

The slides that follow were presented on the first day of the NRC-RES/EPRI Fire PRA Workshop during the extra day of training dedicated to presenting the fundamentals of the various subject areas to be covered during the remainder of the week.

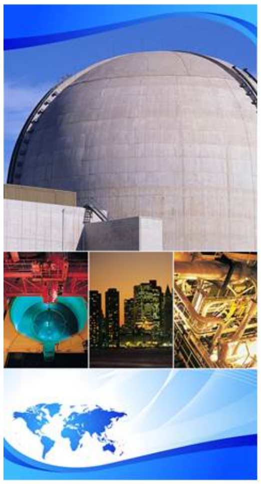
3.1 Fire Fundamentals Definitions

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation
From Science to Solutions



EPRI/NRC-RES FIRE PRA METHODOLOGY

Fire Fundamentals: Definitions

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

What is a Fire?

- Fire:
  - destructive burning as manifested by any or all of the following: light, flame, heat, smoke (ASTM E176)
  - the rapid oxidation of a material in the chemical process of combustion, releasing heat, light, and various reaction products. (National Wildfire Coordinating Group)
  - the phenomenon of combustion manifested in light, flame, and heat (Merriam-Webster)
  - Combustion is an exothermic, self-sustaining reaction involving a solid, liquid, and/or gas-phase fuel (NFPA FP Handbook)

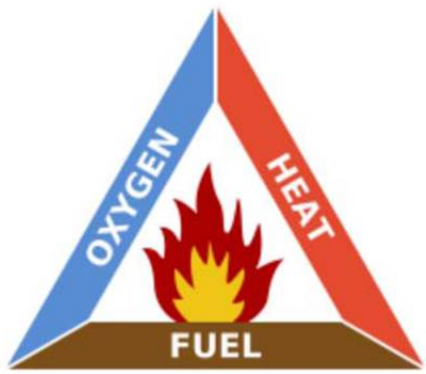
Fire PRA Workshop, 2012, Washington DC
Fire Fundamentals - Definitions

Slide 2

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

What is a Fire?

- Fire Triangle – hasn't change much…
- Fire requires presence of:
  - Material that can burn (fuel)
  - Oxygen (generally from air)
  - Energy (initial ignition source and sustaining thermal feedback)
- Ignition source can be a spark, short in an electrical device, welder's torch, cutting slag, hot pipe, hot manifold, cigarette, …



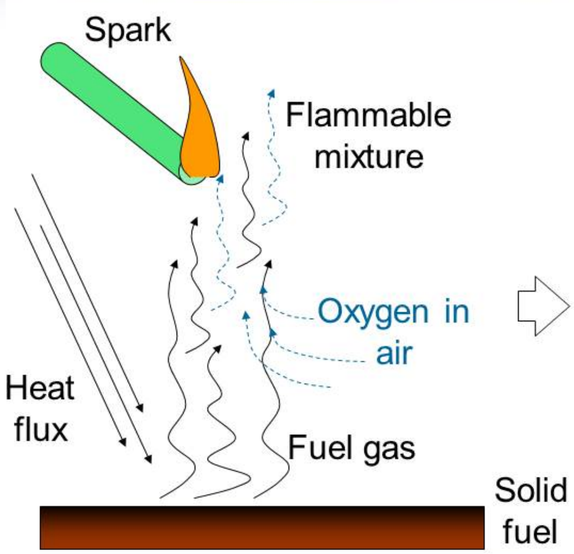
Materials that May Burn

- Materials that can burn are generally categorized by:
  - Ease of ignition (ignition temperature or flash point)
    - Flammable materials are relatively easy to ignite, lower flash point (e.g., gasoline)
    - Combustible materials burn but are more difficult to ignite, higher flash point, more energy needed(e.g., wood, diesel fuel)
    - Non-Combustible materials will not burn under normal conditions (e.g., granite, silica…)
  - State of the fuel
    - Solid (wood, electrical cable insulation)
    - Liquid (diesel fuel)
    - Gaseous (hydrogen)

Combustion Process

- Combustion process involves . . .
  - An ignition source comes into contact and heats up the material
  - Material vaporizes and mixes up with the oxygen in the air and ignites
  - Exothermic reaction generates additional energy that heats the material, that vaporizes more, that reacts with the air, etc.
  - Flame is the zone where chemical reaction is taking place
- Flame - A flame is the visible (light-emitting) part of a fire. It is caused by an exothermic reaction taking place in a thin zone where fuel vapors and oxygen in the air meet.

What is Fire?



Flame Characteristics

- Flame characteristics
  - Flame color depends on the material burning and how it burns
    - The nature of the combustion products
    - How hot material burns
    - How “cleanly” the material burns
      - How efficient the burning is, oxygen availability
  - Most flames are visible to the naked eye
    - What you actually see is glowing particulate (e.g. soot)
    - Fuels that burn cleanly (less soot), have less visible flames
      - e.g., Hydrogen produces a nearly invisible flame
  - Flame temperature can range from 1,500°F to 3,500°F

Definitions

Three “modes” of heat transfer are in play during a fire:

- Conduction – Heat transfer through a solid material or between two adjacent stationary solids directly through the contact interface between them
  - Example: Cooling your hand by putting it on a cold surface
- Convection – Heat transfer between a moving fluid and the surface of a solid or liquid material
  - Example: Blowing across a spoonful of hot soup to cool it
- Radiation – Heat transfer between two objects separated by open space via the transfer of electromagnetic energy. Requires that the objects be within line of sight of each other and separated by a relatively transparent medium (e.g., air or vacuum).
  - Example: Warming your hands by the camp fire

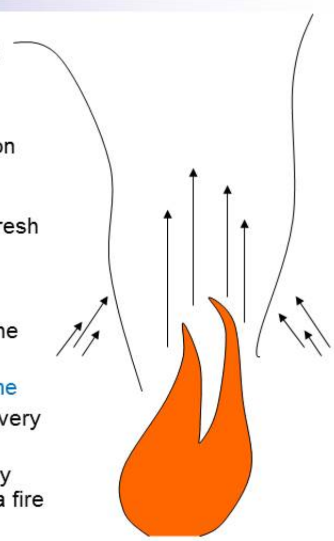
Effects of a Fire

What does a fire do to its surroundings?

- A fire generates heat, smoke and various combustion products
  - Heat is the main adverse effect of concern in a nuclear power plant
- Heat generated by the fire is transferred to nearby targets mainly by radiation and convection
  - Conduction plays a role in fuel heating and heat absorption into a target but, for most cases, not in direct transfer of heat from the fire to targets
- Products of combustion also include carbonaceous soot and other species such as HCl, HCN, water vapor, CO, CO_2, …
  - Smoke and soot can adversely affect equipment
  - Smoke can hinder plant operators and fire response
  - HCl and HCN can be irritants for plant personnel
  - CO kills…

Fire Plume

- Fire plume: the buoyant stream of heated air and combustion products rising above a fire
- The fire plume forms quickly over the fire…
  - The fire produces very high temperature combustion products which rise from the fuel surface due to buoyancy
  - Rising combustion products draw in and mix with fresh air from the surroundings (entrainment)
    - Some of the available oxygen is consumed in the combustion process
  - Entrained air is heated as it absorbs energy from the fire
  - The mixture of hot gases rises forming the fire plume
  - The plume can envelope items above the fire with very hot gases
  - The energy carried away by the fire plume generally accounts for over half of the energy generated by a fire



The fire plume continued

- The fire plume typically carries away ~40%-70% of total heat production from the fire

- The Convective fraction (X_c) is the fraction of the net energy produced by the fire and emitted into the surroundings via heated gasses in the plume
  - $X_c \sim 0.6$ is a typical assumption for most fires

- The fire plume is very important to fire PRA. We often analyze fires where important plant cables are located in the fire plume.
  - Temperatures are higher in the fire plume than anywhere other than the flame zone itself

Definitions

So what happens when the plume hits the ceiling?

- Ceiling Jet – When the fire plume hits the ceiling, the flowing gasses turn 90° and form a relatively thin layer of flowing gas just below the ceiling
  - Important to the activation of sprinklers and fire detectors (more later…)

…and when the ceiling jet hits the walls?

- Wall plume – if/when the ceiling jets reaches a wall, the gasses will turn downward flowing down the wall
  - The wall absorbs energy from the gasses cooling them

Definitions

In the longer term, the compartment will fill with hot gasses…

- Hot Gas Layer – As a fire progresses within an enclosure, the heated air and combustion products tend to collect as a heated layer between the ceiling and somewhere above the floor (sometimes called the smoke layer or upper layer as well)

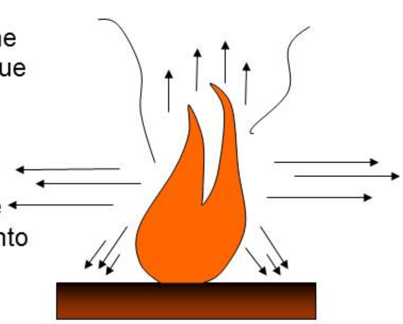
vs. …

- Lower or Cold Gas Layer – The gasses that remain between the bottom of the HGL and the floor and that generally remain at near ambient temperatures

- The depth of the HGL (distance from the ceiling to the bottom of the HGL) will be determined largely by ventilation conditions (e.g., an open door, open window…)

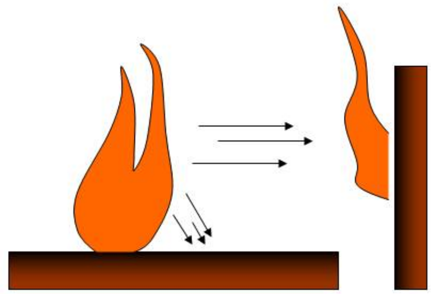
Radiative Heating from a Fire

- Radiative heat is produced by the luminous flames and emitted in all directions
  - Some radiative energy points back towards the fuel and acts to evaporate more fuel to continue the combustion process (thermal feedback)
  - The rest points away from the fire into the surroundings
  - The radiative fraction (X_r) is the fraction of the net energy produced by the fire and emitted into the surroundings via radiation:
    - $X_r = 1.0 - X_c$
      (if it's heat from the fire and it's not convection, it must be radiation…)
    - $X_r \sim 0.4$ is typical



Flame Spread and Fire Propagation

- Flame spread is the propagation of combustion across a fuel surface, to an adjacent fuel material, or to nearby items
  - Radiation, convection, and conduction can all act to heat fuels near the existing burn region
  - Ignition can occur when temperatures ahead of the existing flame reach the point of ignition, and the flame spreads
- Flame spread *usually* refers to spread across or within a single object or fuel package
- Fire propagation *usually* refers to fire spread from one object to another
- Neither is universal so be careful…



Definitions

- Pyrolisis – the breakdown of the molecules of a solid material from exposure to heat into gaseous molecules that may combust in the flame.
- Smoldering – A slow combustion process without visible flames that occurs in a porous solid fuel
  - e.g., charcoal briquettes in the barbeque or wood in a fire pit as the fire burns down
  - Generally occurs because of limited oxygen access to the burning surfaces. It can generate large quantity of carbon monoxide which is lethal if inhaled.

Definitions

- Piloted ignition – Ignition of a combustible or flammable material in the presence of a pre-existing flame (the "pilot" flame)

vs. …

- Non-piloted (or spontaneous) ignition – Ignition of a combustible or flammable material without an ignition source, which is generally caused by raising material temperature above its auto-ignition temperature.

- Piloted ignition generally occurs at a lower temperature than spontaneous ignition
  - the pilot flame provides that extra "oomph" to achieve ignition
- Spontaneous combustion is a little different – the initiation of combustion due to self heating of a fuel without an external heating source or pilot flame (e.g., a pile of oily rags…)

Definitions

- Diffusion Flame – The flame of a burning material (liquid or solid) where the combustion process occurs at the interface where vaporized fuel comes into contact with the oxygen in the air (e.g., flame on top of a candle or the wood in a fireplace.)

vs. …

- Pre-mixed Flame –The flame of burning gaseous material that is mixed with air upstream of the flame (e.g., the flame of a gas range or gas fired furnace)

- Most of the fires we are concerned with involve diffusion flames

Definitions

- Laminar Flame – a flame with smooth, regular and very uniform flow of gases
  - In a laminar flame the mixing of air and fuel vapors is not very efficient and the flame zone is very narrow
  - Laminar flames ~3,500 °F (~1925 °C) e.g., a candle flame

vs. …

- Turbulent Flame – a flame with a more irregular and chaotic flow of gases including the formation of large vortices
  - Turbulent flames are more efficient because mixing entrained air with fuel vapors/products creates a larger region where combustion can ocurr
  - Turbulent flames ~1,500 °F (~815 °C), e.g., most real fires
- Most flames greater than a few inches tall demonstrate turbulent (non-laminar) behavior because of increased gas velocities caused by increased heat.

Definitions

Some key fire characteristics…

- Mass Loss Rate (Burning Rate) – The rate of mass loss of a burning material in a fire
  - May be expressed as either mass released per unit time (g/s) or mass released per unit area per unit time ($g/cm^2 \cdot s$).
- Heat Release Rate (HRR) – The energy released from a fire per unit time (kW)
  - HRR is generally expressed as net energy release which accounts for thermal feedback to the fuel and combustion efficiency – i.e., the net rate of energy released by the fire
- Heat Flux – the rate of heat transfer expressed as energy delivered per unit time per unit area (kW/m^2). Heat flux is a good measure of fire hazard.

Definitions

- Heat Release Rate Profile – The fire's HRR expressed as a function of time
  - Example: NRC/SNL electrical cabinet fire tests . . .
  - A complete HRR profile may involve 5 stages:
    - Incipient
    - Growth
    - Steady state or peak burning
    - Decay
    - Burnout

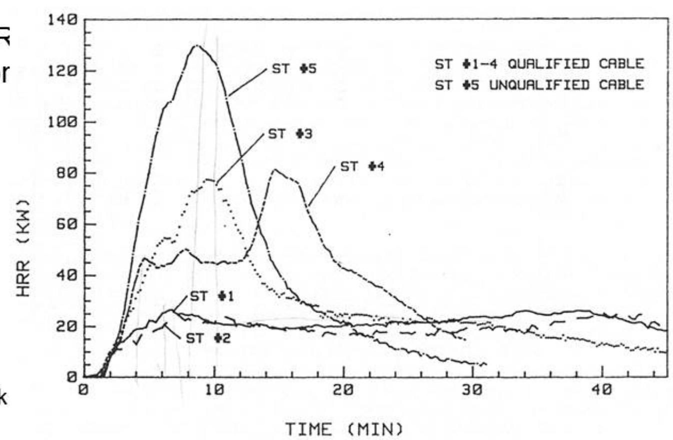


Figure 8. Heat Release Rate Plots for Scoping Tests #1 through 5

Definitions

- Fire in the Open – A fire occurring in a large or unconfined space such that there is no feedback between the fire and the ambient environment

vs. ...

- Compartment Fire (Enclosure Fire) – A fire occurring in an enclosed space such that the fire impact its surroundings creating a feedback effect; e.g.
  - The walls get hot and feed radiant energy back to the fire
  - A HGL forms and feeds radiant energy back to the fire
  - The HGL descends to the floor and reduces the oxygen available to the fire

- We deal mainly with compartment fires

Definitions

- Fuel Limited Fire – A fire where the fuel burning rate is limited only by the surface burning rate of the material.
  - Plenty of oxygen…

vs. …

- Oxygen Limited Fire – A fire (typically inside a compartment or enclosure) where the fuel burning rate is limited by oxygen availability
  - Not enough air for fire to grow beyond a certain point

- We tend to deal primarily with fuel limited fires, but cabinet fires, for example, may be oxygen limited

Definitions

- Lower flammability limit – the minimum concentration of fuel vapor in air in a pre-mixed flame that can sustain combustion
  - A mixture that is too lean (not enough fuel) will not burn
- Upper flammability limit – the maximum concentration of fuel vapor in air that can sustain combustion
  - A mixture that is too rich (too much fuel) will not burn
- Stoichiometric ratio - the optimum theoretical mix of fuel and air to achieve complete combustion of that fuel
  - Fuel burns completely and consumes all available oxygen
- Fuels will burn in air only if the concentration is between the lower and upper flammability limits

Definitions

- Zone-of-Influence (ZOI) – The area around a fire where radiative and convective heat transfer is sufficiently strong to damage equipment or cables and/or heat other materials to the point of ignition.

- Fire Modeling vs. Fire Analysis Tasks – Fire modeling is the analytical process of estimating the behavior of a fire event in terms of the heat flux impinging material near the fire and behavior of those materials as a result of that.

Definitions

We classify cable insulation materials based on two major categories:

- Thermoplastic (TP): capable of softening or fusing when heated and of hardening again when cooled (Marriam-Webster)
  - TP materials melt when heated and solidify when cooled
- Thermoset (TS): capable of becoming permanently rigid when heated or cured (Marriam-Webster)
  - On heating TS materials may soften, swell, blister, crack, smolder and/or burn but they won't melt

- Both types are used in U.S. NPPs
- Much more on cables to come.

Questions…

… before we move on?

- Up next:
  - Fundamental concepts of fire behavior, modeling and analysis

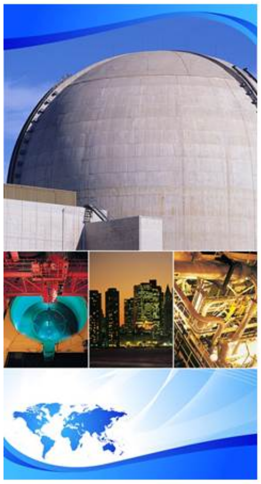
3.2 Fires in the Open and Fully Ventilated Fires

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation
From Science to Solutions



EPRI/NRC-RES FIRE PRA METHODOLOGY

Fires in the Open and Fully Ventilated Fires

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

Recall: Fuel limited fires

- A fire where the fuel burning rate is limited only by the surface burning rate of the material.
- Sufficient air is always available for the fire (plenty of oxygen to support burning)
- Fire generates hot gases (convective fraction) and emits radiative heat (radiative fraction)
- Generally applies to fires in the open or fires in large compartments
  - A nuclear power plant has lots of large compartments…

Fire PRA Workshop, 2012, Washington DC
Fire Fundamentals - Fires in the Open

Slide 2

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

Heat Release Rate (HRR)

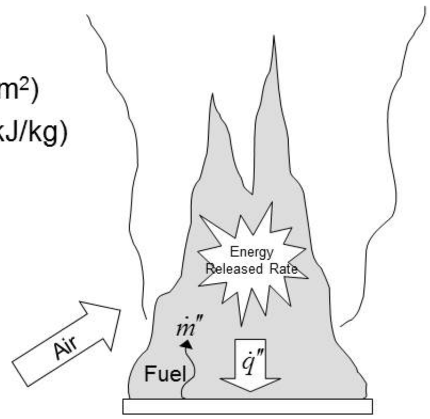
- For a simple fire, the HRR can be estimated using the following equation:

$$\dot{Q} = \dot{m}'' \cdot A \cdot \Delta H_c$$

– $\dot{m}''$ is the burning mass flux (kg/s·m²)
– ΔH_c is the net* heat of combustion (kJ/kg)
– A is the burning area (m²)

So HRR ends up as kJ/s or kW

* "net" heat of combustion implies that a burn efficiency has been included – fuels don't burn at 100% efficiency in real fires

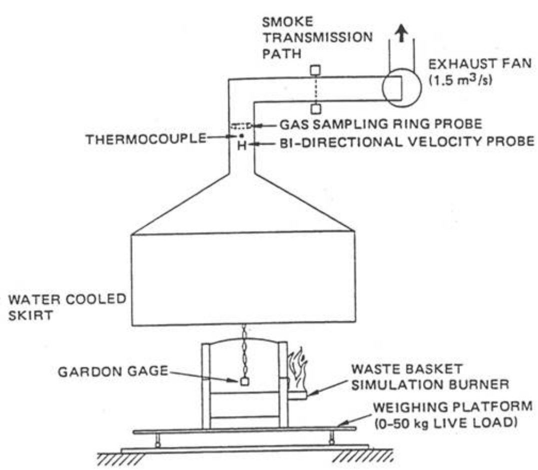


Heat Release Rate

- HRR can be estimated experimentally using oxygen consumption calorimetry

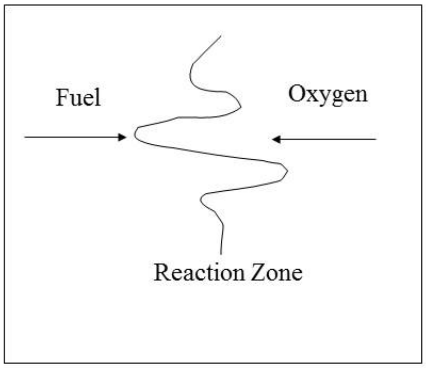
$$\dot{Q} = \dot{m}_{O_2} \cdot \Delta H_c (kJ / kg_{O_2})$$

where:
ΔH_c ~ 13.1 kJ/kg_{O2}
for many common fuels



Flames

- Laminar – very small fires
- Turbulent – most real fires

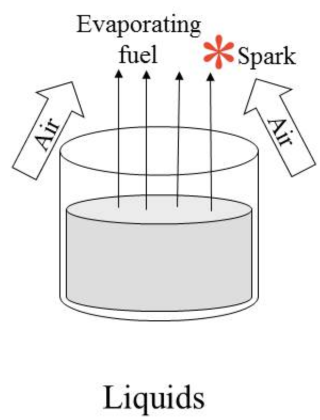


Ignition of Gases

- With a spark or small flame (pilot) present, ignition is based on whether the gaseous fuel concentration is between the upper (rich) and lower (lean) flammability limits.
  - The fuel-air (oxidizer) mixture is said to be flammable if a flame will propagate in this mixture.
- With no pilot present, a gaseous fuel in air can still ignite if the mixture is at or above the auto-ignition temperature.
  - The auto-ignition temperature is usually measured for a stoichiometric mixture – just the right mix so that no fuel or oxygen remains after the reaction.

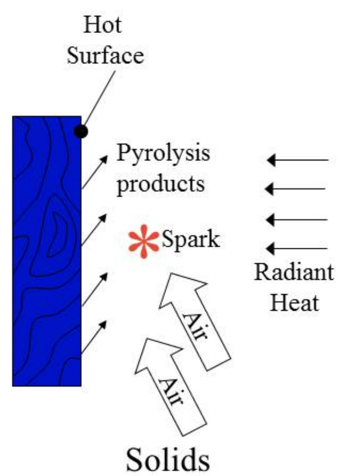
Ignition of Liquids

- For a liquid to ignite, it must first evaporate sufficiently to form a flammable mixture of gaseous fuel and oxygen
  - This occurs at a liquid temperature called a flash-point temperature.
  - In general, this temperature can be called the piloted ignition temperature and the same term carries over to solids.
  - The flash-point is the temperature at which the amount of liquid evaporated from the surface achieves the lower flammable limit.
- If no pilot is present, the mixture must be heated to the auto-ignition temperature in order to ignite.
- The auto-ignition temperature of a gas will be higher than the boiling point of the liquid.



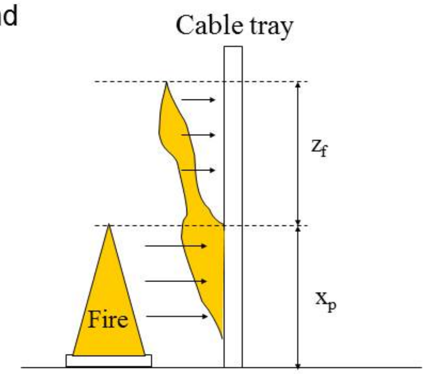
Ignition of Solids

- Solids do not evaporate like liquids when heated. Solids form gaseous decomposition compounds, generally leaving behind char, in a process called pyrolysis.
- At some point, the gases reach the lower flammability limit and may ignite by piloted ignition or, if hot enough, auto-ignition.
- Typically, piloted ignition temperatures for solids range from 250°C (~480°F) to 450°C(~840°F).
- Auto-ignition temperatures can exceed 500°C (~930°F).
  - For a given material, these temperatures are not constants and can change with the nature of heating.
  - For practical purposes, a (piloted) ignition temperature (T_{ig}) may be treated as a property of a combustible solid.
- We shall consider thin (less than ~1 mm) and thick solids to have different time responses to ignition when exposed to impinging heat flux



Flame Spread

- Motion of vaporization front at the ignition temperature for solids and liquids
  - The surface is heated by the existing flames
  - More material pyrolyzes (or evaporates) ahead of the flame front
  - The existing flame acts as the pilot
  - The flame (fire) spreads…



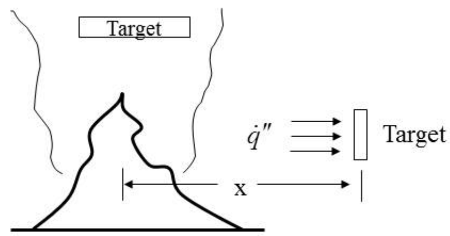
Typical Flame Spread Rates

- It is very difficult to compute flame spread rates because formulas are not completely available, rates may not be steady, and fundamental fuel properties are not generally available.
- Nevertheless, we can estimate approximate magnitudes for spread rates for various cases.

Spread case	Spread Rate (cm/s)
Smoldering solids	0.001 to 0.01
Lateral or downward spread on thick solids	0.1
Upward spread on thick solids	1.0 to 100. (0.022 to 2.2 mph)
Horizontal spread on liquids	1.0 to 100.
Premixed flames (gaseous)	10. to 100.(laminar)
	$\approx 10^5$ (detonations)

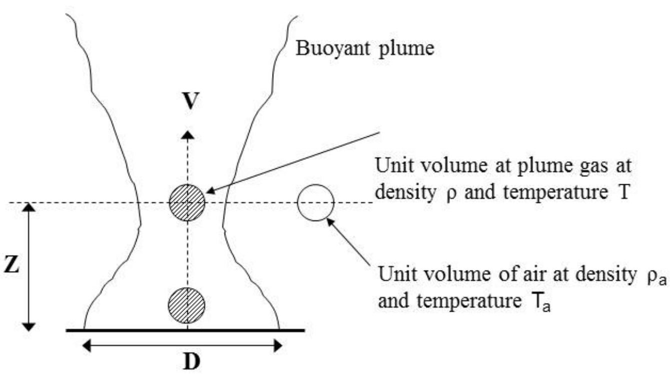
Zone of Influence

- Regions near the fire where damage or fire propagation is expected.
- For fires in the open we consider:
  - Flame Radiation
  - Convection, especially inside the fire plume



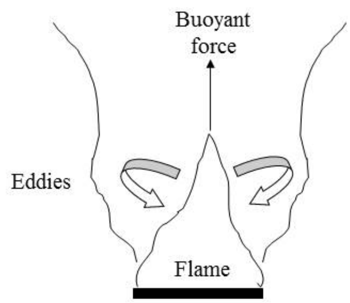
Buoyant Flow

- Temperature rise causes a decrease in gas density
- Potential energy converted into kinetic energy – gasses flow upwards



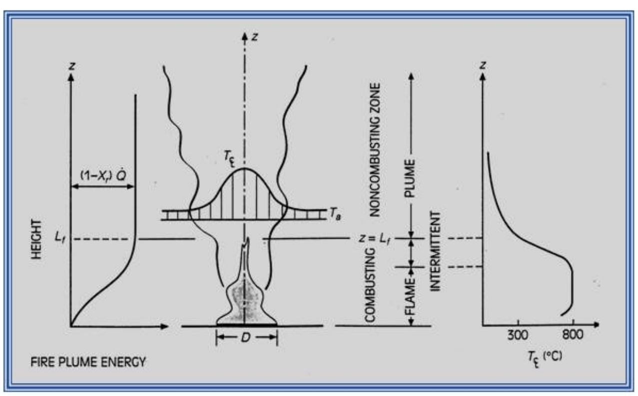
Turbulent Entrainment

- Entrainment is air drawn into the fire plume by upward movement of the buoyant plume
  - Engulfing air from the surroundings into the fire plume
- Eddies: fluctuating and rotating balls of fluid, large scale rolling fluid motion on the edge of the plume.

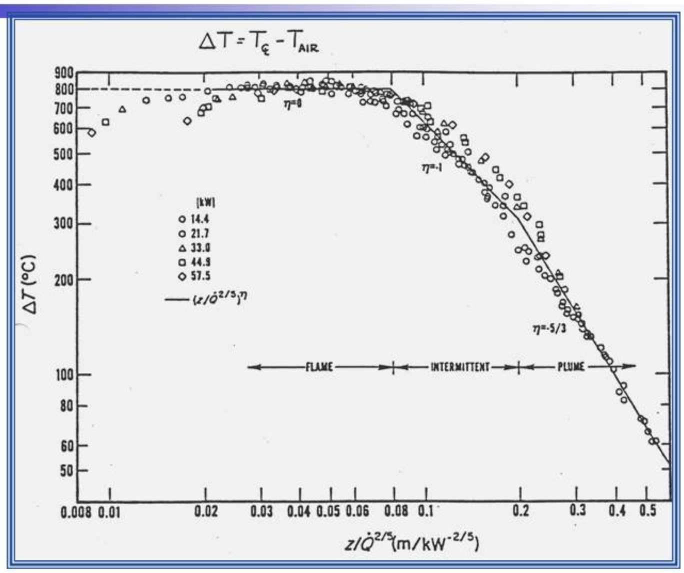


Turbulent Fire Plume

- Very low initial fuel velocity
- Entrainment and flame height controlled by buoyancy



Fire Plume Temperature Along the Centerline



Example Case - Zone-of-Influence Calculation Flame Height and Plume Temperature

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

Heskdestad's Flame Height Correlation

Input

D - Fire diameter [m]	0.6
Q_f - HRR [kW]	250

Result

L - Flame height [m]	1.5

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

where:

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

Heskestad's Plume Temperature Correlation

Input

T_{amb} - Ambient temp. [C]	20
Q_f - HRR [kW]	250
F_e - Fire elevation [m]	0
H_p - Target Elevation [m]	3.7
D - Fire Diameter [m]	1
k_f – Location factor	1 (…2 or 4)
X_r – Radiative Fraction	0.4

Result

T_{pl} - Plume Temp [C]	328

Example Case - Zone-of-Influence Calculation
Radiation Heat Flux

• 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: Radiative fraction (FIVE recommends 0.4)
- D: Fire diameter (m)

Example Case - Zone-of-Influence Calculation
Radiation Heat Flux

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

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**

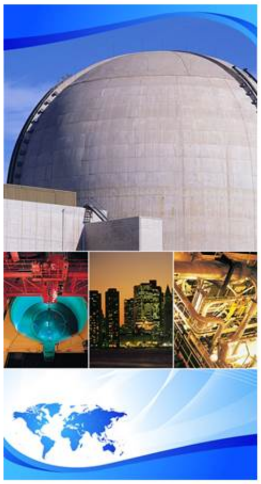
3.3 **Analysis Tools**

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation
From Science to Solutions



EPRI/NRC-RES FIRE PRA METHODOLOGY

Analysis Tools

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

Analysis Tools: Outline

- Fire Modeling in a Fire PRA
- How fire develops in a scenario
- What damage is generated
- When damage is generated
- Timing of detection and suppression activities

Fire PRA Workshop, 2012, Washington DC
Fire Fundamentals – Analysis Tools

Slide 2

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

Five Steps of Fire Modeling

1. Define modeling objectives
2. Select and describe fire scenarios
3. Select the appropriate model(s)
4. Run/apply the model
5. Interpret modeling results

Fire Modeling

- **Fire modeling**: an approach for predicting various aspects of fire generated conditions
- **Compartment fire modeling**: modeling fires inside a compartment
- Requires an idealization and/or simplification of the physical processes involved in fire events
- Any departure of the fire system from this idealization can seriously affect the accuracy and validity of the approach

Capabilities

- Areas of application
  - Thermal effects of plumes, ceiling jets and flame radiation
  - Room heat up, and hot gas layer
  - Elevated fires and oxygen depletion
  - Multiple fires
  - Multi-compartments: corridors and multi-levels
  - Smoke generation and migration
  - Partial barriers and shields
  - Fire detection
  - Special models or areas for future research
  - Cable fires
  - Fire growth inside the main control board
  - Fire propagation between control panels
  - High energy fires
  - Fire suppression
  - Hydrogen or liquid spray fires

Fire Models

- **Hand calculations**: Mathematical expressions that can be solved by hand with a relatively small computational effort
  - Quasi steady conditions
  - Usually semi-empirical correlations developed with data from experiments
- **Zone models**: Algorithms that solve conservation equations for energy and mass in usually two control volumes with uniform properties
- **Field models**: Algorithms that solve simplified versions of the Navier-Stokes equations. The room is divided into large number of cells and conservation equations are solved in each of them.
- **Special models**: There are fire scenarios critical to NPP applications that are beyond capability of existing computational fire models
  - Fire experiments,
  - Operating experience, actual fire events
  - Engineering judgment

Example of Hand Calcs: FDT's

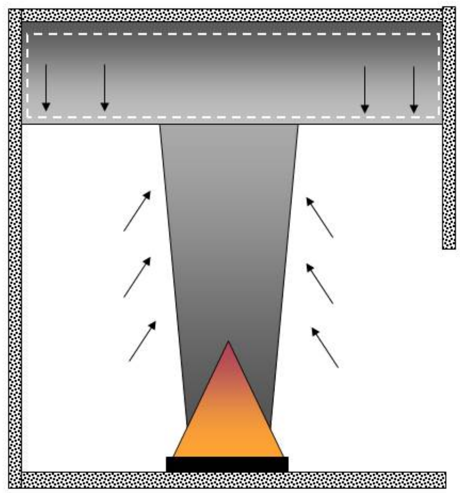
- **FDTs** are a series of Microsoft Excel® spreadsheets issued with **NUREG-1805, "Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program**."
- The primary goal of FDTs was to be a training tool to teach NRC Fire Protection Inspectors.
- The secondary goal of FDTs was to be used in plant inspections and support other programs that required Fire Dynamics knowledge such as, SDP and NFPA 805.

