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Volume 2 of 5

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

Volume 2
Module 2: Electrical Circuits

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

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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.

CONTENTS

FIGURES

ACKNOWLEDGMENTS

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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
UAT	Unit Auxiliary Transformer
VCT	Volume Control Tank
VTT	Valtion Teknillinen Tutkimuskeskus (Technical Research Centre of Finland)
VVER	The Soviet (now Russian Federation) designation for light-water pressurized reactor
XLPE	Cross-Linked Polyethylene
ZOI	Zone of Influence

1
INTRODUCTION

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) 50.48I 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 "EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities" Reference [1].

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.

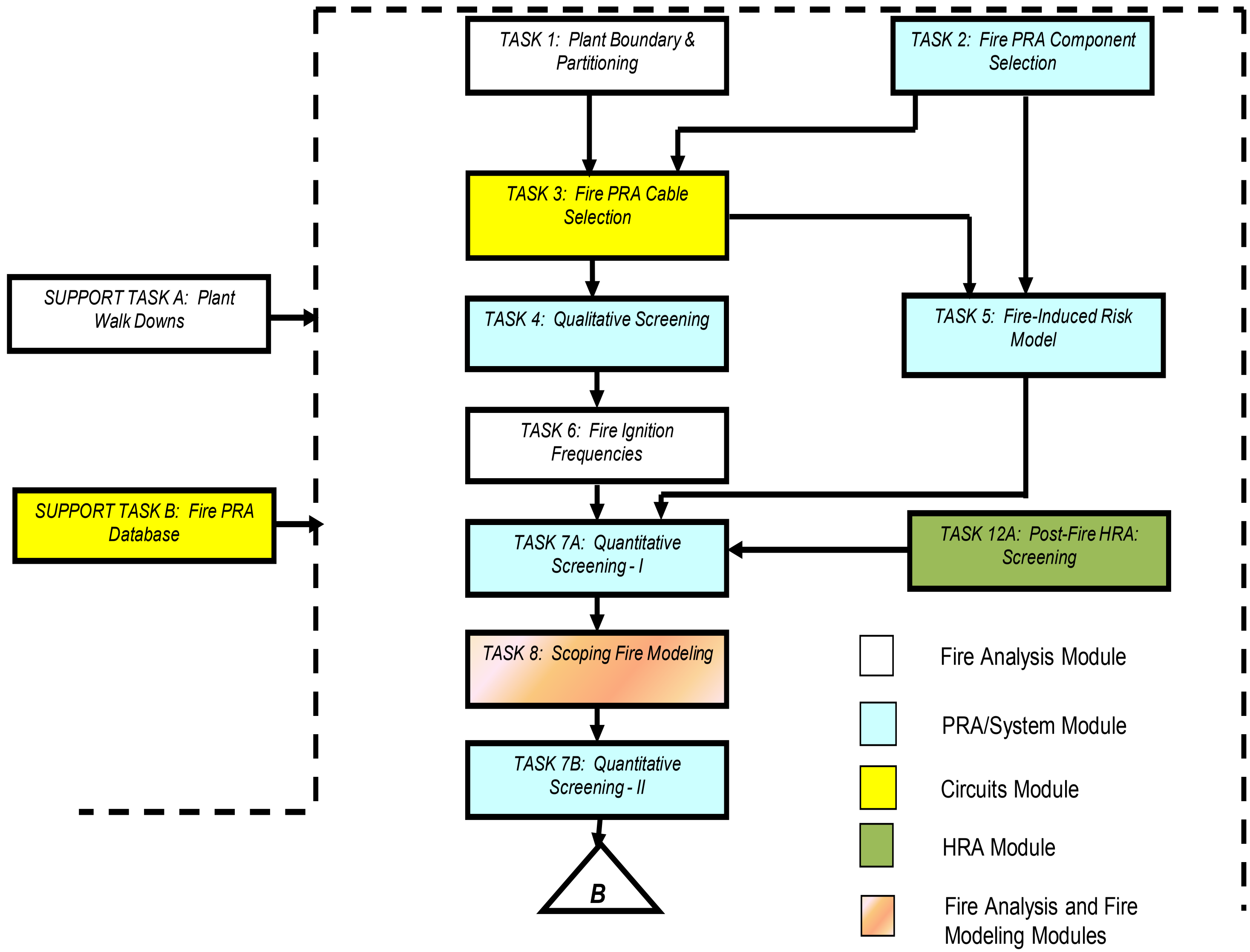


Figure 1-1 Relationship of Technical Tasks in NUREG/CR 6850 Volume 2

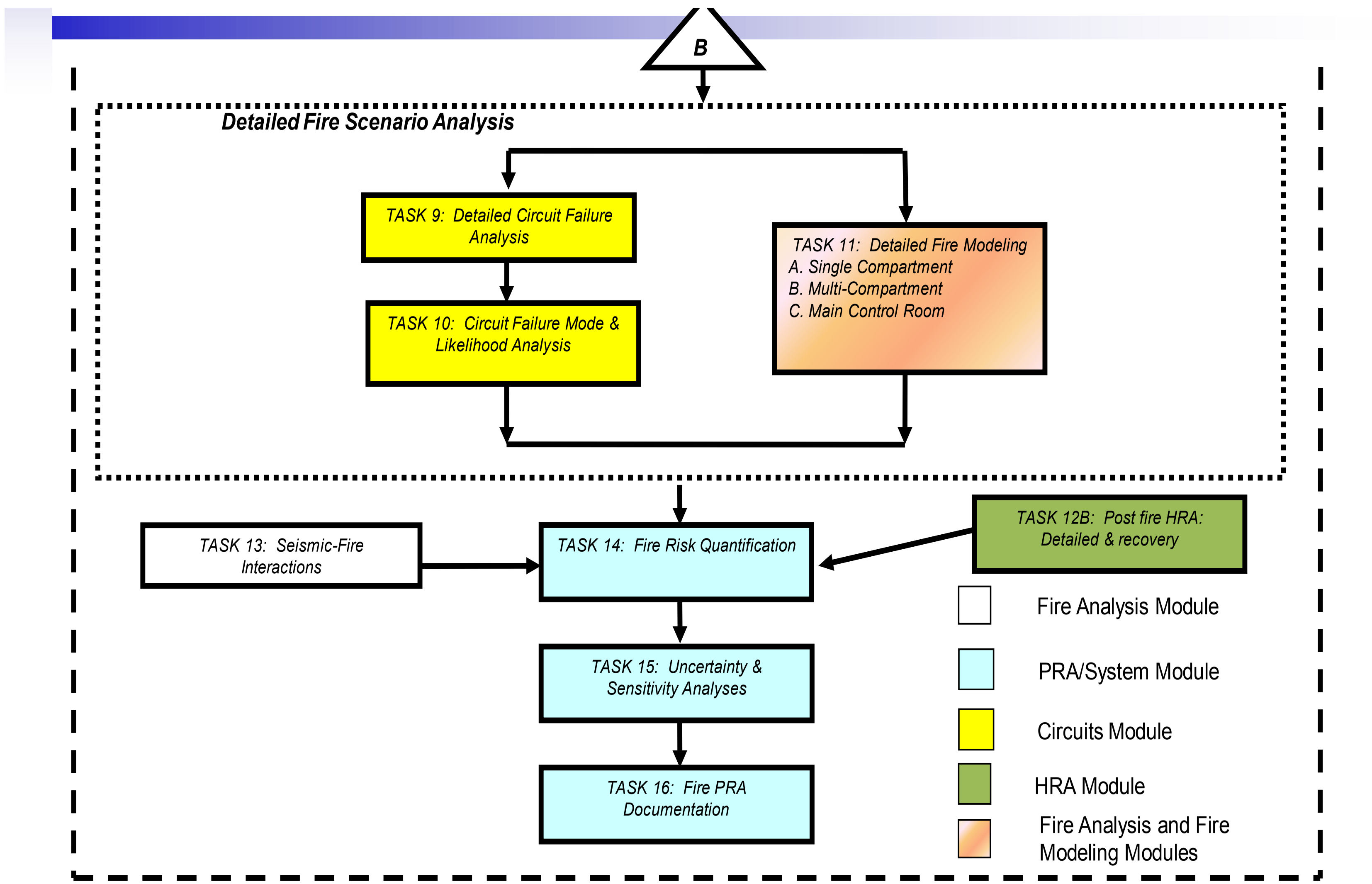


Figure 1-2 Note: "B" is from Task 7B (Previous Page)

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 Plant Layout

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.

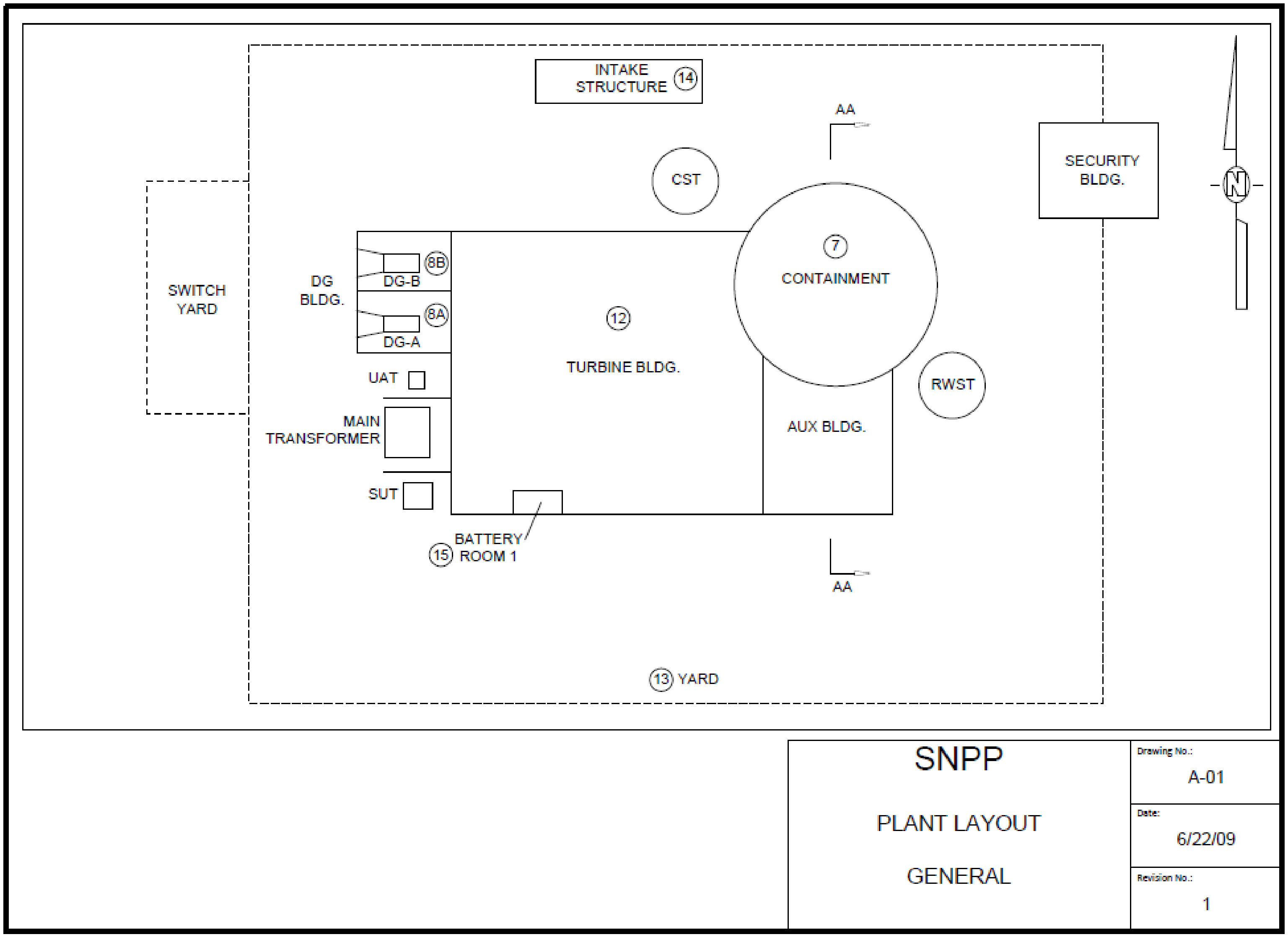


Figure 2-1 General Plant Layout

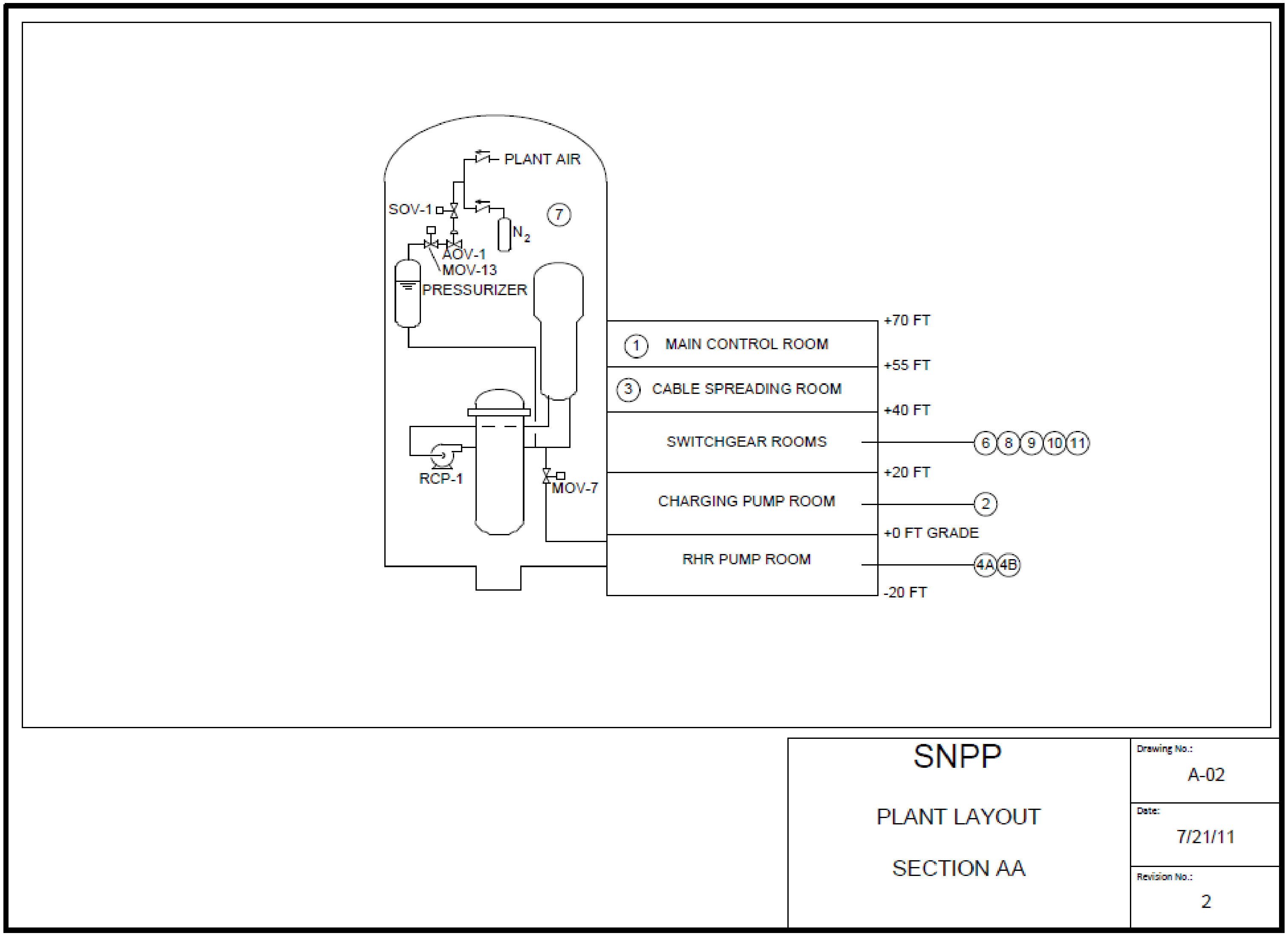


Figure 2-2 Plant Layout Section AA

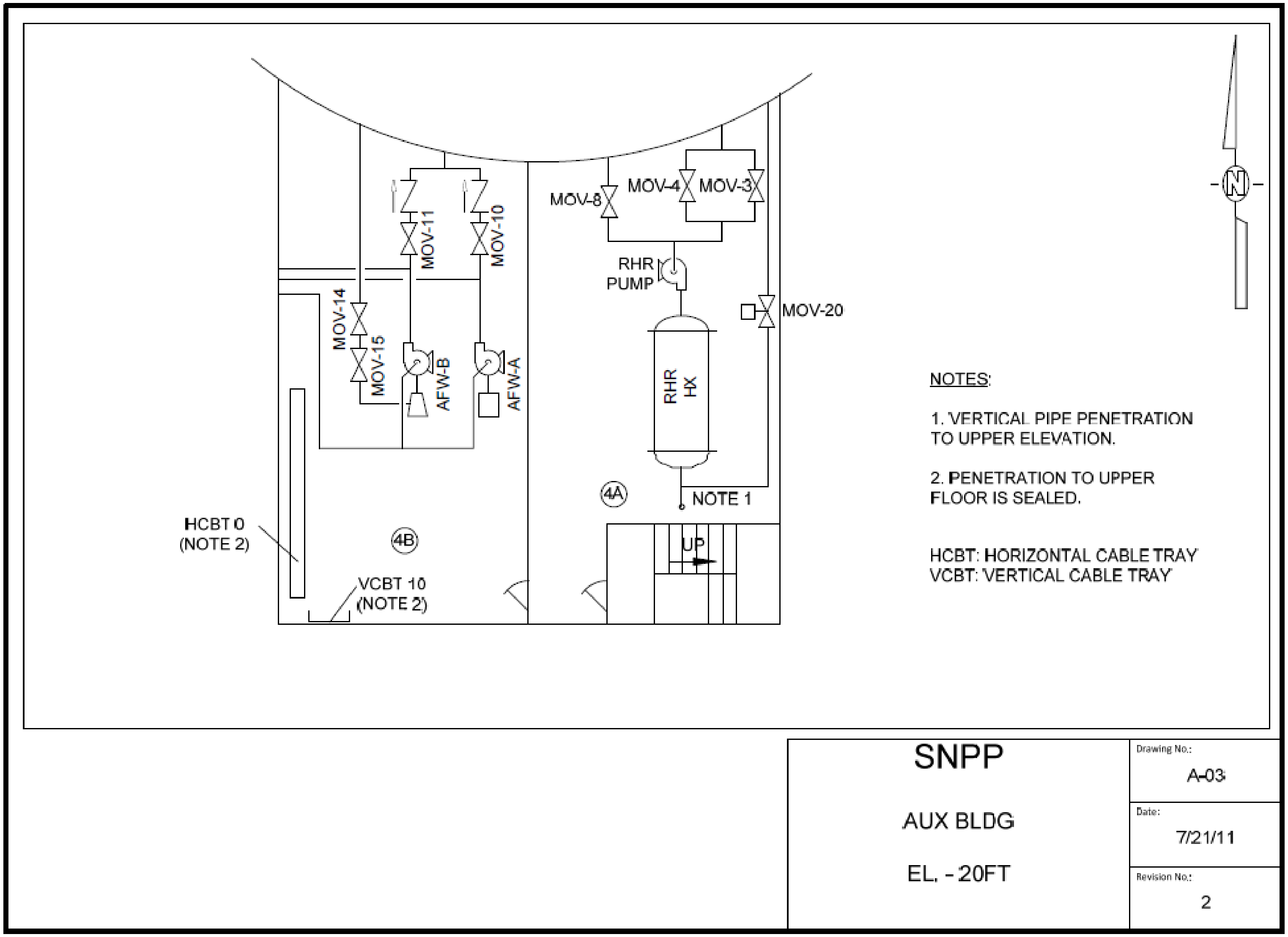


Figure 2-3 Auxiliary Building - Elevation 20 Ft.