Hand Calculations

- Heat release rate, flame height and flame radiation
- Fire plume velocity, temperature heat flux, and entrainment
- Ceiling jet velocity, temperature, and heat flux
- Overall room temperature
- Target temperature, and time to target damage

Zone Models

- Usually two zones
  - Upper hot gas layer
  - Lower layer with clear and colder air
- Mass and energy balance in the zones
  - Entrainment
  - Natural flows in and out
  - Forced flows in and out
- Fire is treated as a point of heat release

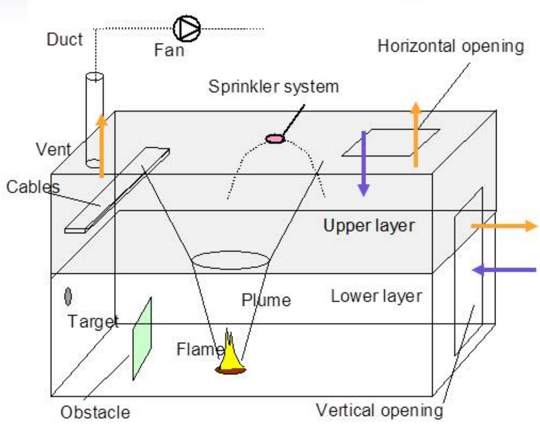


Fire PRA Workshop, 2012, Washington DC
Fire Fundamentals – Analysis Tools

Slide 9

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

Example of a Zone Model: MAGIC



- **Gaseous phase combustion, governed by pyrolysis rate and oxygen availability**
- **Heat transfer between flame, gases and smoke, walls and surrounding air, thermal conduction in multi-layer walls, obstacles to radiation**
- **Mass flow transfer: Fire-plumes, ceiling-jet, openings and vents**
- **Thermal behavior of targets and cables**
- **Secondary source ignition, unburned gas management**
- **Multi-compartment, multi-fire, etc.**

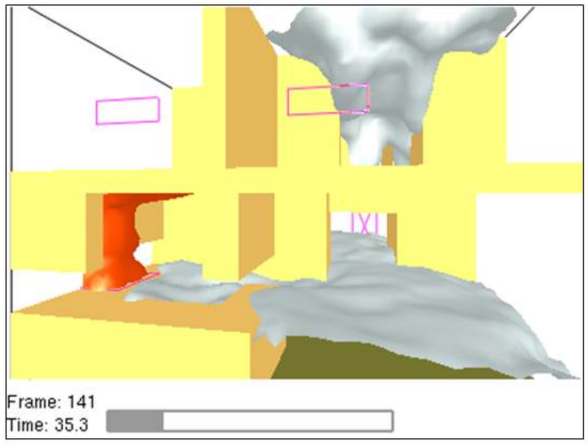
Fire PRA Workshop, 2012, Washington DC
Fire Fundamentals – Analysis Tools

Slide 10

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

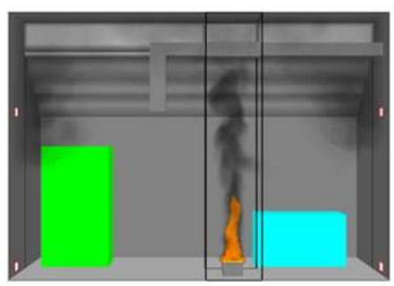
Field Models

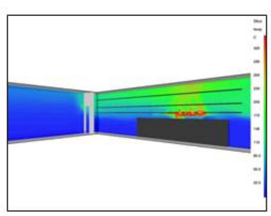
- Solve a simplified form of the Navier Stokes equations for low velocity flows
- Calculation time in the order of hours, days or weeks
- May help in modeling complex geometries

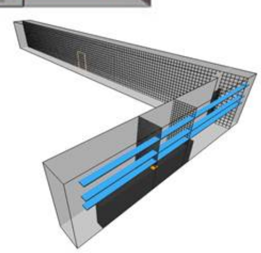


Example of Field Model: FDS

- Fire Dynamics Simulator
- Developed and maintained by NIST







Special Models

- Cable fires
- High energy arcing faults and fires
- Fire growth inside the main control board
- Fire propagation between control panels
- *The method described here is documented in the, EPRI 1011989 & NUREG/CR-6850, "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities."*

Which Model to Choose

- Hand calculations available
  - Combustion - Heat release rates, flame heights
  - Fire generated conditions
    - Plume temperatures and velocities
    - Ceiling jet temperatures and velocities
    - Flow through vents
    - Enclosure temperature
    - Time and temperature to flashover
    - Target temperature and time to target damage
  - Heat transfer: irradiation from flames, plume and ceiling jet convective flux
- Analysts may need to go back and find additional parameters required

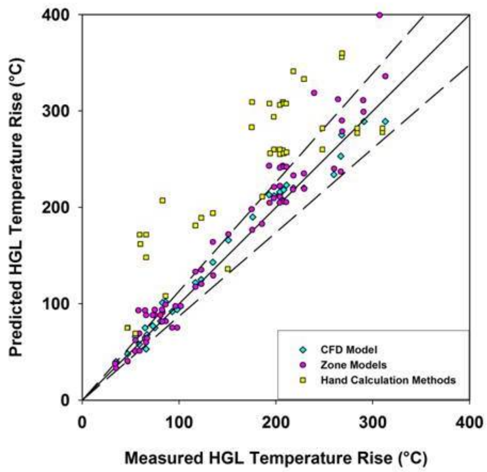
Verification and Validation

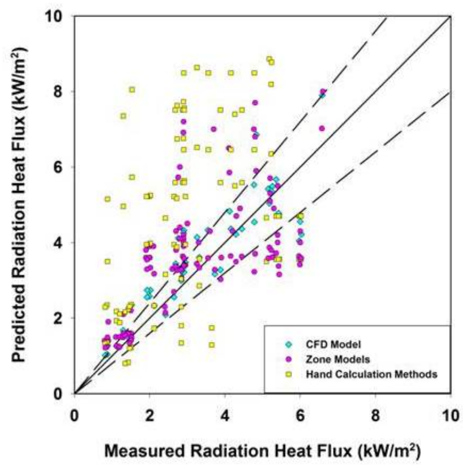
- ***Verification:*** the process of determining that the implementation of a calculation method accurately represents the developer's conceptual description of the calculation method and the solution to the calculation method. *Is the Math right?*
- ***Validation:*** the process of determining the degree to which a calculation method is an accurate representation of the real world from the perspective of the intended uses of the calculation method. *Is the Physics right?*
- *See NUREG-1824*

Verification and Validation

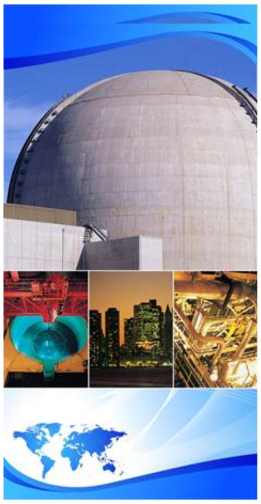
Parameter		Fire Model				
		FDTs	FIVE-Rev1	CFAST	MAGIC	FDS
Hot gas layer temperature ("upper layer temperature")	Room of Origin	YELLOW+	YELLOW+	GREEN	GREEN	GREEN
	Adjacent Room	N/A	N/A	YELLOW	YELLOW+	GREEN
Hot gas layer height ("layer interface height")		N/A	N/A	GREEN	GREEN	GREEN
Ceiling jet temperature ("target/gas temperature")		N/A	YELLOW+	YELLOW+	GREEN	GREEN
Plume temperature		YELLOW–	YELLOW+	N/A	GREEN	YELLOW
Flame height		GREEN	GREEN	GREEN	GREEN	YELLOW
Oxygen concentration		N/A	N/A	GREEN	YELLOW	GREEN
Smoke concentration		N/A	N/A	YELLOW	YELLOW	YELLOW
Room pressure		N/A	N/A	GREEN	GREEN	GREEN
Target temperature		N/A	N/A	YELLOW	YELLOW	YELLOW
Radiant heat flux		YELLOW	YELLOW	YELLOW	YELLOW	YELLOW
Total heat flux		N/A	N/A	YELLOW	YELLOW	YELLOW
Wall temperature		N/A	N/A	YELLOW	YELLOW	YELLOW
Total heat flux to walls		N/A	N/A	YELLOW	YELLOW	YELLOW

Verification and Validation





3.4 **Fire Scenarios**



EPRI/NRC-RES FIRE PRA METHODOLOGY

Fire Scenarios

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

Let's talk about fire scenarios in a risk analysis…

- In fire PRA we look for and analyze fires that may:
  - Cause an initiating event – an upset to normal at-power plant operations such that reactor shutdown is required
  - Damage mitigating equipment – that set of plant equipment that operators would rely on to achieve safe shutdown
- To do this we:
  - Identify fire sources,
  - Analyze the potential impact of fires on the surroundings,
  - Assess fire protection systems and features,
  - Assess the plant and operator's response to fire-induced damage
- The final result is expressed as a fire-induced core damage frequency (CDF) – an estimate of the frequency of fires leading to core damage

Fire PRA Workshop, 2012, Washington DC
Fire Fundamentals – Fire Scenarios

Slide 2

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

So what is a Fire Scenario?

- A set of elements representing a fire event:
  - The ignition source, e.g., electrical cabinets, pumps
  - Intervening combustibles, e.g., cables
  - Targets (e.g., power, instrumentation or control cables) whose fire-induced failure may cause an initiating event and/or complicate post-fire safe shutdown
  - Fire protection features, e.g., automatic sprinklers
  - The compartment where the fire is located
  - A time line

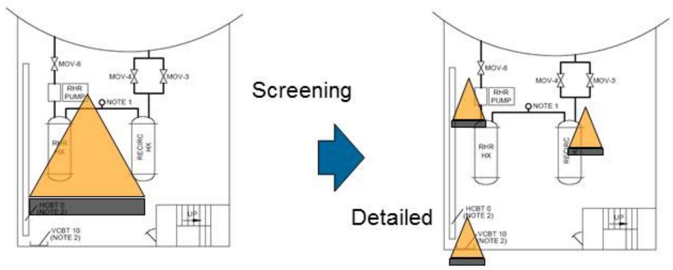
Fire Scenario Time Line

Timeline includes the following elements (not necessarily in this order):

1. Scenario starts with ignition of a fire in a specific fire source
2. Fire growth involving the affected fuel,
3. Heat transfer from the fire to other items within the zone of influence,
4. Propagation of the fire to other materials,
5. Damage to identified PRA targets (e.g., cables and equipment),
6. Detection of the fire
   - Detection can actually occur before ignition given an incipient detection system…
7. Automatic initiation of suppression systems if present,
8. Manual fire fighting and fire brigade response,
9. Successful fire extinguishment ends the scenario.

Fire Scenario - *Level of Detail*

- In practice, varying levels of detail are used to define the fire scenarios in a typical Fire PRA.
  - Level of detail may depend on initial stages of screening, anticipated risk significance of the scenario
- In principle, at any level of detail, a fire scenario represents a collection of more detailed scenarios.



Fire Scenario *Initial Screening Stage*

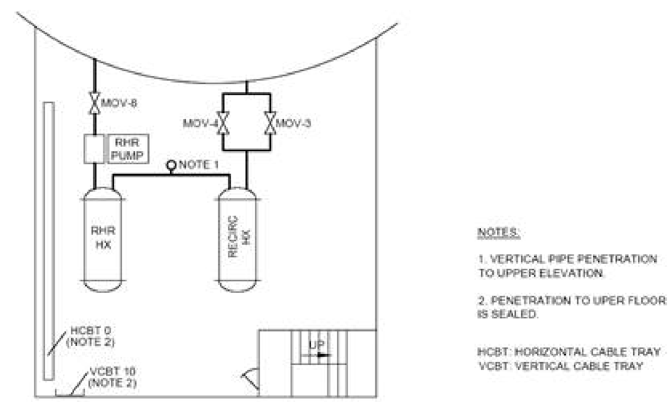
- In the initial stages of screening, fire scenarios are defined in terms of compartments and loss of all items within each compartment.
  - Assumes all items fail in the worst failure mode
  - Detection and suppression occur after the worst damage takes place
  - Fire does not propagate to adjacent compartments
- In multi-compartment fire propagation analysis, a similar definition is used in the initial screening steps for combinations of adjacent compartments.

Detailed Scenario Identification Process

- In the detailed analysis tasks, the analyst takes those fire scenarios that did not screen out in the initial stage and breaks them down into scenarios using greater level of detail.
  - Level of detail depends on the risk significance of the unscreened scenario
  - Details may be introduced in terms of . . .
    - Sub-groups of cables and equipment within the compartment
    - Specific ignition sources and fuels
    - Fire detection and suppression possibilities

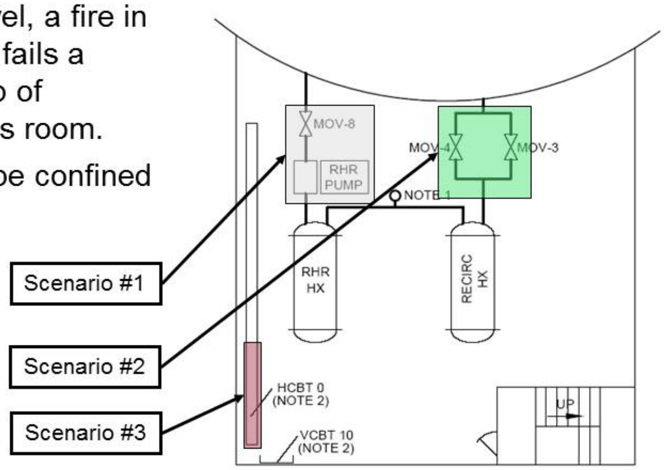
Example – Screening Level

- At the screening level, a fire in this compartment fails all equipment and cables shown in this diagram.
- The fire is assumed to be confined to this room



Example – Detailed Analysis

- At the detailed level, a fire in this compartment fails a specific sub-group of components in this room.
- The fire may still be confined to this room



Select and Describe Fire Scenarios

- Selecting scenarios is dependent on the objectives of the fire risk quantification
  - How many fire scenarios are enough to demonstrate the objective?
  - Which scenarios are the appropriate ones given objectives?
  - What fire conditions are actually modeled?
  - Analysis should represent a complete set of fire sources and conditions as relevant to the analysis objectives
  - A full-scope fire PRA tries to capture all fire scenarios that may represent contributors to plant core damage risk
- Selection of scenarios is dependent on the hazard characteristics of the area
  - Combustibles, layouts, fire protection
- The fire scenario should challenge the conditions being considered
  - Can the fire cause damage? vs. Which fire can cause damage?
  - Fires that don't propagate or cause damage are generally not risk contributors

Select and Describe Fire Scenarios

1. Scenarios begin with an ignition source – what/where does the fire start and what are the fire characteristics
2. Consider intervening combustibles – fire propagation beyond the fire source needs to be considered
3. There should be at least one damage target identified. Often it is a set of damage targets rather than just one (e.g., a group of important cables).
4. Include fire protection system and features (active or passive) that may influence the outcome of the event (there is a pain/gain decision point here)

Select and Describe Fire Scenarios

5. Sometimes, multiple ignition sources or targets can be combined into one scenario (e.g., a bank of cabinets all with the same cables overhead)
6. Sketch the scenario on a compartment layout drawing and try to qualitatively describe the conditions that a fire might generate. After the analysis, compare this qualitative prediction with the modeling results.
7. Do not neglect the importance of details such as ceiling obstructions, soffits, open or closed doors, ventilation conditions, spatial details (e.g., target position relative to fire source), etc.

Scenario Quantification

General quantification of CDF is based on a five-part formula:

$$CDF_{scenario} = \lambda \cdot W \cdot SF \cdot P_{ns} \cdot CCDP$$

- λ = Ignition frequency for the postulated ignition source group (e.g., pumps)
- W = A weighting factor for the likelihood that the fire occurs in a specific ignition source (this pump…) or plant location (this room…)
- SF = A severity factor reflecting percentage of fires large enough to generate the postulated damage if left unsuppressed
- P_{ns} = Non suppression probability – the probability that given the fire, it goes unsuppressed long enough that the target set is damaged
- CCDP = The conditional core damage probability – probability that given loss of the target set, operators fail to achieve safe shutdown and the core is damaged.

In practice, we often quantify scenarios in a progression of more detailed steps:

- A fire in a specific plant location $CDF_{is} \approx \lambda_g \cdot W_{is} \cdot 1 \cdot 1 \cdot 1$
- …That is severe enough to threaten targets $CDF_{is} \approx \lambda_g \cdot W_{is} \cdot SF \cdot 1 \cdot 1$
- …That goes unsuppressed long enough to cause damage $CDF_{is} \approx \lambda_g \cdot W_{is} \cdot SF \cdot P_{ns} \cdot 1$
- …That prevents safe shutdown $CDF_{is} \approx \lambda_g \cdot W_{is} \cdot SF \cdot P_{ns} \cdot CCDP$

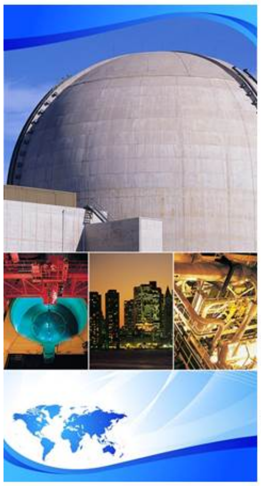
4

FIRE ANALYSIS

The following is a short description of each of the Fire PRA technical tasks covered in Module 3. For further details, refer to the individual task descriptions in Volume 2 of EPRI 1011989, NUREG/CR-6850.

- ***Plant Boundary Definition and Partitioning (Task 1).*** The first step in a Fire PRA is to define the physical boundary of the analysis, and to divide the area within that boundary into analysis compartments.
- ***Fire Ignition Frequency (Task 6).*** This task describes the approach to developing frequency estimates for fire compartments and scenarios. Ignition frequencies are provided for 37 item types that are categorized by ignition source type and location within the plant. For example, ignition frequencies are provided for transient fires in the Turbine Buildings and in the Auxiliary Buildings. A method is provided on how to specialize these frequencies to the specific cases and conditions.
- ***Scoping Fire Modeling (Task 8).*** Scoping fire modeling is the first task in the Fire PRA framework, in which fire modeling tools are used to identify ignition sources that may impact the fire risk of the plant. Screening some of the ignition sources, along with the applications of severity factors to the unscreened ones, may reduce the compartment fire frequency previously calculated in Task 6.
- ***Detailed Fire Modeling (Task 11).*** This task describes the method to examine the consequences of a fire. This includes consideration of scenarios involving single compartments, multiple fire compartments, and the main control room. Factors considered include initial fire characteristics; fire growth in a fire compartment, or across fire compartments; detection and suppression; electrical raceway fire barrier systems; and damage from heat and smoke. Special consideration is given to turbine generator (T/G) fires, hydrogen fires, high-energy arcing faults, cable fires, and main control board (MCB) fires.
- ***Seismic Fire Interactions (Task 13).*** This task is a qualitative approach for identifying potential interactions between an earthquake and fire.

4.1 Introduction and Overview: The Scope and Structure of Fire Analysis Module



EPRI/NRC-RES FIRE PRA METHODOLOGY

Introduction and Overview: the Scope and Structure of Fire Analysis Module

Francisco Joglar-Biloch - Science Applications International Corp.
Dave Stroup – U.S. NCR Office of Nuclear Regulatory Research

Joint RES/EPRI Fire PRA Training Workshop
Washington DC, July 16-20 and September 24-28, 2012

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

What we'll cover in the next four days
An overview…

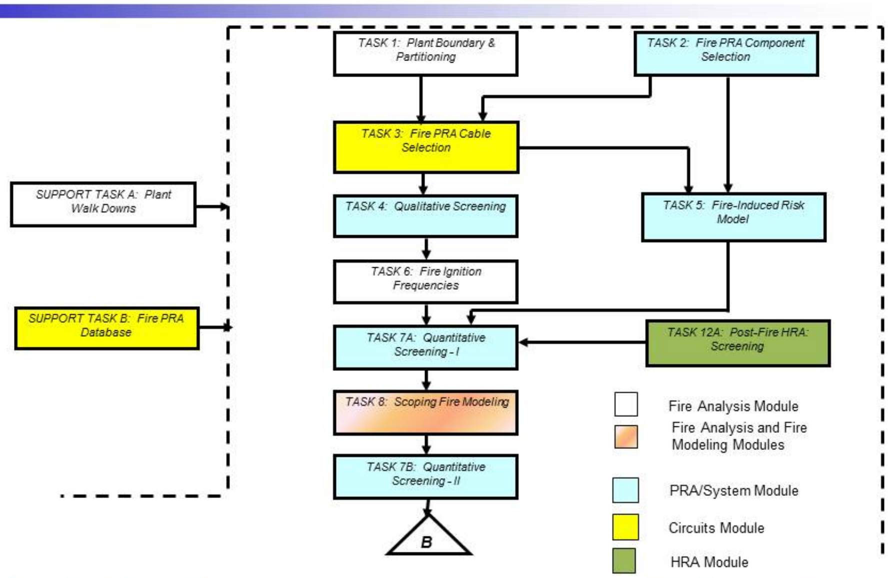
- The purpose of this presentation is to provide an Overview of the Module 3 – Fire Analysis
  - Scope of this module relative to the overall methodology
    - Which tasks fall under the scope of this module
  - General structure of the each technical task in the documentation
  - Quick introduction to each task covered by this module:
    - Objectives of each task
    - Task input/output
    - Task interfaces

Training Objectives

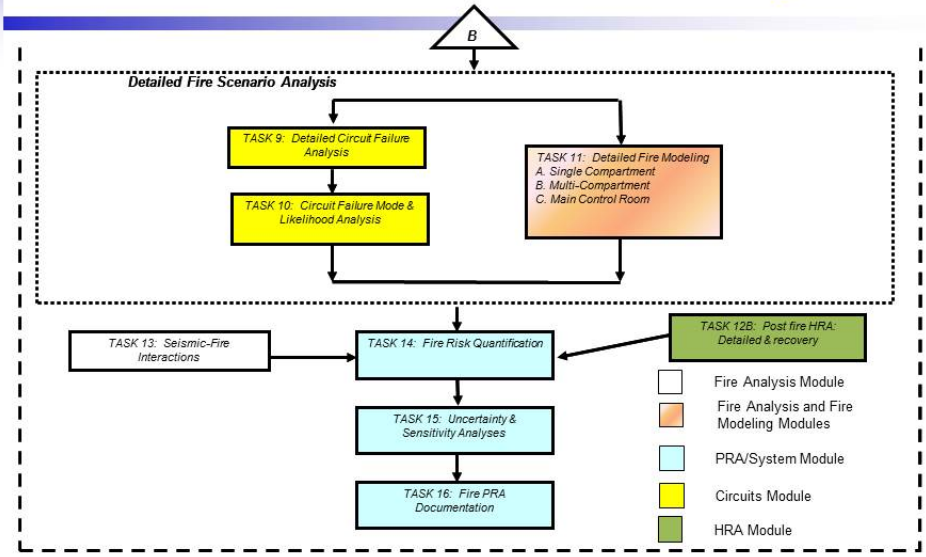
- Our intent:
  - To deliver practical implementation training
  - To illustrate and demonstrate key aspects of the procedures

- We expect and want significant participant interaction
  - Class size should allow for *questions and discussion*
  - We will take questions about the *methodology*
  - We *cannot* answer questions about a *specific application*
  - *We* will moderate discussions, and *we* will judge when the course must move on

Recall the overall fire PRA structure
Module 3 covers tasks in white and white/orange



Recall the overall fire PRA structure (2)
Module 3 covers tasks in white and white/orange



Each technical task has a common structure as presented in the guidance document

1. Purpose
2. Scope
3. Background information: General approach and assumptions
4. Interfaces: Input/output to other tasks, plant and other information needed, walk-downs
5. Procedure: Step-by-step instructions for conduct of the technical task
6. References

Appendices: Technical bases, data, examples, special models or instructions, tools or databases

Scope of Module 3: Fire Analysis

- This module covers those parts of the method specifically related to the identification and analysis of fires, fire damage, and fire protection systems and features

- Tasks covered are:
  - Task 1: Plant Partitioning
  - Task 6: Fire Ignition Frequency
  - Task 8: Scoping Fire Modeling
  - Task 11: Detailed Fire Scenario Analysis
  - Task 13: Seismic/Fire Interactions (briefly)
  - Support Task A: Plant Walkdowns

Task 1: Plant Partitioning (1 of 3)

Module 3

- Objectives:
  - Define the global analysis boundary of the FPRA
  - Divide the areas within the global analysis boundary into fire compartments
- The fire compartments become the "basic units" of analysis
  - Generally we screen based on fire compartments
  - Risk results are often rolled up to a fire compartment level
- A note on terminology:
  - The PRA standard uses "physical analysis units" rather than "fire compartments"
  - Definitions are quite similar, overall role in analysis is identical
    - Don't let the terminology difference trip you up – intent is the same

Task 1: Plant Partitioning (2 of 3)

Module 3

- The global analysis boundary is intended to be a liberal definition of the region potential interest
  - It will likely encompass areas of essentially no risk, but that is OK, screening steps will identify these
- The fire compartments are a matter of analysis convenience
  - Fire compartments may equal fire areas if you so choose
  - You can also subdivide fire areas into multiple compartments
  - The sum of the fire compartments must equal the global analysis boundary
    - No omissions, no overlap between compartments

Task 1: Plant Partitioning (3 of 3)

Module 3

- Ultimately, the FPRA is expected to provide some resolution to each defined fire compartment and to all locations within the global analysis boundary
- Module will cover:
  - Guidance and criteria for defining the global analysis boundary
  - Guidance and criteria for defining fire compartments
- Ultimately, there is not a lot of new guidance in this task
  - A lot like what was done in the IPEEE days

Task 6: Fire Ignition Frequency (1 of 3) Module 3

- Objective: To define fire frequencies suitable to the analysis of fire scenarios at various stages of the FPRA
- Fire frequencies will be needed at various resolutions:
  - An entire fire area
  - A fire compartment (or physical analysis unit)
  - A group of fire ignition sources (e.g., a bank of electrical cabinets)
  - A single ignition source (e.g., one electrical panel)

Task 6: Fire Ignition Frequency (2 of 3) Module 3

- Task begins with generic industry-average statistics on fire
  - EPRI fire event database
  - Events filtered for applicability and sorted into ignition source bins
  - Plant-wide fire frequency is provided for each bin
- The real "trick" is to convert the generic values into values specific to your plant and to a given fire scenario
  - Approach is based on ignition source counting and apportionment of the plant-wide frequency based on local population

Task 6: Fire Ignition Frequency (3 of 3)

Module 3

- Quite a bit is new relative to fire frequency:
  - The fire event data have been re-analyzed entirely to suit the new method
    - That means older IPEEE-vintage frequencies are obsolete
  - There has been a switch towards component-based fire frequencies and away from generic room-based fire frequencies
  - Some areas have received special treatment
    - e.g., main control room

Task 8: Scoping Fire Modeling (1 of 2)

Module 3

- Objective: To identify (and screen out) fire ignition sources that are non-threatening and need not be considered in detailed fire modeling
- Non-threatening means they cannot:
  - Spread fire to other combustibles, or
  - Damage any FPRA equipment item or cable

Task 8: Scoping Fire Modeling (2 of 2)

Module 3

- Scoping fire modeling introduces a number of key concepts associated with the treatment of fire sources and damage targets
  - The Fire Severity Profile approach
  - Damage criteria for cables and equipment
  - Assumptions associated with specific fire sources

Task 11: Detailed Fire Modeling (1 of 3)

Module 3

- Objective: To identify and analyze specific fire scenarios
- Divided into three sub-tasks:
  - 11a: General fire compartments (as individual risk contributors)
  - 11b: Main Control Room analysis
  - 11c: Multi-Compartment fire scenarios

Task 11: Detailed Fire Modeling (2 of 3)

Module 3

- Task 11 involves many key elements
  - Selection of specific fire scenarios
    - Combinations of fire sources and damage targets
  - Analysis of fire growth/spread
    - Application of fire models
  - Analysis of fire damage
    - Time to failure
  - Analysis of fire detection and suppression

Task 11: Detailed Fire Modeling (3 of 3)

Module 3

- Task 11 comes with a wide range of supporting appendices including:
  - Specific fire sources such as high energy arc faults, turbine generator fires, and hydrogen fires
  - Treatment of fire severity and severity factors
  - Treatment of manual fire suppression
  - Treatment for main control board fires
- Module will cover key appendices

Task 13: Seismic/Fire Interactions

Module 3

- Objective: A *qualitative* assessment of potential fire/seismic interactions
- Module will cover this task *briefly*
  - No significant changes from IPEEE guidance (e.g., the Fire PRA Implementation Guide)

Any questions before we move on?

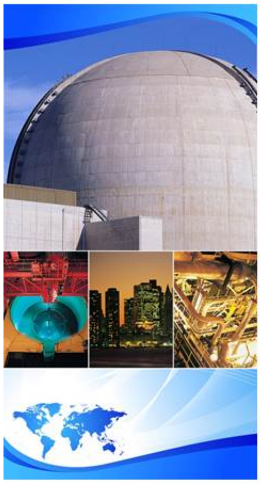
4.2 Task 1: Plant Partitioning

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation
From Science to Solutions



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III

Task 1: Plant Partitioning

Joint RES/EPRI Fire PRA Workshop
July and September 2012
Washington, DC

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

Plant Partitioning
Scope (per 6850/1011989)

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

Corresponding PRA Standard Element

- Task 1 maps to element PP – Plant Partitioning
  - PP Objectives (per the PRA Standard):
    - To define the global analysis boundary
    - To define physical analysis units

PP HLRs (per the PRA Standard)

- HLR- PP-A: The Fire PRA shall define global boundaries of the analysis so as to include all plant locations relevant to the plant-wide Fire PRA (1 SR)

- HLR-PP-B: The Fire PRA shall perform a plant partitioning analysis to identify and define the physical analysis units to be considered in the Fire PRA (7 SRs)

- HLR-PP-C: The Fire PRA shall document the results of the plant partitioning analysis in a manner that facilitates Fire PRA applications, upgrades, and peer review (4 SRs)

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, operator actions HRA
- Walkdowns are generally a team activity so coordinate them to optimize personnel time and resources
- Corresponding PRA Standard SR: PP-B7

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
- May need to work closely with the cable routing experts to ensure coordination among the plant partitioning schemes.

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
- 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 the term used in the PRA standard
  - Meaning is essentially the same

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

Internal vs. external in PRA space and the implications of the Global Analysis Boundary

- The language here is changing!
- Historically we talked about "internal events" and "external events"
  - Terms used to mean that the failures setting off an accident sequence either occurred *internal* or *external* to plant *systems/components*
  - Fire attacks equipment from the outside versus random failures that occur within the system/component
  - Historically, fire was referred to as an external event
- The PRA standard used a different split:
  - Internal Hazards
  - External Hazards
- Under the standard internal fires are an internal hazard; external fires are an external hazard
- Key notion: The global analysis boundary defines the split between *internal* and *external* fires
  - 6850/1011989 deals with internal fires which are an internal hazard…

Task 1: Plant Partitioning
Task Input

- No real input from any other task is required (it is, after all, Task 1)
  - You may also find yourself iterating back to this task later in the analysis – that is fine, just be careful to track any changes
  - A word of Caution: Many things will be traced and assigned based on the fire compartments. If you change partitioning decisions later, there are consequences relative to information tracking
- 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 <u>and</u> elevation drawings are helpful
  - You *will* need to do a walkdown to support/verify decisions

Task 1: Plant Partitioning
Task Breakdown in Steps

- Task 1 has four steps:

Step 1: Selection of Global Plant Analysis Boundary

Step 2: Plant Partitioning

Step 3: Compartment Information Gathering and Characterization

Step 4: Documentation

Task 1: Plant Partitioning
Step 1:Selection of Global Plant Analysis Boundary

- We generally recommend 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
  - Alternative is to explain choices/exclusions in documentation
- Encompass all areas of the plant associated with both normal and emergency reactor operating including support systems and power production
- Sister Units should be included unless they are physically and functionally separated
  - Separated means: no shared areas, no shared systems, no shared components and associated cables, no conjoined areas (e.g., shared walls)

Task 1: Plant Partitioning
Selection of Global Plant Analysis Boundary

- 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 the Global Analysis Boundary to capture it
- Corresponding PRA Standard SR: PP-A1

Task 1: Plant Partitioning
Selection of Global Plant Analysis Boundary

- *Problem Set 01-01 (file: 05_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

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

- 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.