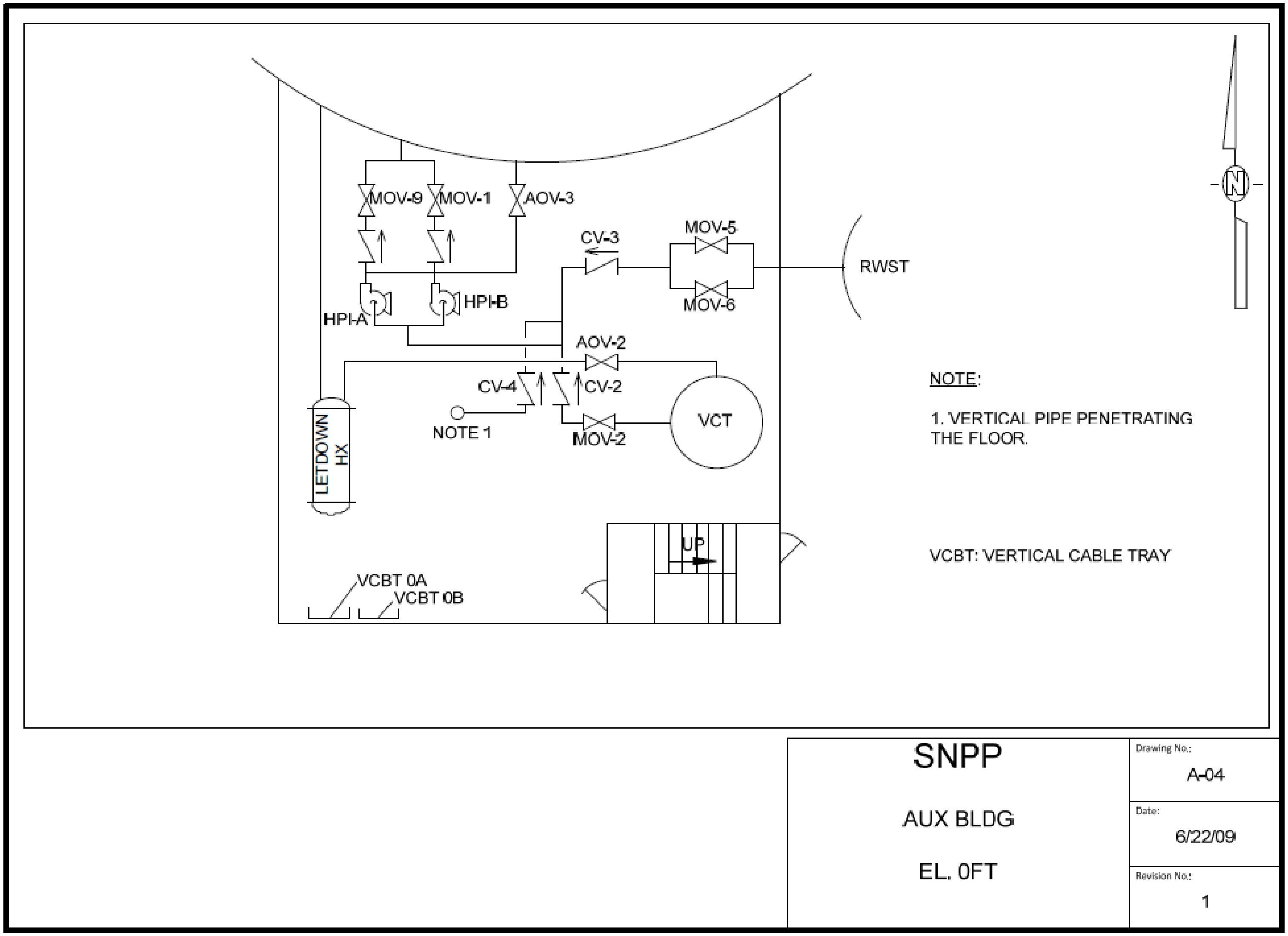


Figure 2-4 Auxiliary Building – Elevation 0 Ft

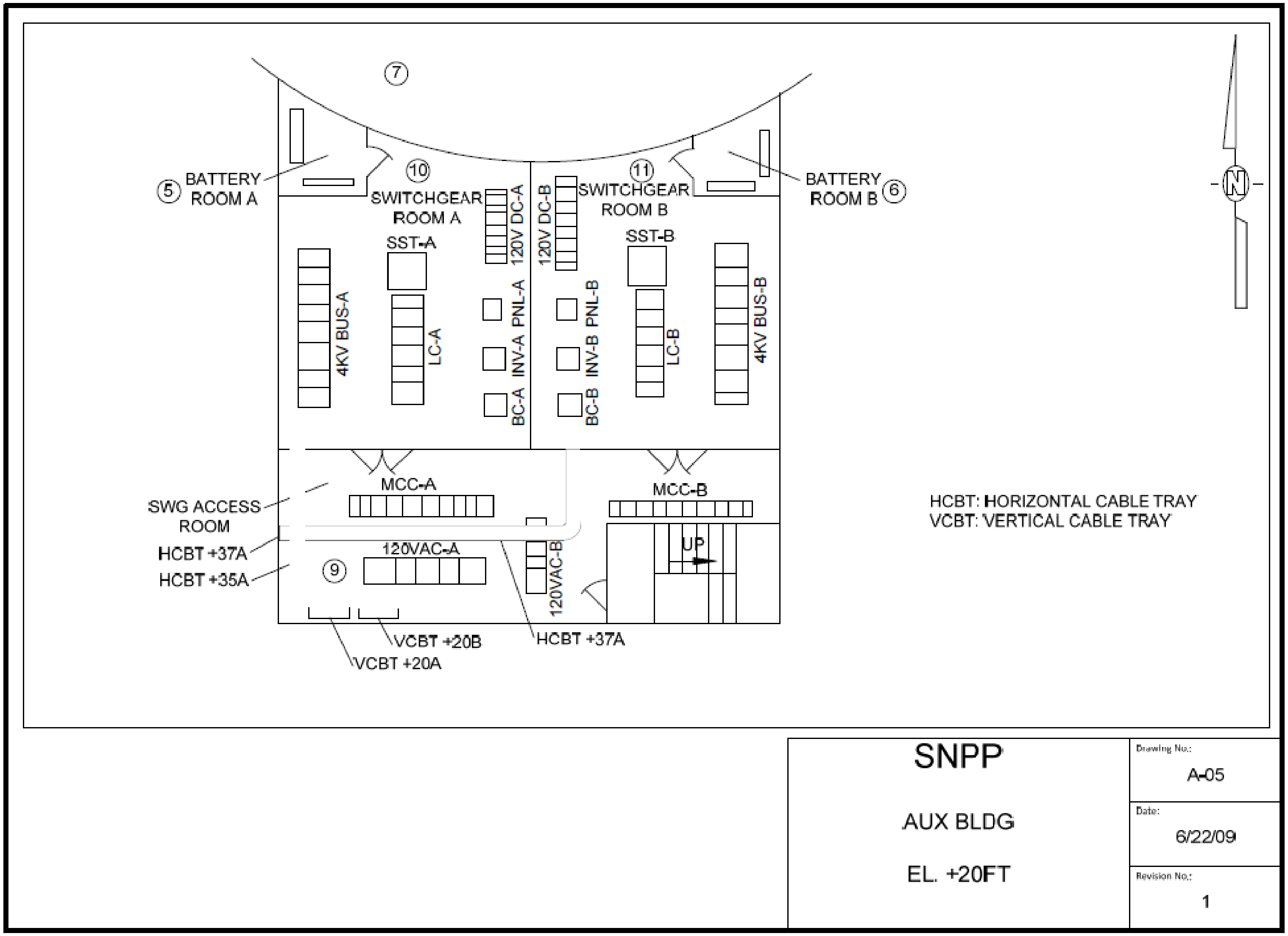


Figure 2-5 Auxiliary Building – Elevation +20 Ft.

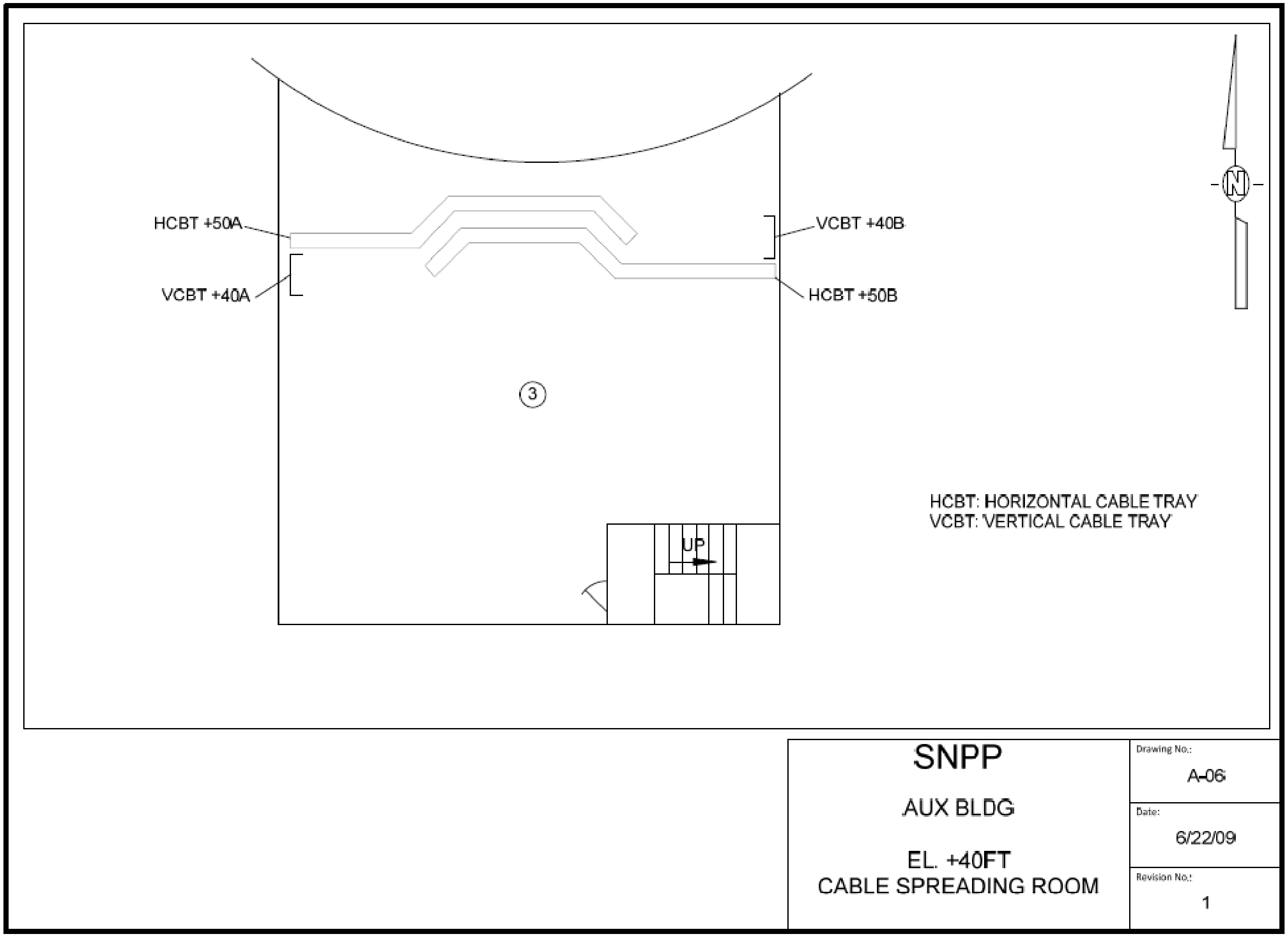


Figure 2-6 Auxiliary Building – Elevation +40 Ft.