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments

- 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?

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments

- 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!
- Corresponding PRA Standard SR: PP-B6

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments

- 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
- Corresponding PRA Standard SR: PP-B1

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments

- It is not recommended to partition based on:
  - Radiant energy shields
  - Beam pockets
  - Equipment obstructions (e.g., pipes)
  - (per Fire PRA Standard: Raceway or other localized fire barriers *cannot be credited* in partitioning)
- Spatial separation credited as partitioning scheme requires justification.
- Corresponding PRA Standard SRs: PP-B2, B3, B4 and B5

- *Problem Set 01-02 (file: 05_01_01…)*

Task 1: Plant Partitioning
Plant Partitioning into Fire Compartments

- 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 routing database, etc.

Task 1: Plant Partitioning
Step 3: Compartment Information Gathering

- 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
  - Identification of all adjacent compartments
  - Access routes to the fire compartment

Task 1: Plant Partitioning
Compartment Information Gathering

- A thorough plant walkdown is needed to confirm and gather information about each fire compartment
- It is unlikely that all information will be collected and documented during the first pass
- 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

Task 1: Plant Partitioning
Summary

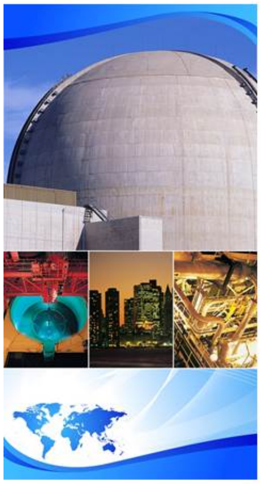
- Plant Partitioning is the first step of fire PRA.

- 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.

Mapping HLRs & SRs for the PP Technical Element to NUREG/CR-6850, EPRI TR 1011989

Technical Element	HLR	SR	6850 Sections	Comments
PP	A	The Fire PRA shall define global boundaries of the analysis so as to include all plant locations relevant to the plant-wide Fire PRA		
		1	1.5.1	
	B	The Fire PRA shall perform a plant partitioning analysis to identify and define the physical analysis units to be considered in the Fire PRA		
		1	1.5.2	
		2	1.3.2 and 1.5.2	
		3	1.3.2 and 1.5.2	
		4	1.3.2 and 1.5.2	Cable raceway fire barriers are not explicitly addressed in 6850
		5	1.3.2 and 1.5.2	
		6	1.5.2	
		7	1.4.3, 1.5.2 and 1.5.3	
	C	The fire PRA shall document the results of the plant partitioning analysis in a manner that facilitates Fire PRA applications, upgrades, and peer review		
		1	n/a	The requirements within these SRs are not specifically addressed in Section 1.5.4 of 6850.
		2	n/a	
		3	1.5.4	
		4	1.5.2	

4.3 **Task 6: Fire Ignition Frequency**



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Task 6: Fire Ignition Frequency

Joint RES/EPRI Fire PRA Workshop
July and September, 2012
Washington, DC

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

FIRE IGNITION FREQUENCIES
Purpose of Task 6 (per 6850/1011989)

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

Fire PRA Workshop, 2012, Washington DC
Task 6: Fire Ignition Frequency

Slide 2

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

Corresponding PRA Standard Element

- Task 6 maps to element IGN – Ignition Frequency
  - IGN Objectives (per the PRA Standard):
    - Establish the plant wide frequency of fires of various types on a generic basis for NPPs
    - Tailor the generic fire frequency values to reflect a particular plant
    - Apportion fire frequencies to specific physical analysis units, and/or fire scenarios

IGN HLRs (per the PRA Standard)

- HLR- IGN-A: The Fire PRA shall develop fire ignition frequencies for every physical analysis unit that has not been qualitatively screened (10 SRs)

- HLR-IGN-B: The fire PRA shall document the fire frequency estimation in a manner that facilitates Fire PRA applications, upgrades, and peer review (5 SRs)

Fire Ignition Frequencies
A note on terminology

- As we have explained (see Task 1 presentation) different documents use different terms
  - 6850/1011989 refers to “fire compartments”
  - The standard refers to “physical analysis units” or PAUs
- This makes no difference to the Task 6 fire frequency analysis
  - You are developing fire ignition frequencies for whatever set of fire locations you have defined
  - Whether you call it a fire area, fire compartment or PAU does not really matter – it is what is in that location that counts
    - The total frequency for any location is simply the sum of the frequencies for the ignition sources present in that location
  - Once you get to the scenario level (individual fire sources or fire source groups) the differences are totally irrelevant
    - You are estimating fire frequency for a very specific ignition source

FIRE IGNITION FREQUENCIES
Assumptions

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

- Frequencies remain constant over time
- Ignition source types are grouped into Ignition Source Bins
  - See Table 6-1, Bins 1-37 (e.g., electrical cabinets, motors, pumps…)
- Total plant-wide ignition frequency for each ignition source type is the same for all units in the U.S. fleet
  - Unit A at Plant X has the same plant-wide frequency of electrical cabinet fires as Unit B at Plant Y
- Within each plant, ignition frequency is the same for all individual items or equipment of the same type
  - e.g., At Unit A of Plant X, the fire frequency for electrical cabinet A is the same as the fire frequency for electrical cabinet B

FIRE IGNITION FREQUENCIES
General Approach

To establish the fire frequency of a fire compartment or PAU, the ignition frequencies associated with each ignition source present in the location are simply 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 PAU 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

- Corresponding PRA Standard SR: IGN-A7

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

- Plant level fire ignition frequencies are given for each ignition source bin, for example*:
  - Bin 21 gives 1.42E-02/ry as the frequency of fires within a unit that involve general pumps greater than 5hp
  - Bin 37 gives 3.4E-03/ry as the frequency of transient fuel fires (not associated with hot work) within the turbine building of a unit
- These values are then distributed to the individual members of each ignition frequency bin or to those locations covered by the bin

*Reference: These example values are taken from EPRI 1019259, NUREG/CR-6850 Supplement 1

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	[illegible]sel 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

Note that these slides use the original 6850/1011989 frequency table, not the updated table from the supplement.

Fire PRA Workshop, 2012, Washington DC
Task 6: Fire Ignition Frequency

Slide 9

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

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	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].16	0.84	0	0	0	0
11	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	1.0	0	0
14	[illegible]	[illegible]	[illegible]	[illegible]	1.0	0	0	0	0	0
15	[illegible]	[illegible]	[illegible]	[illegible]	1.0	0	0	0	0	0
20	[illegible]	[illegible]	[illegible]	[illegible]	0	0	0	0	1.0	0
27	[illegible]	[illegible]	[illegible]	[illegible]	1.0	0	0	0	0	
32	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].11	0.89	0	0	0	0

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

Note that these slides use the original 6850/1011989 frequency table, not the updated table from the supplement.

Fire PRA Workshop, 2012, Washington DC
Task 6: Fire Ignition Frequency

Slide 10

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

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

Table 6-1
Fire Frequency Bins and Generic Frequencies

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

Note that these slides use the original 6850/1011989 frequency table, not the updated table from the supplement.

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

Table 6-1
Fire Frequency Bins and Generic Frequencies

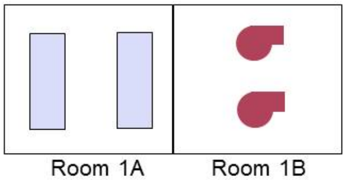
Ignition Source (Equipment Type)	Mode	Generic Freq (per rx yr)	Split Fractions for Fire Type: Electrical	Oil	Transient	Hotwork	Hydrogen	HEAF[1]
Batteries	All	7.5E-04	1.0	0	0	0	0	0
Reactor Coolant Pump	Power	6.1E-03	0.14	0.86	0	0	0	0
Transients and Hotwork	Power	2.0E-03	0	0	0.44	0.56	0	0
Main Control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

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

Note that these slides use the original 6850/1011989 frequency table, not the updated table from the supplement.

Fire Ignition Frequency Quantification

Single Unit Plant



Count	1A	1B	Total
Elec. Cab.	2		2
PMP		2	2

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{2} \cdot 1$$

$$\lambda_{room-1B} = \lambda_{pmp-i} \cdot N_{pmp} = \lambda_{pmp-i} \cdot 2$$

Fire Ignition Frequency Quantification

Two Units, Two Units in Scope

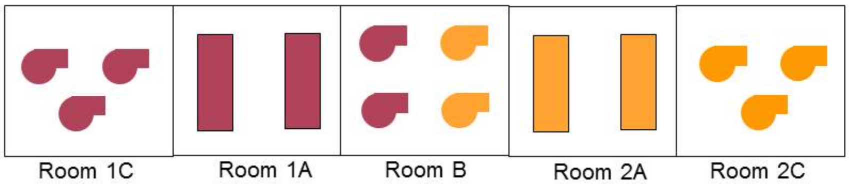
Count	1A	1B	2A	2B	Total
Elec. Cab.	2		2		4
Pump		2		2	4

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{4} \cdot 2$$

$$\lambda_{room-1B} = \lambda_{pmp-i} \cdot N_{pmp-1B} = \lambda_{pmp-i} \cdot 2$$

Fire Ignition Frequency Quantification

Two Units, Two Units in Scope, Shared Room

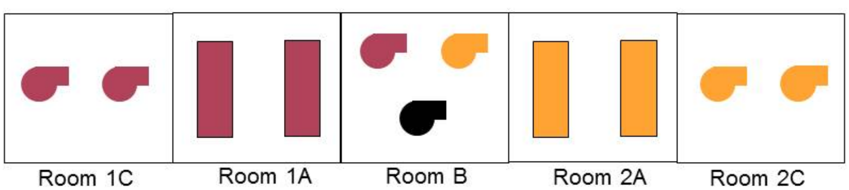


Count	1A	1C	2A	2C	B	Total
Elec. Cab.	2		2			4
Pump		3		3	4	10

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{10} \cdot 2 \qquad \lambda_{room-B} = \lambda_{pmp-i} \cdot N_{pmp-B} = \lambda_{pmp-i} \cdot 4$$

Fire Ignition Frequency Quantification

Two Units, Two Units in Scope, Shared Room, Swing Pump

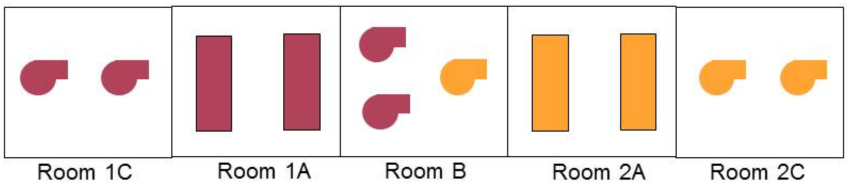


Count	1A	1C	2A	2C	B	Total
Elec. Cab.	2		2			4
Pump		2		2	3	7

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{7} \cdot 2 \qquad \lambda_{room-B} = \lambda_{pmp-i} \cdot N_{pmp-B} = \lambda_{pmp-i} \cdot 3$$

Fire Ignition Frequency Quantification

2 Units, One Unit in Scope, Shared Room



Count	1A	1C	2A	2C	B	Total
Elec. Cab.	2					2
Pump		2			2	4

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{4} \cdot 1 \qquad \lambda_{room-B} = \lambda_{pmp-i} \cdot N_{pmp-B} = \lambda_{pmp-i} \cdot 3$$

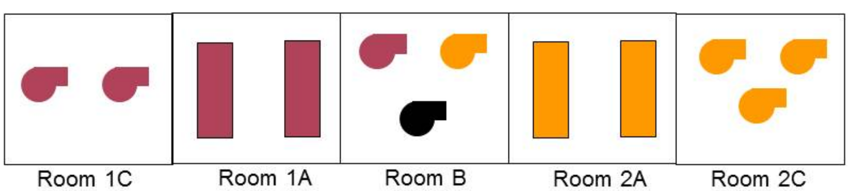
Fire PRA Workshop, 2012, Washington DC
Task 6: Fire Ignition Frequency

Slide 17

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

Fire Ignition Frequency Quantification

2 Units, One Unit in Scope, Shared Room, Swing Pump



Count	1A	1C	2A	2C	B	Total
Elec. Cab.	2					2
Pump		2			1.5	3.5

$$\lambda_{pmp-i} = \lambda_g \cdot W_{is} \cdot W_L = \lambda_g \cdot \frac{1}{3.5} \cdot 1 \qquad \lambda_{room-B} = \lambda_{pmp-i} \cdot N_{pmp-B} = \lambda_{pmp-i} \cdot 3$$

Fire PRA Workshop, 2012, Washington DC
Task 6: Fire Ignition Frequency

Slide 18

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

FIRE IGNITION FREQUENCIES
Procedure

Task 6 develops location and item specific fire frequency values for each fire frequency bin using an 8-step process:

- 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 (PAU) fire frequency evaluation.

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 within the global analysis boundary
    - Exclude items in locations that will be screened out qualitatively (e.g., the office building, the guard shack…)
- If no matching bin can be found for an ignition source, then the following approach may be used:
  - Consider the characteristics of the source and try to match to an existing ignition source bin and provide explanation
  - Consider past fire histories within the plant – if there is a history of fires, that may be enough to establish frequency
  - Consider relevant past fire histories for similar items at other plants
  - Consider fire history in other industries – with caution…
- *Problem Set 06-01 (file: 05_01_02…)*

FIRE IGNITION FREQUENCIES
Step 2. Plant Fire Event Data Collection

- Common practice is to perform a Bayesian update of the generic fire frequencies to reflect plant-specific fire experience
- You need to gather plant-specific fire event data to establish plant-specific fire ignition frequencies
  - Gather and review plant reports relating to fire events over some reasonable time period
    - 10-15 years if possible
    - Look at the "potentially challenging" screening criteria from 6850/1011989 and think about your events in the same context – are they risk-relevant or not?
  - First question to ask is "are plant specific fire ignition frequencies warranted?"
    - If the plant has experienced a repeated set of similar events
    - Events that cannot be mapped to a bin
  - Unusual fire occurrence patterns
  - May be selective in which plant specific frequencies are updated
- Corresponding PRA Standard SR: IGN-A4

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

Example:

- The following events have taken place at the unit under analysis over the past 10 years of plant operation:
  - Event 1: Fire in MCC-A because breakers were 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.
- Both events would map to "Electrical Cabinets – non HEAF"
  - Per NUREG/CR 6850/1011989 this is bin 15
  - EPRI 1019259 (Supplement 1 to NUREG/CR-6850) calls this bin 15.1
- A Bayesian update given 2 fires in 10 years will increase mean fire frequency from 0.024/ry to 0.084/ry

- *Problem Sets 06-02 and 06-03 (Examples) (file: 05_01_02…)*

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

- Again, Bayesian update approach is the accepted method used to estimate plant-specific fire ignition frequencies
  - PRA Standard endorses/requires Bayesian methods in the SR's related to formal data analysis
    - You'll find this in the Internal Events Section (Part 2) rather than the fire section (Part 4)
    - Look for the "DA" technical element
  - Uncertainty distributions of generic frequencies are used as the prior
  - Update does raise possible double-counting issue since same events identified in update may already be in the FEDB
    - Generally not considered a significant issue, but be aware…

- Corresponding PRA Standard SRs: IGN-A5, IGN-A6, and IGN-A10

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		

- Corresponding PRA Standard SR: IGN-A7
- *Problem Sets 06-04 and 06-05 (file: 05_01_02…)*

FIRE IGNITION FREQUENCIES
Step 6. Fixed Fire Ignition Source Counts

- To establish ignition source weighting factor, $W_{IS,J}$, for each PAU, it is necessary to obtain the total number of relevant items per bin.
  - For shared locations, entire site should be considered
    - i.e., At a multi-unit site with some shared equipment or locations it may actually be easier to count all of the units at once rather than individually
  - Visual examination is the recommended approach
    - Walk it down, look for ignition sources fitting each frequency bin
  - Document your efforts
    - Consider using walk-down forms, photos, drawings, record item tags/labels…
  - Strongly recommend a computerized database
  - Counting method varies for each bin
- Corresponding PRA Standard SR: IGN-A7

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. Don't count the individual cells 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 15– 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, . . .

FIRE IGNITION FREQUENCIES
Step 6. Related FAQs

There is one overarching FAQ related to fire frequencies:

- FAQ 08-0048 Fire Frequency Trends
  - Reference: ML092190457, EPRI1019259, NUREG/CR-6850 Supplement 1
  - Issue:
    - 6850/1011989 fire frequencies did not consider potential industry trends (i.e., towards reduced fire frequencies)
    - EPRI/Industry proposed that some ignition source bin fire frequencies have decreased based on analysis of post-1990 data
  - Resolution
    - A new set of generic frequencies has been calculated that weighs recent data (1991 forward) heavily
  - When selecting frequency values, be sure you know which set you are working from – pre- or post-FAQ 48
  - Also watch for updated frequencies within the next year…

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

A word of caution for FAQ 08-0048:

- Review the NRC staff position on FAQ 08-0048 (ML092190457)!
  - The NRC accepts use Fire PRAs conducted for NFPA 805 transition with one provision
  - The fire PRA and plant change evaluations must evaluate sensitivity of the risk and delta-risk results to change in fire frequency values (i.e., difference in results using original versus revised values)
  - Identify cases where the results sensitivity evaluation indicates a change in risk significance based on values used
    - e.g., what is acceptable with the new frequencies might not be acceptable with the original frequencies
  - For these cases the licensee must consider measures to provide additional defense-in-depth

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

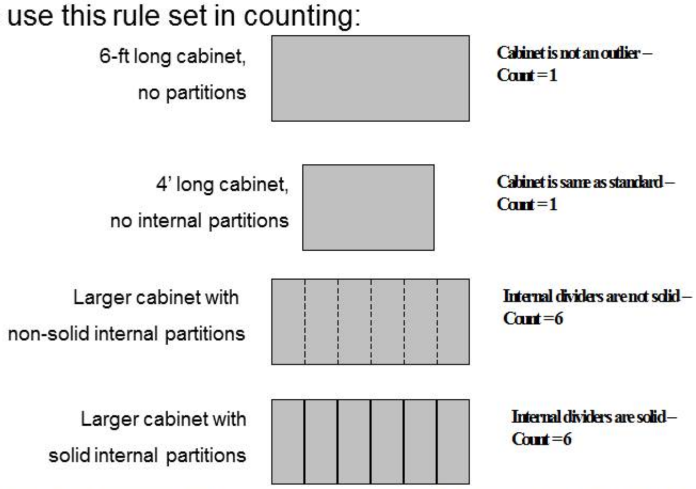
FAQ 06-0016 - Ignition source counting guidance for electrical cabinets

- Reference: ML072700475
- FAQ clarifies guidance on counting electrical cabinets and for treating "outlier" cabinets
  - Counting guidance gets applied to a wide range of panel sizes
  - Ignition frequency is more a function cabinet contents than cabinet size
  - A basis is needed to address outlier conditions
- Each user should establish criteria for identifying outliers and a basis for counting them
- Examples of possible rule-set approaches:
  - Establish a nominal 'standard' or reference cabinet size
  - Consider cabinet internals relative to a defined 'standard' or reference configuration

FIRE IGNITION FREQUENCIES
Step 6. FAQ06-0016 Example

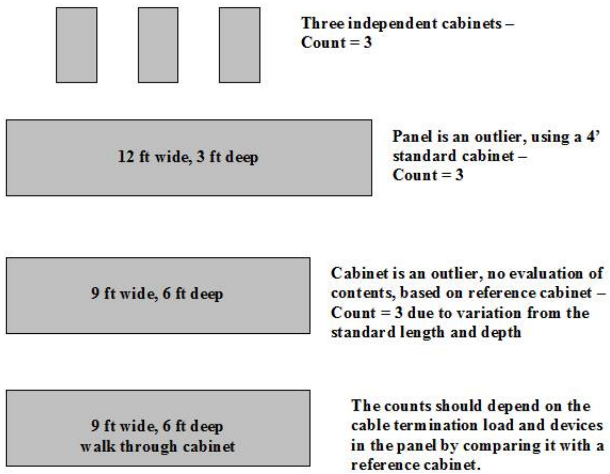
- A user defines a 'standard' cabinet as nominally 4' long x 3' deep and an outlier is any cabinet with any horizontal dimension more than 8'

How to use this rule set in counting:



FIRE IGNITION FREQUENCIES
Step 6. FAQ06-0016 Example (cont.)

How to count using example rule set…



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

FAQ 06-0017 - Ignition source counting guidance for high energy arcing faults in electrical switching equipment

- Reference: ML072500300, EPRI1019259, Supplement to NUREG/CR-6850
- Issue: Originally, all HEAF events were lumped in one ignition source bin (16) and was applied across all voltages (440V and up)
  - Resolution: Split Bin # 16 into 2 parts:
    - Bin 16a – Low-voltage panels (440 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 bin

* "Supp. 1" refers to NUREG/CR-6850 Supplement 1, EPRI TR 1019259.

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

- A caution: Fire ignition source Bin numbers and frequency basis (pre- and post-FAQ 48) for panel fire HEAFs vary among documents

Mapping of electrical panel HEAF frequency sets by source document

	Frequency calculation basis:	
Fire source binning basis:	Frequency based on full event set (1965-2000)	Frequencies updated using FAQ 48 approach
One Bin for all panel HEAF	NUREG/CR-6850 EPRI 1011989 (see Bin 16)	- FAQ 48 - EPRI 1016735 - Supp. 1*, Ch. 10 (see Bin 15.2)
Split Bins for panel HEAF based on voltage level	- FAQ 17 - Supp. 1*, Ch. 4 (see Bins 16a and 16b)	Not currently available

* "Supp. 1" refers to NUREG/CR-6850 Supplement 1, EPRI TR 1019259.

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

FAQ 06-0018 - Ignition source counting guidance clarification for Main Control Board (MCB)

- Reference: ML072500273, EPRI1019259, Supplement to NUREG/CR-6850
- There is a one-to-one correspondence between App. L and Bin 4
- Main Control Board is just the horseshoe (or equivalent)
- All other electrical cabinets in the Main Control Room should be counted with other cabinets in the plant

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

FAQ 06-0031: Ignition source counting guidance clarifications and extensions

- Reference: ML072840658, EPRI1019259, Supplement to NUREG/CR-6850
- Clarifies and modifies counting guidance for certain ignition source bins:
  - **Bin 14 – Electric motors**: clarifies guidance, provides for excluding small motors of 5 hp or less and totally enclosed motors.
  - **Bin 21 – Pumps**: provides for excluding small sampling pumps, and other pumps of 5 hp or less
  - **Bin 23 – Transformers**: provides for excluding dry transformers of 45 KVA or less
  - **Bin 26 – Ventilation subsystems**: clarifies that intent is to exclude small subsystems powered by motors of 5 hp or less (consistent with electric motors Bin 14)

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

FAQ 07-0035: High energy arc faults in bus ducts

- Reference: ML091620572, EPRI1019259, NUREG/CR-6850 Supplement 1
- Issue:
  - NUREG/CR-6850/EPRI 1011989 was silent on this topic
- Resolution:
  - Acknowledge the potential for such events (e.g., Diablo Canyon 5/2000)
  - Provides plant wide frequency and counting/partitioning guidance
  - Provides zone of influence and scenario development guidance
  - Two categories of bus duct are defined:
    - Segmented Bus Duct
    - Iso-Phase Bus Duct
  - Bins 16.1 and 16.2 in EPRI 1019259, and in Chapter 10 of Supplement 1

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

- A caution: There are two sets of frequency values for bus ducts (i.e., pre- and post-FAQ 48)

Mapping of electrical bus duct HEAF frequency sets by source document

	Frequency calculation basis:	
	Frequency based on full event set (1965-2000)	Frequencies updated using FAQ 48 approach
Source documents	- FAQ 35 - Supp. 1*, Ch. 7 (No bin numbers given)	- FAQ 48 - EPRI 1016735 - Supp. 1*, Ch. 10 (see Bins 16.1 and 16.2)

* "Supp. 1" refers to NUREG/CR-6850 Supplement 1, EPRI TR 1019259.

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

FAQ 08-0042: Cabinet Fire Propagation

- Reference: ML092110537, EPRI1019259, Supplement to NUREG/CR-6850
- Issue:
  - NUREG/CR-6850/EPRI1011989 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)
- Resolution:
  - FAQ clarifies and expands definition of "well-sealed and robustly secured cabinets" (which will not propagate fires)

FIRE IGNITION FREQUENCIES
Exercises

- *Problem Sets 06-06 and 06-07* *(file: 05_01_02…)*

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

- Ignition source weighting factors are evaluated for all the PAUs identified in Task 1 and for all ignition sources identified in Step 1 of this Task.
  - Countable items
    - Example: 2 pumps in compartment/PAU 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
- Corresponding PRA Standard SRs: IGN-A7, A9
- *Problem Sets 06-08, 06-09 and 06-10* *(file: 05_01_02…)*

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.
- Currently five rating levels are used:
  - No (0) - Can be used only for those PAUs where transients are precluded by design (administrative restrictions do not apply).
    - Corresponding PRA Standard SR: IGN-A9
  - 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).

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

Some notes regarding the weighting factor method

- It's all relative *within each of the applicable ignition source bins - DO* NOT weigh across bins; for example:
  - For transients in the turbine building (Bin 37), weigh locations in the turbine building against each other
  - For transients in the Aux/Control/Reactor building complex (Bin 7), weigh locations in that complex against each other
  - Do NOT compare the turbine building to the control building. That comparison is built into the base frequencies
- A ranking of **3** is considered Normal/Average!
- The method is designed to reflect real differences in the likelihood of these kinds of fires in different locations
  - You need to exercise the full range of ranking values to take full advantage of the method
  - Otherwise, frequency for each bin will be distributed evenly to each compartment

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

- Based on feedback from applications, an effort is ongoing that may lead to modified transient (and hot work) fire frequency weighting factors
  - This effort is NOT YET FINISHED – no method has yet been endorsed
  - The original method allows for roughly a factor of 70 between highest and lowest frequency rooms (a 50-10-10 room versus 1-0-0 room)
  - That range may increase if a revised method gains acceptance
- Under the proposed revision, the overall process remains largely the same
  - The ranking values may allow for fractional assignments (e.g., 0.1 or 0.5) but *only* to those rooms with *very* strict administrative controls
  - Maintenance may be split in two – hot work and other general maintenance
  - The formula for transients caused by hot work may be revised
- For now, the 6850/1011989 method is the method to use, but stay tuned for updates within the next year

FIRE IGNITION FREQUENCIES
Step 7. $W_{IS,J,L}$ – Transients (4)

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.

FIRE IGNITION FREQUENCIES
Step 7. $W_{IS,J,L}$ – Transients (5)

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 or PAUs 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 compartments or PAUs 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 or PAUs of location L)

- <u>Problem Set 06-11</u> *(file: 05_01_02…)*

Fire PRA Workshop, 2012, Washington DC
Task 6: Fire Ignition Frequency

Slide 45

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

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.

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

Where:

$\lambda_{J,L}$: Fire frequency associated with PAU 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

- Corresponding PRA Standard SR: IGN-A7

Fire PRA Workshop, 2012, Washington DC
Task 6: Fire Ignition Frequency

Slide 46

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

FIRE IGNITION FREQUENCIES
Determination of Generic Fire Frequencies

- The generic fire frequencies are based on the collective experience of U.S. nuclear power industry.
  - Uncertainties
    - Consistency among plants reporting practices,
    - Completeness of event descriptions
    - Etc.
  - Two stage Bayesian approach
  - EPRI Fire Event Database (FEDB) up to December 31, 2000
  - Analysis of each event
- Corresponding PRA Standard SRs: IGN-A1, A5, A10
- Also review FAQ 08-0048 - Fire Ignition Frequency

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

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

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

FIRE IGNITION FREQUENCIES
Reactor Years

- For each plant, two time periods were established:
  - Power production mode and
  - Low power or shutdown mode
- In analysis of data:
  - 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
- Corresponding PRA Standard SR: IGN-A5

FIRE IGNITION FREQUENCIES
Generic Fire Ignition Frequencies

Fire Ignition Bin Adjusted Counts and Associated Reactor Years				
	1968-1990		1991-2000	
Bin #	Counts	Rx Yrs	Counts	Rx Yrs
1	1	1376.2	0	1075.3
2	5.5	641.2	1	585.6
3	2.1	641.2	1.2	585.6
4	4.5	1376.2	0.5	1075.3
5	0	994.9	1.8	861.5
6	10.5	994.9	1.7	861.5
7	2.2	994.9	4.5	861.5
8	43	1376.2	5	1075.3
9	0.5	1376.2	4.5	1075.3
10	3	1376.2	1	1075.3
11	2	994.9	0.5	861.5
12	10.5	1376.2	1	1075.3
13	5.5	1376.2	0	1075.3

Note: The industry generic plant-wide fire frequency values presented in Appendix C of NUREG/CR-6850/1011989 and in Chapter 10 of EPRI 1019259 were developed using a method consistent with PRA Standard requirements IGN-A1, A5, and A10.

FIRE IGNITION FREQUENCIES
Concluding Remarks

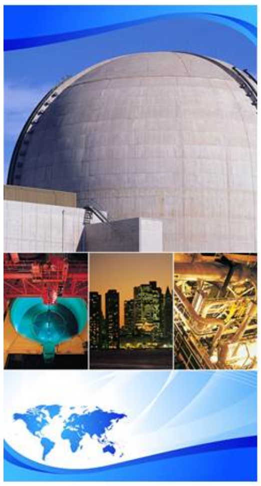
Fire ignition frequency evaluation (Task 6) uses a mix of plant specific and generic information to establish the ignition frequencies for specific fire compartments or PAUs and from that for specific fire scenarios.

- 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 fire compartment or PAU

Mapping HLRs & SRs for the IGN Technical Element to NUREG/CR-6850, EPRI TR 1011989

Technical element	HLR	SR	6850 sections	Comments
IGN	A	The Fire PRA shall develop fire ignition frequencies for every physical analysis unit that has not been qualitatively screened.		
		1	Appendix C	The generic frequencies have been modified in EPRI 1019259 to reflect changes in fire event frequency trends. The methodology used in that study is also consistent with this SR.
		2	6.5.1	
		3	n/a	Using engineering judgment to establish a frequency is not addressed in 6850/1011989.
		4	6.5.2, 6.5.3	
		5	6.5.3 and Appendix C	The generic frequencies of EPRI 1019259 are also consistent with this SR.
		6	6.5.3	
		7	6.5.1, 6.5.4, 6.5.5, 6.5.6, 6.5.7	
		8	n/a	Although it is effectively implied in Section 6.5.7.2, this SR is not explicitly discussed in 6850/1011989.
		9	6.5.7	Inherent in transient weighting factor ranking approach
		10	6.5.3, Appendix C	Generic frequencies consistent with this SR
	B	The Fire PRA shall document the fire frequency estimation in a manner that facilitates Fire PRA applications, upgrades, and peer review.		
		1	n/a	Documentation is covered in minimal detail in 6850/1011989
		2	n/a	
		3	n/a	
		4	n/a	
		5	n/a	

4.4 Appendix G: Heat Release Rates



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Appendix G: Heat Release Rates

Joint RES/EPRI Fire PRA Course
July and September, 2012
Washington, DC

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

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 NPPs
3. Describe the method provided for developing heat release rate profiles for fixed and transient ignition sources in NPPs

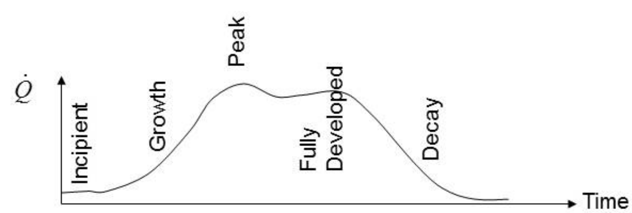
NOTE: Appendix G recommends values for ignition sources only. Heat release rates associated with fires propagating outside of the ignition source have to be evaluated accordingly.