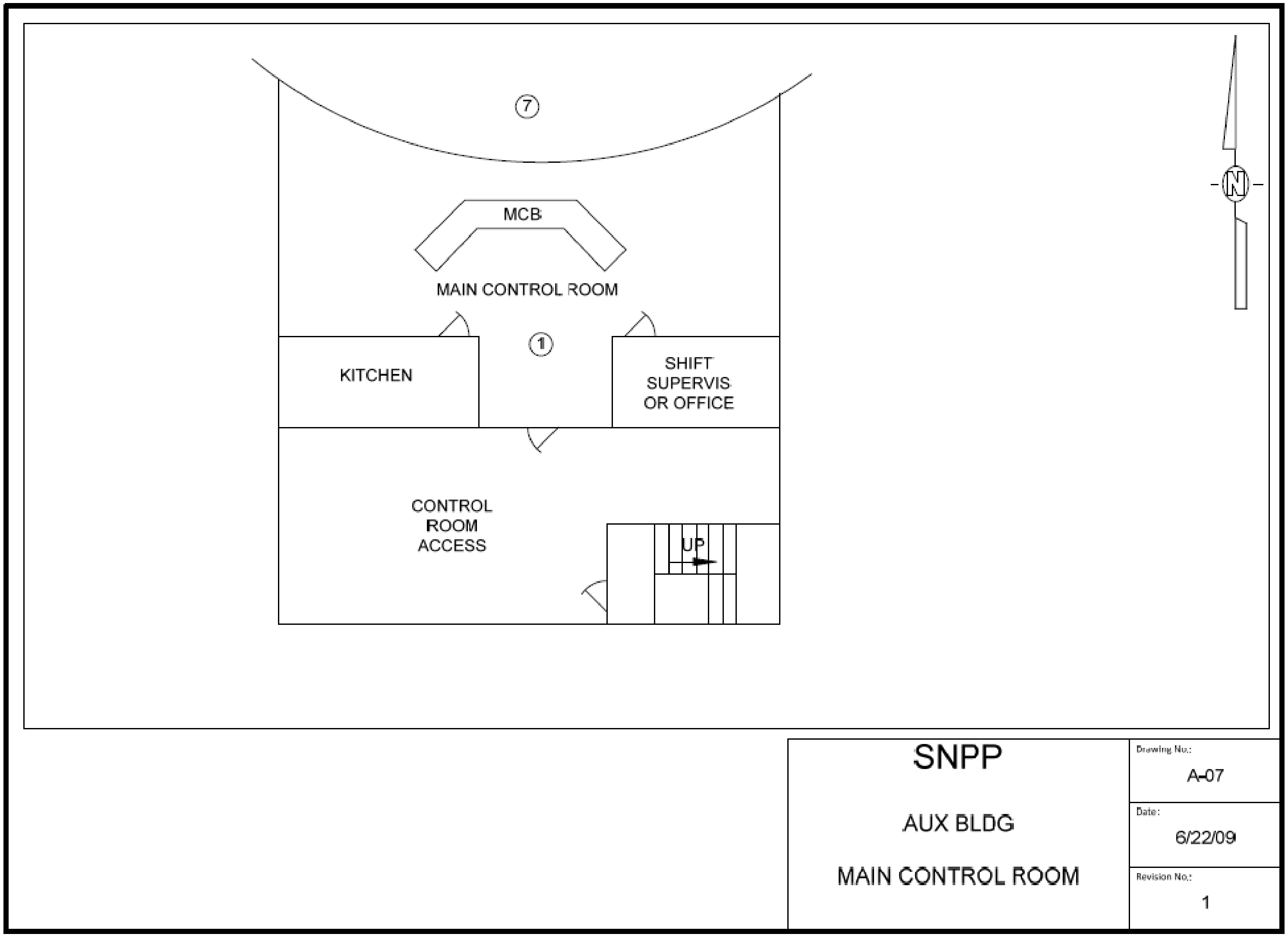


Figure 2-7 Auxiliary Building Main Control Room

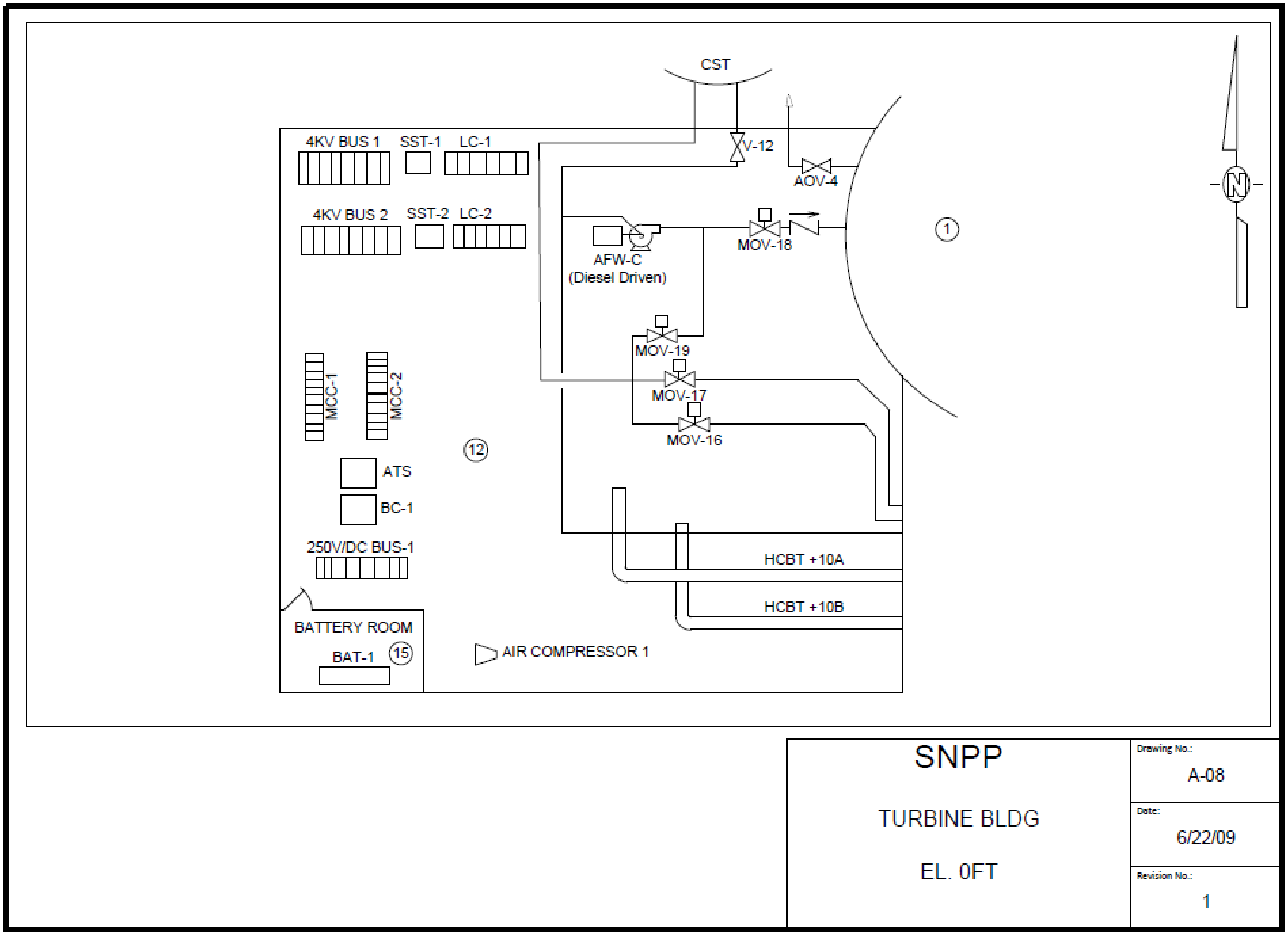


Figure 2-8 Turbine Building – Elevation 0 Ft.