Fire PRA Workshop, 2012, Washington, DC
Module III: Appendix G - Heat Release Rates
Slide 2
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)11

HEAT RELEASE RATES
Definition

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

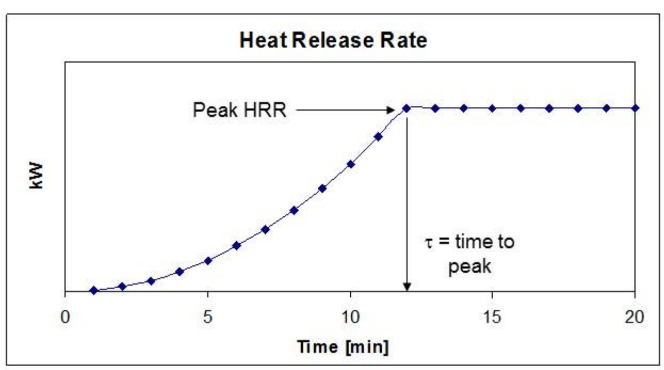
- $\dot{Q} = \dot{m}'' \cdot \Delta H_c \cdot A$ BTU/sec or KW
- m" is burning rate [kg/s-m^2], ΔH_c is heat of comb [kJ/kg], A is area [m^2]
- Equivalent terms: energy release rate, fire intensity, fire power
- HRR profile describes fire intensity as a function of time



HEAT RELEASE RATES
Fire Growth in Electrical Cabinets

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

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



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 be the peak heat release rate of the profile
- Decay: In general, less hazardous conditions than the growth and fully developed stage

FAQ 08-0052: Transient Fires

- This FAQ asked two questions:
  - Clarify which manual suppression curve applies to transient fires in the MCR
  - Clarify and update guidance provided for treatment of transient fires growth times
- Reference:
  - EPRI 1019259, NUREG/CR-6850 Supplement 1

FAQ 08-0052: Solution

- Answer to the first question:
  - Use the MCR non-suppression probability curve for <u>ALL</u> fires in the main control room
    - e.g., electrical fires, transient fires, …

FAQ 08-0052: Solution

- Answer to the second question covers three types of transient fires:
  - Common trash can (refuse in a trash receptacle):
    - Can be associated with a t^2 fire growth that grows from zero to peak in approximately 8 minutes.
  - Common trash bag (refuse in plastic bags not in a recepticle):
    - Can be associated with a t^2 fire growth that grows from zero to peak in approximately 2 minutes.
  - Flammable or combustible liquid spills:
    - Negligible growth time (near infinite growth rate)
    - Assume peak heat release rate for the spill through the entire duration of the fire (ignition through burnout)

FAQ 08-0044: MFW pump fires

- FAQ questioned application of pump fire guidance to MFW pumps
  - Spill of very large oil volume led to unrealistic (high) frequency for very large oil fires
- Solution provides a new approach for MFW pumps:
  - Determine the amount of oil available in the system for the large and very large oil spill fires. The MFW pump oil fire plant-wide fire frequency remains unchanged.
  - Assign a severity factor of 0.0034 (0.34%) to *very large fires: scenarios involving 100% of* the total oil inventory spilled and ignited.
  - Assign a severity factor of 0.0306 (3.06%) to *large fires: scenarios involving 10% of the* total oil inventory spilled and ignited.
  - Assign a severity factor of 0.966 (96.6%) for *small fires: scenarios involving a leak that leads* to a fire that only impacts the MFW pump.

  - Reference:
    - EPRI 1019259, Supplement to NUREG/CR-6850.

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 using the equation $\dot{Q} = \dot{m}'' \cdot \Delta H_c \cdot A$
- Separate guidance for cables, pressurized oil and hydrogen fires

HEAT RELEASE RATES
Recommended Peak HRR Values

Recommended peak HRR values were developed based on expert judgment

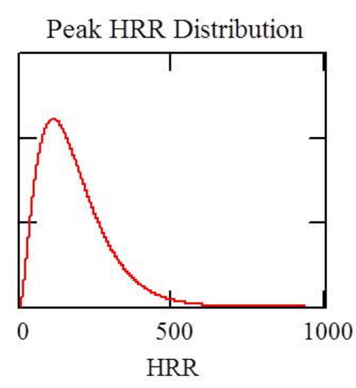
- Expert panel included the EPRI/NRC-RES Fire Risk Re-quantification Study research team with expertise in fire behavior/phenomena.
- Values are expressed as probability distributions. The panel identified the 75th and 98th percentiles of the distribution for peak HRR.
- Primary sources of information included NUREG/CR-4527 and VTT publications
- Gamma distribution selected:
  - Only positive values starting at 0 kW
  - Values in the same order of magnitude
- Corresponding PRA Standard SR: FSS-D5, E3

Fire PRA Workshop, 2012, Washington, DC
Module III: Appendix G - Heat Release Rates
Slide 11
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)11

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



Fire PRA Workshop, 2012, Washington, DC
Module III: Appendix G - Heat Release Rates
Slide 12
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)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

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/CR-4527

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

HEAT RELEASE RATES
Assigning HRR Values to Electrical Cabinets

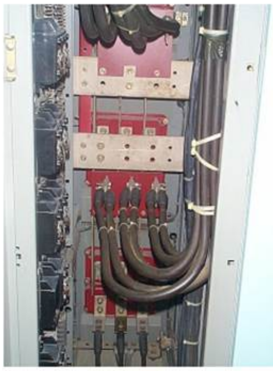
A visual examination of the interior of the cabinet is recommended

- 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

HEAT RELEASE RATES
Examples

By visual examination:

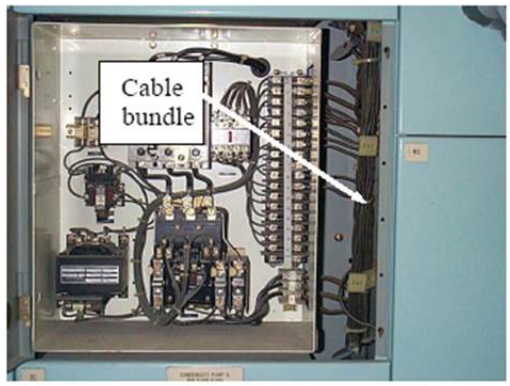
- More than one cable bundle
- Assuming qualified cable, select distribution with percentiles:
  - 75^{th} = 211 kW
  - 98^{th} = 702 kW



HEAT RELEASE RATES
Examples

By visual examination:

- Only one cable bundle
- Assuming qualified cable, select distribution with percentiles:
  - 75th = 69 kW
  - 98th = 211 kW



FAQ 08-0042: "Fire Propagation From Electrical Cabinets"

- Purpose & Scope
  - Provide clarification on conflicting language in NUREG/CR-6850 related to the description of fire propagation from unvented cabinets
    - Guidance in Appendix G is in conflict with the guidance in chapters 6 and 11 of NUREG/CR-6850
  - The scope of this FAQ is limited to the clarification of the conflicting guidance provided in NUREG/CR-6850 related to fire propagation outside unvented cabinets.
  - Reference:
    - EPRI 1019259, Supplement to NUREG/CR-6850.

FAQ 08-0042: Solution

- Chapter 11 of NUREG/CR-6850 provides the consensus position on fire propagation outside of unvented cabinets
  - The following, from the second paragraph on section G.3.3 should be disregarded:

Electrical cabinets that are not vented do not propagate a fire. … It is assumed that in the absence of other ventilation *(other than those listed in Table G.3)*, penetrations will not allow sufficient air exchange to replace oxygen consumed by the fire, and an incipient fire will self-extinguish when there is no longer enough oxygen to support combustion. [Italics added for clarity.]

FAQ 08-0042: Solution

- Modified language includes description of electrical cabinet features that should be present to prevent fire propagation outside the cabinet.
  - Fire sealed (not fire rated) at cable entry points
  - No vents
  - Robustly secured

FAQ 08-0043: "Location of Fires Within Electrical Cabinets"

- Purpose & Scope
  - This FAQ provides clarification on the location of fires within an electrical cabinet.
  - The scope of this FAQ is limited to describing the location of a fire postulated in an electrical cabinet in a Fire PRA.
- Reference:
  - EPRI 1019259, Supplement to NUREG/CR-6850.

FAQ 08-0043: Solution

- For cabinets with no vents, the fire should be postulated approximately 1' below the top of the cabinet
- Analysts should inspect cabinets to determine vent location or the possibility of door openings.
  - For vented cabinets, fires should be postulated at the location of the vents
  - Fire should be postulated at the top of open doors

HEAT RELEASE RATES
Transient Ignition Sources

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

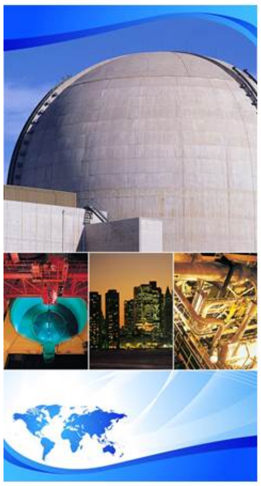
- Gamma distribution percentiles:
  - 75^{th} = 135 BTU/s, 98^{th} = 300 BTU/s (142 & 317 kW respectively)
  - $\alpha = 1.9$, $\beta = 53.7$
- Applicable only to localized transient combustibles (trash cans, etc.)
- Not applicable to flammable liquid transient fires

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

4.5 Appendix E: Fire Severity



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Appendix E: Fire Severity

Joint RES/EPRI Fire PRA Course
July and September, 2012
Washington, DC

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

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
- Applicable SRs: FSS-C2, C3, C4,

Fire PRA Workshop, 2012, Washington, DC
Module III: Appendix E: Fire Severity

Slide 2

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

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*.

FIRE SEVERITY
Severity Factor Concept

HRR (kW)	Probability	Probability of exceeding	Damage?
11	0.445	1.000	No
36	0.219	0.555	No
61	0.129	0.336	No
87	0.078	0.207	No
112	0.048	0.129	Yes
137	0.030	0.081	Yes
162	0.019	0.051	Yes
187	0.012	0.032	Yes
212	0.007	0.020	Yes
237	0.005	0.013	Yes
262	0.003	0.008	Yes
287	0.002	0.005	Yes
312	0.001	0.003	Yes
337	0.001	0.002	Yes
405	0.001	0.001	Yes
Total	1.000		

$\lambda_{damage} = \lambda_{Fire} \times 0.129$

FIRE SEVERITY
Severity Factor Concept

HRR (kW)	Probability P_i	Probability of exceeding	Damage	t_s (min)	$P_{NS,i}$	$P_i P_{NS,i}$
11	0.445	1.000	No	No Damage	0.0	0.0E+00
36	0.219	0.555	No	No Damage	0.0	0.0E+00
61	0.129	0.336	No	No Damage	0.0	0.0E+00
87	0.078	0.207	No	No Damage	0.0	0.0E+00
112	0.048	0.129	Yes	28	0.03	1.7E-03
137	0.030	0.081	Yes	24	0.06	1.7E-03
162	0.019	0.051	Yes	20	0.09	1.7E-03
187	0.012	0.032	Yes	16	0.15	1.8E-03
212	0.007	0.020	Yes	13	0.21	1.5E-03
237	0.005	0.013	Yes	11	0.27	1.3E-03
262	0.003	0.008	Yes	9	0.34	1.0E-03
287	0.002	0.005	Yes	7	0.43	8.6E-04
312	0.001	0.003	Yes	5	0.55	5.5E-04
337	0.001	0.002	Yes	3	0.70	7.0E-04
405	0.001	0.001	Yes	1	0.89	8.9E-04
Total	1.000					0.014

* t_s: Time available for suppression

** P_{NS} = Prob. of non-suppression = $\exp(-\lambda t_s)$

ts = time do damage – time to detection

$$\lambda_{damage} = \lambda_{Fire} \times 0.014$$

Fire PRA Workshop, 2012, Washington, DC

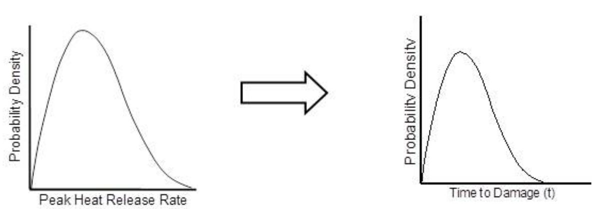
Module III: Appendix E: Fire Severity

Slide 5

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

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



Fire PRA Workshop, 2012, Washington, DC

Module III: Appendix E: Fire Severity

Slide 6

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

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

Fire PRA Workshop, 2012, Washington, DC
Module III: Appendix E: Fire Severity
Slide 7
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

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

Fire PRA Workshop, 2012, Washington, DC
Module III: Appendix E: Fire Severity
Slide 8
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

FIRE SEVERITY
Severity Factor for Oil Spill Fires

- The severity factors for oil spills are recommended to be established from the following steps:
  1. Determine the amount of oil that can be spilled in the room.
  2. Assign a severity factor of 0.02 to a scenario consisting of 98% or more of the amount of oil spilled and ignited.
  3. Assign a severity factor of 0.98 to a scenario consisting of 10% of the amount of oil spilled and ignited.

- Note that a modified approach for the MFW pump oil fire was developed via FAQ 07-0044
  - See presentation on Appendix G for details

FIRE SEVERITY
Severity Factor for Other Ignition Sources

- The following notes address ignition sources not covered in the preceding discussions:
  - Cable fires:
    - Heat release rate is established using fire propagation modeling
    - Severity factor = 1.0 may be used where target damage can be ascertained
  - High-energy arcing faults:
    - Severity factor = 1.0 within zone of influence
  - Catastrophic transformer fires in the transformer yard:
    - Severity factor = 1.0 within zone of influence
  - Non-catastrophic transformer fires in the transformer yard:
    - Generally not modeled, otherwise use severity factor = 1.0 within zone of influence
  - Other fires in the transformer yard:
    - Depending on the item burning, the heat release rate of similar devices may be used.

FIRE SEVERITY
Frequency Bins and HRR Distributions

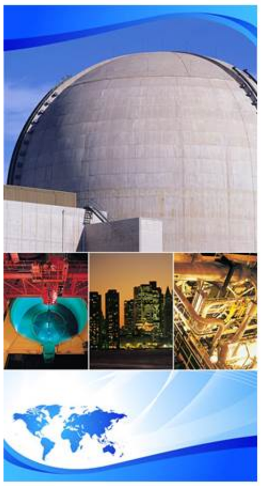
Table 11-1
Recommended Severity Factors . . . for Ignition Sources in the Frequency Model

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

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

4.6 <u>Appendix H: Damage Criteria</u>



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Appendix H: Damage Criteria

Joint RES/EPRI Fire PRA Course
July and September, 2012
Washington, DC

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

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 time scale 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)
- Corresponding PRA Standard SRs: FSS-C5, C6 and D9

Fire PRA Workshop, 2012, Washington, DC
Module III: Appendix H: Damage Criteria

Slide 2

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

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

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

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)

Damage Criteria
Damage Thresholds

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

Table H-1 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)

- And electronics:
  - 3 kW/m^2 (0.25 BTU/ft^2) and 65°C (150°F)
  - If needed, assume ignition properties same as thermoplastic cables:
    6 kW/m^2 (0.5 BTU/ft^2) and 205°C (400°F).

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, I/C, 600 V	385-388
Samuel Moore	Dekoron 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	394
Okonite	Okonite Okolon, EPR Insulation, CSPE Jacket, 12 AWG, I/C, 600 V	387

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?

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

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

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
- Corresponding PRA Standard SR: FSS-D9

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

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

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 are 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

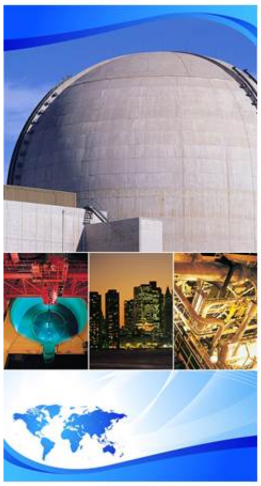
4.7 Task 8: Scoping Fire Modeling & Appendix F

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation
From Science to Solutions



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III:
Task 8: Scoping Fire Modeling & Appendix F

Joint RES/EPRI Fire PRA Course
July and September, 2012
Washington, DC

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

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 walkdown
- Review the walkdown forms
- Describe how to update the fire ignition frequencies calculated in Task 6 with the screening results

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

SCOPING FIRE MODELING
Screening Ignition Sources

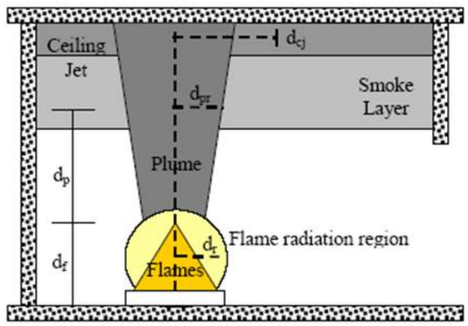
Any ignition source can be screened if a postulated fire will not damage or ignite equipment in the compartment.

- By screening the ignition source, its frequency contribution is eliminated, reducing the compartment frequency.
- It is recommended to use the 98th percentile of the probability distributions for peak HRR.
- A walkdown is strongly recommended.
  - Related SRs: FSS-D10, D11

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



SCOPING FIRE MODELING
Task 8: Recommended Steps

5 steps for conducting Task 8

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

SCOPING FIRE MODELING
Step 1: Preparation for Walkdown

It is recommended that walkdown forms be prepared for each compartment to be visited

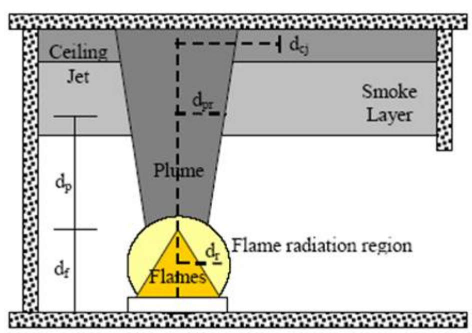
- Create a list of ignition sources in each compartment.
  - Equipment counted in Task 6
  - Flag equipment in the PRA equipment list created in Task 2
  - Assigned a HRR to each ignition source (98th percentile of the pdf)
- Workshop Problem 08-01 (file: 05_01_03… part 1)
- Collect damage criteria information for the equipment in the room
  - Qualified/Unqualified cables, solid state equipment etc.
- Workshop Problem 08-02 (file: 05_01_03… part 2)
- Develop and document zone of influences in each compartment
- Corresponding PRA Standard SRs: FSS-D10 and D11

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)

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**

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

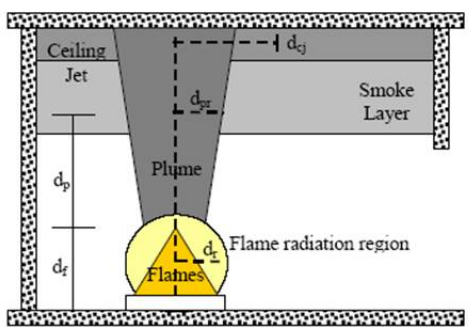
- Flame height and fire plume: Heskestad's models

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

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)

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

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

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

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

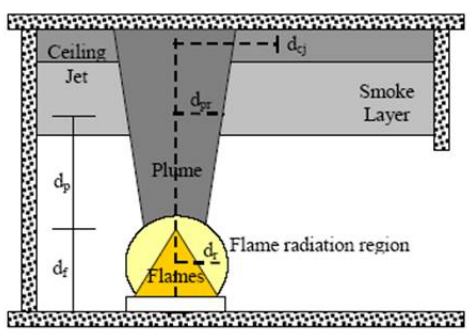
Heskdestad's Flame Height Correlation	
Inputs	
Fire diameter [m]	0.6
HRR [kW]	250
Results	[m]
Flame height [m]	**1.5**

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**

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)

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 (file: 05_01_03… part 3)

SCOPING FIRE MODELING
Step 2: Walkdown (Screen Ignition Sources)

During the walkdown, 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 (file: 05_01_03… part 4)

SCOPING FIRE MODELING
Step 3: Verify Screened Ignition Sources

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

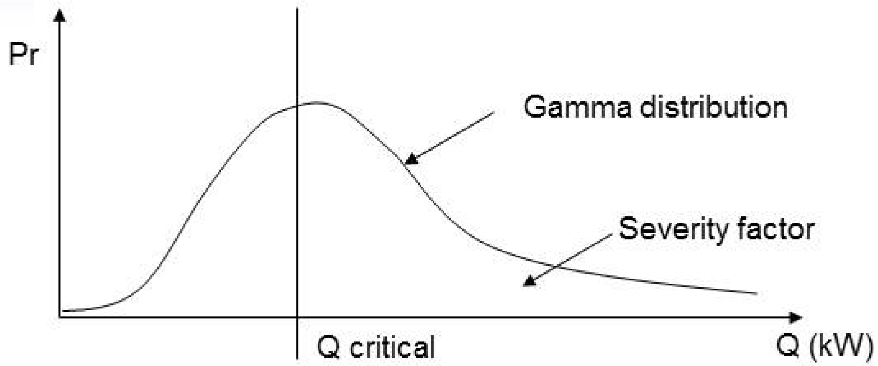
1. Do not screen equipment in the PRA equipment list
2. If loss of the ignition source results in a trip (automatic or manual), but no equipment contributing to the CCDP is lost, compare the ignition source fire frequency with the random frequency of the trip it causes.
3. If loss of the ignition source 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 (failure probability = 1.0).

SCOPING FIRE MODELING
Task 8: Calculation of Severity Factors

For each unscreened ignition source, calculate the severity factor using the appropriate probability distribution for peak HRR.

- Determine the heat release rate required for damaging equipment
- This require information gathered during the walkdowns!

SCOPING FIRE MODELING
Task 8: Calculation of Severity Factors



Case	Ignition Source	HRR kW (Btu/s) HRR	HRR kW (Btu/s) 98th	Gamma Distribution α	Gamma Distribution 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) Lower	Upper	Point Value	Severity Factor (P_i)
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)	0.015
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

- Workshop problem 08-05

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
					Adusted compartment frequency, λ_c =				3.7E-05

SCOPING FIRE MODELING
Concluding Remarks

Task 8 is intended for screening fixed ignition sources. As a result of the screening, the compartment frequencies may be reduced, and a preliminary list of potential fire scenarios for detailed evaluation in Task 11 is developed.

- A detailed walkdown is recommended
- Analysts should take the opportunity to review the equipment count made for Task 6 and/or improve it.

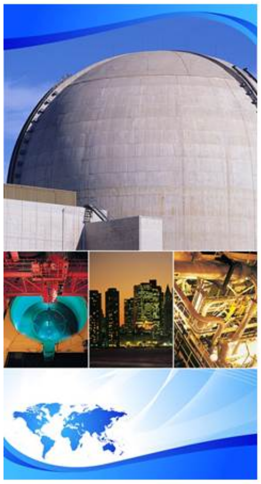
4.8 Task 11: Special Fire Models Part 1

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation
From Science to Solutions



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Task 11, Special Fire Models Part 1

Joint RES/EPRI Fire PRA Course
July and September 2012
Washington, DC

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

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

Joint Fire PRA Course, 2012, Washington, DC
Module III: Task 11, Special Fire Models Part 1
Slide 2
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

SPECIAL MODELS

- Cable fires (modified from IPEEE approaches)
  - Cable tray stack and fire spread models
- High energy arcing faults (new)
  - Switchgear room
- Fire propagation to adjacent cabinets (consolidation)
  - Relay room
- Passive fire protection features (consolidation)

SPECIAL MODELS (Part 2)

- Main control board (new)
- Hydrogen fires (new)
- Turbine generator fires (new)

CABLE FIRES

- 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

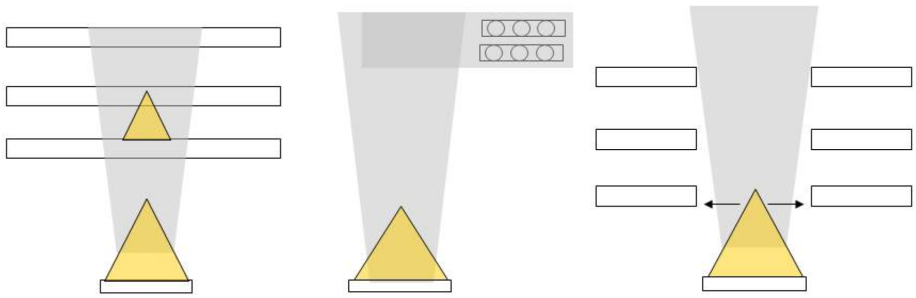
CABLE FIRES

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.

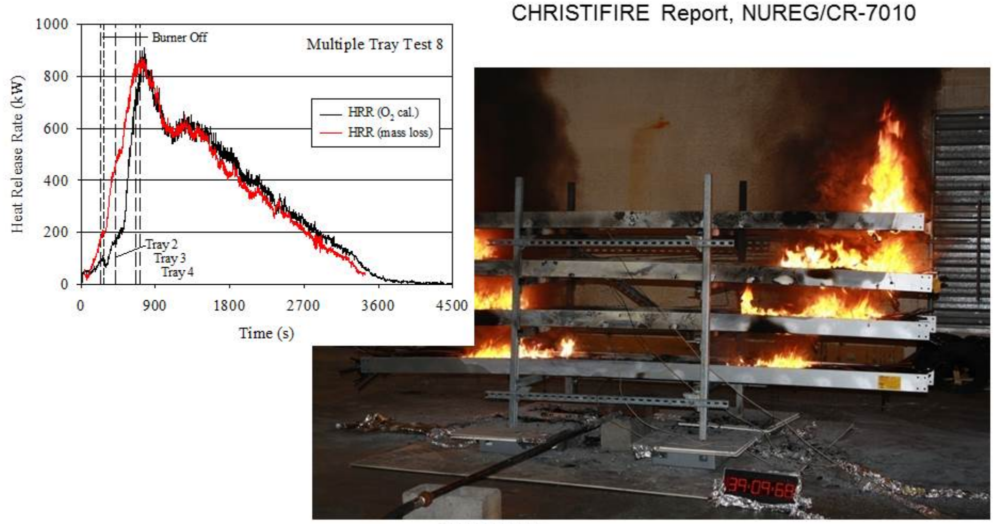
CABLE FIRES

Cable tray ignition: Simplified cases

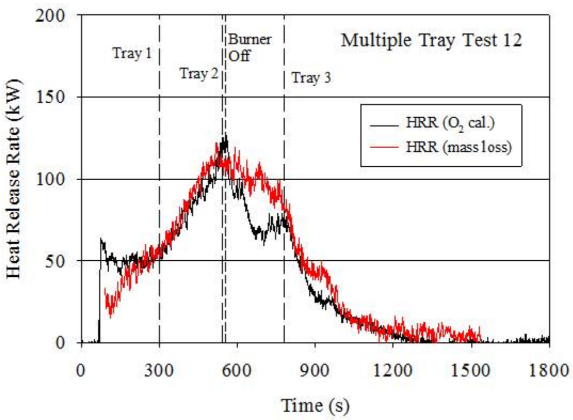


Thermoplastic Cable

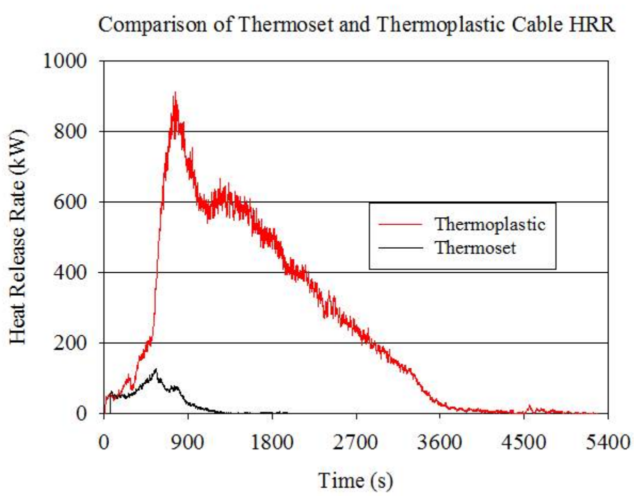
CHRISTIFIRE Report, NUREG/CR-7010



Thermoset Cable

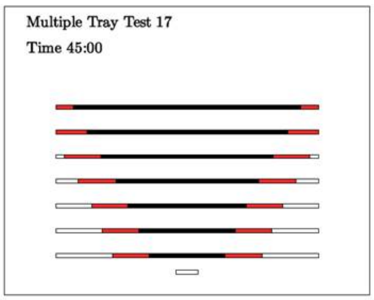


Example: Thermoset VS Thermoplastic

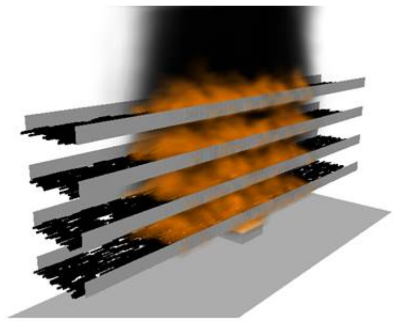


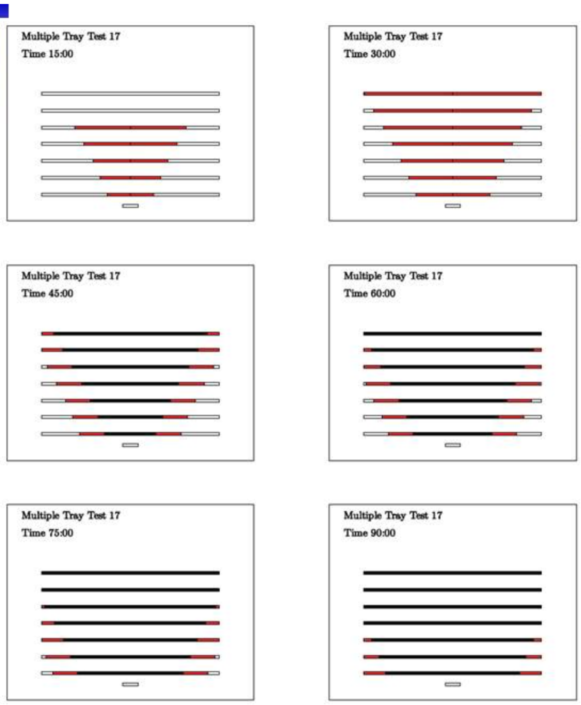
Modeling

The Easy Way



The Hard Way





FLASH-CAT

Flame Spread over Horizontal Cable Trays

Required Data
- Cable mass/length
- Non-metal mass fraction

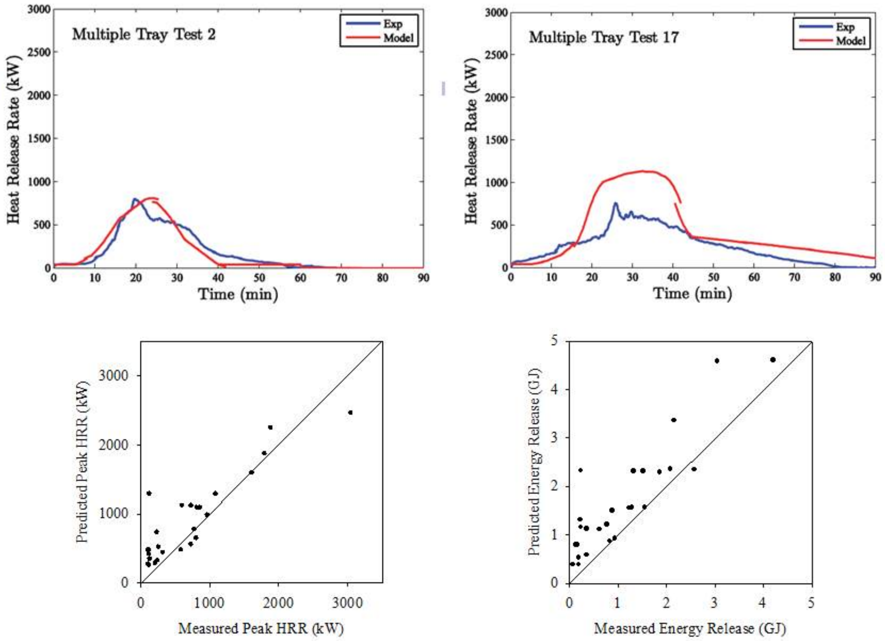
Ignition
- 5-4-3-2-1 minute rule

Upward Spread
- 35° spread angle

Burning Rate
- 250 kW/m² thermoplastics
- 150 kW/m² thermosets

Lateral Spread
- 3.2 m/h thermoplastics
- 1.1 m/h thermosets

Heat of Combustion
- 16 MJ/kg for all



CABLE FIRES

Modeling cable fires- Appendix R of NUREG/CR-6850

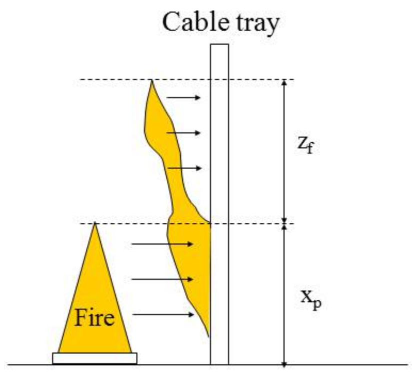
- Cable tray heat release rate using bench scale data
  - Replaced with the modeling approach in CHRISTIFIRE Report
- Horizontal Flame spread rates
  - Similar to the ones observed in the CHRISTIFIRE fire test series
- Fire propagation in cable trays
  - Similar to the ones observed in the CHRISTIFIRE fire test series

CABLE FIRES

Flame spread

- k_f is a constant with a value of 0.01 m^2/kW

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

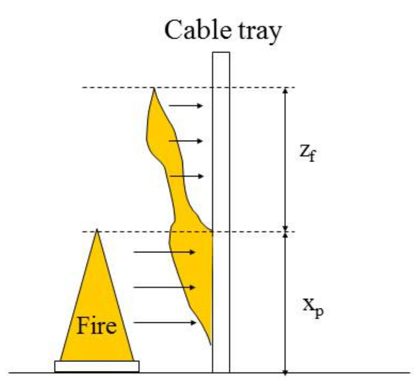


CABLE FIRES

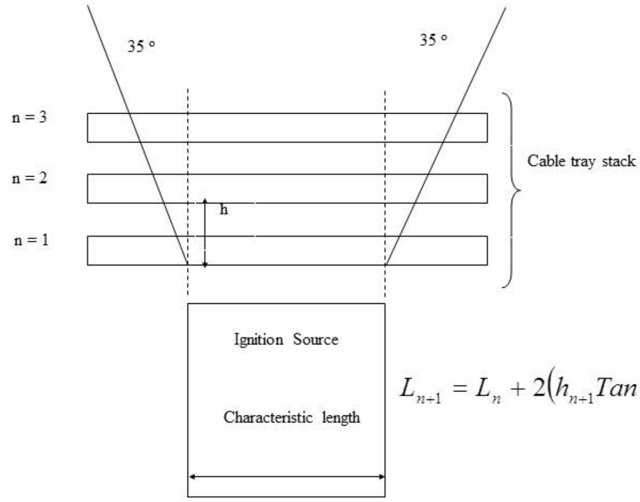
Flame spread model

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

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



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



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

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

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

FAQ 08-0049: "Cable Tray Fire Propagation"

- Purpose & Scope
  - Clarify use of the empirical model for fire propagation within a cable tray stack as presented in Appendix R of NUREG/CR-6850 – EPRI TR 1011989.
  - The clarifications in the FAQ are limited to the use of the empirical model for fire propagation in a cable tray stack
- Reference:
  - EPRI 1019259, Supplement 1 to NUREG/CR-6850.

FAQ 08-0049:Solution

- The FAQ clarifies that the model for fire propagation among cable trays should be used only for the configurations described in Appendix R of NUREG/CR-6850
  - Angle of propagation
  - Rate of propagation
  - Cable tray stacks within the zone of influence
- DO NOT extend the model beyond, at most, three cable tray stacks

FAQ 08-0049: Ongoing and Future Work

- NRC has been doing research program to assess cable tray fire behavior (NIST)
  - Full scale testing of fire propagation in cable trays
  - Test for different cable types
  - Measuring both heat release rate and flame propagation rates
  - Intent is to develop better models and guidance for predicting cable fire behavior
- First phase complete
  - See CHRISTI-Fire NUREG/CR-7010
- Second phase in progress
  - See CHRISTI-Fire NUREG/CR-7010

CHRISTIFIRE 2, Corridor Cable Fires

CHRISTIFIRE 2

Vertical Cable Fires

HIGH ENERGY ARCING FAULTS (1 of 15)

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.

HIGH ENERGY ARCING FAULTS (2 of 15)

Scope

- Switchgears
- Load centers
- Bus bars

(Switchgears, load centers, bus bars: Greater than or equal to 440 V)

- Oil filled outdoor transformers are addressed separately
- Bus ducts are addressed separately (via FAQ 07-0035)

HIGH ENERGY ARCING FAULTS (3 of 15)

General characteristics of switchgear based 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, 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.

HIGH ENERGY ARCING FAULTS (4 of 15)

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.

HIGH ENERGY ARCING FAULTS (5 of 15)

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.

HIGH ENERGY ARCING FAULTS (6 of 15)

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.

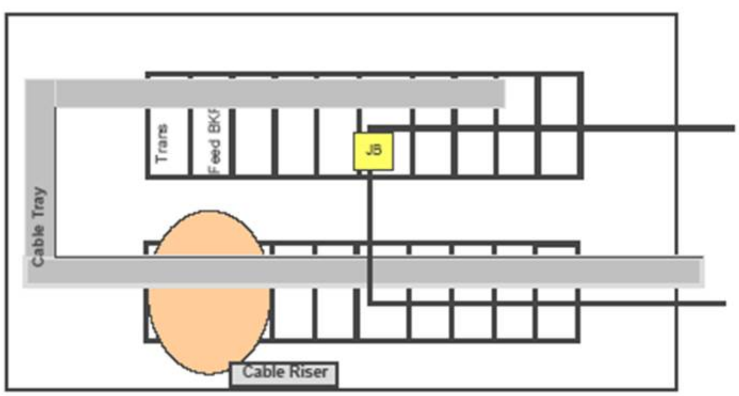
- The first phase is a short, rapid release of electrical energy followed by ensuing fire(s) that may involve the electrical device itself, as well as any external exposed combustibles, such as overhead exposed cable trays or nearby panels, that may be ignited during the energetic phase.

HIGH ENERGY ARCING FAULTS (6 of 15) (cont'd)

- The second phase, i.e., the ensuing fire(s), is treated similar to electrical cabinet fires described elsewhere 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.

HIGH ENERGY ARCING FAULTS (7 of 15)

The zone of influence



HIGH ENERGY ARCING FAULTS (8 of 15)

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.

HIGH ENERGY ARCING FAULTS (9 of 15)

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.

HIGH ENERGY ARCING FAULTS (10 of 15)

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

HIGH ENERGY ARCING FAULTS (11 of 15)

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).

HIGH ENERGY ARCING FAULTS (12 of 15)

Detection and Suppression

- The amount of smoke from any damaging HEAF event is 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.

HIGH ENERGY ARCING FAULTS (13 of 15)

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).

HIGH ENERGY ARCING FAULTS (14 of 15)

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.

HIGH ENERGY ARCING FAULTS (15 of 15)

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 $CDF_i = \lambda_g \cdot W_L \cdot W_{is} \cdot P_{ns} \cdot CCDP_i$

FAQ 07-0035 – Bus Duct HEAF

- Issue:
  - The guidance was silent on bus duct fires
- Resolution:
  - This was an unintended oversight
  - Evidence for bus duct HEAF exists
    - Diablo Canyon, May 2000
    - Columbia, August 2009
  - A method for bus duct HEAF was developed
- Reference:
  - EPRI 1019259, Supplement 1 to NUREG/CR-6850.

BUS DUCT HEAF (1 of 4)

- Bus duct physical configurations can influence the HEAF event.
- Four basic types:
  - Cable ducts
  - Nonsegmented or continuous bus ducts
  - Segmented bus ducts
  - Iso-phase bus ducts
- HEAF only associated with segmented and iso-phase
  - Separate approaches developed for segmented and iso-phase ducts
  - No HEAF for cable ducts or non-segmented ducts

BUS DUCT HEAF (2 of 4)

General characteristics of bus duct HEAF events

- Rapid release of energy
- Potential for physical and thermal damage
- Potential for secondary fires
- Potential for release of molten metals

BUS DUCT HEAF (3 of 4)

Zone of influence of HEAF events for <u>segmented bus ducts</u>.

- Assume HEAF event at transition points of segmented bus ducts
- Molten metal to be ejected from bottom of the bus duct in right conical form at 15° angle
  - <u>Not on your slides:</u> Cone will expand to a maximum diameter of 20 feet (37 feet below origin) then fall vertically from there
- Molten metal to be ejected outward up to 1.5 feet spherical zone of influence
- Subsequent fires depend on cables and other combustible materials within the zone of influence

BUS DUCT HEAF (4 of 4)

Analyzing HEAF events for iso-phase bus ducts.

- Assume a 5 foot spherical damage zone centered at the fault point
- Covers initial fault and hydrogen gas explosion and fire
- Subsequent fires depend on cables and other combustible materials within the zone of influence
- If fault is assumed at main transformer termination point, oil fire may need to be considered

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

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.

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.

PASSIVE FIRE PROTECTION FEATURES (1 of 7)

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

PASSIVE FIRE PROTECTION FEATURES (2 of 7)

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

PASSIVE FIRE PROTECTION FEATURES (3 of 7)

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 should be evaluated only with the objective of analyzing smoke migration.

PASSIVE FIRE PROTECTION FEATURES (4 of 7)

- Empirical approaches are possible if you can match your conditions to the fire tests that have been performed
- SNL tests performed in the 1970's on several coatings
  - Cable tray configurations included single cable tray and a two-tray stack
  - Exposure fires included gas burner or diesel fuel pool fire
  - Tests results:
    - coated nonqualified cables did not ignite for at least 12 minutes
    - coated, nonqualified cables did not fail for at least 3 minutes and in some cases 10 minutes or more.
  - Tests are very difficult to extrapolate – high plant-to-plant variability
- A basis needs to be established for any credit given to coatings

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

PASSIVE FIRE PROTECTION FEATURES (5 of 7)

- 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 1975-1978
  - 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.
- Again, a basis needs to be established for any credit taken
  - Tests are not definitive for all cases

PASSIVE FIRE PROTECTION FEATURES (6 of 7)

- 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.
- Again: use the test data, but establish a basis for your application!

PASSIVE FIRE PROTECTION FEATURES (7 of 7)

Probabilistic modeling of passive fire suppression systems

- Dampers: Equipment unavailability obtained from inspection results

- Penetration seals: Equipment unavailability obtained from inspection results

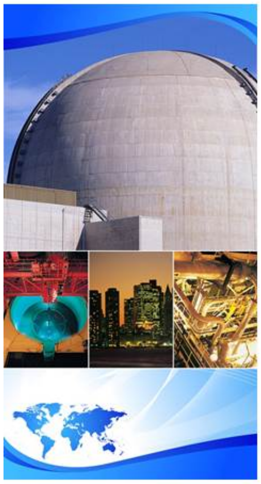
4.9 Task 11: Special Fire Models Part 2

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation
From Science to Solutions



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Task 11, Special Fire Models Part 2

Joint RES/EPRI Fire PRA Workshop
July and September 2012
Washington, DC

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

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)

Fire PRA Workshop, 2012, Washington, DC
Module III Pt. 2: Special Fire Models Part 2

Slide 2

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

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

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

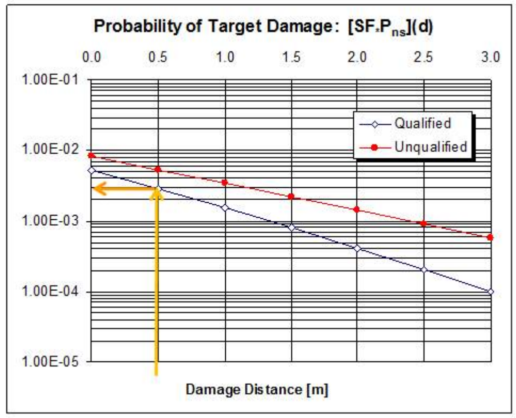
- The MCB model is built on several assumptions that are specific to the MCB and the MCR
  - MCB fire frequency partitioning approach
  - Suppression times for MCR fires
  - Fire characteristics of a MCR type control panel (peak HRR and growth profile)
  - Damage limits for control components
- This 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 room or other similar areas

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 separation distance between the most remote members of the damage set (those furthest apart)
  - 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!

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 0.5 m 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



Main Control Room Fire Analysis
Step 8: Fire Growth . . . (cont'd)

A probabilistic model of fire spread in the main control board 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

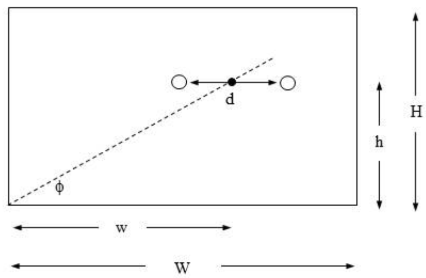
$$\lambda(d) = \lambda_{MCB}\,[SF \cdot P_{ns}](d)$$

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



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

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

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)

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

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

- Database shows 13 T/G set hydrogen fires, two categorized as severe, with the rest being fires due to 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)

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

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 involved 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

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

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

  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
    - Related SRs: FSS-F1, F2, F3
  - Estimate screening CDF contribution, refine as appropriate

Not in your slide set – How to use Table O-2

- Table O-2 (page O-5)contains the following:

			the structural integrity of the building.
T/G fires involving H_2, oil, and possibly blade ejection	Catastrophic	0.025	Widespread damage inside the building, potential damage to the adjoining buildings, and to the structural integrity of the building.
		(5E-4/yr)	Suppression can prevent these consequences.
		(1E-5/yr)	

- To use this table (we'll use the 6850/1011989 frequencies):
  - You start with total TG fire frequency (sum bins 33,34,35): 2.0E-2
  - Assume 1 in 38 is a catastrophic event (split fraction): x 0.025
  - For a raw frequency of catastrophic events: 5.0E-4 events/yr
  - Given automatic sprinklers/deluge apply system un-reliability: x 0.02

  For a total net frequency of unsuppressed catastrophic events: 1.0E-5 events/yr

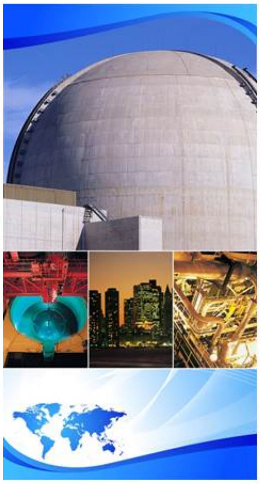
Module III-11, Pt. 2: Special Models Part 2
Hydrogen Fires

- This discussion (Appendix N) applies to general hydrogen fires
  - Including T/G set fires
  - Also fires from other sources 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

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

- Two general types of fires:
  - Jet fires originating at point of a H_2 leak
    - Critical question will be flame length
  - Explosions
    - If there is a mechanism for the release of large quantities of H_2 (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

4.10 **Detection and Suppression Appendix P**



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III
Detection and Suppression Appendix P

Joint RES/EPRI Fire PRA Course
July and September, 2012
Washington, DC

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

DETECTION & SUPPRESSION
Objectives

The objectives of this module are:

- Describe the process for calculating the non-suppression probability
- Describe the assumptions underlying the recommended approach for determining the non-suppression probability.
- Related SR: FSS-C7

Joint Fire PRA Course, 2012, Washington DC
Module III: Detection and Suppression Appendix P
Slide 2
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

DETECTION & SUPPRESSION
Generalities

- Time to target damage and non suppression probabilities are independent calculations
  - It's like a probabilistic horse race – will damage win or will suppression win?
  - We calculate time to damage through fire modeling and use that as an input to detection/suppression analysis
  - We then ask what's the probability that suppression succeeds before damage occurs?
- Fire models cannot model the effects of all the different fire detection and suppression strategies available in NPP fire scenarios.
  - We do pretty well with simple things like smoke detection time, sprinkler head activation time
  - We currently don't do things like water droplets interfering with fire physics (although there are folks working on those kinds of problems…)

DETECTION & SUPPRESSION
Crediting a Fire Det or Supp System

Detection and suppression systems can and should 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
- Availability – Probability of the system actually operating as designed upon demand

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 (by plant personnel)
- Fire Suppression
  - Prompt suppression
  - Automatic suppression
  - Manual suppression

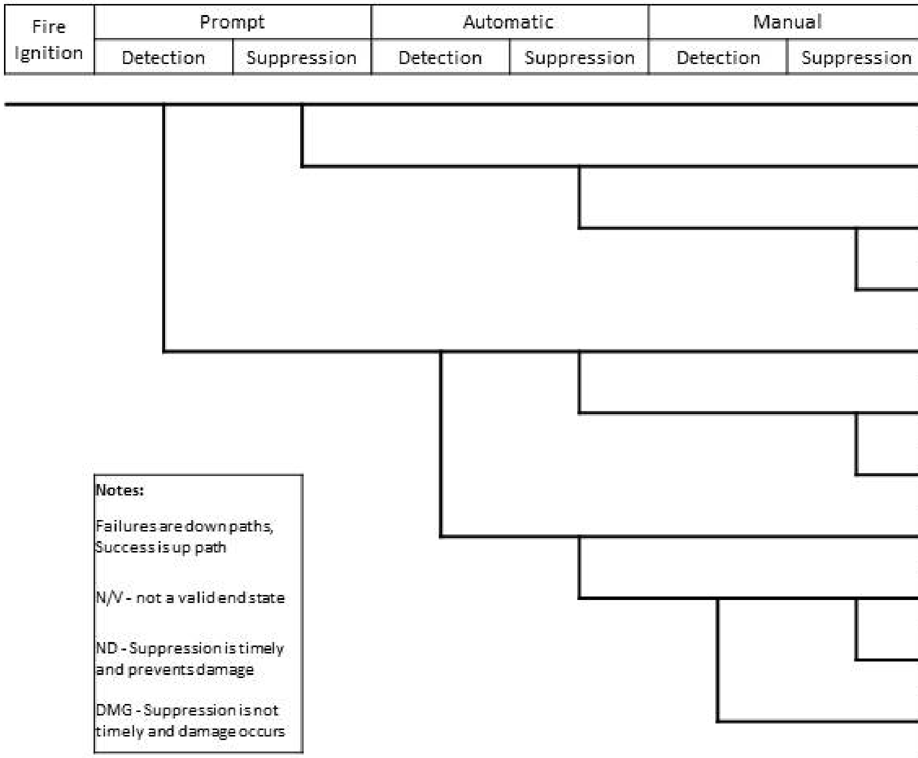
DETECTION & SUPPRESSION
FAQ-50 Updated Approach

- In the original 6850/1011989 method, manual fire fighting was not assumed to begin until two things happened:
  - The fire had to be detected
  - The fire brigade had to respond to the scene
- In practice, this approach gave no credit to early suppression by plant personnel unless the space was continuously manned or given a fire watch and was not consistent with the actual fire experience
- A revised method was developed under FAQ-50

DETECTION & SUPPRESSION
Event Tree Changes if Applying FAQ-50 Solution

- FAQ 50 changes the detection/suppression event tree:
  - Collapses "manual/fixed" and "fire brigade" into one top event – "manual suppression"
  - "Manual suppression" top event credits any plant personnel suppressing fire, not just the fire brigade (all actors)
    - For plant specific cases: Top event "manual suppression" can include manual actuation of fixed suppression, but timing may be different (i.e., the generic PNS curves may not apply) and dependencies must be addressed
- FAQ 50 solution assumes <u>no delay</u> in initiating manual fire fighting once fire <u>has been detected</u>
  - Per NRC closure memo – if manual actuation of fixed suppression is credited, plant specific analysis must be performed and must address:
    - procedures and training for manually actuating a fixed suppression system, and
    - explain how dependencies between manual actuation of a fixed suppression system and other manual suppression activities.(e.g., manual suppression by portable extinguishers and hose stream) are addressed.

DETECTION & SUPPRESSION
Detection-Suppression Event Tree



Sequence	End State	Outcome
A	ND	Propmt detection and prompt suppression succeed
B	ND	Automatic suppression succeeds
C	ND	Prompt detection and manual suppression succeed
D	DMG	All means of suppression fail
E	ND	Automatic suppression succeeds
F	ND	Automatic detection and successful manual suppression
G	DMG	All means of suppression fail
H	ND	No auto detection but auto suppression succeeds
I	ND	Delayed manual detection and successful manual suppresion
J	DMG	Delayed manual detection but manual suppression fails
K	DMG	Fire is not detected in time to prevent damage

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

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!

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.

FAQ 08-0046: Incipient Fire Detection

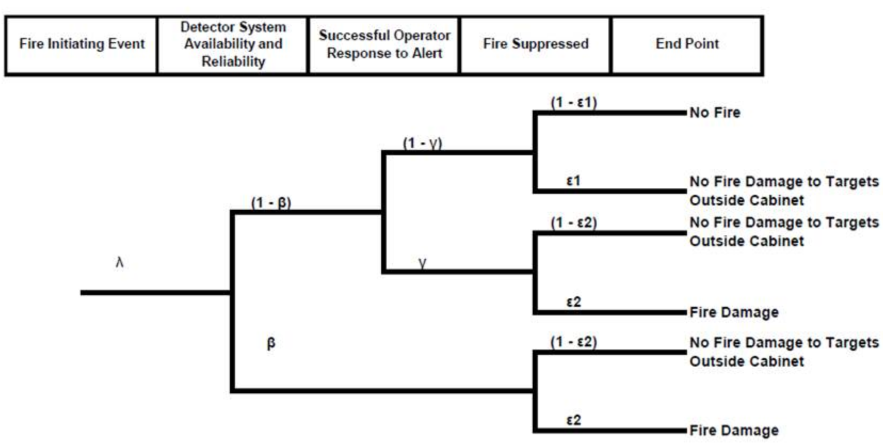
- Issue
  - The guidance is silent on the topic of incipient detection systems
- Resolution
  - Provide guidance on the treatment of incipient fire detection systems
  - An incipient fire detection system is considered one that provides very early warning.
    - Systems design to detect faulting electrical equipment or other overheating materials before an actual fire breaks out
    - Example: aspirated smoke or ionization particle detection type systems
  - FAQ largely based on knowledge about the use of incipient fire detection systems in the telecommunications industry.
- Reference:
  - EPRI 1019259, Supplement 1 to NUREG/CR-6850.

FAQ 08-0046: Solution

- Credit systems for electrical/electronic component fires:
  - Less than 250vdc or 480vac
  - Excluding HEAF
  - Excluding cabinets with certain fast-acting failure components such as electrical/electronic circuit boards that contain electrolytic capacitors, chart recorder drives, cooling fan motors, mechanical timers driven by electric motors, etc.
- Need to assess system availability and reliability
- Need to assess human response to alarm
- See NRC closure memo for additional cautions and guidance
- Credit acts as, in effect, large reduction in PNS given:
  - early detection
  - presence of a trained operator who acts to limit size and growth rate of fire such that damage outside cabinet is not expected

Joint Fire PRA Course, 2012, Washington DC
Module III: Detection and Suppression Appendix P
Slide 13
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

FAQ 08-0046: Solution



Joint Fire PRA Course, 2012, Washington DC
Module III: Detection and Suppression Appendix P
Slide 14
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

FAQ 08-0046: Solution

- Fault tree branch probability values
  - Variable β: can be determined using the process provided by EPRI in report 1016735 or set equal to 1E-02.
  - Variable γ: calculate using detailed HRA analysis, 1E-02 if the system is addressable to multiple cabinets or 5E-03 if the system is addressable to an individual cabinet.
  - Variable ε_1: may be set to 1E-3
  - Variable ε_2: use manual suppression probability curve

FAQ 08-0046: References

– EPRI 1019259, Supplement 1 to NUREG/CR-6850.

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, or self-extinguished fires.
- Do not include time to detection or fire brigade response.

FAQ 08-0050: “Manual Non-Suppression Probability”

- Issue:
  - NUREG/CR-6850/1011989 gives too little credit to manual fire suppression before the fire brigade arrives on the scene compared to experience
- Resolution
  - Updated guidance for treatment of manual suppression and the fire brigade response
  - Includes a process to adjust the non-suppression analysis for scenario-specific fire brigade responses.
- Reference
  - PRI 1019259, Supplement 1 to NUREG/CR-6850.

FAQ 08-0050: Solution
How the P_{ns} curves are calculated

- Original NUREG/CR-6850/1011989 analysis used suppression time if available
  - If no suppression time was given, fire duration was used (many such cases)
- FAQ uses the *fire duration* field for all events
  - Fire duration is either the same (zero detection time) or longer than suppression time
  - Result: the base P_{ns} curves are *slightly* more conservative, but…
- FAQ also assumes fire control and suppression activities start at the time of detection
  - Credits suppression by plant personnel other than fire brigade
  - Time delay for brigade arrival is no longer applied
  - More than makes up for shift in curves
- New non-suppression (P_{ns}) curves for all bins
- Includes method to adjust for above or below average fire brigade response time

FAQ 08-0050: Solution
The new P_{ns} curves

		Original NUREG/CR-6850		Revised Analysis	
Suppression Curve	No. of original events/revised events	Original Total Suppression Time	Original Mean Suppression Rate [/min]	Revised Total Duration	Revised Mean Suppression Rate [/min]
T/G fires	21/21	749	0.03	846	0.025
Control room	6/6	18	0.33	18	0.33
PWR containment	3/3	23	0.13	40	0.075
Outdoor transformers	14/14	373	0.04	390	0.036
Flammable gas	5/5	195	0.03	197	0.025
Oil fires	36/36	404	0.09	474	0.076
Cable fires	5/5	21	0.24	31	0.161
Electrical fires	114/113	942	0.12	1113	0.102
Welding fires	19/18	99	0.19	106	0.188
Transient fires	24/22	199	0.12	174	0.126
High-energy arcing faults	3/3	239	0.01	276	0.011
All fires	245[21] /246	3113	0.08	3655	0.067

DETECTION & SUPPRESSION
FAQ 50 changes the calculation of P_{ns}

Original 6850/1011989 approach:

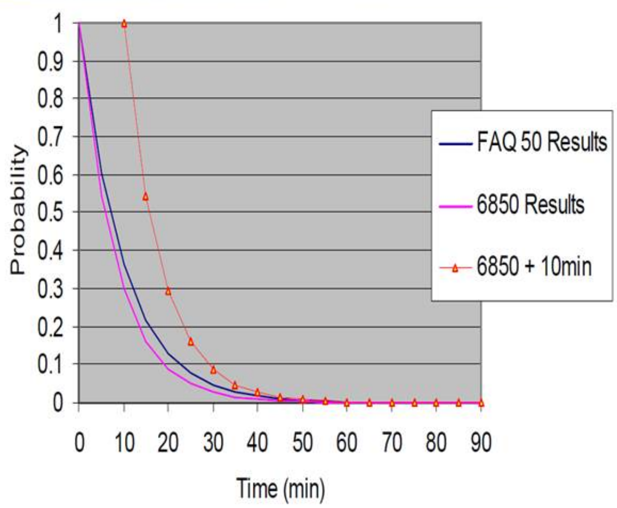
$$P_{ns} = e^{-\lambda\left[t_{damage} - \left(t_{detection} + t_{brigade-response}\right)\right]}$$

Revised FAQ 50 approach:

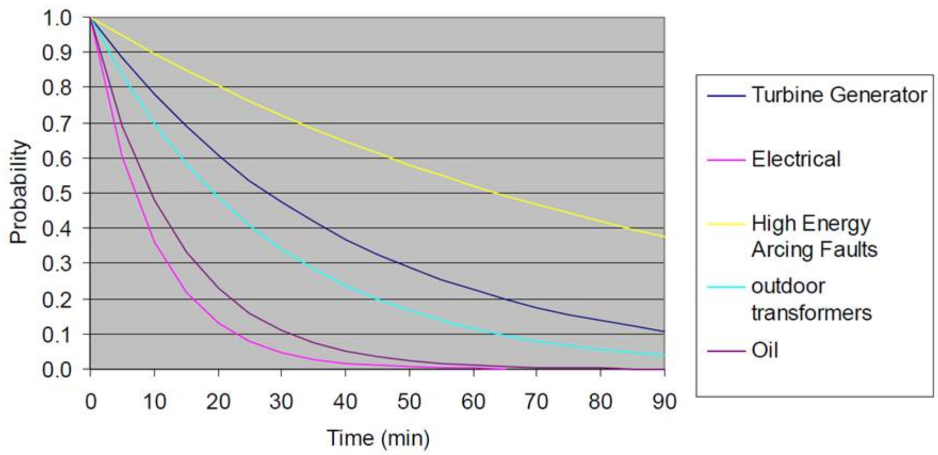
$$P_{ns} = e^{-\lambda\left[t_{damage} - t_{detection}\right]}$$

FAQ 08-0050: Solution
Electrical fires example for comparison

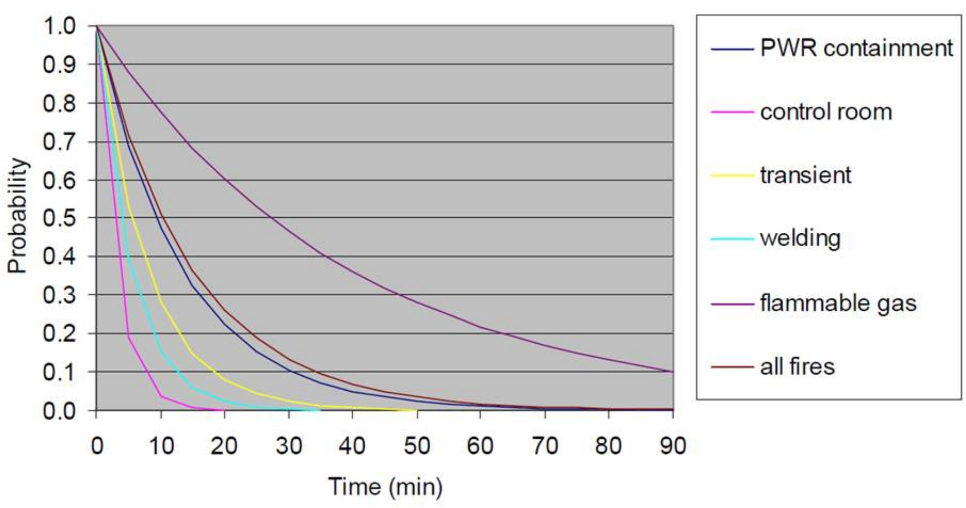
- Revised suppression *rates* are *lower* so base curve says you are *less* likely to put out fire in a given time
  - Revised blue curve vs. original pink curve
  - Not much difference…
- You more than make up for that by *not* subtracting fire brigade response time from time available before damage
  - Revised blue curve vs. original orange curve that includes a 10 minute brigade response time



DETECTION & SUPPRESSION
Revised Suppression Curves (1 of 2)



DETECTION & SUPPRESSION
Revised Suppression Curves (2 of 2)



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.

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

DETECTION & SUPPRESSION
Conceptual 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 automatqic sprinklers
- Using fire modeling
  - Time to smoke detection = 1 min
  - Time to sprinkler activation = 8 min
  - Time to target damage = 15 min
- From fire drill records and/or plant procedures
  - Time to delayed detection is assumed to be 15 min

DETECTION & SUPPRESSION
Example for the 6850/1011989 approach

Fire	Prompt		Automatic		Manual		Sequence	End State	Pr(non-suppression)
Fire	Detection	Suppression	Detection	Suppression	Detection	Fire Brigade			
FI	PD	PS	AD	AS	MD	FB			
1	0	0					A	Not valid	
		1		0.98			B	Not valid	
				0.02		0.78	C	Not valid	
						0.22	D	Not valid	
	1		0.95	0.98			E	OK	
				0.02		0.76	F	OK	
						0.24	G	NS	4.6E-03
			0.05	0.98			H	OK	
				0.02	0		I	Not Valid	
					1		J	NS	1.0E-03
								Total	5.6E-03

Note typos in your set at bottom of tree (yellow boxes)…

- No prompt detection
- Failure of auto. det.
  - P = 0.05
- Failure of sprinklers:
  - P = 0.02

  Both require justification
- Manual suppression:
  - Damage time: 15 min
  - Auto detect: 1 min
  - Time available for manual suppression: 15 - 1 = 14 min
  - Use electrical fire curve: P = EXP(-0.102·14) **P = 0.24**
- Overall solution for this scenario:

$$P_{ns} = G + J$$

$$P_{ns} = 5.6E - 3$$

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

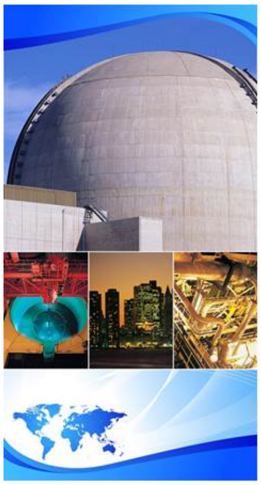
4.11 Task 11: Detailed Fire Modeling, and the PRA Standard's Fire Scenario Selection and Analysis (FSS) Technical Element

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation
From Science to Solutions



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III:
Task 11, Detailed Fire Modeling, and the PRA Standard's Fire Scenario Selection and Analysis (FSS) Technical Element

Joint RES/EPRI Fire PRA Course
July and September, 2012
Washington, DC

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

Corresponding Technical Element
…and a note on structure

- Task 11 maps to FSS – Fire Scenario Selection and Analysis
  - FSS has 8 HLRs and a total of 50 SRs
  - FSS has more SRs than any other fire technical element
- We are going to quickly go over structure of FSS technical element, and then we will get into the various elements of Task 11 in more detail.

Joint Fire PRA Course, 2012, Washington, DC
Module III: Task 11, Detailed Fire Modeling, & the PRA Standard Technical Element FSS
Slide 2
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

Corresponding Technical Element
...and a note on structure (cont.)

- Task 11 has 3 subtasks and there are presentations for each:
  - 11a - Single compartment analysis
  - 11b - Main control room analysis
  - 11c - Multi-compartment analysis
- We will cover the FSS HLRs just once (here)
- SRs specific to a subtask will be cited as appropriate, but…
  - While there are SRs that are subtask specific:
    - e.g., FSS-B for MCR abandonment, FSS-G for multi-compartment scenarios…
  - Some SRs will apply to all subtasks:
    - e.g., define targets, characterize source, provide basis…

Corresponding Technical Element
...and a note on structure (cont.)