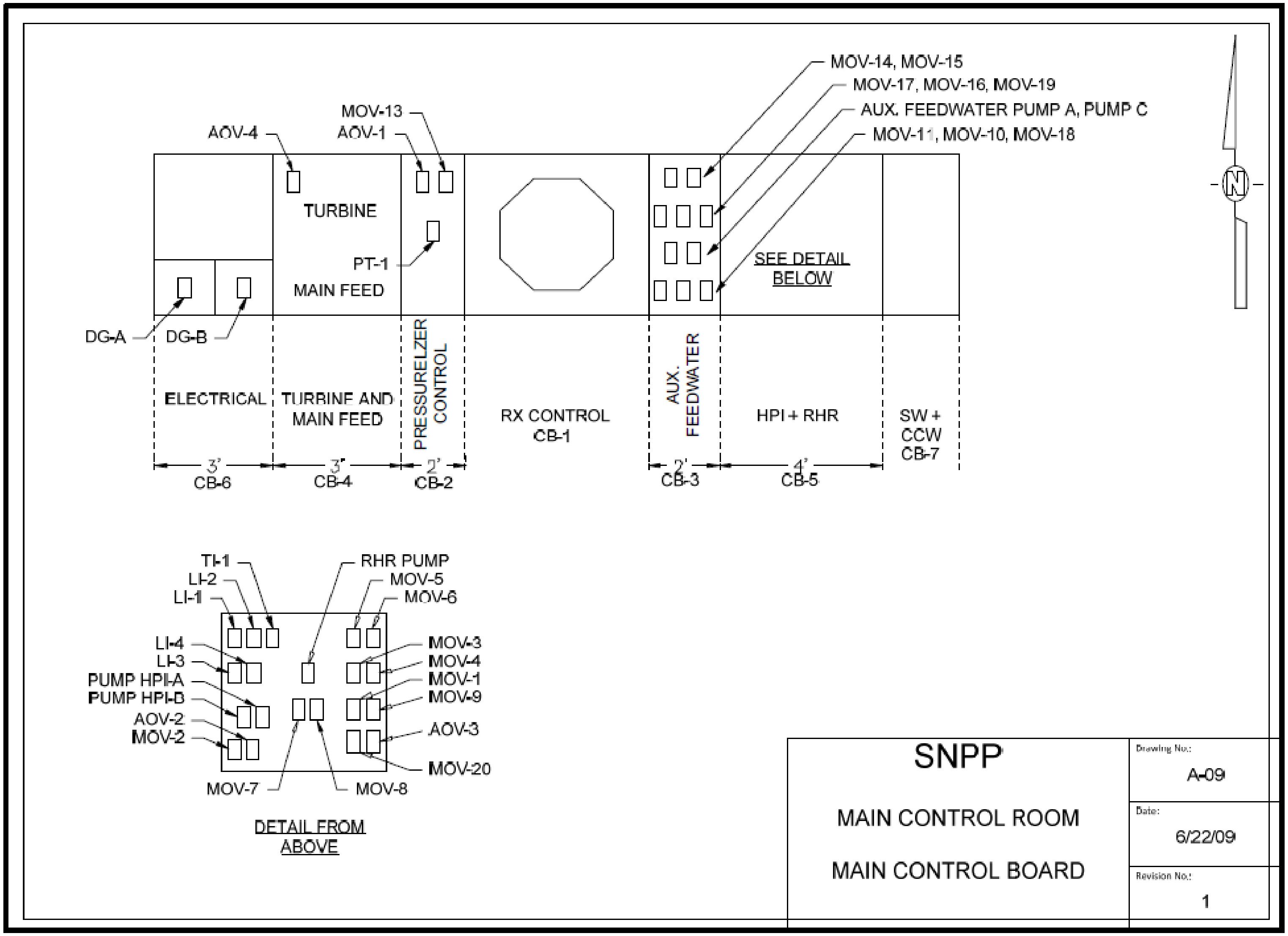


Figure 2-9 Main Control Board

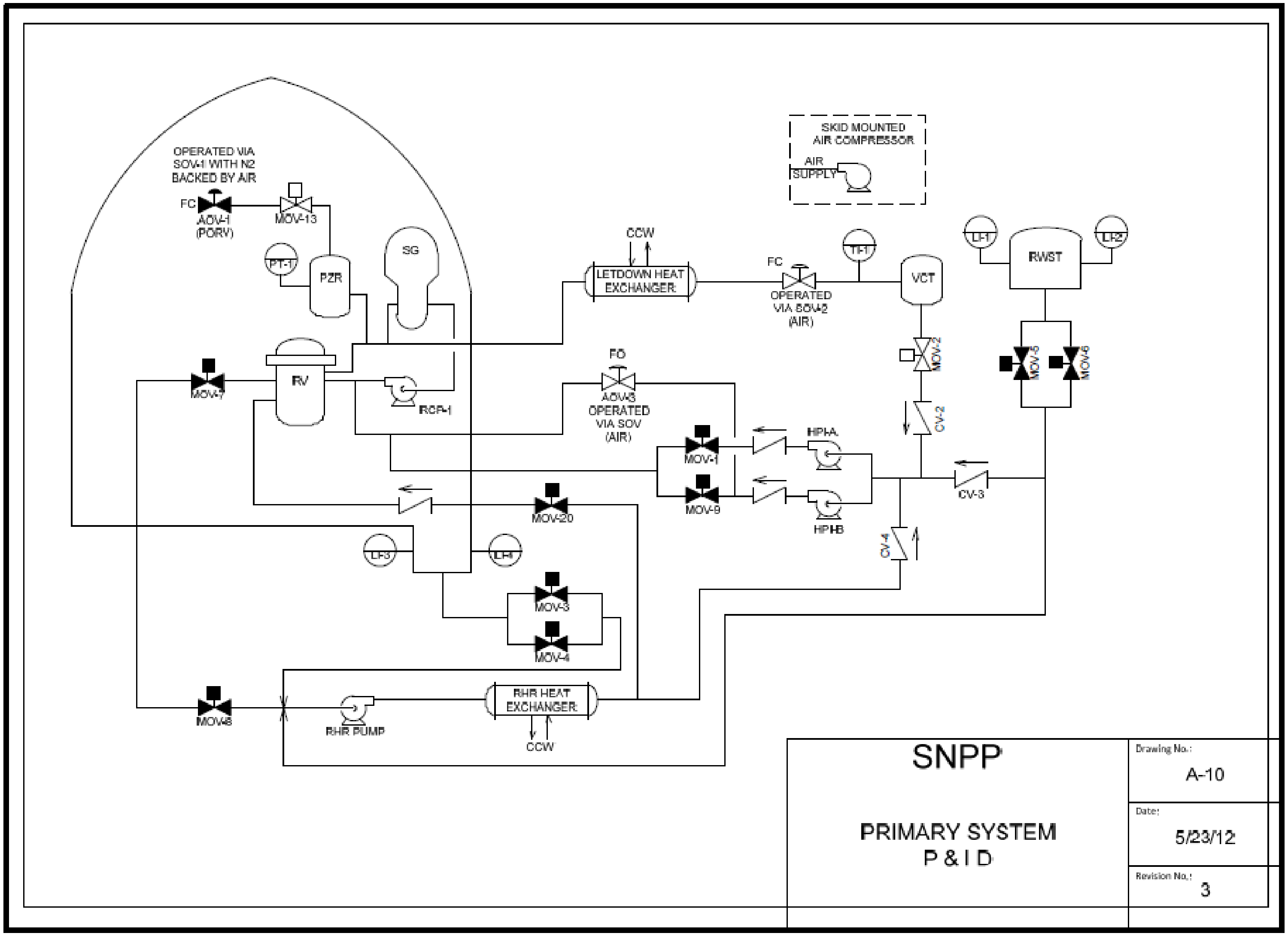


Figure 2-10 Primary System P&ID

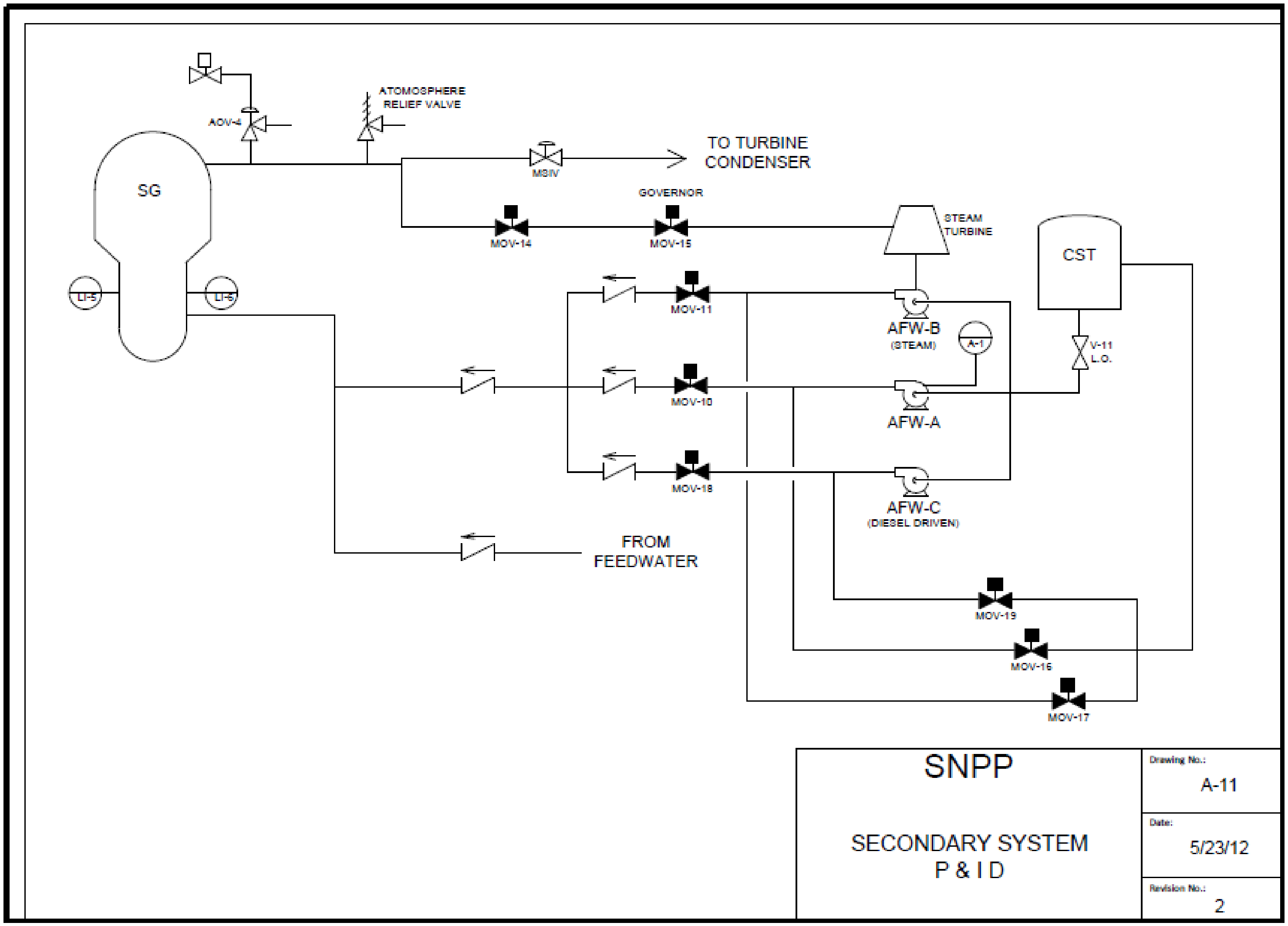


Figure 2-11 Secondary System P&ID

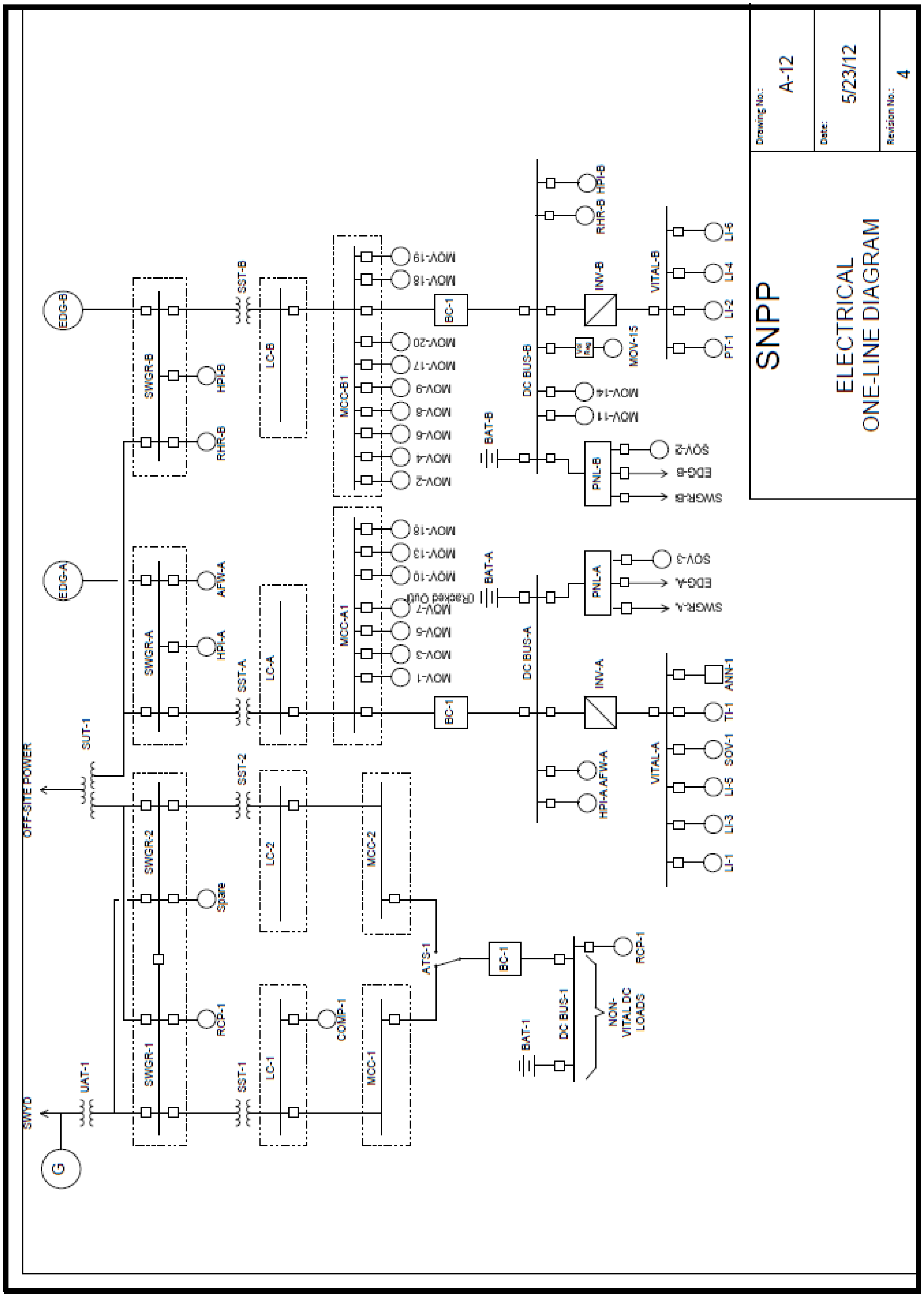


Figure 2-12 Electrical One-Line Diagram

3
CIRCUIT ANALYSIS BASICS

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 Circuit Analysis Basics

ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

SAIC Science Applications International Corporation
From Science to Solutions

EPRI/NRC-RES FIRE PRA METHODOLOGY

Circuit Analysis Basics

Dan Funk – Kleinsorg Group
Gabriel Taylor – U.S. NRC
Office of Nuclear Regulatory Research

Joint RES/EPRI Fire PRA Training Workshop
Bethesda, MD, July and September 2012

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

CIRCUIT ANALYSIS BASICS
Introduction

- Who Should Attend?
  - Nuclear plant personnel with rudimentary electrical and plant operating knowledge, but very limited experience with electrical control circuits, power distribution systems, and instrument circuits
  - Nuclear plant personnel with no previous exposure to Appendix R, NFPA 805, or Fire PRA circuit analysis concepts and methods
- Who's Here?
  - Name, Organization, Experience
  - What do you want from this "Basics" course?

CIRCUIT ANALYSIS BASICS
Objectives

- This Course is Intended to:
  - For less experienced personnel, provide a 1-day introduction to electrical fundamentals from a perspective of fire-induced circuit failure analysis
  - Provide fundamental information necessary to grasp the concepts and methods of fire PRA circuit analysis that are covered by the main Module 2 course
  - Present overviews of typical nuclear plant electrical power, control, and instrumentation circuits
  - Introduce fire-induced cable failure modes and explain their impact on circuit operation
  - Describe the evolution of circuit analysis for nuclear power plant fire protection

CIRCUIT ANALYSIS BASICS
Topics

- Circuit Design Basics
- Plant Electric Distribution System Design
- Plant Electrical Equipment
- Fire-Induced Cable Failures
- Evolution of Fire Protection Circuit Analysis

CIRCUIT ANALYSIS BASICS
Circuit Design Basics

- Typical Circuit Devices & Symbols
- Types of Drawings and How to Read Them
- General Conventions
- Grounded vs. Ungrounded Circuits
- ANSI/IEEE Standard Device Numbers

CIRCUIT ANALYSIS BASICS
Typical Circuit Devices & Symbols

- Circuit Breakers & Fuses
- Motor Starters & Contactors
- Relays & Contacts
- Terminal Blocks
- Control Power Transformers
- Actuating Coils
- Indicating Lamps & Alarms
- Switches
  - Control/Hand (maintained, momentary, spring-return to normal)
  - Limit & Torque
  - Sensors
  - Transfer & Isolation
  - Position

CIRCUIT ANALYSIS BASICS
Typical Circuit Devices & Symbols, cont…

Refer to

Symbol Library

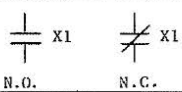
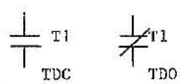
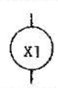
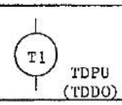
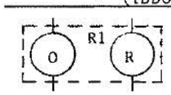
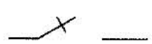
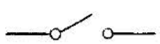
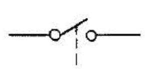
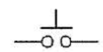
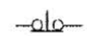
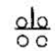
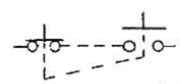
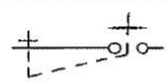
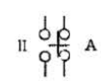
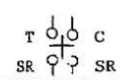
Handout

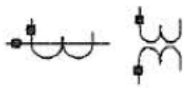
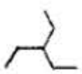
3.1.1 Symbol Library Handout

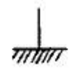
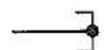
TYPICAL ELECTRICAL DRAWING SYMBOLS AND CONVENTIONS

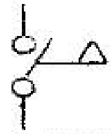
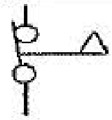
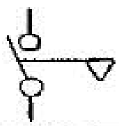
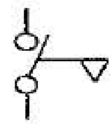
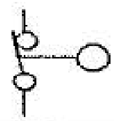
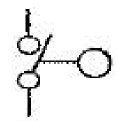
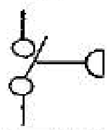
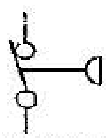
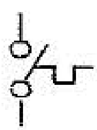
ELECTRICAL SYMBOLS

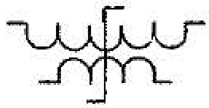
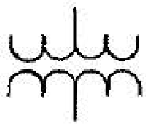
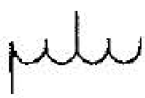
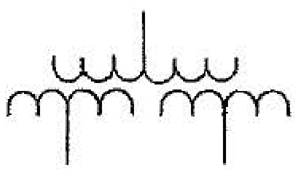
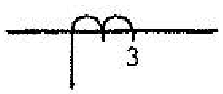
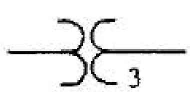
CONTACTS, SWITCHES, CONTACTORS AND RELAYS

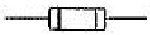
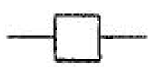
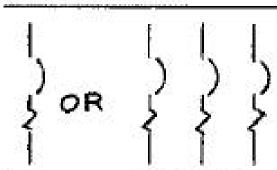
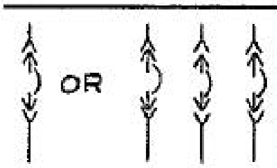
SYMBOL	DESCRIPTION
	Relay contact - Shown with relay in de-energized or in reset position. (Show relay coil designation near contact.)
	Timing Relay Contact - TDC indicates contact closes at end of timing period. TDO contact opens at end of timing period.
	Coil - Relay, contactors, circuit breaker, solenoid etc. (Show device designation, X1)
	Coil - Timing Relay - TDPU indicates timing period starts when coil is energized. TDDO indicates timing period starts when coil is de-energized.
	Latching Relay or Mechanically-Held Contactor O=operate; R=reset; TC=trip coil; CC=closing coil. (Coils may be separated on diagram)
	Knife Switch, general. (If shown closed, terminals must be added.)
	Switch - General, single pole, single throw.
	Switch - One pole of multi-pole switch shown. Other poles shown elsewhere.
	Pushbutton - Momentary or spring return. Single Circuit (make)
	Pushbutton - Momentary or spring return. Single Circuit (break)
	Pushbutton - Momentary or spring return. Two Circuit
	Pushbutton - Maintained, two circuit
	Pushbutton - Maintained, single circuit
	Selector Switch - Two position, maintained (designate position shown; i.e. A=Auto; H=Hand)
	Selector Switch - Three position, SR indicates spring return from position so labeled. ("TRIP-(NORMAL)-CLOSE" position shown)
	Limit Switch - Normally open - Not applicable for Motor Operated Valves and Solenoid Valves.
	Limit Switch - Normally closed - Not applicable for Motor Operated Valves and Solenoid Valves.

	Used with other symbols to indicate device is adjustable
+ (Positive) — (Negative)	Polarity markings - Direct current.
	Instantaneous Polarity Markings
	3-phase, 3-wire, delta
	3-phase, 3-wire, open delta grounded
	3-phase, 3-wire, wye
	3-phase, 3-wire, wye grounded neutral
	3-phase, 3-wire, zigzag

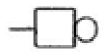
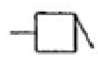
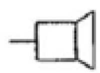
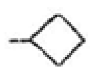
	3-phase, 3 wire zigzag, grounded neutral
	Connection to earth ground (may be plant grounding system)
	Connection to chassis or frame
	Terminal - may be added to any of the following symbols at connection points.
	Short circuit (not a fault)
	Terminal - Designates termination point of field run cables to main control board, emergency power board, main control board termination cabinet or emergency power board termination cabinet.

	Flow Switch - Closes on increase in flow at value shown
	Flow Switch - Opens on increase in flow at value shown
	Flow Switch - Closes on decrease in flow at value shown.
	Flow Switch - Opens on decrease in flow at value shown.
	Liquid Level Switch - Opens on rising level (Closes on low level)
	Liquid Level Switch - Closes on rising level (Opens on low level)
	Pressure or Vacuum Switch - Closes on rising pressure
	Pressure or Vacuum Switch - Opens on rising pressure (Closes on increase in vacuum)
	Temperature Switch - Closes on increasing temp.
	Torque Switch - Opens on high torque

	Transductor - Control winding shown with 5 loops. Power winding shown with 3 loops.
	Transformer - General, two winding
	Autotransformer - General
	Transformer - General, three winding
 	Current Transformer - number represents quantity (Add instantaneous polarity marks and ratio)
	Bushing Type Current Transformer
 	Potential Transformer - number represents quantity (Show instantaneous polarity marks, voltage rating, vectors, etc.)

	Fuse - General
	High Voltage Primary Fuse Cutout
	Lightning Arrester - General Gap Type
	Lightning Arrester - Valve or film type
	Circuit Breaker - General
	Power Circuit Breaker - (Show location of operating mechanism)
	Circuit Breaker, 3-pole with magnetic - overload device in each pole. (Show rating)
	Circuit Breaker, 3-pole, drawout type (Used in metal clad switchgear groups)

INDICATORS & ALARMS

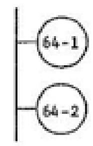
	Bell, electric
	Buzzer
	Horn - General
	Annunciator - General
	Indicating Light - General

Use the following to specify color:

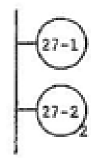
A - Amber
B - Blue
C - Clear
G - Green
NE - Neon
O - Orange
OP - Opalescent
P - Purple
R - Red
W - White
Y - Yellow

RELAYS

The following methods are used on drawings to identify relays:

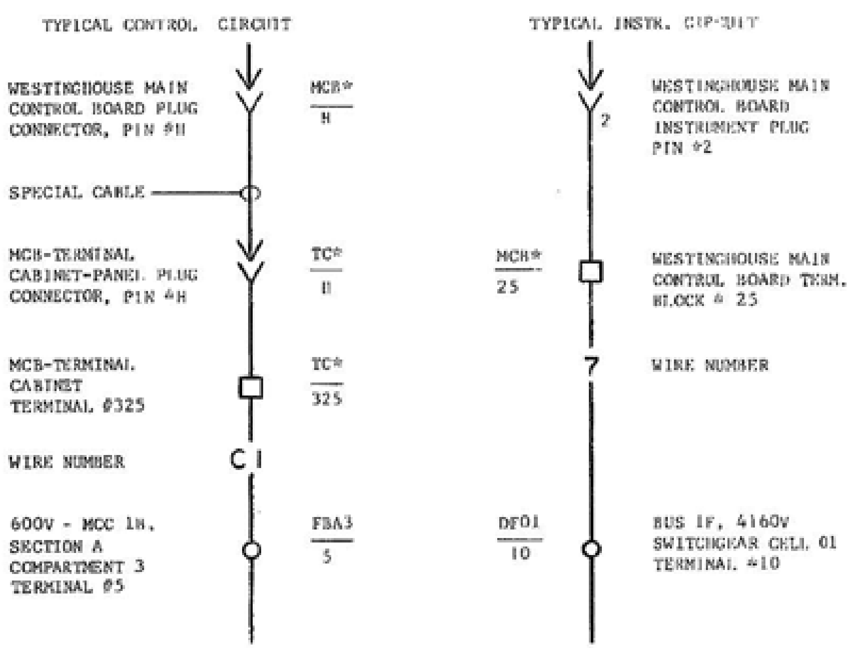
1) 

Two (2) 64 devices 64-1 and 64-2 in same cell.

2) 

Three (3) 27 devices 27-1, 27-2 and 27-3. The two (2) below the 27-2 device indicates there are two (2) 27 devices and their sequence numbers are in numerical order starting with -2.

ELEMENTARY DIAGRAM CONNECTIONS



*Abbreviation for equipment - The corresponding equipment number will appear in a table on the elementary diagram (e.g. MCB = Q1H12C005)

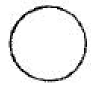
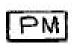
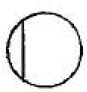
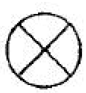
WIRE NUMBERING

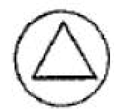
WIRE NUMBERING SYSTEM

1. The following standard interconnecting wire numbers shall be used wherever applicable (for computer - schedule programming).

Wire Number	Purpose
1	A - Phase Power
2	B - Phase Power
3	C - Phase Power
(Note 1)	Annunciator
N	D. C. Negative (See Note 2)
P	D. C. Positive (See Note 2)
U	115 volt A. C.-Ground Return (see Note 2)
X	115 volt A. C. (See Note 2)
C	Closing (See Note 2)
T	Tripping (See Note. 2).
O	Opening, MOV Only (See Note 2)
F	Instrumentation (e.g. indicator, recorder, etc.) See Note 2)
H	Computer (See Note 2)
M	General Control (Neither tripping nor closing; See Note 2)
A	Amber Lamp (See Note 2)
B	Blue Lamp (See Note 2)
L	Green Lamp (See Note 2)
R	Red Lamp (See Note 2)
W	White Lamp (See Note 2)

Wire Number	Purpose
4	A - Phase Potential (See Notes 3 & 5)
5	A - Phase Current (See Notes 3 & 5)
6	B - Phase Potential (See Notes 3 & 5)
7	B Phase Current (see Notes 3 & 5)
8	C - Phase Potential (See Notes 3 & 5)
9	C - Phase Current (See Notes 3 & 5)
0	Potential (or Current) Neutral (See Notes 4 & 5)

	Basic, Generator or Motor
	Field, Compensating, Generator or Motor
	Field, Series, Generator or Motor
	Field, Short or Separately Excited, Generator or Motor
	Field, Permanent Magnet, Generator or Motor
	1-phase
	2-phase
	3-phase, wye

	3-phase wye, grounded
	3-phase delta

ABBREVIATIONS

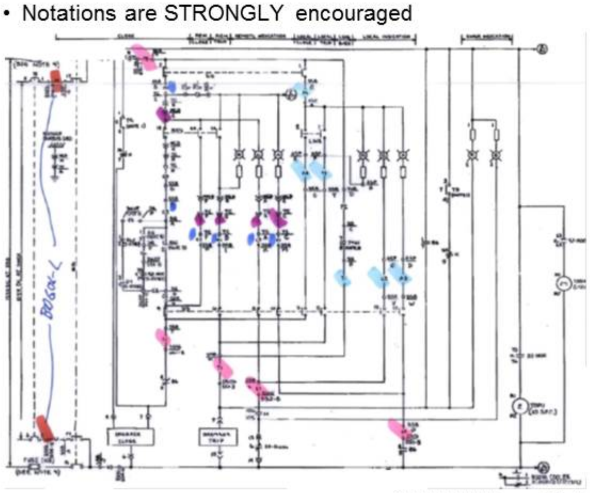
A	Ammeter
AH	Ampere-hour
C	Coulombmeter
CMA	Contact-making (or breaking) ammeter
CMC	Contact-making (or breaking) clock
CMV	Contact-making (or breaking) voltmeter
CRO	Oscilloscope or cathoderay oscillograph
DB	DB (decibel) meter' Audio level/meter
DBM	DBM (decibels referred to 1 milliwatt (meter)
DM	Demand meter
DTR	Demand-totalizing relay
F	Frequency meter
G	Galvanometer
GD	Ground detector
I	Indicating
INT	Integrating
UA	Microammeter
MA	Milliammeter
NM	Noise meter
OHM	Ohmmeter
OP	Oil pressure
OSCG	Oscillograph, string
PF	Power factor
PH	Phasemeter
PI	Position indicator
RD	Recording demand meter
REC	Recording
RF	Reactive factor
SY	Synchroscope
t^o	Temperature meter
THC	Thermal converter
TLM	Telemeter
TT	Total time; Elapsed time
V	Voltmeter
VA	Volt-ammeter
VAR	Varmeter
VARH	Varhour meter
VI	Volume indicator; Meter, audio level
VU	Standard volume indicator Meter, audio level
W	Wattmeter
WH	Watthour meter

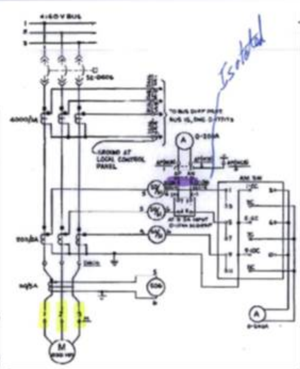
CIRCUIT ANALYSIS BASICS
Types of Drawings and How to Read Them

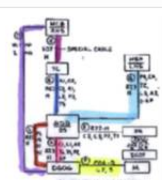
- Single-Line Drawings
- Three-Line Drawings
- Elementary or Schematic Diagrams
- Block Diagrams
- Cable Raceway Schedules
- Wiring or Connection Drawings
- Instrument Loop Diagrams
- Vendor Shop Drawings
- Equipment Arrangement or Location Drawings
- Tray & Conduit Layout Drawings
- Underground & Duct-Bank Layout Drawings
- Specialty Drawings (Electrical Penetration, Logic, Load Lists, Coordination Diagrams, Short Circuit Calculations)
- Piping & Instrument Diagrams

CIRCUIT ANALYSIS BASICS
Types of Drawings and How to Read Them, cont…

- Review, Study, and Understand Drawings…
- Color markers will be needed & used
- Notations are STRONGLY encouraged







CIRCUIT ANALYSIS BASICS
General Conventions

- Polarity – AC & DC Circuits
- 3-Phase vs. Single-Phase Power
- Delta vs. Wye Connected Circuits
- Normally Open vs. Normally Closed Contacts
- Conductor, Cable, & Raceway IDs
- Electrical vs. Physical Connectivity
- Others ?