- This training also covers several 6850/1011989 "special models"
  - Detailed analysis tools for specific problems (methodology)
- Recall that the standard sets high-level scope and quality metrics, but does not prescribe methodology
- The special model presentations map to SRs where a direct link does exist:
  - e.g., define failure thresholds, characterize ignition source…
- SRs other than those we cite will likely apply:
  - e.g.: basis, validation, defining input variables, uncertainty…
- Note that 6850/1011989 provides a basis for the modeling tools it presents

Technical Element FSS

- FSS Objectives (per the PRA Standard):
  - To select the fire scenarios to be analyzed
  - To characterize the selected fire scenarios
  - To determine the likelihood and extent of risk-relevant fire damage for each selected fire scenario including
    - An evaluation of the fire generated conditions at the target location including fire spread to secondary combustibles
    - An evaluation of the thermal response of damage targets to such exposure
    - An evaluation of fire detection and suppression activities
  - To examine multi-compartment fire scenarios

FSS HLRs (per the PRA Standard)

- HLR- FSS-A: The Fire PRA shall select one or more combinations of an ignition source and damage target sets to represent the fire scenarios for each unscreened physical analysis unit upon which estimation of the risk contribution (CDF and LERF) of the physical analysis unit will be based. (6 SRs)
- HLR-FSS-B: The Fire PRA shall include an analysis of potential fire scenarios leading to the MCR abandonment. (2 SRs)
- HLR-FSS-C: The Fire PRA shall characterize the factors that will influence the timing and extent of fire damage for each combination of an ignition source and damage target sets selected per HLR-FSS-A. (8 SRs)

IGN HLRs (per the PRA Standard)

- HLR- FSS-D: The Fire PRA shall quantify the likelihood of risk-relevant consequences for each combination of an ignition source and damage target sets selected per HLR-FSS-A. (11 SRs)
- HLR-FSS-E: The parameter estimates used in fire modeling shall be based on relevant generic industry and plant-specific information. Where feasible, generic and plant-specific evidence shall be integrated using acceptable methods to obtain plant-specific parameter estimates. Each parameter estimate shall be accompanied by a characterization of the uncertainty. (4 SRs)

IGN HLRs (per the PRA Standard)

- HLR- FSS-F: The Fire PRA shall search for and analyze risk-relevant scenarios with the potential for causing fire-induced failure of exposed structural steel. (3 SRs)
- HLR-FSS-G: The Fire PRA shall evaluate the risk contribution of multi-compartment fire scenarios. (6 SRs)
- HLR-FSS-H: The Fire PRA shall document the results of the fire scenario and fire modeling analyses including supporting information for scenario selection, underlying assumptions, scenario descriptions, and the conclusions of the quantitative analysis, in a manner that facilitates Fire PRA applications, upgrades, and peer review. (10 SRs)

Mapping HLRs & SRs for the FSS Technical Element to NUREG/CR-6850, EPRI TR 1011989

Technical Element	HLR	SR	6850 Sections	Comments
FSS	A	The Fire PRA shall select one or more combinations of an ignition source and damage target sets to represent the fire scenarios for each unscreened physical analysis unit upon which estimation of the risk contribution (CDF and LERF) of the physical analysis unit will be based.		
		1	11.3.3, 11.5.1.3, 11.5.2.6	
		2	11.3.2, 11.5.1.5, 11.5.2.5	
		3	11.5.1.5	These sections of 6850/1011989 imply the requirements of these SRs.
		4	11.3.2, 11.5.1.5	
		5	11.5.1.6, 11.5.2.7	
		6	11.5.2.7	
	B	The Fire PRA shall include an analysis of potential fire scenarios leading to the MCR abandonment.		
		1	11.5.2.11	
		2	11.5.2.11, 11.5.3	

Mapping HLRs & SRs (continued)

Technical Element	HLR	SR	6850 Sections	Comments
FSS	C	The Fire PRA shall characterize the factors that will influence the timing and extent of fire damage for each combination of an ignition source and damage target sets selected per HLR-FSS-A.		
		1	8.5.1, 11.3.3, 11.3.4, 11.5.1.3	Section 8 of 6850/1011989 partly address the requirements of this SR
		2	8.5.1, 11.3.3, 11.3.4, 11.5.1.3	
		3	11.3.3, 11.3.4, 11.5.1.3	These sections of 6850/1011989 imply the requirements of this SR.
		4	11.5.1.9, Appendices E and G	Section 11.3 of 6850/1011989 directs the reader to these Appendices where discussions relevant to the requirements of this SR are provided.
		5	8.5.1.2, Appendix H	
		6	11.5.1.7.6, Appendix H	
		7	n/a	Appendix P of 6850/1011989 implies the requirements of this SR but does not explicitly address it.
		8	11.5.1.7.3, Appendices M and Q	Referenced section and appendices of 6850/1011989 do not fully address the requirements of this SR.

Mapping HLRs & SRs (continued)

Technical Element	HLR	SR	6850 Sections	Comments
FSS	D	The Fire PRA shall quantify the likelihood of risk-relevant consequences for each combination of an ignition source and damage target sets selected per HLR-FSS-A.		
		1	11.5.1.7.1	
		2	11.5.1.7.1	
		3	11.5.1.7.1	Several other sections and appendices of 6850/1011989 collectively address the requirements of this SR.
		4	11.5.1.7.1, Appendices E, F, G, H, M, N, O, R, S	
		5	Appendices E, G, P	
		6	11.5.1.7.1, Appendices H, M, N, O, P	
		7	11.5.1.8, Appendix P	
		8	11.5.1.8, Appendix P	
		9	11.5.1.5, 11.5.1.7.1, Appendix T	
		10	8.5.2, 11.4.3	Referenced sections of 6850/1011989 imply the requirements of this SR.
		11	8.5.2, 11.4.3	

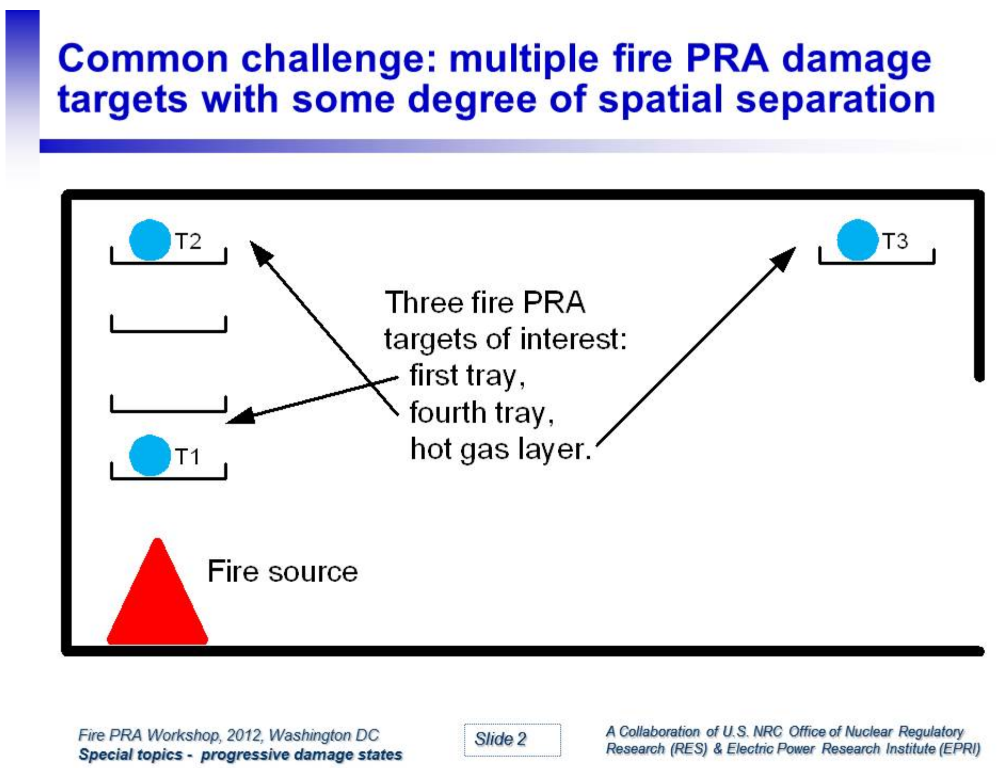
Mapping HLRs & SRs (continued)

Technical Element	HLR	SR	6850 Sections	Comments
FSS	E	The parameter estimates used in fire modeling shall be based on relevant generic industry and plant-specific information. Where feasible, generic and plant-specific evidence shall be integrated using acceptable methods to obtain plant-specific parameter estimates. Each parameter estimate shall be accompanied by a characterization of the uncertainty.		
		1 2	11.3, 11.5.1, Appendices G, H, L, N, O, R, and S	6850/1011989 does not discuss plant-specific fire modeling parameters. However, the discussions in the referenced sections and appendices imply the requirements of this SR.
		3	11.3, 11.5.1, Appendices E, G and P	
		4	n/a	The requirement in this SR is not explicitly addressed in 6850/1011989
	F	The Fire PRA shall search for and analyze risk-relevant scenarios with the potential for causing fire-induced failure of exposed structural steel.		
		1	n/a	Failure of exposed structural steel from fire impact is not explicitly discussed in 6850/1011989. Appendix Q addresses passive fire protection features but does not address exposed structural steel.
		2	n/a	
		3	n/a	

Mapping HLRs & SRs (continued)

Technical Element	HLR	SR	6850 Sections	Comments
FSS	G	The Fire PRA shall evaluate the risk contribution of multicompartment fire scenarios.		
		1	11.5.4.6	
		2	11.5.4	
		3	11.5.4	
		4	11.5.4.4	
		5	11.5.4.4	
		6	11.5.4.5, 11.5.4.6	
	H	The Fire PRA shall document the results of the fire scenario and fire modeling analyses including supporting information for scenario selection, underlying assumptions, scenario descriptions, and the conclusions of the quantitative analysis, in a manner that facilitates Fire PRA applications, upgrades, and peer review.		
		1	n/a	Documenting the analysis and the results is discussed in Chapter 16 and in several parts of Chapter 11 of 6850/1011989. The specific requirements of these SRs is generally not explicitly addressed.
		2	n/a	
		3	n/a	
		4	n/a	
		5	n/a	
		6	n/a	
		7	n/a	
		8	n/a	
		9	n/a	
		10	n/a	

4.12 Special Topic in Detection and Suppression Analysis – General Approach for Treatment of Progressive Damage States



Damage state progresses in time

Fire will damage closest tray first:

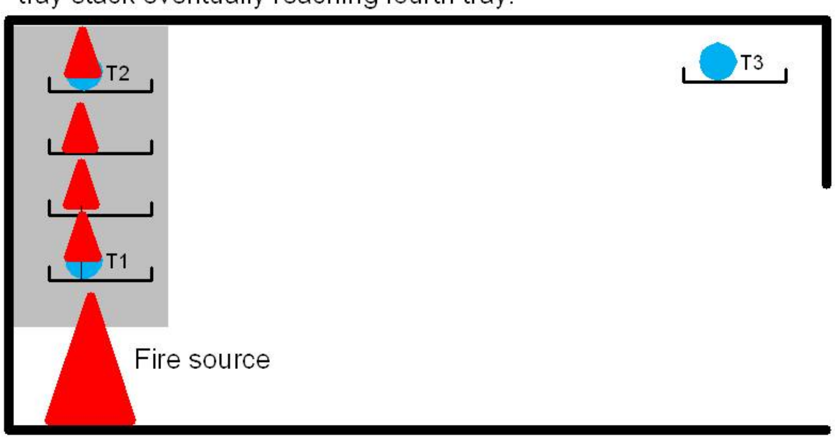
Fire PRA Workshop, 2012, Washington DC
Special topics - progressive damage states

Slide 3

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

Damage state progresses in time

As fire grows and spreads, it will progress through tray stack eventually reaching fourth tray:

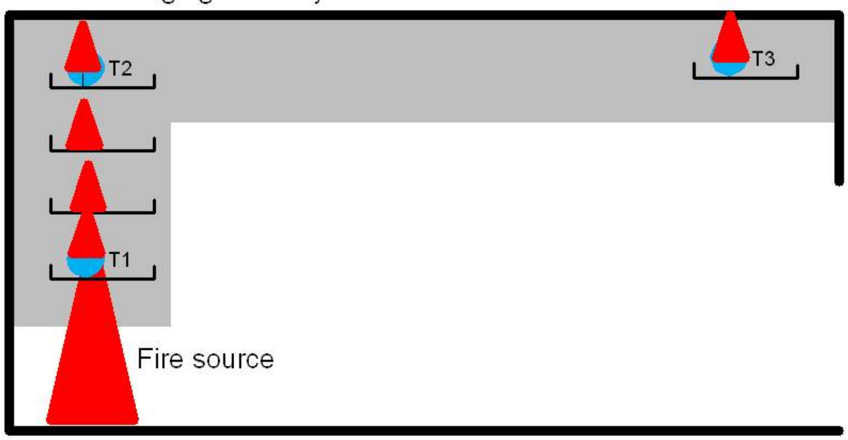


Fire PRA Workshop, 2012, Washington DC
Special topics - progressive damage states

Slide 4

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

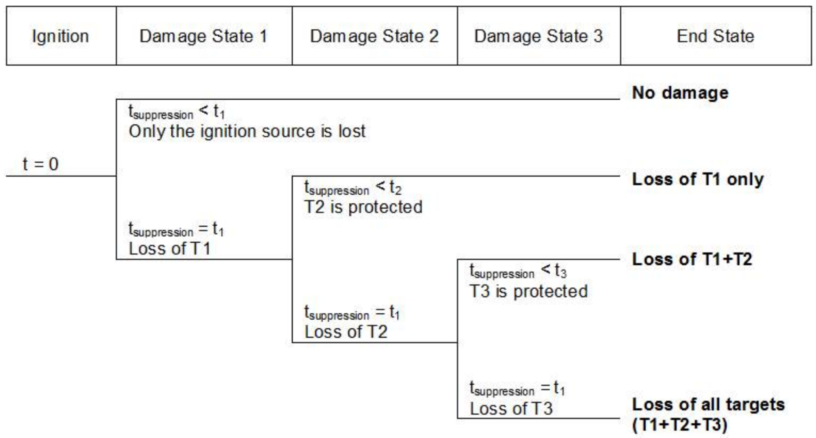
Damage state progresses in time



You can build an event tree to reflect a progressive damage state increasing with time

- The key is that the fire must burn long enough to cause the postulated damage, and the more extensive damage states take additional time
  - Damage to first tray may be short time,
  - Tray at top of stack takes longer
  - Hot gas layer takes even longer (generally…)
- The likelihood of successful fire suppression gets better and better with longer times
  - Said another way – the probability of non-suppression gets smaller and smaller with longer time available before damage
- We can reflect this credit through a modified suppression event tree

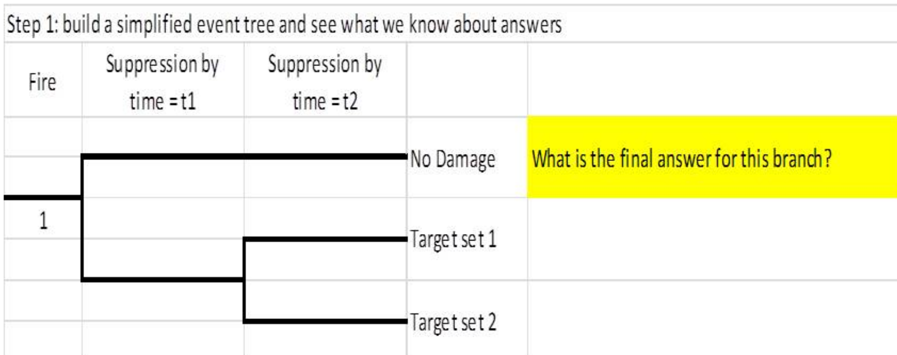
A modified suppression event tree for a three-stage set of fire PRA targets



The key is to properly calculate the branch point split fractions

- Branch point values depend on time to damage and the applicable non-suppression probability curve, but…
- The events are *dependent*
  - You can't just pick numbers off suppression curve for each branch
- For example - the second split fraction, for damage to T2, is:
  - the *conditional probability* that *given the fire was not suppressed before time* $t=t_1$, the fire will remain unsuppressed through time $t=t_2$
  - Same goes for final split fraction
- The formal approach to calculate these conditional split fractions lies beyond the scope of our course
  - You need to integrate the density function across time intervals…
- We can, however, illustrate the concept with an even simpler example that we can solve by inspection

Reduce our problem to a two-stage damage state

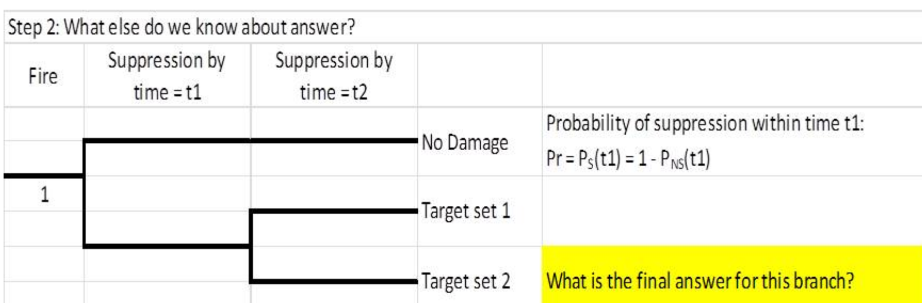


Fire PRA Workshop, 2012, Washington DC
Special topics - progressive damage states

Slide 9

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

Two-stage example (cont.)

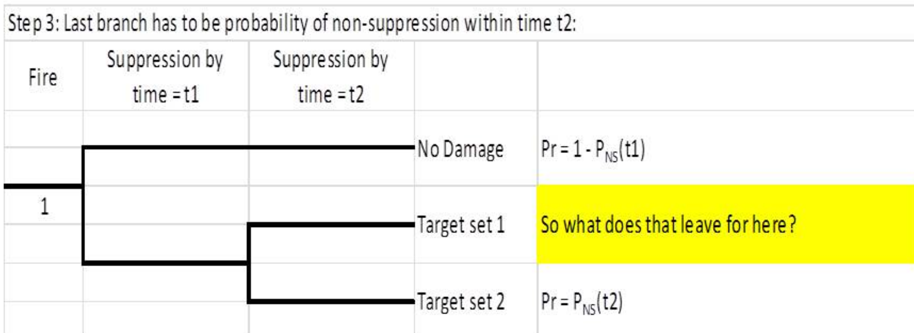


Fire PRA Workshop, 2012, Washington DC
Special topics - progressive damage states

Slide 10

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

Two-stage example (cont.)

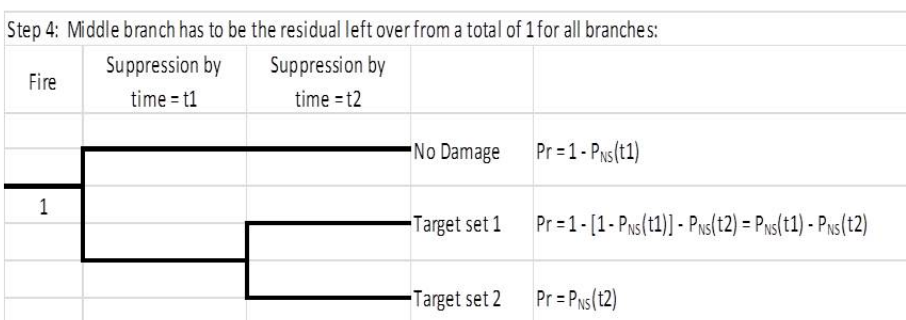


Fire PRA Workshop, 2012, Washington DC
Special topics - progressive damage states

Slide 11

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

Two-stage example (cont.)

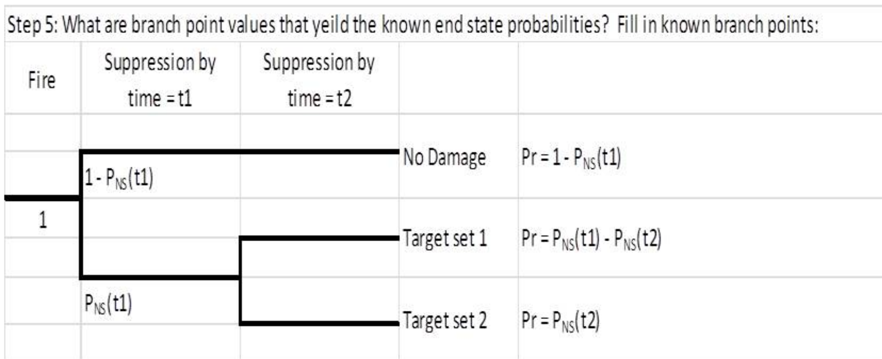


Fire PRA Workshop, 2012, Washington DC
Special topics - progressive damage states

Slide 12

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

Two-stage example (cont.)

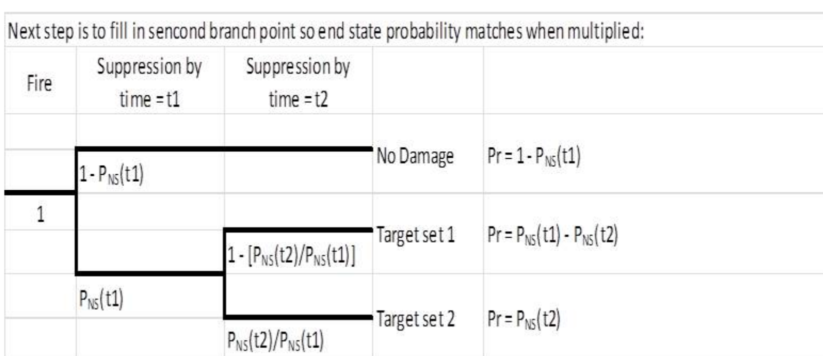


Fire PRA Workshop, 2012, Washington DC
Special topics - progressive damage states

Slide 13

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

Two-stage example (cont.)



Fire PRA Workshop, 2012, Washington DC
Special topics - progressive damage states

Slide 14

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

Two-stage example (conclusion)

One final simplification is possible given the behavior of exponentials:

$P_{NS}(t) = e^{-\lambda t}$

<u>so</u>

$P_{NS}(t2)/P_{NS}(t1) = e^{-\lambda t2}/e^{-\lambda t1} = e^{-\lambda(t2-t1)} = P_{NS}(t2-t1)$

Fire	Suppression by time = t1	Suppression by time = t2		
1	$1 - P_{NS}(t1)$		No Damage	$Pr = 1 - P_{NS}(t1)$
	$P_{NS}(t1)$	$1 - [P_{NS}(t2-t1)]$	Target set 1	$Pr = P_{NS}(t1) - P_{NS}(t2)$
		$P_{NS}(t2-t1)$	Target set 2	$Pr = P_{NS}(t2)$

Summary – multi-stage damage states

- The multi-stage damage state approach is a powerful tool
  - Any scenario with multiple targets threatened by the same fire source with discrete damage times
  - The key is some degree of spatial separation between targets
    - Tray stacks
    - Above the fire versus away from the fire
- The more damage stages you develop the more complicated it gets
  - You may need to seek the help of a good statistics person
- Two-to-three discrete states is relatively easy and works for many scenarios
- The event tree approach help
  - Individual end states must be properly weighed
  - Very easy to double count overlapping damage states

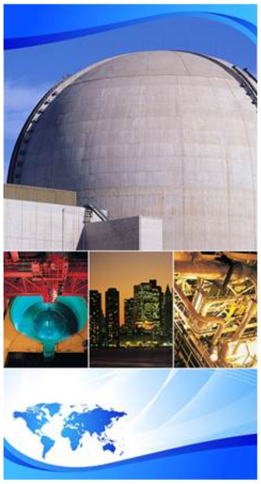
4.13 Task 11a: Detailed Fire Modeling and Single Compartment Scenarios

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation
From Science to Solutions



EPRI/NRC-RES FIRE PRA METHODOLOGY

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

Joint RES/EPRI Fire PRA Course
July and September, 2012
Washington, DC

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

Module III: 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

Joint Fire PRA Course, 2012, Washington DC
Module III: Task 11a - Detailed Fire Modeling & Single Compartment Fire Scenarios

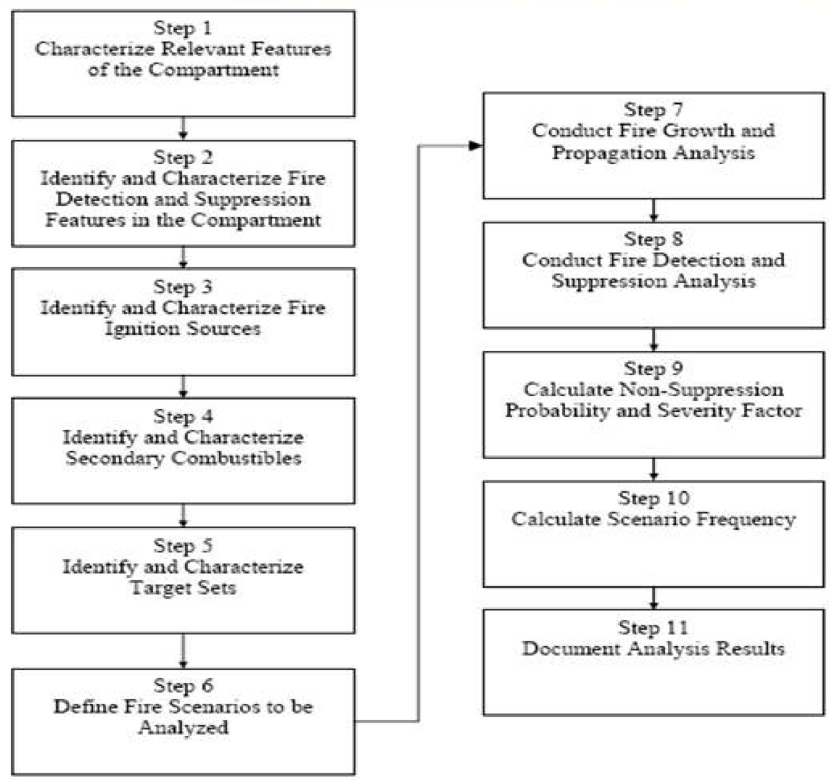
Slide 2

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

Module III: 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 event
  - 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 (cables), habitability, etc.

Module III: PROCESS
General Task Structure



Module III: 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 (file: 05_01_04…)

Module III: PROCESS
Identify/Characterize Ignition 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 fire 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 (file: 05_01_04…)
- Corresponding PRA Standard SR: FSS-A1, FSS-C1 through C4

Module III: 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

Module III: 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, once damaged component failure probabilities are set to 1.0.
  - 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
- Corresponding PRA Standard SR: FSS-A2 through A4

Module III: 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 (targets)
  - 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
- Corresponding PRA Standard SR: FSS-A5

Module III: 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 sources and combustibles and the location and number of potential targets. In general,
  - In compartments with few fire sources and many target sets (e.g., a switchgear room), start with an ignition source, postulate potential growth and propagation to other combustibles and then 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 targets (e.g., a PWR auxiliary building),
    - Nearby 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 (file: 05_01_04…)

Module III: PROCESS
Conduct Fire Growth and Propagation

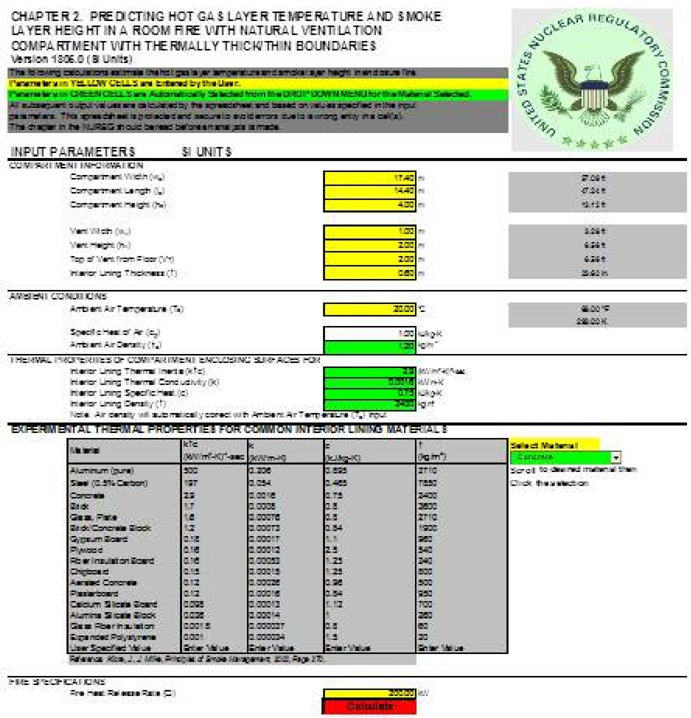
- Select fire modeling tool depending on the characteristics of each scenario
  - Empirical rule sets
  - Hand calculations
  - Zone models
  - Field models
- Analyze fire growth and spread to secondary combustibles
- Estimate resulting environmental conditions
- Estimate time to target set damage
- Workshop problem 11a-05 to 11a-08 (file: 05_01_04…)
- Corresponding PRA Standard SRs: FSS-C6, D1 through D6

Module III: 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

Module III: 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)

INPUT PARAMETERS SI UNITS

COMPARTMENT INFORMATION

Compartment Width (w_c)	17.40	m	57.09 ft
Compartment Length (l_c)	14.40	m	47.24 ft
Compartment Height (h_c)	4.00	m	13.12 ft
Vent Width (w_v)	1.00	m	3.28 ft
Vent Height (h_v)	2.00	m	6.56 ft
Top of Vent from Floor (V_T)	2.00	m	6.56 ft
Interior Lining Thickness (δ)	0.60	m	23.62 in

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	20.00	°C	68.00 °F / 293.00 K
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 ($k\rho c$)	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	$k\rho c$ (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

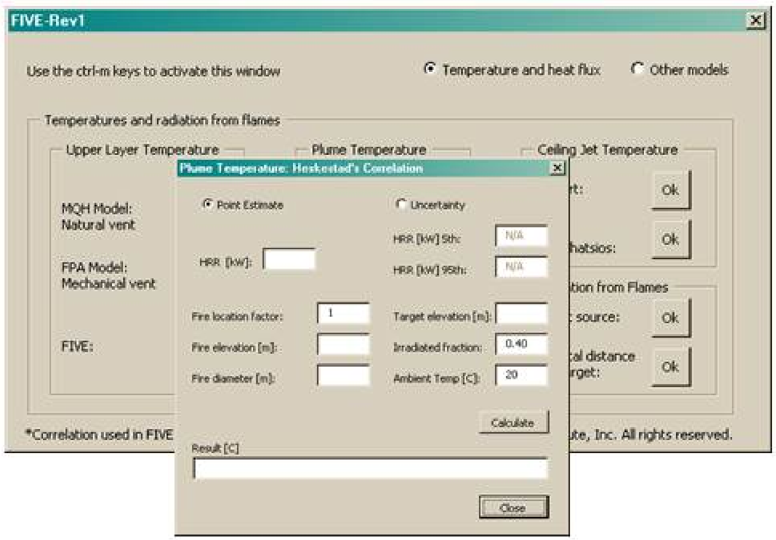
Fire Heat Release Rate (Q) 200.00 kW

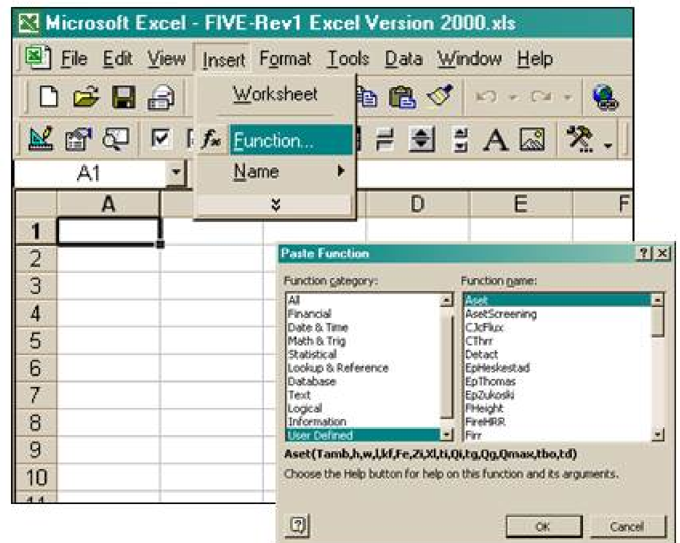
Calculate

Module III: PROCESS
Hand Calcs – FIVE-Rev1

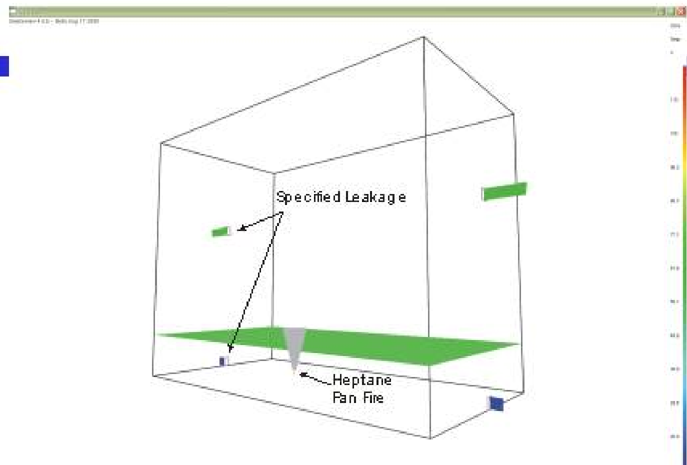
- More than ten years after FIVE, most of the equations are still considered "State-of-the-Art"
- A revision of the quantitative fire hazard techniques in FIVE
- Most of the hand calculations in the original EPRI publication and some other models available in the fire protection engineering literature
  - 4 stage heat release rate profile based on t^2 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 III: PROCESS
Hand Calcs – FIVE-Rev1