CIRCUIT ANALYSIS BASICS
Grounded vs. Ungrounded Circuits

- How can you tell?
- Why one or the other?
- Advantages & disadvantages
- Affect during normal circuit operation?
- Affect during abnormal circuit operation?
- Where will you likely see in practice?
- Types of grounding
  - Solid
  - High Impedance or Resistance
  - Low Impedance or Resistance
- Where is ground point established?
- Why do we care so much about grounding?

Refer to
Standard Device Number
Handout

3.1.2 ANSI/IEEE Standard Device Numbers Handout

ANSI/IEEE Standard Device Numbers

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1 - Master Element
2 - Time Delay Starting or Closing Relay
3 - Checking or Interlocking Relay
4 - Master Contactor
5 - Stopping Device
6 - Starting Circuit Breaker
7 – Rate of Change Relay
8 - Control Power Disconnecting Device
9 - Reversing Device
10 - Unit Sequence Switch
11 – Multifunction Device
12 - Overspeed Device
13 - Synchronous-speed Device
14 - Underspeed Device
15 - Speed - or Frequency-Matching Device
20 - Elect. operated valve (solenoid valve)
21 - Distance Relay
23 - Temperature Control Device
24 – Volts per Hertz Relay
25 - Synchronizing or Synchronism-Check Device
26 - Apparatus Thermal Device
27 - Undervoltage Relay
29 - Isolating Contactor
30 - Annunciator Relay
32 - Directional Power Relay
36 - Polarity or Polarizing Voltage Devices
37 - Undercurrent or Underpower Relay
38 - Bearing Protective Device
39 - Mechanical Conduction Monitor
40 – Loss of Field Relay
41 - Field Circuit Breaker
42 - Running Circuit Breaker
43 - Manual Transfer or Selector Device
46 - Reverse-phase or Phase-Balance Relay
47 - Phase-Sequence Voltage Relay
48 - Incomplete-Sequence Relay
49 - Machine or Transformer Thermal Relay
50 - Instantaneous Overcurrent
51 - AC Time Overcurrent Relay
52 - AC Circuit Breaker
53 - Exciter or DC Generator Relay
54 - High-Speed DC Circuit Breaker
55 - Power Factor Relay
56 - Field Application Relay
59 - Overvoltage Relay
60 - Voltage or Current Balance Relay
62 - Time-Delay Stopping or Opening Relay
63 - Pressure Switch
64 - Ground Detector Relay
65 - Governor
66 – Notching or jogging device
67 - AC Directional Overcurrent Relay
68 - Blocking or “out of step” Relay
69 - Permissive Control Device
71 - Level Switch
72 - DC Circuit Breaker
74 - Alarm Relay
75 - Position Changing Mechanism
76 - DC Overcurrent Relay
78 - Phase-Angle Measuring or Out-of-Step Relay
79 - AC-Reclosing Relay
81 - Frequency Relay
83 - Automatic Selective Control or Transfer Relay
84 - Operating Mechanism
85 - Carrier or Pilot-Wire Receiver Relay
86 - Lockout Relay
87 - Differential Protective Relay
89 - Line Switch
90 - Regulating Device
91 - Voltage Directional Relay
92 - Voltage and Power Directional Relay
94 - Tripping or Trip-Free Relay

B – Bus
F – Field
G – Ground or generator
N – Neutral
T – Transformer

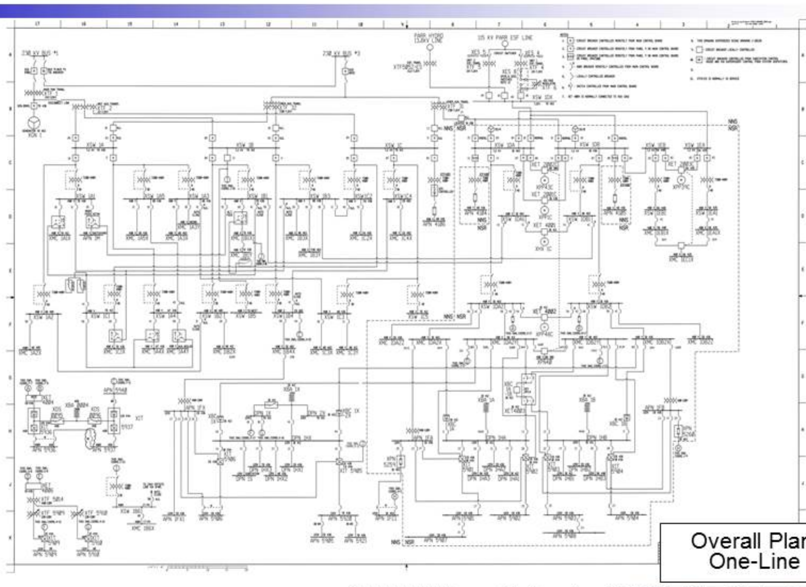
CIRCUIT ANALYSIS BASICS
Plant Electrical Distribution System Design

- Voltage Levels
- Off-site Power Components
- High-voltage Switchgear and Related Equipment
- Protective Relays
- Load Centers (LC) and Station Service Transformers (SST)
- Motor Control Centers (MCC)
- Battery & DC Distribution System
- Vital AC Distribution System
- Plant Process Instrumentation (NSSS Instruments)
- Reactor Protection and Accident Mitigation Systems

CIRCUIT ANALYSIS BASICS
Plant Electrical Distribution System Design, cont…

- Primary Distribution Breakdown
  - Voltage Levels
  - Off-site Power Components
  - High-voltage Switchgear and Related Equipment
  - Protective Relays
  - Load Centers (LC) and Station Service Transformers (SST)
  - Motor Control Centers (MCC)
  - Battery & DC Distribution System
  - Vital AC Distribution System

CIRCUIT ANALYSIS BASICS
Plant Electrical Distribution System Design, cont…



CIRCUIT ANALYSIS BASICS
Plant Electrical Equipment

- Cables and Panel Wiring
- Raceway Types
- Transformers – Big to Small
- Air Operated Valves (AOV)
- Solenoid Valves (SOV)
- Motor Operated Valve (MOV)
- High & Medium Voltage Switchgear
- Protective Relays

CIRCUIT ANALYSIS BASICS
Plant Electrical Equipment, cont…

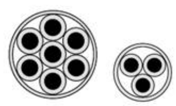
- Circuit Breakers – Big to Small
- AC Motors – Big to Small
- DC Motors
- Instrumentation Circuits
- Electrical Control Panels
- Electrical Power Panels
- Batteries & Chargers
- Inverters

Fire PRA Workshop, 2012, Bethesda, MD
Fire PRA Circuit Analysis Basics

Slide 17

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

CIRCUIT ANALYSIS BASICS
Cables & Raceways



- Cables and Panel Wiring
  - Single-conductor cable
  - Multi-conductor cable
  - Triplex cable
  - Size conventions and ampacity
  - Shielded, unshielded, & armored
  - Materials – Conductor, insulation, & jacket
- Raceway Types
  - Conduit
  - Tray – ladder and solid
  - Wireways
  - Pull boxes
  - Junction boxes
  - Terminal boxes
  - Duct-banks
  - Embedded conduit
  - Air drops
  - Fire wraps

Fire PRA Workshop, 2012, Bethesda, MD
Fire PRA Circuit Analysis Basics

Slide 18

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

CIRCUIT ANALYSIS BASICS
Transformers

- Power Transformers
  - Main transformers
  - Unit auxiliary transformers (UAT)
  - Startup or reserve auxiliary transformer (SUT, RAT)
  - Station service transformer (SST)
- Control Power Transformers (CPT)
- Instrument Transformers
  - Potential transformer (PT)
  - Current transformer (CT)
  - Zero sequence current transformer
- Specialty Transformers

CIRCUIT ANALYSIS BASICS
Valves

- Air Operated Valves (AOV)
  - Pilot solenoid operated
  - Bi-modal function
  - Modulate function
- Solenoid Valves (SOV)
  - AC & DC operated
- Motor Operated Valve (MOV)
  - Typical design
  - Inverted design

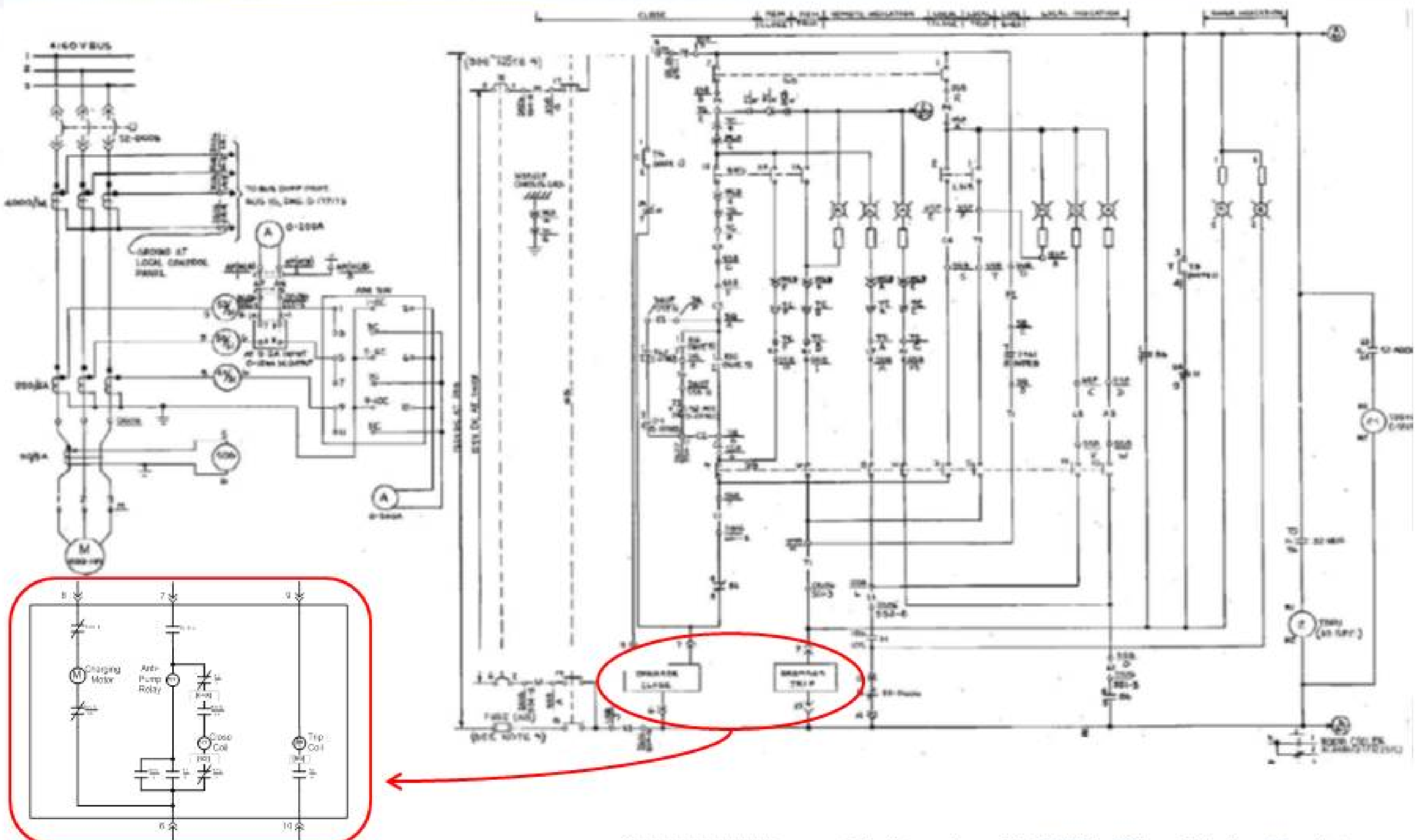
CIRCUIT ANALYSIS BASICS
Switchgear & Relays

- High Voltage Switchgear
  - Switchyard equipment
  - Typically individual components
- Medium Voltage Switchgear
  - 12.47 kV, 7.2 kV, 6.9 kV, & 4.16 kV
  - Typically metal-clad, indoor, draw-out design
  - Separate control power circuit and protective devices
- Protective Relays
  - Overcurrent relays (50, 51, 50N, 51N, 50G)
  - Differential relays (87, 87T, 87B)
  - Undervoltage relays (27)
  - Frequency relays (81)
  - Reverse power relays (32, 67)
  - Lockout relays (86)

CIRCUIT ANALYSIS BASICS
Circuit Breakers

- Medium Voltage Power Circuit Breakers
  - Often called Power Circuit Breakers (PCB) or Vacuum Circuit Breakers (VCB)
  - 1,000 V – 15 kV
  - Separate 125 VDC control power
  - Separate close and trip coils
  - Fails "as-is" on loss of control power
  - No overcurrent protection w/o control power
  - Separate trip devices – protective relays
- Low Voltage Power Circuit Breakers (LVPCB)
  - Below 1,000 V
  - Same basic features as medium voltage power breakers
  - Internal or external trip devices
- Molded Case Circuit Breakers
  - Internal trip devices – thermal and/or magnetic
  - Generally manually operated

CIRCUIT ANALYSIS BASICS
Medium Voltage Circuit Breaker Control



CIRCUIT ANALYSIS BASICS
Motors

- AC, DC, 1-phase, 3-phase
- Synchronous vs. induction design
- Large motors controlled by circuit breaker
- Smaller motors often controlled by a “motor starter”
- Continuous duty (pump) vs. intermittent duty (MOV)
- MOVs and DC motors are most often reversing design
- High temp is usually an alarm or time-delay trip
- Locked rotor current must be considered
- We don’t know anything else about motors

CIRCUIT ANALYSIS BASICS
Process Instruments & Reactor Protection

- Process Instrumentation
  - Temperature
  - Level
  - Flow
  - Pressure
- Reactor Trip
  - Trip signals
  - Actuation circuitry
- Engineered Safety Features Actuation System
  - Input signals
  - Actuation logic
  - Solid-state protection system (SSPS)

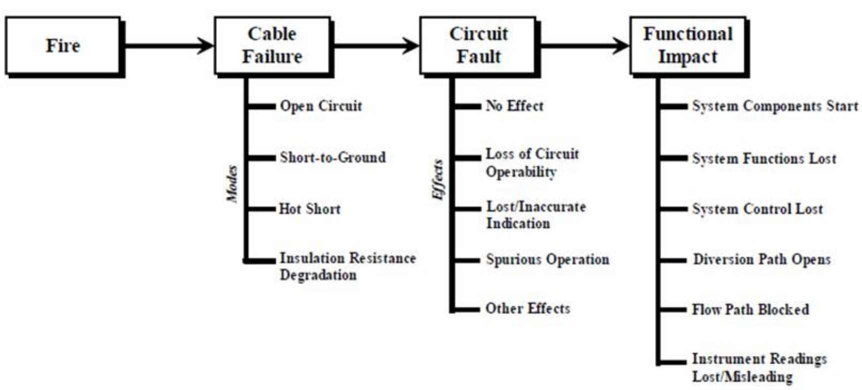
CIRCUIT ANALYSIS BASICS
Instruments

- 4-20 mA output signal design is common
- Twisted shielded pair (TSP), coaxial cables
- Key elements of instrument loop
  - Loop power supply
  - Transmitter/sensor
  - Bi-stables for control and actuation signals
  - Indicators
- Provide
  - Indication
  - Alarm
  - RPS & ESFAS input
  - Control signals
- Comprised of multiple modules/cards
- Highly integrated signals – isolation is challenging
- Distinctly different from a circuit analysis perspective

CIRCUIT ANALYSIS BASICS
Miscellaneous Equipment

- Control Panels
- Power Panels
- Batteries
- Battery Chargers
- Inverters
- Other ??

CIRCUIT ANALYSIS BASICS
Fire-Induced Cable Failures

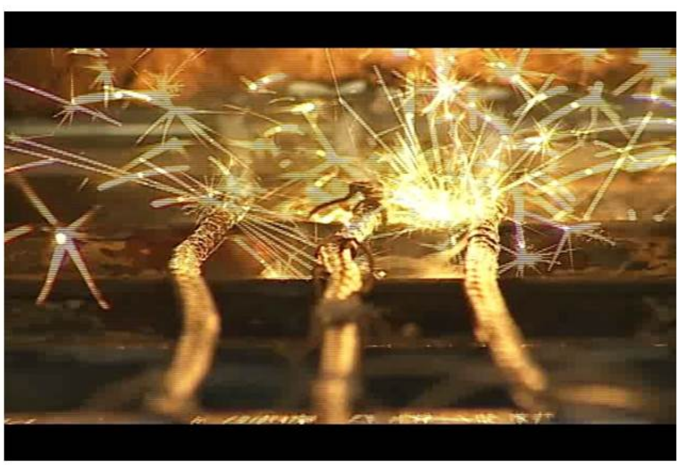


CIRCUIT ANALYSIS BASICS
Fire-Induced Cable Failures

- Short circuits
  - Short to earth ground
  - Short to reference ground
  - Conductor-to-conductor
- Open Circuits
- Hot Shorts
  - Intra-cable hot shorts
  - Inter-cable hot shorts
  - 3-Phase proper polarity hot shorts
  - Ungrounded DC proper polarity hot shorts
  - Multiple hot shorts

CIRCUIT ANALYSIS BASICS
Fire-Induced Cable Failures, cont…

- [Video clip & some photos from DC Tests]



CIRCUIT ANALYSIS BASICS
Evolution of Fire Protection Circuit Analysis

- Appendix R – the early years
- Appendix R – the later years
- Appendix R – redux
- Early Generation Fire PRA
- Cable Fire Tests
- Operator Manual Actions
- NFPA 805
- EPRI 1011989 - NUREG/CR-6850 & Next Generation Fire PRA
- Multiple Spurious Operations (MSO)
- 10 CFR 50.48(c) – RIPB voluntary alternative to fire protection requirements
- NFPA 805 Transition Projects
- ANSI/ANS-58.23-2007 (now ASME/ANS RA-Sa-2009) "PRA Standard"
- Frequently Asked Questions (FAQ) Process

CIRCUIT ANALYSIS BASICS
Fire PRA Circuit Analysis – Module 2 Training Topics

- Task 3: Fire PRA Cable Selection
  - What cables are associated with the FPRA components?
- Task 9: Detailed Circuit Analysis
  - Task 9A & 9B Split
  - Which cables can affect the credited functionality?
  - What failure modes are possible given fire damage to the cable?
- Task 10: Circuit Failure Mode Likelihood Analysis
  - How likely to occur are the failure modes of concern?
- Support Task B: Fire PRA Database
  - Warehousing data and determining impacts

CIRCUIT ANALYSIS BASICS
Questions

Questions ?

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Fire PRA Circuit Analysis Basics

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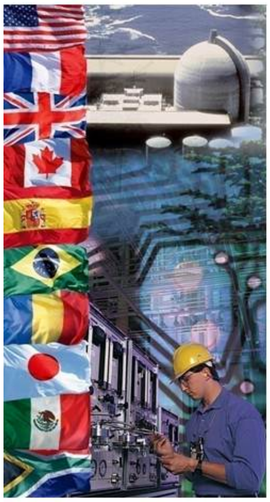
4

ELECTRICAL ANALYSIS

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

- ***Fire PRA Cable Selection (Task 3).*** This task provides instructions and technical considerations associated with identifying cables supporting those components selected in Task 2. In previous Fire PRA methods (such as EPRI FIVE and Fire PRA Implementation Guide) this task was relegated to the SSD analysis and its associated databases. This document offers a more structured set of rules for selection of cables.
- ***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 this document benefits from the knowledge gained from the tests performed in response to the circuit failure issue.

4.1 Fire PRA Circuit Analysis Overview



EPRI/NRC-RES FIRE PRA METHODOLOGY

Fire PRA Circuit Analysis Overview

Dan Funk – Kleinsorg Group
Gabriel Taylor – U.S. NRC
Office of Nuclear Regulatory Research

Joint RES/EPRI Fire PRA Training Workshop
Bethesda, MD, July and September 2012

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CIRCUIT ANALYSIS OVERVIEW
Introductions

- Instructors
  - Daniel Funk, P.E., Kleinsorg Group
  - Gabriel Taylor, NRC Office of Nuclear Regulatory Research
- Who's here and Why?
  - Name, Organization, Experience
  - What do you want from this course?
- Logistics

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Fire PRA Circuit Analysis Overview
Slide 2
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CIRCUIT ANALYSIS OVERVIEW
Course Prerequisites

- Who Should Attend?
  - Nuclear plant personnel with electrical and plant operating knowledge, but limited exposure to Appendix R and PRA
  - Nuclear plant personnel with substantial Appendix R and/or PRA experience, but limited circuit analysis experience
  - Anyone who went to the Circuit Analysis Basics course

CIRCUIT ANALYSIS OVERVIEW
Objectives

- This module covers technical tasks for analysis of fire-induced circuit failures in support of a Fire PRA
- This module is geared toward PRA practitioners and fire safe shutdown analysts with a practical understanding of the concepts and methods of fire-induced circuit failure analysis within the context of Fire PRA or Appendix R circuit failure assessments. Specifically, familiarity with the following topics is recommended:
  - General circuit design and operational control for typical plant equipment
  - Basic circuit analysis techniques for identifying and classifying fire-induced circuit failure modes
  - Working level knowledge of typical electrical drawings, including one-line diagrams, schematic diagrams, electrical block diagrams, wiring/connection diagrams, raceway layout drawings, instrument loop diagrams, etc.
  - Cable and raceway, Appendix R safe shutdown, and Fire PRA database structures and software
  - Appendix R safe shutdown circuit analysis
  - Emerging issues and challenges associated with the analysis of multiple spurious operations

CIRCUIT ANALYSIS OVERVIEW
Objectives, cont…

- It is expected that upon completion of the Circuit Analysis Module, attendees will have sufficient working knowledge of techniques and methods to perform at a practical level the electrical analysis tasks associated with supporting a Fire PRA

- **NEW!** Methodology presentations will show relationships to the PRA Standard and NEI 00-01, Rev. 2

Note: NEI 00-01, Rev 3 is issued but not yet approved by the NRC. Delta analysis for NFPA 805 is to Rev. 2

CIRCUIT ANALYSIS OVERVIEW
Presentation Road Map

- Course Introduction
- Circuit Analysis Process, Methods, and Criteria
- Walk Through Sample Problems
- Hands-on Sample Problem Exercises
- Database & Data Management
- Project Strategy, Key Considerations, and Lessons Learned

CIRCUIT ANALYSIS
Schedule / Agenda

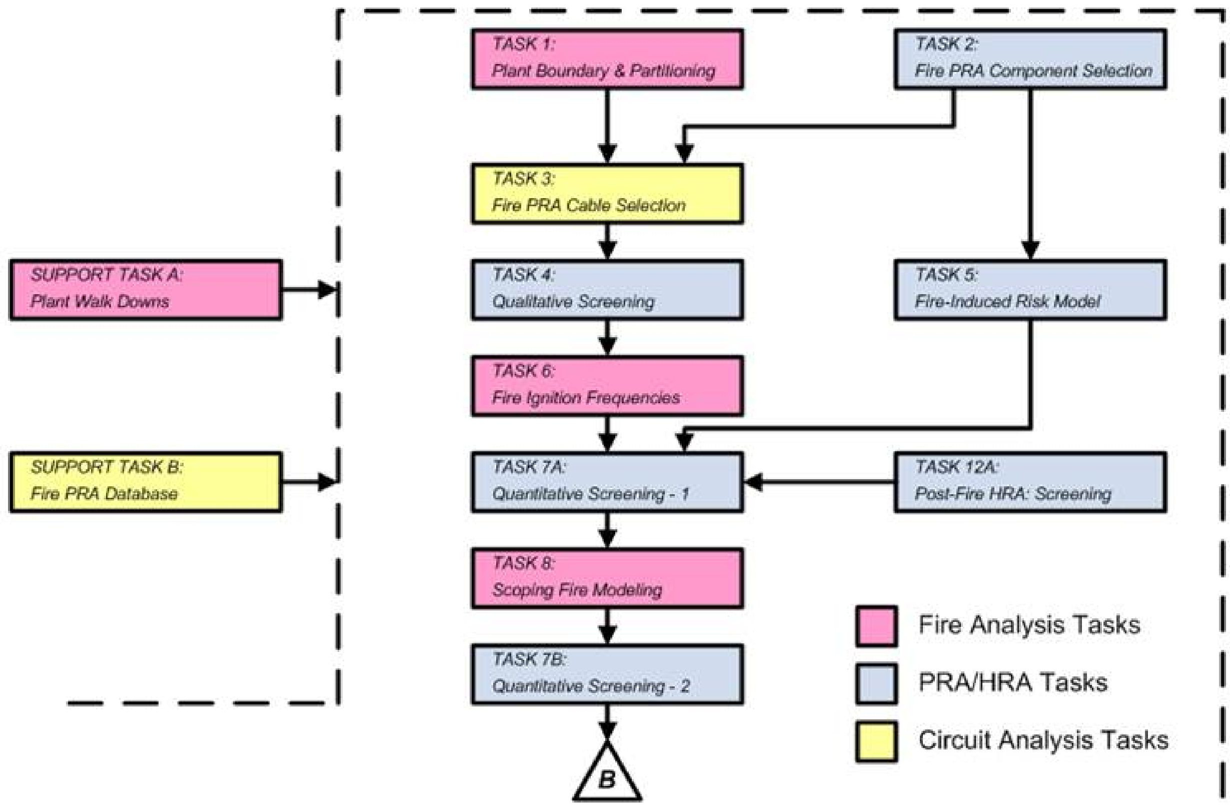
	Tuesday	Wednesday	Thursday	Friday
8:30	General Session Introduction to all Modules	Presentation Detailed Circuit Failure Analysis (Task 9)	Presentation Fire PRA Database	Exercises Task 9/10 Sample Problems
8:45				
9:00				
9:15				
9:30				
9:45			Break	Break
10:00			Presentation Fire PRA Database (Continued)	General Session Closing All Modules
10:15	Break	Break		
10:30	Presentation Fire PRA Circuit Analysis Overview	Presentation Task 3 & Task 9 Sample Problem Definition and Examples		
10:45				
11:00			Discussion Open, Q&A, etc.	
11:15				
11:30				
11:45				
12:00	Lunch Break	Lunch Break	Lunch Break	Adjourn
13:00	Presentation - Fire PRA Circuit Analysis Summary	Exercises Work Task 3 & Task 9 Sample Problems	Presentation Circuit Failure Mode Likeliood Analysis (Task 10)	
13:15				
13:30	Open Discussion			
13:45				
14:00				
14:15				
14:30	Break		Break	
14:45	Presentation Fire PRA Cable Selection (Task 3)		Exercises Circuit Failure Mode Likelihood Analysis (Task 10)	
15:00				
15:15				
15:30				
15:45	Break	Break	Break	
16:00	Presentation Fire PRA Cable Selection (continued)	Discussion Task 3 & 9 Sample Problems	Additional Exercises	
16:15				
16:30				
16:45				
17:00	Adjourn	Adjourn	Adjourn	

CIRCUIT ANALYSIS OVERVIEW
Circuit Analysis Tasks

- Task 3: Fire PRA Cable Selection
  - What cables are associated with the FPRA components?
- Task 9: Detailed Circuit Analysis
  - Which cables can affect the credited functionality?
  - Task 9A / 9B Split
  - What failure modes are possible given fire damage to the cable?
- Task 10: Circuit Failure Mode Likelihood Analysis
  - How likely to occur are the failure modes of concern?
- Support Task B: Fire PRA Database
  - Warehousing data and determining impacts

CIRCUIT ANALYSIS OVERVIEW

PRA Task Flow Chart



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Fire PRA Circuit Analysis Overview

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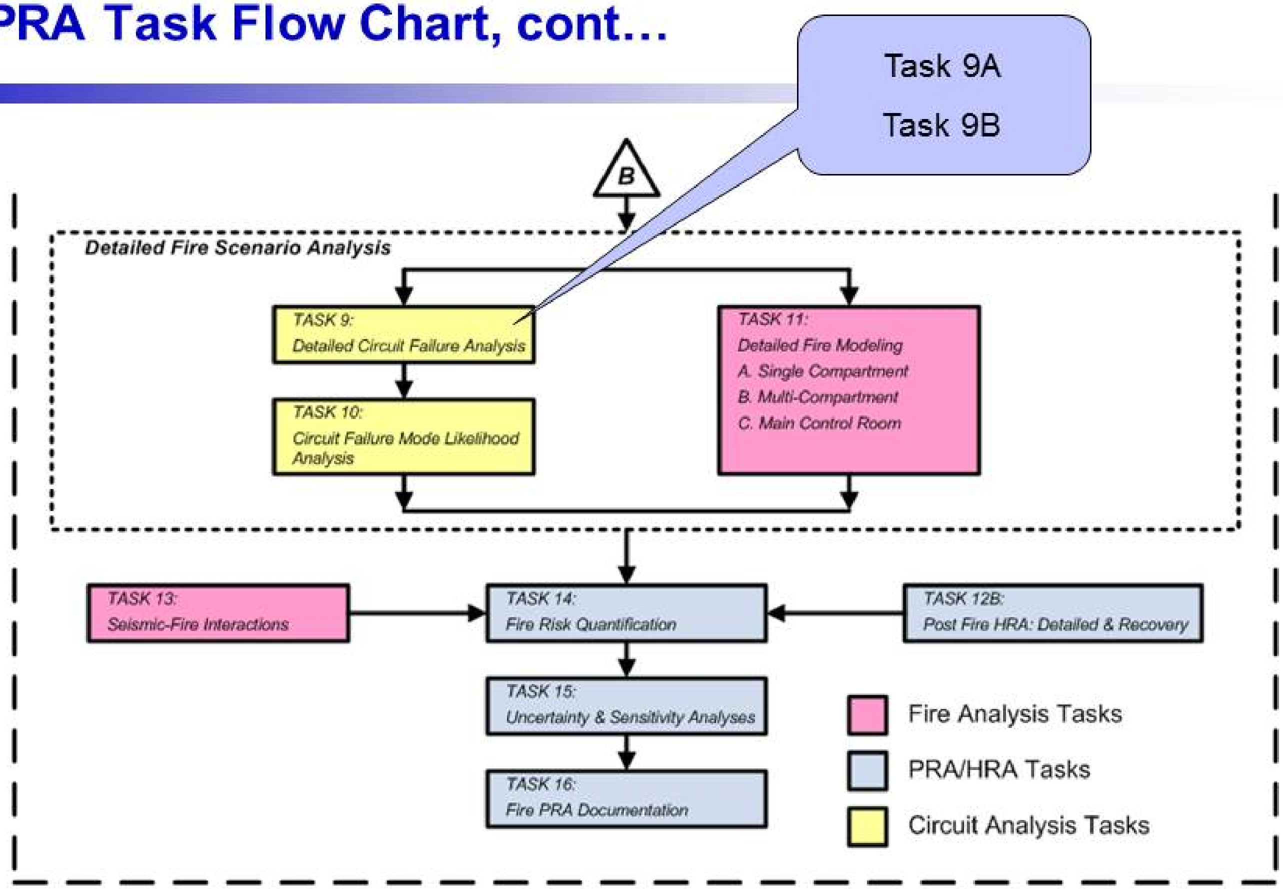
CIRCUIT ANALYSIS OVERVIEW
PRA Task Flow Chart, cont…



CIRCUIT ANALYSIS OVERVIEW
Key Considerations

- Each Circuit Analysis task represents a refined level of detail (i.e., graded approach)
- Existing Appendix R Circuit Analysis is **NOT** as useful as originally envisioned
- Circuit Analysis for Fire PRA is more complex and difficult compared to Appendix R
- Circuit Analysis (including cable tracing) can consume 40%-70% of overall budget
- Circuit Analysis scope **MUST** be a primary consideration during project planning

CIRCUIT ANALYSIS OVERVIEW
Questions

Any questions before we start ???