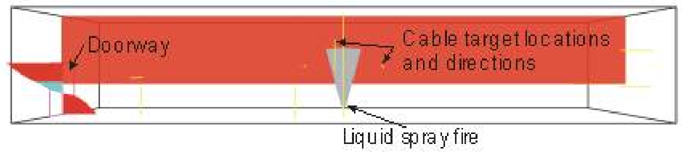




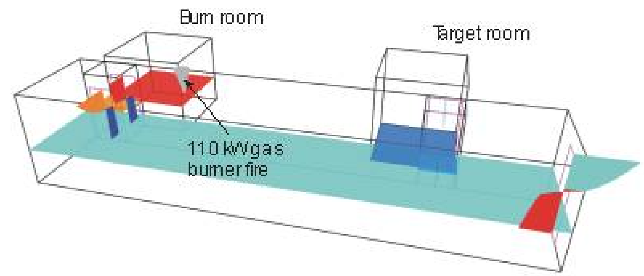
CFAST



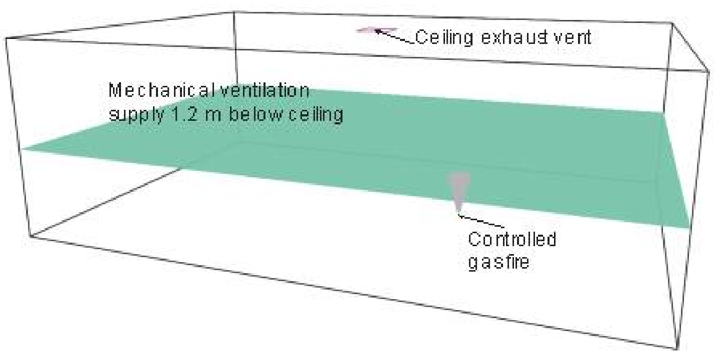
Specified Leakage
Heptane
Pan Fire



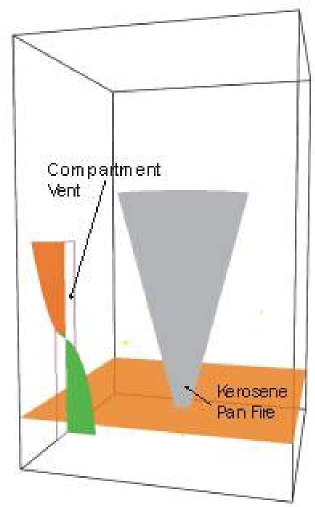
Doorway
Cable target locations
and directions
Liquid spray fire



Burn room
Target room
110 kW gas
burner fire

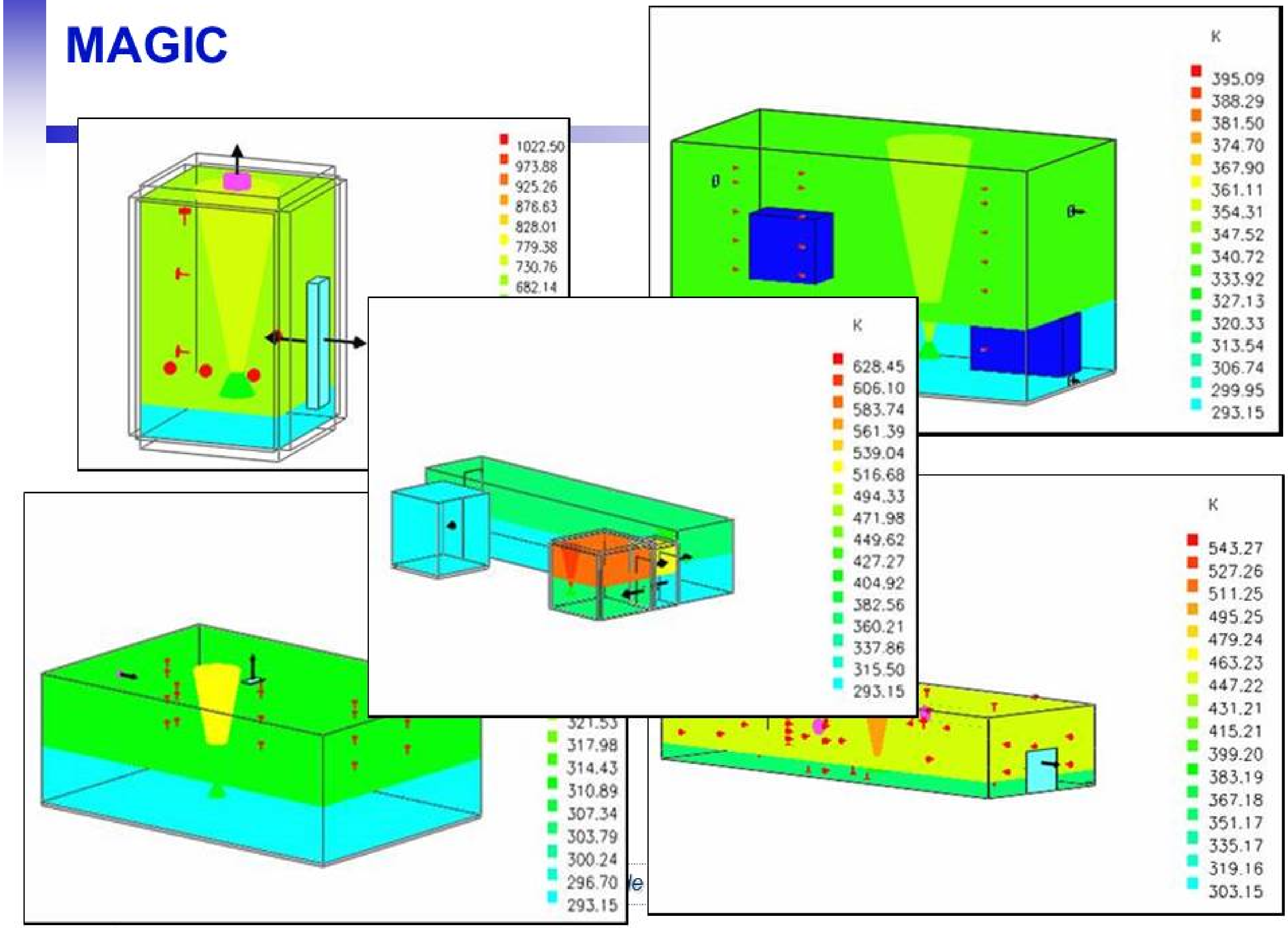


Ceiling exhaust vent
Mechanical ventilation
supply 1.2 m below ceiling
Controlled
gas fire



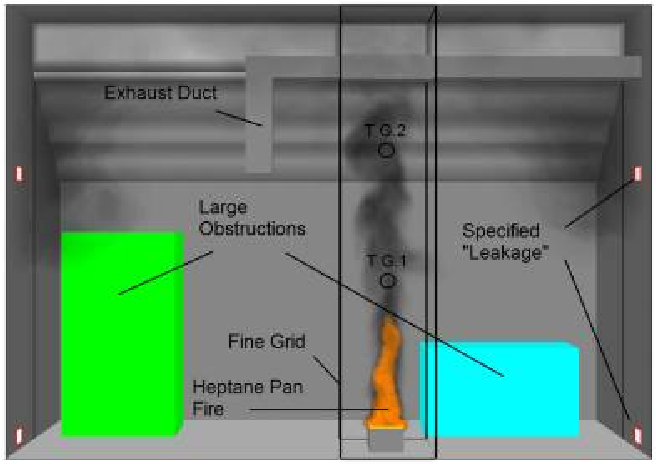
Compartment
Vent
Kerosene
Pan Fire

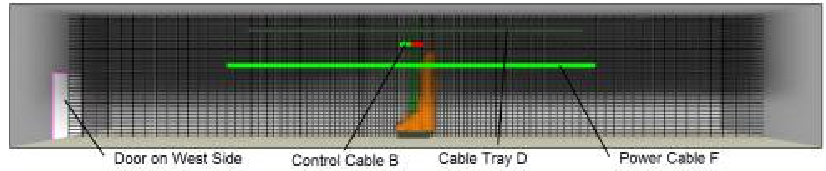
MAGIC

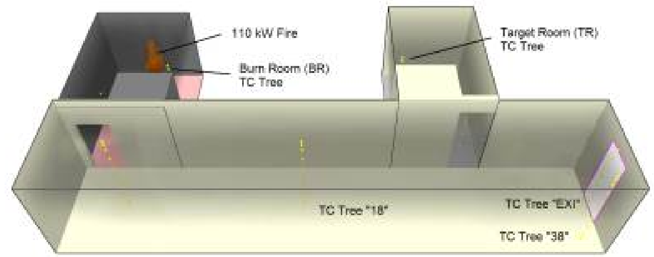


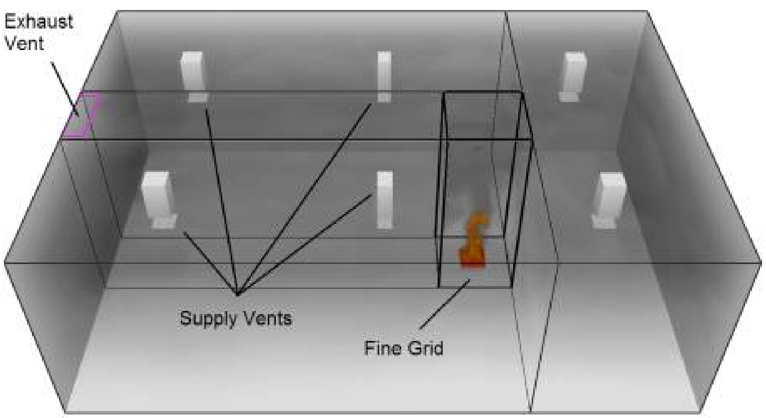
1022.50
973.88
925.26
876.63
828.01
779.38
730.76
682.14
K
395.09
388.29
381.50
374.70
367.90
361.11
354.31
347.52
340.72
333.92
327.13
320.33
313.54
306.74
299.95
293.15
K
628.45
606.10
583.74
561.39
539.04
516.68
494.33
471.98
449.62
427.27
404.92
382.56
360.21
337.86
315.50
293.15
317.98
314.43
310.89
307.34
303.79
300.24
296.70
293.15
K
543.27
527.26
511.25
495.25
479.24
463.23
447.22
431.21
415.21
399.20
383.19
367.18
351.17
335.17
319.16
303.15

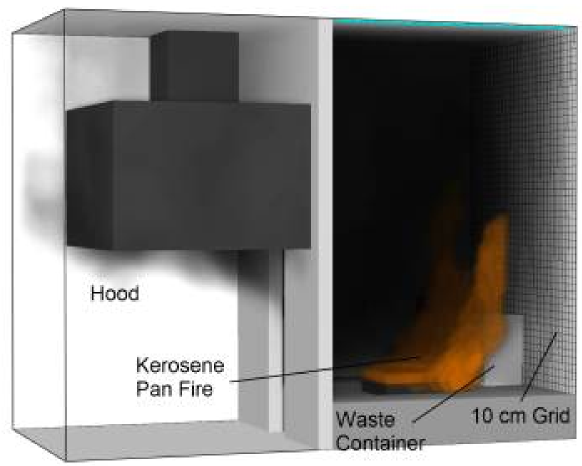
FDS











Joint Fire PRA Course, 2012, Washington DC
Module III: Task 11a - Detailed Fire Modeling & Single Compartment Fire Scenarios

Slide 18

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

Module III: 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 (file: 05_01_04…)
- Corresponding PRA Standard SRs: FSS-D6, D7, D8

Module III: 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 (file: 05_01_04…)
- Corresponding PRA Standard SRs: FSS-C4, D5

Module III: PROCESS
Calculate Fire Scenario Frequency

Severity factor for scenario k

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

Ignition frequency for scenario k

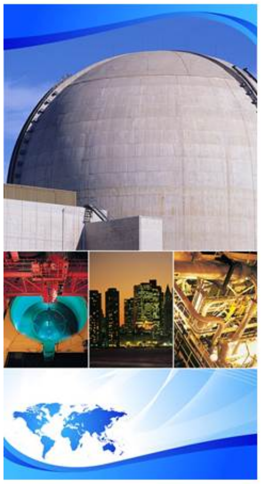
Integrated over all HRRs

Non-suppression probability for scenario k

Module III: 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.

4.14 Task 11b: Main Control Room Fire Analysis and Appendix L



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III

Task 11b: Main Control Room Fire Analysis and Appendix L

Joint RES/EPRI Fire PRA Workshop
July and September 2012
Washington, DC

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

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 analyze:
    - Conditional probability of damage to a target set
    - Forced control room abandonment time

Fire PRA Workshop, 2012, Washington, DC
Task 11b - Main Control Room Fire Analysis

Slide 2

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

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 can be within a short distance of each other
  - Small fires within control panels could be risk-significant
  - Related SR: FSS-A6
- The room is continuously occupied, which provides the capability for "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).
  - Related SRs: FSS-B and its two SRs

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

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
- False ceiling features and the ceiling above it

- *Problem Set 11b-01 (Example)* (file: 05_01_05…)

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

The features of alternate shutdown capability vary widely among NPPs

- 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)* (file: 05_01_05…)

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* (file: 05_01_05…)
- Corresponding PRA Standard SRs: FSS-A2 through A4

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

- *Problem Set 11.b-06* (file: 05_01_05…)

Main Control Room Fire Analysis
Step 7: Define Fire Scenarios

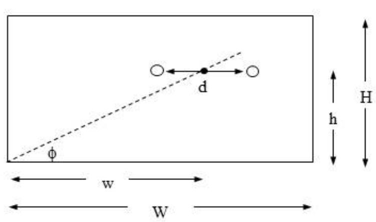
Four types of fire scenarios are specifically recommended for evaluation

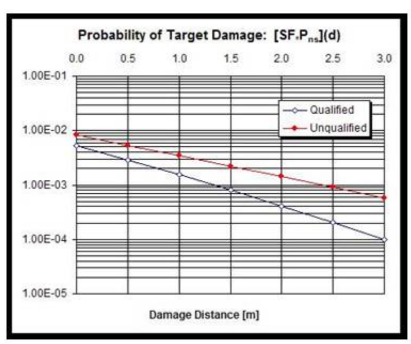
- Fire inside the main control board and stand-alone electrical cabinets that open into each other,
- Fires affecting two adjacent electrical cabinets that do not open into each other,
- Fires affecting two non-adjacent electrical cabinets, and
- Transient fires
- Corresponding PRA Standard SR: FSS-A6

Main Control Room Fire Analysis
Steps 8 and 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





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 successful usage of 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.

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

The final decision to abandon the control room is assumed to depend on habitability conditions.

- The analyst may postulate that the alternate shutdown procedure would be activated
- The time to activate the alternate shutdown procedure is suggested to be established based on plant operating procedures rather than control room habitability conditions
- Abandonment possibility should be examined for all postulated target damage scenarios

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/m[2]. 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 it is more than 0.4 m away. A light-emitting object will not be seen if it is more than 1 m away.
- A panel fire affects two target items 2.13 m (7′) apart.

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.
- Corresponding PRA Standard SRs: FSS-B1 and FSS-B2

- Note that this is typical HRR distribution discretization approach…

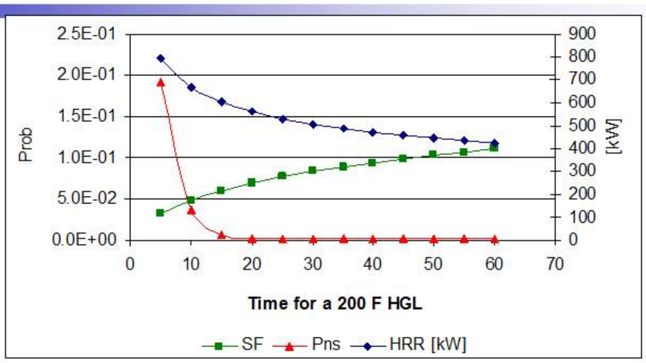
Main Control Room Fire Analysis
Example

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

- *Problem Set 11.b-08 (Example)* (file: 05_01_05…)

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

Main Control Room Fire Analysis
Example – (alternate discretization approach based on abd. time)



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

Main Control Room Fire Analysis
Concluding Remarks

The main control room has unique characteristics that are addressed in detail in Task 11b.

- Recommended fire scenarios for the MCR

- Evaluation of MCR abandonment due to fire generated conditions

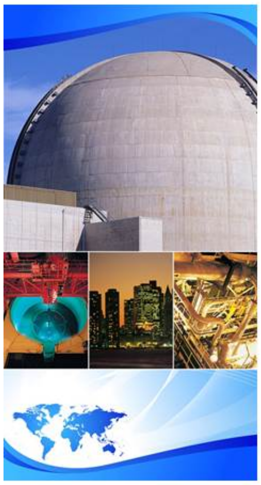
4.15 EPRI/NRC-RES Fire PRA Methodology and Its Relationship to NRC's Regulatory Structure

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation
From Science to Solutions



EPRI/NRC-RES FIRE PRA METHODOLOGY AND ITS RELATIONSHIP TO NRC's REGULATORY STRUCTURE

Mary Drouin
U.S. Nuclear Regulatory Commission

Fire PRA Workshop 2012
Bethesda

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

How Does NUREG/CR-6850 Fit into the NRC Regulatory Structure?

- The objective here is to provide an understanding, from a regulatory perspective, the need for a fire probabilistic risk assessment (PRA) methodology document, and therefore, its role in the regulatory structure.
- A major aspect of this objective is understanding what is meant by regulatory structure.

Fire PRA Workshop 2012, Bethesda, Maryland
Fire PRA Methodology and its Relationship to NRC'S Regulatory Structure

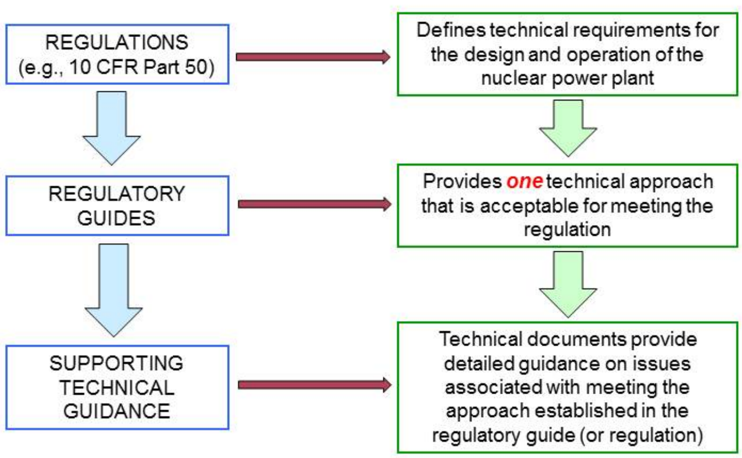
Slide 2

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

NRC Regulatory Structure

- Congressional Mandate
  - Atomic Energy Act indicates that the mission of the NRC is to ensure that commercial nuclear power plants are operated in a manner that provides adequate protection of public health and safety and is consistent with the common defense and security.
- NRC provides for public health and safety via a licensing, oversight and enforcement process.
- Licensing, oversight and enforcement all involve establishing regulations and developing the necessary supporting structure (e.g., regulatory guides).

What is the Relationship Between a Regulation and a Methodology Document?



What is the Relationship in the Context of a Fire PRA?

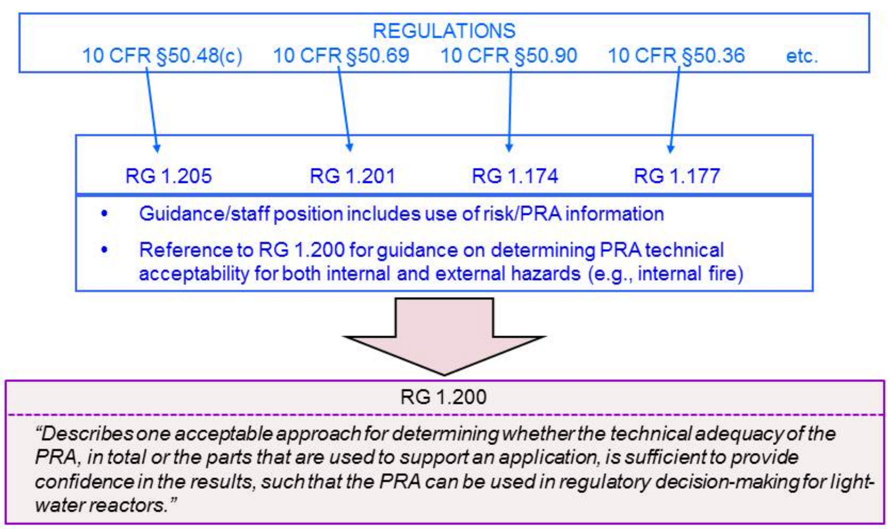
- Example relevant regulations:
  - 10 CFR §50.48(c), Fire Protection, National Fire Protection Association Standard NFPA 805
  - 10 CFR §50.69, Risk-informed categorization and treatment of structures, systems and components for nuclear power reactors
  - 10 CFR §50.90, Application for amendment of license, construction permit, or early site permit
  - 10 CFR §50.36, Technical Specifications
- What is the common element among these regulations?
  - The use of risk information, and therefore, ***the need to have confidence in the risk analyses (or PRAs)*** being used to generate the information
  - ***Risk contributors to be addressed include internal fires.***

Fire PRA Workshop 2012, Bethesda, Maryland
Fire PRA Methodology and its Relationship to NRC'S Regulatory Structure

Slide 5

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

How is This Confidence Achieved?



Fire PRA Workshop 2012, Bethesda, Maryland
Fire PRA Methodology and its Relationship to NRC'S Regulatory Structure

Slide 6

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

How is This Confidence Achieved (cont'd)?

- The approach provided in RG 1.200 defines the attributes and characteristics of a technically acceptable PRA.
  - The defined attributes and characteristics are very high level.
- For example, characteristics and attributes provided in RG 1.200 for Fire Ignition Frequencies:
  - Frequencies are established for ignition sources and consequently for physical analysis units.
  - Transient fires should be postulated for all physical analysis units regardless of administrative controls.
  - Appropriate justification must be provided to use nonnuclear experience to determine fire ignition frequency.

How is This Confidence Achieved (cont'd)?

- RG 1.200 allows the use of a consensus standard (as endorsed by the NRC) with a peer review to demonstrate conformance with the defined attributes and characteristics.
  - RG 1.200 endorses and provides a position on the ASME/ANS PRA Standard (ASME/ANS RA-Sa-2009).
  - ***Part 4 of the ASME/ANS standard provides the requirements for fires at-power PRA.***
- The PRA Standard, however, only defines ***what*** is required for a technically acceptable PRA and an acceptable peer review.

How is This Confidence Achieved (cont'd)?

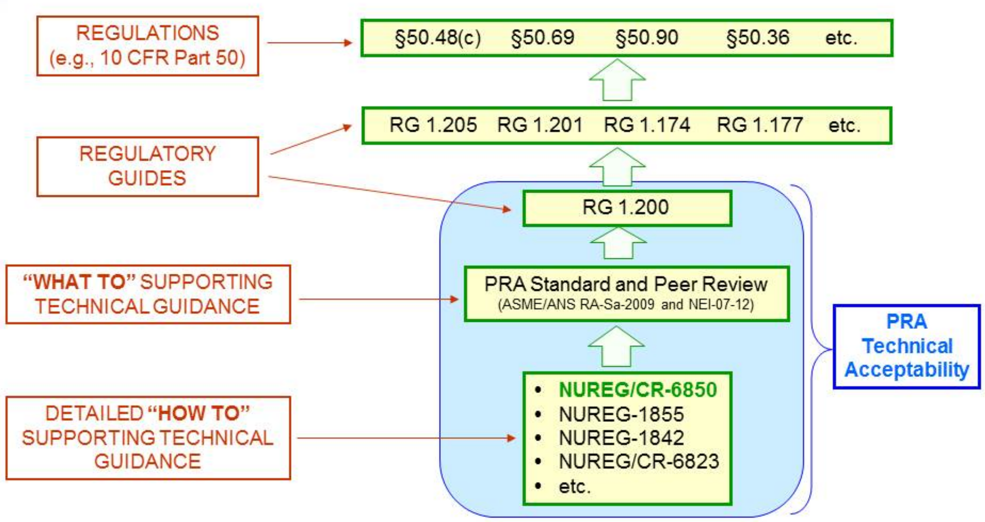
- Guidance is needed for ***how*** to accomplish the requirements in the standard and guidance is needed for the peer review in determining whether the intent of requirement is met.
- This guidance is particularly needed for those aspects in the PRA where the model is not well known.
- One major objective of NUREG/CR-6850 is to provide the detailed guidance for how to accomplish meeting the requirements for Fire PRA.
  - As such, NUREG/CR-6850 supports both the PRA standard and the PRA peer review guidance

Fire PRA Workshop 2012, Bethesda, Maryland
Fire PRA Methodology and its Relationship to NRC'S Regulatory Structure

Slide 9

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

Overall Relationship

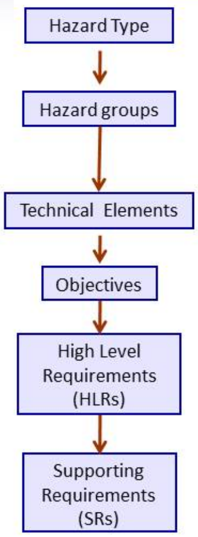


Fire PRA Workshop 2012, Bethesda, Maryland
Fire PRA Methodology and its Relationship to NRC'S Regulatory Structure

Slide 10

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

Structure of PRA Standard

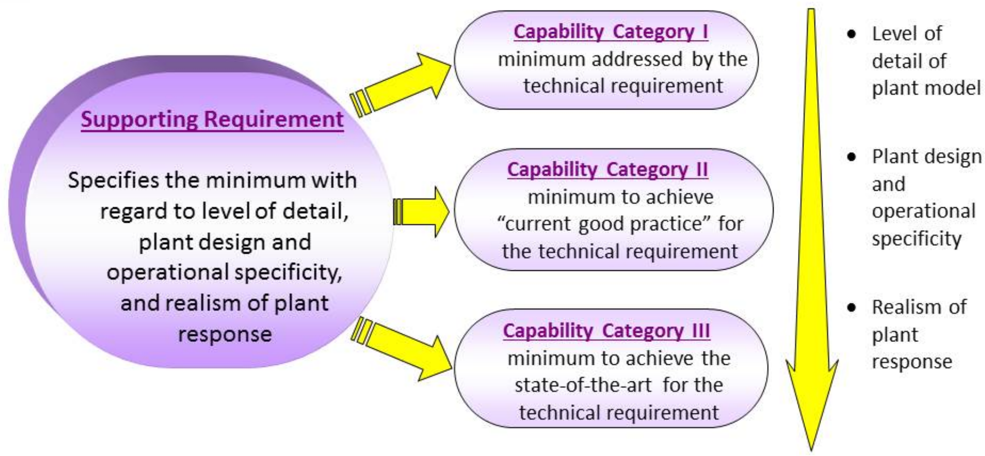


- Two different hazard types are defined in the Standard which include both internal and external hazards.
- For each hazard type, the various groups of hazards are defined, for example for internal hazards: internal events, internal flood and internal fires.
- For each hazard group, the technical elements are defined for developing the hazard-specific PRA model.
- The objective of each technical element is defined.
- High level requirements are defined which specify what is needed to accomplish the defined objective of the technical element.
- Supporting requirements are defined which, in turn, specify what is needed to accomplish the defined high level requirement.

Structure of PRA Standard (cont'd)

- At the supporting requirement level, it was recognized that the extent or to which the level of detail, the level of plant specificity and the level of realism of the PRA model can vary
- Consequently, the minimum defined by the requirement can also vary
- Consequently, three "categories of capability" were defined for the supporting requirements.
  - ***Capability Category I:*** the very basic needed.
  - ***Capability Category II***: the minimum to support majority of applications
  - ***Capability Category III***: the minimum to support application with high reliance on the fidelity of the PRA results.

Standard Capability Categories



Fire PRA Workshop 2012, Bethesda, Maryland
Fire PRA Methodology and its Relationship to NRC'S Regulatory Structure

Slide 13

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

Standard Capability Categories (cont'd)

PRA Attribute	Capability Category I	Capability Category II	Capability Category III
Scope and Level of Detail	Sufficient to identify relative importance at the system or train level	Sufficient to identify relative importance of significant component level contributors	Sufficient to identify relative importance of all component level contributors
Plant-Specificity	Generic data/models except for unique design and operational features	Plant-specific data/models for the significant contributors	Plant-specific data/models for all contributors
Realism	Departures from realism will have moderate impact*	Departures from realism will have small impact*	Departures for realism will have negligible impact*

*Differentiation from moderate, to small, to negligible is determined by the degree that the conclusions and risk insights could affect a decision under consideration.

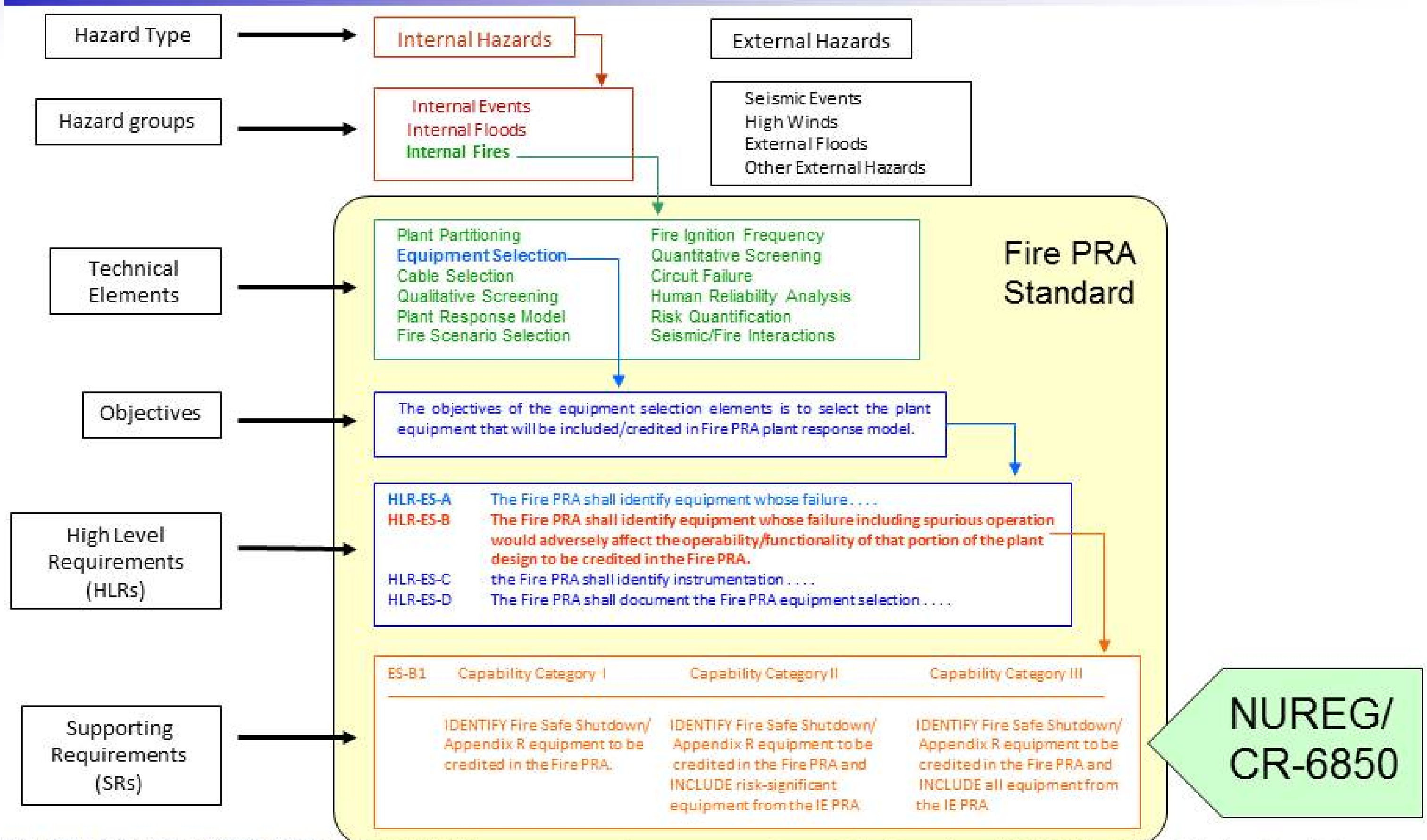
- Moderate: likely that a decision could be affected
- Small: unlikely a decision could be affected
- Negligible: a decision would not be affected.