4.2 Task 3 – Fire PRA Cable Selection

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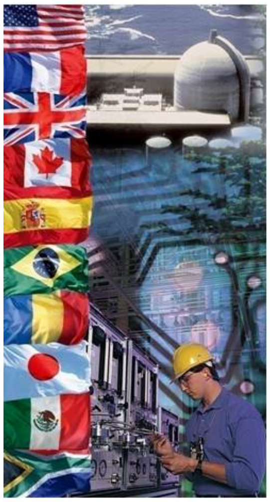
From Science to Solutions

Sandia National Laboratories



EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 3 - Fire PRA Cable Selection

Dan Funk – Kleinsorg Group
Gabriel Taylor – U.S. NRC
Office of Nuclear Regulatory Research

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FIRE PRA CABLE SELECTION
Purpose & Scope (per 6850/1011989)

- Identify circuits/cables associated with Fire PRA components
- Determine routing/location of the identified cables
- Use component-to-cable-to-location relationships to determine what components could be affected for postulated Fire Scenarios

Note: A Fire Scenario can involve a Fire Area, Room/Compartment, Raceway, or Other Specific Location

- Identify Fire PRA power supplies

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Task 3 - Fire PRA Cable Selection

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FIRE PRA CABLE SELECTION
Corresponding PRA Standard Element

- Primary match is to element CS – Cable Selection
  - CS Objectives (as stated in the PRA standard):

    "[T]o ensure that

    (a) all cables needed to support proper operation of equipment selected per technical element ES (see 4-2.2) are identified and assessed for relevance to the Fire PRA plant response model

    (b) the plant location information for selected cables is sufficient to support the Fire PRA and its intended applications."

FIRE PRA CABLE SELECTION
HLRs (per the PRA Standard)

- HLR-CS-A: The Fire PRA shall identify *and* locate the plant cables whose failure could adversely affect credited equipment or functions included in the Fire PRA plant response model, as determined by the equipment selection process (HLR-ES-A, HLR-ES-B, and HLR-ES-C). (11 SRs)
- HLR-CS-B: The Fire PRA shall
  (a) perform a review for additional circuits that are either required to support a credited circuit (i.e., per HLR-CS-A) or whose failure could adversely affect a credited circuit
  (b) identify any additional equipment and cables related to these additional circuits in a manner consistent with the other equipment and cable selection requirements of this Standard. (1 SR)
- HLR-CS-C: The Fire PRA shall document the cable selection and location process and results in a manner that facilitates Fire PRA applications, upgrades, and peer review. (4 SRs)

FIRE PRA CABLE SELECTION
NEI 00-01, Rev. 2, Section 3.3 – Safe Shutdown Cable Selection and Location

- NEI 00-01, Rev. 2, "Guidance for Post-Fire Safe Shutdown Circuit Analysis," May 2009.
- Generally follows the Task 3 methodology of NUREG/CR-6850, EPRI TR 1011989.
- Figure 3-4 in NEI 00-01 provides a flowchart illustrating the steps involved in selecting the cables necessary for performing a post-fire safe shutdown analysis:

Step 1 – Define safe shutdown equipment.

Step 2 – Identify circuits (power, control, instrumentation) required for the operation of each safe shutdown equipment.

Step 3 – Identify equipment whose spurious operation or mal-operation could affect safe shutdown.

FIRE PRA CABLE SELECTION
NEI 00-01, Rev. 2, Section 3.3 – Safe Shutdown Cable Selection and Location (continued)

Step 4 – Identify interlocked circuits and cables whose failure may cause spurious actuations.

Step 5 – *Decision:* Is power required for equipment operation?

Step 6 – If power is required, identify closest upstream power supply and verify that it is on the safe shutdown list.

Step 7 – Assign cables to equipment.

Step 8 – Identify routing of cables.

Step 9 – Identify location of cables by fire area.

FIRE PRA CABLE SELECTION
Introduction (per 6850/1011989)

- Conducted for all Fire PRA Components

  Note: Exceptions do exist

- Cable selection is a **Deterministic** process

- Selected cables are associated to components based on specified functionality
  - Basic circuit analysis (Task 9A) incorporated into Task 3 work to prevent overwhelming the PRA model with inconsequential cable failures
  - Final product is a listing of defined Basic Events (component and credited function) that could be impacted by a fire in a given location (Fire Area, Compartment, etc.) or for a specific Fire Scenario

FIRE PRA CABLE SELECTION
Introduction (continued)

- Cable Selection procedure is subdivided into six (6) distinct steps

  Step 1: Compile and Evaluate Prerequisite Information and Data

  Step 2: Select Fire PRA Circuits/Cables

  Step 3: Identify and Select Fire PRA Power Supplies

  Step 4: Perform Associated Circuits Review

  Step 5: Determine Cable Routing and Plant Locations

  Step 6: Generate Fire PRA Cable List and Target Equipment Location Reports

FIRE PRA CABLE SELECTION
Task Interfaces - Input

- Plant Boundary Partitions (Task 1)
- Fire PRA Component List (Task 2)
- Fire PRA Database (Support Task B)
- Appendix R Circuit Analysis
- Plant Cable & Raceway Database
- Plant Drawings

FIRE PRA CABLE SELECTION
Task Interfaces - Output

- Fire PRA Cable List
- Fire PRA Power Supply List
- Associated Circuits Review
- Component Analysis Packages
- Target Equipment Loss Reports (potential equipment functional losses broken down by location or fire scenario)

FIRE PRA CABLE SELECTION
Step 1 – Prerequisite Information

- Confirm Plant Partitioning is compatible
  - Do partitions align with cable location data?
  - What data is available and what is missing?
- Confirm PRA Equipment List is final
  - Input into a formal and controlled database
  - For NFPA-805 transition projects a joint "consistency" review of NSP task and PRA component selection task is highly recommended

    NOTE: Consistency checks are recommended for all Fire PRAs
  - *Critical that electrical analysts understand what the Basic Events really mean*

  (Corresponds to NEI 00-01, Rev. 2, Step 1)
- Evaluate Database Requirements
  - What currently exists?
  - What is needed to support work?
  - How is data to be managed and controlled?
  - This is a "Biggie"

FIRE PRA CABLE SELECTION
Step 2 – Select Fire PRA Cables

- Analysis Cases
  - Appendix R Component with *same* functional requirements
    - Must consider which (if any) automatic features are included in the existing analysis
    - Aligning existing analyses to Fire PRA Basic Events is not straightforward
  - Appendix R Component with *different* functional requirements
  - Non-Appendix R Component *with* cable location data
  - Non-Appendix R Component *without* cable location data
- Analysis Sub-Steps
  - *Step 2.1:* Analysis Strategy
  - *Step 2.2:* Plant Specific Rules
  - *Step 2.3:* Select Cables

- Corresponding PRA Standard SRs: CS-A1, A3
- Corresponding NEI 00-01, Rev. 2, Steps: 2 & 4

FIRE PRA CABLE SELECTION
Step 2.1 – Analysis Strategy

- Coordinate with Systems Analysts to establish Functional Requirements and General Rules
  - Equipment functional states, basic events, initiators
  - Initial conditions and equipment lines (i.e., normal state)
  - Consistent conventions for equipment functions/state/position
  - Equipment-level dependencies and primary components
  - Multiple function components
  - "Super" components
- Evaluate Appendix R Component & Circuit Data
  - Ensure equipment list comparison was conducted during Task 2
  - Review in detail the comparison list – ask questions!!!
  - Essential that comparison includes detailed review/assessment of "desired functional state(s)"

FIRE PRA CABLE SELECTION
Step 2.1 – Analysis Strategy (continued)

- Goal – Efficient and accurate process to obtain required information
- Revisit past assumptions, conventions, and approach
- Potential trouble areas
  - How is off-site power going to be handled?
  - Instrument circuits – understand exactly what is credited
  - ESFAS, Load-Shed, EDG Sequencer, other automatic functions
  - Medium-voltage switchgear control power
- Extent that Circuit Analysis is to be conducted concurrently

  Note: This will be discussed as part of the Task 9 presentation
- Determine how analysis will be documented

FIRE PRA CABLE SELECTION
Step 2.2 – Plant Specific Cable Selection Rules

- Objective is Consistency
- Approach for Groups of Components
- Approach for Spurious Actuation Equipment
- Auxiliary Contacts – Critical Area for Completeness
- System-Wide Actuation Signals
- Bus or Breaker?
- Subcomponents & Primary Components
- Identification of Permanent Damage Scenarios
- Procedure - Develop Circuit Analysis Procedure/Guidelines

FIRE PRA CABLE SELECTION
Step 2.2 – Ready to Start?

- Develop Written Project Procedure/Guidelines
  - Consistency, Consistency, Consistency
  - Checking Process?
  - Data Entry
  - Problem Resolution
- Training for Analysts
  - Prior circuit analysis experience is a prerequisite for key team members
  - Familiarity with plant drawings and circuits is highly beneficial
  - A junior engineer with no prior circuit analysis experience will not be able to work independently

FIRE PRA CABLE SELECTION
Step 2.3 – Select Cables

- *Case 1:* Incorporate Existing Appendix R Analysis
  - Confirm adequacy of existing analyses IAW plan
  - Careful consideration of automatic functions
  - Exact alignment for credited functionality

- *Case 2:* New Functional State/Component w/ Cable Routing Data
  - Collect drawings and/or past analysis information
  - Identify/select cables IAW plant specific procedure/guidelines
  - Conduct circuit analysis to the extent decided upon
  - Formally document cable selection IAW established procedures/guidelines

FIRE PRA CABLE SELECTION
Step 2.3 – Select Cables (continued)

- *Case 3:* New Component w/o Cable Routing Data Available
  - Same as Case 2, plus…
  - Determine cable routing and associate with plant locations, including cable end points

- Analysis Work Packages
  - Retrieve from past Appendix R Analysis
  - Highly recommended for new components
  - Major time saver for future work

Note: More on Work Packages later in this presentation…

FIRE PRA CABLE SELECTION
Step 3 – Select Fire PRA Power Supplies

- Identify Power Supplies as integral part of Cable Selection
  - Make sure to differentiate between "Required" and "Not Required" power supplies
  - Switchgear and instrument power supplies can be tricky
  - Useful to identify the applicable breaker/fuse
- Add Power Supplies to Fire PRA Component List
- Make sure Fire PRA model, equipment list, and circuit analysis are consistent
- Does Fire PRA model consider spurious circuit breaker operations?
  - Must understand how this is modeled to correctly select cables
- Corresponding PRA Standard SRs: CS-B1
- Corresponding NEI 00-01, Rev. 2, Steps: 5 & 6

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Task 3 - Fire PRA Cable Selection

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FIRE PRA CABLE SELECTION
Step 4 – Associated Circuits Review

- Objective is to confirm existing studies are adequate
- View the process as a "Gap Analysis"
- Common Power Supply Circuits - Assess Plant Coordination Studies
- Common Enclosure Circuits - Assess Plant Electrical Protection
- Roll up results to Circuit Analysis or Model as appropriate

  Note: Ensure switchgear internal fusing supports analysis assumptions

- Corresponding PRA Standard SRs: CS-A6, CS-B1
- Corresponding NEI 00-01, Rev. 2: Step 3 and Sections 3.5.2.4 & 3.5.2.5 (circuit analysis and evaluation)

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Task 3 - Fire PRA Cable Selection

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FIRE PRA CABLE SELECTION
Step 5 – Determine Cable Routing and Locations

- Correlate Cables-to-Raceways-to-Locations
- Conceptually Straightforward
- Logistically Challenging
  - Labor intensive
  - Manual review of layout drawings
  - Plant walkdowns often required
- Determine Cable Protective Features
  - Fire wraps
  - Embedded conduit

- Corresponding PRA Standard SRs: CS-A10
- Corresponding NEI 00-01, Rev. 2, Steps: 7, 8, & 9

FIRE PRA CABLE SELECTION
Step 6 – Target Equipment Loss Reports

- Data Entered into Fire PRA Database
- Sorts and Queries to Generate Target Equipment Loss Reports

Perspective – Cable selection process should be viewed as providing "Design Input" to the Fire PRA. It does not, however, provide any risk-based results. In its simplest form it provides a list of equipment that could be affected by a fire at a specified location or for a specific fire scenario.

- Corresponding PRA Standard SRs: CS-C1, C2, C4

FIRE PRA CABLE SELECTION
Work Packages

- A work package for each Fire PRA component consists of a compilation of drawings and documents that provide the basis of the circuit analysis results for that component
- Contents typically include
  - One-line diagram(s) (highlighted to show the component's power supply)
  - Elementary diagram(s) (marked up to show cable associations)
  - Block diagram(s) (highlighted)
  - Loop diagram(s) (if applicable)
  - Component circuit analysis worksheets
  - Other descriptive/supporting information

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Task 3 - Fire PRA Cable Selection

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FIRE PRA CABLE SELECTION
Questions

Any Questions?

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Task 3 - Fire PRA Cable Selection

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FIRE PRA CABLE SELECTION

Mapping HLRs & SRs for the CS technical element to NUREG/CR-6850, EPRI TR 1011989

Technical Element	HLR	SR	6850/1011989 Sections that cover SR	Comments
CS	A	The Fire PRA shall identify and locate the plant cables whose failure could adversely affect credited equipment or functions included in the Fire PRA plant response model, as determined by the equipment selection process (HLR-ES-A, HLR-ES-B, and HLR-ES-C).		
		1	3.5.2	
		2	9.5.2	Covered in "Detailed Circuit Failure Analysis" chapter
		3	3.5.2, 9.5.2	Also covered in "Detailed Circuit Failure Analysis" chapter
		4	3.5.3	
		5	9.5.2	Covered in "Detailed Circuit Failure Analysis" chapter
		6	3.5.4, 9.5.2	Also covered in "Detailed Circuit Failure Analysis" chapter
		7	9.5.2	Covered in "Detailed Circuit Failure Analysis" chapter
		8	9.5.2	Covered in "Detailed Circuit Failure Analysis" chapter
		9	9.5.2	Covered in "Detailed Circuit Failure Analysis" chapter
		10	3.5.5	
		11	3.5.5	
	B	The Fire PRA shall (a) perform a review for additional circuits that are either required to support a credited circuit (i.e., per HLR-CS-A) or whose failure could adversely affect a credited circuit (b) identify any additional equipment and cables related to these additional circuits in a manner consistent with the other equipment and cable selection requirements of this Standard		
		1	3.5.3, 3.5.4	
	C	The Fire PRA shall document the cable selection and location process and results in a manner that facilitates Fire PRA applications, upgrades, and peer review.		
		1	3.5.6	
		2	3.5.6	
		3	3.5.6	
		4	3.5.6	

FIRE PRA CABLE SELECTION

Mapping NEI 00-01, Rev. 2, Safe Shutdown Cable Selection to NUREG/CR-6850, EPRI TR 1011989

NEI 00-01, Rev. 2, Section	NEI 00-01, Figure 3-4 Step	6850/1011989 Sections that cover step	Comments
3.3 - Safe Shutdown Cable Selection and Location	1	3.5.1	
	2	3.5.2	
	3	3.5.4	
	4	3.5.2	
	5	3.5.3	
	6	3.5.3	
	7	3.5.5	
	8	3.5.5	
	9	3.5.5	

4.3 Task 9 – Detailed Circuit Failure Analysis

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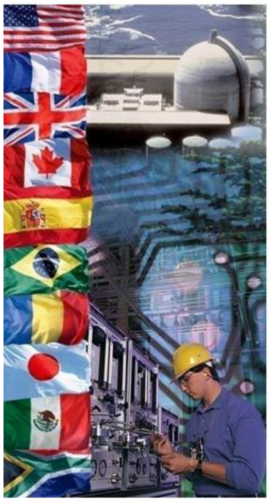

EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 9 - Detailed Circuit Failure Analysis

Dan Funk – Kleinsorg Group
Gabriel Taylor – U.S. NRC
Office of Nuclear Regulatory Research

Joint RES/EPRI Fire PRA Training Workshop
Bethesda, MD, July and September 2012

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DETAILED CIRCUIT FAILURE ANALYSIS
Purpose & Scope (per 6850/1011989)

The Detailed Circuit Failure Analysis Task is intended to:

- Identify the potential response of circuits and components to specific cable failure modes associated with fire-induced cable damage
- Screen out cables that do not impact the ability of a component to complete its credited function

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Task 9 - Detailed Circuit Failure Analysis

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DETAILED CIRCUIT FAILURE ANALYSIS
Corresponding PRA Standard Elements

- One match is to element CS – Cable Selection
  - CS Objectives (as stated in the PRA standard):

    "[T]o ensure that

    (a) all cables needed to support proper operation of equipment selected per technical element ES (see 4-2.2) are identified and assessed for relevance to the Fire PRA plant response model

    (b) the plant location information for selected cables is sufficient to support the Fire PRA and its intended applications."