Fire PRA Workshop 2012, Bethesda, Maryland
Fire PRA Methodology and its Relationship to NRC'S Regulatory Structure

Slide 14

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

Illustration of Fire PRA Standard Structure and NUREG/CR-6850



Fire PRA Workshop 2012, Bethesda, Maryland
Fire PRA Methodology and its Relationship to NRC'S Regulatory Structure

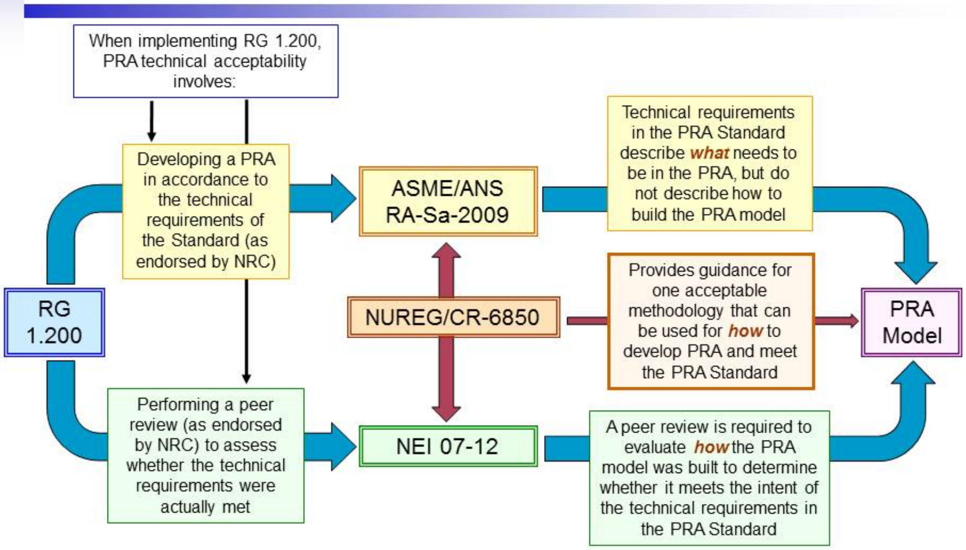
Slide 15

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

Fire PRA Standard and NUREG/CR-6850:
Illustration of the Mapping of HLRs & SRs to 6850

Technical element	HLR	SR	6850/1011989 sections that cover SR	Comments
ES	A	The Fire PRA shall identify equipment whose failure caused by an initiating fire including spurious operation will contribute to or otherwise cause an initiating event.		
		1	2.5.3	
		2	3.5.3	Covered in "Cable Selection" chapter
		3	2.5.3	
		4	2.5.1, 2.5.4	
		5	2.5.4	
		6	2.5.6	
	B	The Fire PRA shall identify equipment whose failure including spurious operation would adversely affect the operability/functionality of that portion of the plant design to be credited in the Fire PRA.		
		1	2.5.2	
		2	2.5.4	
		3	5.5.1	Covered in "Fire-Induced Risk Model" chapter
		4	3.5.3	Covered in "Cable Selection" chapter
		5	n/a	Exclusion based on probability is not covered in 6850/1011989
	C	The Fire PRA shall identify instrumentation whose failure including spurious operation would impact the reliability of operator actions associated with that portion of the plant design to be credited in the Fire PRA.		
		1	2.5.5	
		2	2.5.5	
	D	The Fire PRA shall document the Fire PRA equipment selection, including that information about the equipment necessary to support the other Fire PRA tasks (e.g., equipment identification; equipment type; normal, desired, failed states of equipment; etc.) in a manner that facilitates Fire PRA applications, upgrades, and peer review.		
		1	n/a	Documentation not covered in 6850/1011989

Overall Process



Fire PRA Workshop 2012, Bethesda, Maryland
Fire PRA Methodology and its Relationship to NRC'S Regulatory Structure

Slide 17

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

Summary/Conclusion

- NUREG/CR-6850 is a methodology document and, while not required to be met, plays a major role in defining a technically acceptable Fire PRA to support NRC activities where a Fire PRA model is needed and the results of the Fire PRA model are used to meet a regulation.

Fire PRA Workshop 2012, Bethesda, Maryland
Fire PRA Methodology and its Relationship to NRC'S Regulatory Structure

Slide 18

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

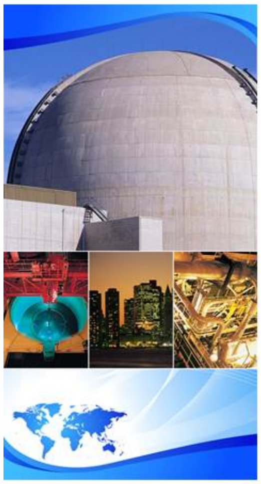
4.16 **Example: Pump Room Fire**

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation
From Science to Solutions



EPRI/NRC-RES FIRE PRA METHODOLOGY

Example: Pump Room Fire

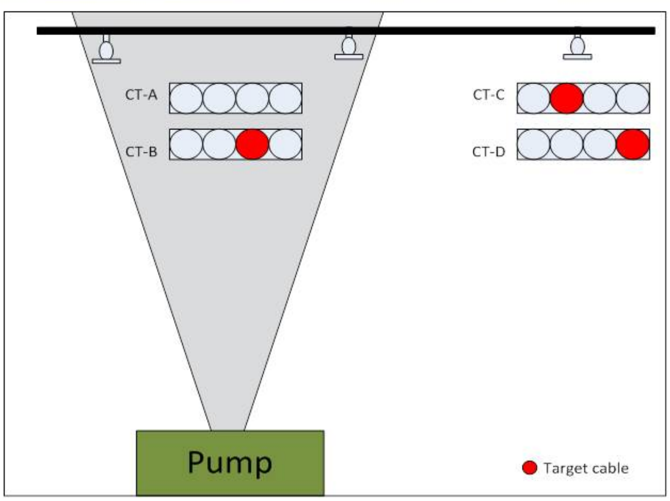
RES/EPRI Fire PRA Training Course

Classroom Exercise

July and September, 2012

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

The scenario: an electric motor driven pump fire with three fire PRA damage targets (cables)



Fire PRA Workshop, 2012, Washington DC
An example problem for pump fires

Slide 2

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

Scenario Assumptions

- A fire is postulated in an electrical motor-driven pump located in a typical pump room.
- The room is protected by automatic sprinklers.
- There are four cable trays in the room and three of them contain target cables that are within the scope of the Fire PRA.
  - The first tray of interest is CT-B which is located 6-feet above the pump and does contain a PRA target cable.
  - The other target cables are in CT-C and CT-D which will fail only given a damaging hot gas layer.
- The cable types are unknown – Implications???
- Damage threshold is 205°C

We will use the multi-stage damage state approach

- Through inspection of the ignition source and cable tray layout during walk-downs and using plant drawings, the following damage sets are evaluated:
  - Target Set 1: Pump only (Ignition source)
  - Target Set 2: Pump + CT-B (Damage in the fire plume)
  - Target Set 3: Pump + CT-B + CT-C + CT-D (Damage in the hot gas layer)
- What about Target Set 1?

Loss of the ignition source

- In most cases loss of the ignition source alone is not significant to fire risk
  - For a component like a pump, a failure of the pump with no other damage is part of the internal events reliability estimates (just another loss of function failure)
- Be careful to verify, but for this case we will dismiss fire risk implications for loss of just the pump

We need an ignition frequency

- Where do we start?
- Base frequency tables (Table 6-1)*

  * we'll use the original 6850/1011989 values for this example
- Bin 21: λ_{pumps} = 2.1E-2/ry
- What else do we need?
- Weighting factor / plant population
  - Lets say 50 total Bin 21 pumps
  - Frequency per pump: $\lambda_{one\ pump} = \lambda_{pumps}$ / 50 = 4.2E-4/ry

Fire Characterization

- What kind of fire are we dealing with?
- Two, actually
  - Electric motor fire (54% of pump fires)
  - Oil fires (46% of pump fires)
- We can use these to get individual fire frequencies:
  - $\lambda_{pump/motor}$ = 4.2E-4 * 0.54 = 2.27E-4/ry
  - $\lambda_{pump/oil}$ = 4.2E-4 * 0.46 = 1.93E-4/ry
- Now about those oil fires…

General pump oil fires (ML12171A583)

- 6850/1011989 originally said:
  - 98% of oil fires involve a release of 10% of the oil inventory
  - 2% of oil fires involve a release of 100% of the oil inventory
- A new approach has been developed that uses three spill levels instead of two:
  - Very small leaks (non-pooling spills)
  - Medium oil spills – 10% of inventory
  - Large oil spills – 100% of inventory
- And the new numbers (based on NRC staff position):
  - Very small – 88% of oil fires
  - Medium – 7% of oil fires
  - Large – 5% of oil fires

What is impact of new approach?

- In most cases the very small oil fires will be non-damaging / non-spreading (but you need to verify)
  - Most of these involve oil-soaked insulation which creates a low intensity and highly localized fire
  - If it's not oil soaked insulation, then it's a *non-pooling* oil fire
    - e.g., oil on pipe surface, oil at a bearing surface… not enough oil to form a pool fire
  - Need to verify that no PRA targets or other combustibles located very near source of leak (e.g., close to piping where oil might leak)
  - If you can show very small leak fires are non-damaging, implies a severity factor of SF=0.12 (1.0-0.88) minimum.
- Medium spill fires are down substantially compared to old numbers
- On the other side, large spills are up by a factor of 2.5

So now we have four fires

- Electrical motor fire: $\lambda_{pump/motor}$ = 2.27E-4 /ry
- Very small oil spill: $\lambda_{pump/VSoil}$ = 1.70E-04 /ry
- Medium oil spill: $\lambda_{pump/Moil}$ = 1.35E-05 /ry
- Large oil spill: $\lambda_{pump/Loil}$ = 9.66E-06 /ry

Fire analysis tasks

- We are left with four fire sub-scenarios:
  - Motor, very small oil spill, medium oil spill, large oil spill
- What steps will we need to go through, what questions will we need answers to?
- We'll need to…
  - Establish fire characteristics for each
  - Screen each sub-scenario (for damage states 2 and 3)
  - Develop severity factors for each damage state were possible
  - Estimate detection time
  - Determine if we can credit sprinklers – yes/no and when
  - Time to damage for each case where damage is possible
  - P_{NS} for each case where damage is possible

Let's start with analysis of the motor fire:

- We need HRR…
- Use Case 6 Table E-1
- Screen using the 98th percentile (211 kW):
  - Can fire spread or cause damage to first target?
  - Definitely big enough to cause damage to first tray ($T_{plume} \approx 300°C$)
  - Remember - our damage threshold is 205°C
- Find severity factor - minimum damaging fire:
  - Plume correlations says: 130kW is minimum fire where T=205°C @ 6'
  - HRR_{peak} distribution says: 130kW is 92nd percentile in profile
- So: SF_{motor} = 0.08

Continuing the motor fire

- Next step: screen for damage state 3 - HGL damage
  - Can it cause a damaging hot gas layer?
    - Assume we did analysis and found answer is no (room is too big to get to 205°C even with both motor and two trays burning
- Can we credit sprinklers for motor fire?
  - We look at fire geometry, do temperature calc. for nearest sprinkler head (plume/ceiling jet calculations)
  - Assume we did analysis and found ceiling jet is not hot enough to set of sprinklers
- So at this point we have our motor fire down to:
  - SF = 0.08
  - Only Damage State 2 in play (pump + CT-B)
- Next we do the horse race…

Crediting fire detection and suppression for the motor fire

- At this point is it all about timing – damage versus suppression
- Start with time to damage
  - For now lets work with 98th percentile fire (211 kW)
  - Recall that we calculated a plume temperature of just under 300°C during screening step
  - How can we use that information?
- Go to Table H-6

Damage time table…

- A TP cable exposed to 290-300°C has an estimated time to damage of 7 min.

Table H-6
Failure Time-Temperature Relationship for Thermoplastic Cables
(Table A.7.2 from Reference H.6)

Exposure Temperature °C	Exposure Temperature °F	Time to Failure (min)
205 ≤ T < 220	400 ≤ T < 425	30
220 ≤ T < 230	425 ≤ T < 450	25
240 ≤ T < 245	450 ≤ T < 475	20
245 ≤ T < 260	475 ≤ T < 500	15
260 ≤ T < 275	500 ≤ T < 525	10
275 ≤ T < 290	525 ≤ T < 550	8
290 ≤ T < 300	550 ≤ T < 575	7
300 ≤ T < 315	575 ≤ T < 600	6
315 ≤ T < 330	600 ≤ T < 625	5
330 ≤ T < 345	625 ≤ T < 650	4
345 ≤ T < 355	650 ≤ T < 675	3
355 ≤ T < 370	675 ≤ T < 700	2
T ≥ 370	T ≥ 700	1

On to fire detection and suppression…

- We need detection time:
  - We do the analysis and get <1 min for detection
  - Assume 1 minute detection time
- Time available for manual suppression:
  - $t_{avail} = t_{damage} - t_{detect} = 6$ min
- Which suppression curve?
- A: Electrical fires
  - Table 11-1 in 6850/1011989 says for Bin 21 use Electrical/Oil suppression curves
  - We are in motor fire part so that means electrical fires curve
  - see FAQ 50, Table 2: electrical fires - mean suppression rate = 0.102
  - $P_{NS} = e^{-(0.102 \times 6)} = 0.54$

Detection suppression continued

- We also want to know if we can credit sprinklers:
  - Need to see if sprinklers go off and if so when
  - We do temperature calc. for closest sprinkler head (ceiling jet)
  - If temperature exceeds link melt temperature, then we may be able to credit
  - Look at sprinkler response time to estimate activation time
    - CFAST will do this calculation for you…
  - If activation time < damage time, credit the system
- For our example, assume we get:
  - Motor fire – sprinklers do not activate, won't be credited

Motor fire summary

- Frequency = 2.27E-4 / ry
- 98^{th} percentile fire is 211 kW
- SF = 0.08 (130 kW fire minimum damaging fire)
- Damage state is loss of pump plus CT-B only (no hot gas layer)
- Time to detection = 1 min
- Time to damage = 7 minutes
- P_{NS} = 0.54 (manual suppression)
- No credit for sprinkler system

That leaves us with analysis of the oil fires

- Start with the very small oil spill fires…
  - By inspection, there is nothing within less than 6ft of our pump
  - We want to dismiss oil-soaked insulation fires as non-threatening
  - In practice, you'll need to justify this conclusion but no specific guidance for this in the new methodology
  - Potential arguments to consider:
    - Oil-soaked insulation fires can last a long time, but they are low intensity
      - Oil smoldering/burning within the porous insulation, lots of smoke, not much heat
      - Occasional flare-ups especially as fire fighters tear away insulation during suppression efforts
      - Long duration is associated with managed suppression efforts
    - In our case we already found that it takes a 130kW fire to reach a conservative damage threshold for first tray above fire
    - Clearly that exceeds intensity of a very small spill fire or oil-soaked insulation fire
    - We will not consider further in our example

On to the other oil spills (medium and large)

- For the larger oil fires follow the same pattern as for the motor fire:
  - Oil fire severity factor is largely built into the fire frequencies (spill size split fractions)
  - You have to characterize spill
    - Quantity of oil, oil properties, spill size
    - Use pool fire correlation to get HRR
  - Note there is a balance between spill size and fire duration
    - Larger spill means more intense fire but shorter burn - have to balance using judgment
    - Check the containment berm – recognize that 10% spill will likely not cover the whole surface of a berm designed to contain a 100% spill
    - Look for a low spot (there is always a low spot…)
  - Screening for no damage, no spread
    - Larger spills will generally be in play unless targets are pretty far away or oil volume is very small
    - Compare oil fire HRR to minimum fire required to cause damage (plume and HGL)
    - Consider re-balancing size versus duration to ensure the case is covered
  - In our example first target is 6' above fire so medium and large oil spill fires won't screen out for plume damage, medium fire assumed to screen out for HGL
    - see handout for details

Medium and large spill oil fires (cont)

- Analysis pattern (cont):
  - Calculate exposure temperatures and convert to damage time
    - e.g., back to Appendix H
    - In our case we find medium fire is too small to create damaging HGL…
  - Calculate time to detection (likely <1 min)
  - Calculate time available for suppression (damage-detection)
  - Go to suppression curve for oil fires to get PNS
  - Check the sprinklers
    - In our example we will assume sprinklers will activate for oil fires
    - Estimate time to activation and compare to damage time
    - If sprinklers activate before damage, we'll credit sprinklers

Putting it all together

- These are the event timing factors we got for our case example (details in the handout)

	Event Time / Damage Times (Min)			
Event:	**Electrical fire**	**Oil/Small**	**Oil/Medium**	**Oil/Large**
Ignition	0	0	0	0
Smoke Detection	1	1	1	1
Sprinkler activation	No Activation*	No Activation*	5	2
Damage Target Set 2	7	No Damage*	6	3
$t_{damage} - t_{detection}$	6	-	5	2
Damage Target Set 3	No Damage*	No Damage*	No Damage*	8
$t_{damage} - t_{detection}$	-	-	-	7

* For these cases, the fire is simply not large enough to activate the sprinklers and/or to create a damaging hot gas layer.

Putting it all together (cont)

- And these are corresponding P_{NS} values:

	"Raw" Manual Suppression Failure Probabilities (P_{NS})			
Event	Electrical fire	Oil/Small	Oil/Medium	Oil/Large
Damage to Target Set 2	$e^{(-0.102 \times 6))} = 0.54$	-	$e^{(-0.076 \times 5)} = 0.74$	$e^{(-0.076 \times 1)} = 0.86$
Damage to Target Set 3	-	-	-	$e^{(-0.076 \times 7)} = 0.59$

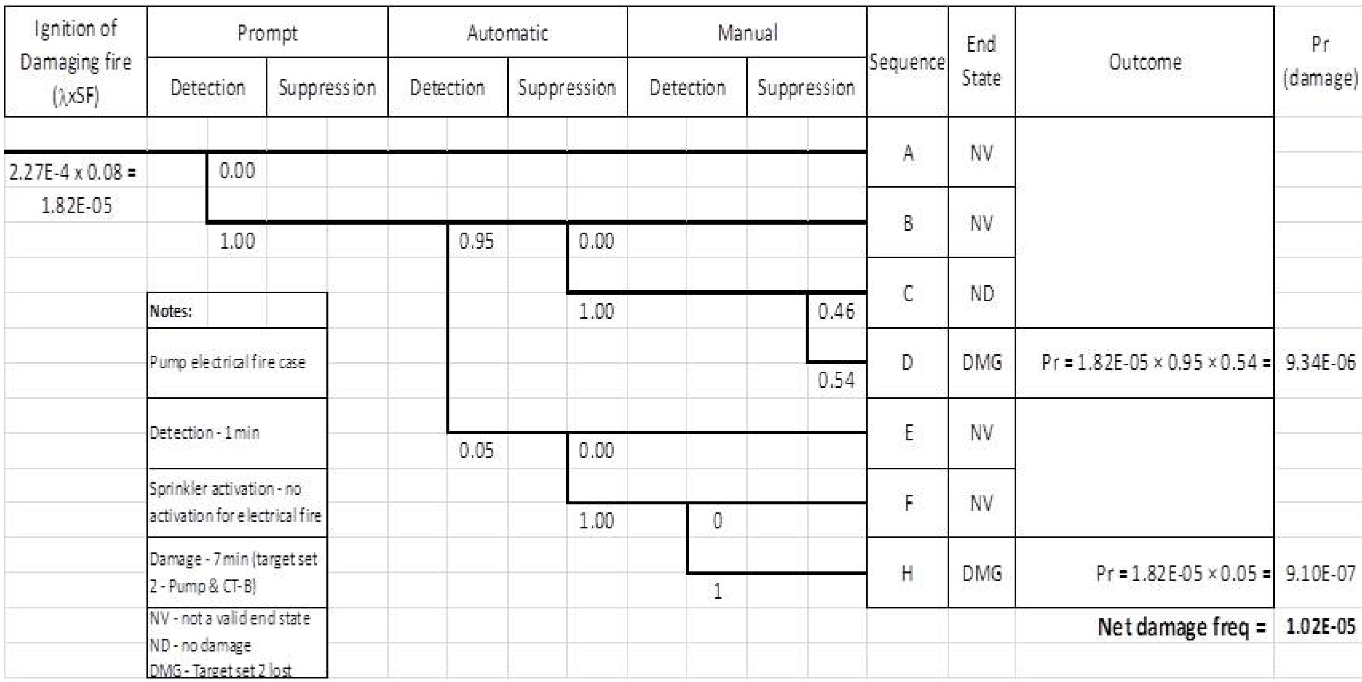
- And our finding relative to the sprinklers:

	Automatic Suppression Failure Probabilities			
Event	Electrical fire	Oil/Small	Oil/Medium	Oil/Large
Damage to Target Set 2	1.0*	-	0.02	0.02
Damage to Target Set 3	-	-	-	0.02

* In this case the sprinklers never activate.

Now we need our event trees

- This is the tree for the motor fires:



Now we need our event trees (cont)

- And for the medium oil spill fire:

Ignition of medium spill fire	Prompt Detection	Prompt Suppression	Automatic Detection	Automatic Suppression	Manual Detection	Manual Suppression	Sequence	End State	Outcome	Pr (damage)
1.35E-05	0.00						A	NV		
	1.00		0.95	0.98			B	ND		
				0.02		0.32	C	ND		
						0.68	D	DMG	Pr = 1.35E-05 × 0.95 × 0.68 =	1.74E-07
			0.05	0.98			E	ND		
				0.02	0		F	NV		
					1		H	DMG	Pr = 1.35E-05 × 0.05 × .02 =	1.35E-08
									Net damage freq. =	**1.88E-07**

Notes:
Medium oil spill sub-scenario
Detection - 1 min
Sprinkler activation - 5 minutes
Damage - 6 min (target set 2 - Pump & CT-B)
NV - not a valid end state ND - no damage DMG - Target set 2 lost

Now we need our event trees (cont)

- And for the large oil spill fire (we are re-arranging and simplifying a bit…):

Fire Ignition	Applicable to both target set cases: Automatic Detection	Automatic Suppression	Manual suppression case for damage to Target Set 2: Manual Detection	Manual Suppression	Manual suppression case for damage to Target Set 3: Manual Detection	Manual Suppression	Sequence	End State	Outcome	net Freq.
9.66E-06	0.95	0.98					A	ND	no damage	8.99E-06
		0.02		0.20			B	ND	no damage	3.74E-08
				0.80		0.26	C	TS-2	Pr = 9.66E-06 × 0.95 × 0.02 × 0.80 × 0.26 =	**3.83E-08**
						0.74	D	TS-3	Pr = 9.66E-06 × 0.95 × 0.02 × 0.80 × 0.74 =	**1.08E-07**
	0.05	0.98					E	ND	no damage	4.73E-07
		0.02					F	TS-3	Pr = 9.66E-06 × 0.05 × 0.02 =	**9.66E-09**
									Net damage freq TS-2 =	**3.83E-08**
									Net damage freq TS-3 =	**1.17E-07**
									checksum for all end states:	9.66E-06

Notes:

Pump large spill oil fire case

Detection - 1 min

Sprinkler activation - 3 min (timely - prevents damage)

Damage TS-2 = 4 min
Damage TS-3 = 8 min

Raw' P_{NS} calculations:

	$P_{NS}(t1)$	$P_{NS}(t2)$	ratio
lambda	0.076	0.076	
Det time	1	1	
Dmg time	4	8	
Pns	0.80	0.59	0.74

And now for the final results…

- Our final damage state frequencies for each of our two target sets are:

Scenario ID	Sub-scenario Frequency	Severity Factor	P_{NS} (Manual)	P_{NS} (Fixed)	P_{NS} (net)	P_S (net) (1- P_{NS})	Scenario Frequency	Scenario damage end state*
Pump-Electrical-2	2.27E-04	0.08	0.54	1	3.6E-01	6.4E-01	3.7E-04	Target Set 2
Pump-Oil-Medium-2	1.35E-05	1	0.68	0.02	1.4E-02	9.9E-01	1.88E-07	Target Set 2
Pump-Oil-Large-2	9.66E-06	1	0.8	0.02	3.97E-03	9.9E-01	3.83E-08	Target Set 2
Pump-Oil-Large-3	9.66E-06	1	0.54	0.02	1.22E-02	9.9E-01	1.17E-07	Target Set 3
					Total frequency for loss of target set 2 (per – ry)		**3.7E-04**	CCDP would be calculated based on loss of target set 2
					Total frequency for loss of target set 3 (per – ry)		**1.2E-07**	CCDP would be calculated based on loss of target set 3

What more might you do to refine analysis if desired?

- Refine assumptions on motor fire
  - Don't use 98th percentile fire for all damaging fires
  - Discretize the HRR distribution above 92nd percentile into 2-5 bins
  - In fact, Standard would say use at least a 2-point representation for damaging fires in order to meet Cat II…
- You could apply THIEF model to refine damage time estimate
- You could run a compartment fire model to characterize hot gas layer over time for large oil fire
- You could find out what kind of cables these are
  - This one is generally a "high bang for the buck" option

Summary

- Example intended to illustrate process
  - How you define the sub-scenarios when there is more than one fire type
  - Dealing with multiple damage states
  - Screening
  - Detailed analysis
  - Putting together the fire event tree
  - Combining the sub-scenarios into a final set of quantification results

- Questions???

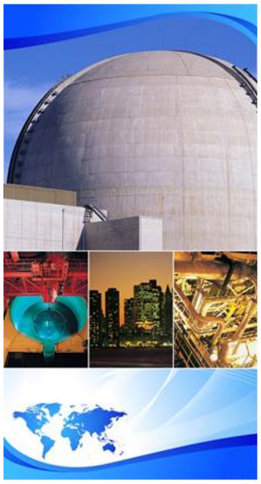
4.17 **Task 11c: Multi Compartment Fire Analysis**

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation
From Science to Solutions



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module III

Task 11c - Multi-Compartment Fire Analysis

Joint RES/EPRI Fire PRA Workshop
July and September 2012
Washington, DC

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

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

Fire PRA Workshop, 2012, Washington, DC
Task 11c - Multi-Compartment Fire Analysis

Slide 2

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

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

- Corresponding PRA Standard SRs: FSS-G1 through FSS-G6

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 Compartments*: The compartments to which fire from the exposing compartment propagates

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

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

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

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

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 or less than those in the exposing compartment.

- Corresponding PRA Standard SRs: FSS-G2 and FSS-G3

Fire PRA Workshop, 2012, Washington, DC
Task 11c - Multi-Compartment Fire Analysis

Slide 9

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

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

- Corresponding PRA Standard SRs: FSS-G2 and FSS-G3

Fire PRA Workshop, 2012, Washington, DC
Task 11c - Multi-Compartment Fire Analysis

Slide 10

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

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

- Corresponding PRA Standard SRs: FSS-G2 through FSS-G5

Fire PRA Workshop, 2012, Washington, DC
Task 11c - Multi-Compartment Fire Analysis

Slide 11

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

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

Fire PRA Workshop, 2012, Washington, DC
Task 11c - Multi-Compartment Fire Analysis

Slide 12

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

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

- Corresponding PRA Standard SR: FSS-G6

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)

- Corresponding PRA Standard SR: FSS-G1

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

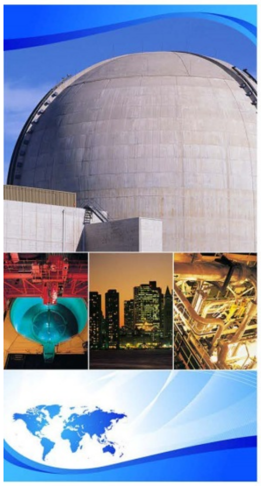
4.18 **Task 13: Seismic Fire Interactions**

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

HUGHES ASSOCIATES



EPRI/NRC-RES FIRE PRA METHODOLOGY

Module 3
Fire Fundamentals
Task 13: Seismic Fire Interactions

Joint RES/EPRI Fire PRA Workshop
July and October 2013
Charlotte, NC

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

Task 13 - Seismic Fire Interactions
Scope of this Task

- Task 13 covers the Seismic Fire Interactions review
  - 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.

Fire PRA Workshop, 2013, Charlotte, NC
Module 3: Fire Fundamentals

Slide 2

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

Corresponding PRA Standard Element

- Task 13 maps to element SF – Seismic Fire
  - SF Objective (per the PRA Standard):
    - To qualitatively assess the potential risk implications of seismic/fire interaction issues

SF HLRs (per the PRA Standard)

- HLR- SF-A: The Fire PRA shall include a qualitative assessment of potential seismic/fire interaction issues in the Fire PRA (5 SRs)

- HLR-SF-B: The Fire PRA shall document the results of the seismic/fire interaction assessment in a manner that facilitates Fire PRA applications, upgrades, and peer review (1 SR)

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.

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.

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

Task 13: Seismic Fire Interactions
Seismically-Induced Fires

- Potential sources:
  - Unanchored electrical equipment such as that 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.

- Corresponding PRA Standard SR: SF-A1

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; 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.
- Corresponding PRA Standard SR: SF-A2

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
- Corresponding PRA Standard SRs: SF-A2 and SF-A3

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.
- Corresponding PRA Standard SR: SF-A4

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
- Corresponding PRA Standard SR: SF-A5

Task 13: Seismic Fire Interactions
Summary

- Seismic fire interaction is considered a low risk phenomenon
- 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

Mapping HLRs & SRs for the PP Technical Element to NUREG/CR-6850, EPRI TR 1011989

Technical Element	HLR	SR	6850 Sections	Comments
SF	A	The Fire PRA shall include a qualitative assessment of potential seismic/fire interaction issues in the Fire PRA		
		1	13.3.1 and 13.6.2	
		2	13.3.2, 13.3.3, 13.6.3, 13.6.4, and 13.6.5	
		3	13.3.2,	
		4	13.3.1, 13.3.2, 13.3.3, 13.6.3, 13.6.4, and 13.6.5	Although 6850/1011989 does not explicitly reference seismic response procedures, the suggested guidance implies review of such procedures.
		5	13.3.4 and 13.6.6	
	B	The Fire PRA shall document the results of the seismic/fire interaction assessment in a manner that facilitates Fire PRA applications, upgrades, and peer review		
		1	13.6.7	6850/1011989 provides minimal discussions on documenting SF

NRC FORM 335
(12-2010)
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-0303, Volume 3
EPRI 3002005205

2. TITLE AND SUBTITLE
Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES)-2012
Volume 3
Module 3: Fire Analysis

3. DATE REPORT PUBLISHED

MONTH	YEAR
April	2016

4. FIN OR GRANT NUMBER

5. AUTHOR(S)
K. Wright; P. Smith; F. Gonzalez; K. Hamburger; T. Rivera; D. Stroup

6. TYPE OF REPORT
Technical

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.)

Division of Risk Analysis
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 94304

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.)

10. SUPPLEMENTARY NOTES
NRC–RES/EPRI Fire PRA Workshop conducted July 16–20, 2012, and September 24–28, 2012 in Bethesda, MD

11. ABSTRACT (200 words or less)

The U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Regulatory Research (RES) and the Electric Power Research Institute (EPRI) working under a memorandum of understanding (MOU) jointly conducted two sessions of the NRC–RES/EPRI Fire Probabilistic Risk Assessment (PRA) Workshop on July 16–20, 2012, and September 24–28, 2012, at the Bethesda Marriott in Bethesda, MD. The purpose of the workshop was to provide detailed, hands-on training on the fire PRA methodology described in the technical document, NUREG/CR-6850 (EPRI 1011989) entitled "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities." This fire PRA methodology document supports implementation of the risk-informed, performance-based rule in Title 10 of the Code of Federal Regulations (10 CFR) 50.48(c) endorsing National Fire Protection Association (NFPA) Standard 805, as well as other applications such as exemptions or deviations to the agency's current regulations and fire protection significance determination process (SDP) phase 3 applications.

This NUREG/CP documents both of the two sessions of the NRC-RES/EPRI Fire PRA Workshop delivered in 2012 and includes the slides and handout materials delivered in each module of the course as well as video recordings of the training that was delivered. This NUREG/CP can be used 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 could also be useful preparatory material for those planning to attend future sessions.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)
fire, risk-informed regulation, fire hazard analysis (FHA), fire safety, fire protection, nuclear power plant, probabilistic risk assessment (PRA), Fire modeling, circuit analysis, human reliability analysis

13. AVAILABILITY STATEMENT
unlimited

14. SECURITY CLASSIFICATION
(This Page)
unclassified
(This Report)
unclassified

15. NUMBER OF PAGES

16. PRICE

NUREG/CP-0303, Vol. 3

Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES) – 2012
Module 3: Fire Analysis

April 2016