DETAILED CIRCUIT FAILURE ANALYSIS
Corresponding PRA Standard Elements (continued)

- Another match is to element CF – Circuit Failures
  - CF Objectives (as stated in the PRA standard):

    "[T]o

    (a) refine the understanding and treatment of fire-induced circuit failures on an individual fire scenario basis

    (b) ensure that the consequences of each fire scenario on the damaged cables and circuits have been addressed"

DETAILED CIRCUIT FAILURE ANALYSIS
HLRs (per the PRA Standard) – CS element

- HLR-CS-A: The Fire PRA shall identify *and* locate the plant cables whose failure could adversely affect credited equipment or functions included in the Fire PRA plant response model, as determined by the equipment selection process (HLR-ES-A, HLR-ES-B, and HLR-ES-C). (11 SRs)
- HLR-CS-B: The Fire PRA shall
  - *(a)* perform a review for additional circuits that are either required to support a credited circuit (i.e., per HLR-CS-A) or whose failure could adversely affect a credited circuit
  - *(b)* identify any additional equipment and cables related to these additional circuits in a manner consistent with the other equipment and cable selection requirements of this Standard. (1 SR)
- HLR-CS-C: The Fire PRA shall document the cable selection and location process and results in a manner that facilitates Fire PRA applications, upgrades, and peer review. (4 SRs)

DETAILED CIRCUIT FAILURE ANALYSIS
HLRs (per the PRA Standard) – CF element

- HLR-CF-A: The Fire PRA shall determine the applicable conditional probability of the cable and circuit failure mode(s) that would cause equipment functional failure and/or undesired spurious operation based on the credited function of the equipment in the Fire PRA. (2 SRs)
- HLR-CF-B: The Fire PRA shall document the development of the elements above in a manner that facilitates Fire PRA applications, upgrades, and peer review. (1 SR)

DETAILED CIRCUIT FAILURE ANALYSIS
NEI 00-01, Rev. 2, Section 3.5 – Circuit Analysis and Evaluation

- NEI 00-01, Rev. 2, "Guidance for Post-Fire Safe Shutdown Circuit Analysis," May 2009.
- Generally follows the Task 9 methodology of NUREG/CR-6850, EPRI TR 1011989.
- Types of circuit failures to be considered:
  - Open circuits (available fault energy)
  - Shorts-to-ground
  - Hot shorts (new insights)
- Other considerations:
  - Common power supplies (i.e., inadequate coordination)
  - Common enclosures (i.e., inadequate circuit protection)

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Slide 7
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DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (1) (per 6850/1011989)

- Fundamentally this is a deterministic analysis
- Perform coincident with cable selection (Task 3) to the extent feasible and cost effective ("Task 9A")
- Difficult cases generally reserved for situations in which Quantitative Screening indicates a clear need and advantage for further analysis
- Detailed Failure Modes Analysis
  - Requires knowledge about desired functionality and component failure modes
  - Conductor-by-conductor evaluation (Hot Probe method recommended)
- Objective is to screen out all cables that **CANNOT** impact the ability of a component to fulfill the specific function of interest

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DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (2)

- Failure modes considered
  - Single shorts-to-ground (reference ground)
    - Grounded system
    - Ungrounded system
    - Resistance grounded system
  - Single hot shorts
  - Compatible polarity multiple hot shorts for ungrounded AC and DC circuits (surrogate path through raceway)
  - Coincident independent hot shorts on separate cables
  - Multiple intra-cable hot shorts
  - Cables associated through a common power supply

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Task 9 - Detailed Circuit Failure Analysis

Slide 9

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DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (3)

- Failure modes **NOT** considered
  - 3-phase proper sequence hot shorts (except high consequence equipment with thermoplastic insulated conductor or ungrounded configuration)
  - Inter-cable hot shorts for armored cable and cable in dedicated conduit
  - Open circuit conductor failures (Reconsider)
  - Multiple high-impedance faults

Note: If conducting a combined NFPA-805 and Fire PRA circuit analysis, NEI 00-01 requires open circuits be considered.

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Task 9 - Detailed Circuit Failure Analysis

Slide 10

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DETAILED CIRCUIT FAILURE ANALYSIS
Introduction (4)

Application of Task 9A versus Task 9B:

- Task 9A circuit analysis performed as part of the Task 3, Cable Selection, process
  - Intended to be a very quick screening determination about whether a given cable is able to adversely impact the ability of a required component to complete its credited function, and thus should be put on the Fire PRA Cable List
- Detailed circuit analysis (Task 9B) is performed as described by the Task 9 methodology (i.e., the basis of this presentation)
  - Intended to be a more robust assessment of a cable's potential impact on the Fire PRA component of interest and is performed later in the overall Fire PRA process, after some screening has occurred

Note: The more experience an analyst has performing Task 9B level analyses, the more proficient they become in performing Task 9A level screening.

DETAILED CIRCUIT FAILURE ANALYSIS
Assumptions

The following assumptions form the basis for Task 9:

- An Appendix R analysis for the plant has been completed and is available for identifying equipment failure responses to specific cable failure modes
- Component **Work Packages** have been assembled as part of the Task 3 activities or previous Appendix R analyses
- Equipment is assumed to be in its normal position or operating condition at the onset of the fire – the equipment state might be variable
- Users of this procedure are knowledgeable on and have experience with circuit design and analysis methods

DETAILED CIRCUIT FAILURE ANALYSIS
Process

- The Task 9 procedure is subdivided into three (3) primary steps:
  - Step 1: Compile and Evaluate Prerequisite Information and Data
  - Step 2: Perform Detailed Circuit/Cable Failure Analysis
  - Step 3: Generate Equipment Failure Response Reports

DETAILED CIRCUIT FAILURE ANALYSIS
Task Interfaces - Inputs

- Fire PRA Components List (Task 2)
- Fire PRA Cable List (Task 3)
- Fire PRA Database (Support Task B)
- Results of Quantitative Screening (Task 7)
- Results of Detailed Fire Modeling (Task 11)
- Appendix R Circuit Analysis
- Plant Drawings
- CRS Database

DETAILED CIRCUIT FAILURE ANALYSIS
Task Interfaces - Outputs

- Equipment Failure Response Reports
- Component Analysis ("Work") Packages (Updated)
- Revised Cable List
- Fire PRA Database & Model Updates

DETAILED CIRCUIT FAILURE ANALYSIS
Step 1 - Compile Prerequisite Information

- Ensure that prerequisite information and data are available and usable before beginning the analyses (ideally the necessary drawings are already in the Work Packages).
- Step 1.1: Confirm Fire PRA Cable List is Available in the Fire PRA Database
  - Component ⇒ Cable ⇒ Raceway ⇒ Compartment
- Step 1.2: Confirm Unscreened Plant Compartments and Scenarios are Identified
  - Target Equipment Loss Reports
  - Equipment ID, Normal Status, Functional Requirements, etc.

DETAILED CIRCUIT FAILURE ANALYSIS
Step 2 - Perform Circuit Failure Analysis

- Perform a *Deterministic-Based* detailed circuit analysis for the Fire PRA cables of interest that are located in the unscreened plant locations.
- Step 2.1: Develop Strategy/Plan for Circuit Analysis
- Step 2.2: Develop Plant-Specific Rules for Performing the Detailed Circuit Analysis
- Step 2.3: Perform Detailed Circuit Failure Analysis
- Document Analysis Results ⇒ Component Work Packages
- Corresponding PRA Standard SRs: CS-A2, A3, A5, A6, A7, A8, A9
- Corresponding NEI 00-01, Rev. 2, Section: 3.5.2

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Task 9 - Detailed Circuit Failure Analysis

Slide 17

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DETAILED CIRCUIT FAILURE ANALYSIS
Considerations in Developing Plant-Specific Rules

- Consider the following while developing the plant-specific circuit analysis rules:
  - The types of cable failure modes (hot shorts, shorts to ground) and the effects of concern (spurious actuation, loss of power, loss of control, etc.) on the Fire PRA component.
  - Three-phase proper polarity hot shorts on AC power cables
    - Grounded AC systems using thermoset-insulated cable
    - Ungrounded AC systems **or** thermoplastic-insulated cable
    - Armored cable or cable in dedicated conduit
  - Intra-cable versus Inter-cable hot shorts
  - DC circuit cable failures
  - Coincident independent hot shorts involving separate cables
  - Compatible polarity multiple hot shorts on ungrounded circuits

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Task 9 - Detailed Circuit Failure Analysis

Slide 18

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DETAILED CIRCUIT FAILURE ANALYSIS
Step 3 - Generate Equipment Failure Response Reports

- Enter results into Fire PRA Database
- Generate Equipment Failure Response Reports
  - A listing by location (room, zone, area) of equipment and associated cables affected by fire
  - Provides specific equipment responses (cable failure consequences) that affect the credited function being analyzed
  - Equipment losses should be correlated to each Basic Event
- Corresponding PRA Standard SRs: CF-B1

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Task 9 - Detailed Circuit Failure Analysis

Slide 19

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DETAILED CIRCUIT FAILURE ANALYSIS
Caveats & Recommendations

- This detailed circuit failure analysis methodology is a Static Analysis (no timing issues are considered)
- Be aware of possible Cable Logic Relationships
- Work Packages (Highly Recommended!)
- "Hot Probe" (Conductor-to-Conductor) analysis must be rolled-up to cable/component level
- Outputs need to be Compatible with Fire PRA Database format and field structure
- Coordinate with the Fire PRA Modelers/Analysts early-on to Define the Fire PRA Component Failure Modes of Concern

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Task 9 - Detailed Circuit Failure Analysis

Slide 20

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DETAILED CIRCUIT FAILURE ANALYSIS
Recommended Notation for Analysis

- It is highly recommended that the analysts employ a consistent notation for documenting their results
- In this training course, we will use the following notations:

Primary Circuit Failure Mode Descriptions

EI	Erroneous Indication
EIS	Erroneous Indicating Signal
LIS	Loss of Indicating Signal
LOC	Loss of Control
LOCP	Loss of Control Power (usually applies only to metalclad switchgear that depend on a separate control power source to actuate)
LOI	Loss of Indication
LOP	Loss of Power (to the circuit)
SA	Spuriously Actuates or Spurious Actuation
SC	Spuriously Closes
SO	Spuriously Opens
SS	Spuriously Starts/Runs

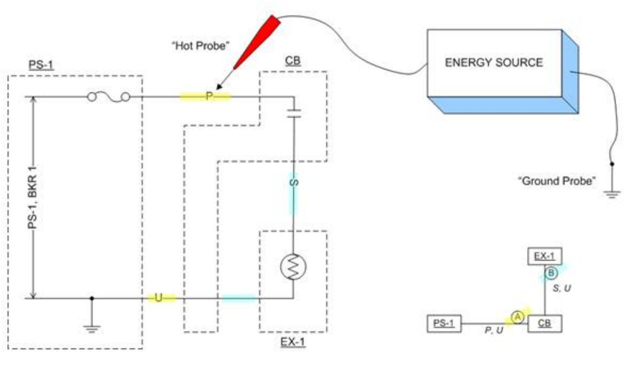
Causal Modifiers

BF	Blown Fuse
HS	Hot Short
PR	Protective Relay
SG	Short to Ground

Example Usage:

LOP-BF:	Loss of power due to a blown fuse
SO-HS:	Spuriously opens due to a hot short
LOC-PR:	Loss of control due to a protective relay

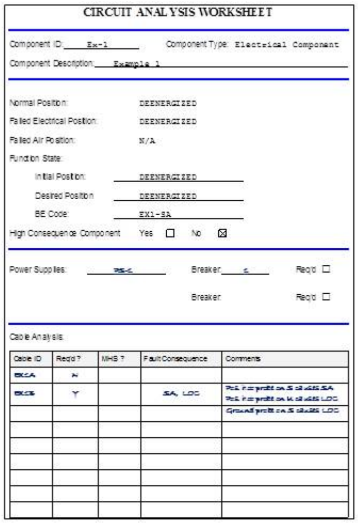
DETAILED CIRCUIT FAILURE ANALYSIS
Hot Probe Method – A very simple example



What happens when the **Hot** & **Ground** probes contact:

Conductor	Hot (+) Probe	Ground Probe
P?		
S?		
U?		

DETAILED CIRCUIT FAILURE ANALYSIS
Hot Probe Method Results & Documentation


CIRCUIT ANALYSIS WORKSHEET

Component ID: Ex-1 Component Type: Electrical Component

Component Description: Example 1

Normal Position: DEENERGIZED

Failed Electrical Position: DEENERGIZED

Failed Air Position: N/A

Function State:

Initial Position: DEENERGIZED

Desired Position: DEENERGIZED

BE Code: EX1-SA

High Consequence Component Yes ☐ No ☒

Power Supplies: [illegible] Breaker: [illegible] Req'd ☐

Breaker: Req'd ☐

Cable Analysis:

Cable ID	Req'd?	MHS?	Fault Consequence	Comments
[illegible]	N			
[illegible]	Y		SA, LOC	[illegible]
				[illegible]

This part will be provided.

If not complete, then ***ask*** for the missing information.

This part and 2nd page ***you*** will complete.

Basically, this documents your analysis.

Note: More about performing Circuit Analysis will be provided in the Electrical Examples presentation.

DETAILED CIRCUIT FAILURE ANALYSIS
Questions

Any Questions?

DETAILED CIRCUIT FAILURE ANALYSIS

Mapping HLRs & SRs for the CS technical element to NUREG/CR-6850, EPRI TR 1011989

Technical Element	HLR	SR	6850/1011989 Sections that cover SR	Comments
CS	A	The Fire PRA shall identify and locate the plant cables whose failure could adversely affect credited equipment or functions included in the Fire PRA plant response model, as determined by the equipment selection process (HLR-ES-A, HLR-ES-B, and HLR-ES-C).		
		1	3.5.2	Covered in "Fire PRA Cable Selection" chapter
		2	9.5.2	
		3	3.5.2, 9.5.2	Also covered in "Fire PRA Cable Selection" chapter
		4	3.5.3	Covered in "Fire PRA Cable Selection" chapter
		5	9.5.2	
		6	3.5.4, 9.5.2	Also covered in "Fire PRA Cable Selection" chapter
		7	9.5.2	
		8	9.5.2	
		9	9.5.2	
		10	3.5.5	Covered in "Fire PRA Cable Selection" chapter
		11	3.5.5	Covered in "Fire PRA Cable Selection" chapter
	B	The Fire PRA shall (a) perform a review for additional circuits that are either required to support a credited circuit (i.e., per HLR-CS-A) or whose failure could adversely affect a credited circuit (b) identify any additional equipment and cables related to these additional circuits in a manner consistent with the other equipment and cable selection requirements of this Standard		
		1	3.5.3, 3.5.4	Covered in "Fire PRA Cable Selection" chapter
	C	The Fire PRA shall document the cable selection and location process and results in a manner that facilitates Fire PRA applications, upgrades, and peer review.		
		1	3.5.6	Covered in "Fire PRA Cable Selection" chapter
		2	3.5.6	Covered in "Fire PRA Cable Selection" chapter
		3	3.5.6	Covered in "Fire PRA Cable Selection" chapter
		4	3.5.6	Covered in "Fire PRA Cable Selection" chapter

DETAILED CIRCUIT FAILURE ANALYSIS

Mapping HLRs & SRs for the CF technical element to NUREG/CR-6850, EPRI TR 1011989 (continued)

Technical Element	HLR	SR	6850/1011989 Sections that cover SR	Comments
CF	A	The Fire PRA shall determine the applicable conditional probability of the cable and circuit failure mode(s) that would cause equipment functional failure and/or undesired spurious operation based on the credited function of the equipment in the Fire PRA.		
		1	10.5.2, 10.5.3	Covered in "Circuit Failure Mode Likelihood Analysis" chapter
		2	10.5.3	Covered in "Circuit Failure Mode Likelihood Analysis" chapter
	B	The Fire PRA shall document the development of the elements above in a manner that facilitates Fire PRA applications, upgrades, and peer review.		
		1	9.5.3, 10.5.3	Also covered in "Circuit Failure Mode Likelihood Analysis" chapter

DETAILED CIRCUIT FAILURE ANALYSIS

Mapping NEI 00-01, Rev. 2, Circuit Analysis and Evaluation to NUREG/CR-6850, EPRI TR 1011989

NEI 00-01, Rev. 2, Section	NEI 00-01, Section 3.5.2 – Types of Circuit Failures	6850/1011989 Sections that cover step	Comments
3.5 – Circuit Analysis and Evaluation	3.5.2.1: Due to an Open Circuit	N/A	Open circuits not considered in 6850/1011989 as discussed in 9.5.2
	3.5.2.2: Due to a Short-to-Ground	9.5.2	
	3.5.2.3: Due to a Hot Short	9.5.2	
	3.5.2.4: Due to Inadequate Circuit Coordination	3.5.4	Covered in "Fire PRA Cable Selection" chapter
	3.5.2.5: Due to Common Enclosure Concerns	3.5.4	Covered in "Fire PRA Cable Selection" chapter

4.4 Task 10 – Circuit Failure Mode Likelihood Analysis

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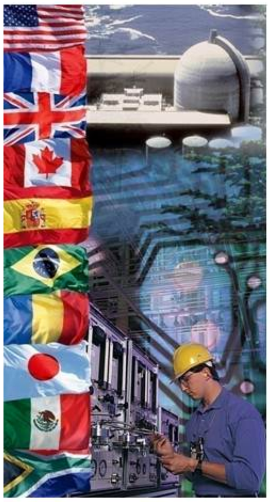
Sandia National Laboratories

SAIC Science Applications International Corporation



EPRI/NRC-RES FIRE PRA METHODOLOGY

Task 10 - Circuit Failure Mode Likelihood Analysis

Dan Funk – Kleinsorg Group
Gabriel Taylor – U.S. NRC Office of Nuclear Regulatory Research

Joint RES/EPRI Fire PRA Training Workshop
Bethesda, MD, July and September 2012

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CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Purpose & Scope (per 6850/1011989)

The Circuit Failure Mode Likelihood Analysis Task is intended to:

- Establish first-order probability estimates for the Circuit Failure Modes of interest

AND

- Correlate those Failure Mode Probabilities to specific components

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Task 10 - Circuit Failure Mode Likelihood Analysis

Slide 2

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CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Corresponding PRA Standard Element

- Primary match is to element CF – Circuit Failures
  - CF Objectives (as stated in the PRA standard):

    "[T]o

    (a) refine the understanding and treatment of fire-induced circuit failures on an individual fire scenario basis

    (b) ensure that the consequences of each fire scenario on the damaged cables and circuits have been addressed"

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
HLRs (per the PRA Standard) – CF element

- HLR-CF-A: The Fire PRA shall determine the applicable conditional probability of the cable and circuit failure mode(s) that would cause equipment functional failure and/or undesired spurious operation based on the credited function of the equipment in the Fire PRA. (2 SRs)

- HLR-CF-B: The Fire PRA shall document the development of the elements above in a manner that facilitates Fire PRA applications, upgrades, and peer review. (1 SR)

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS

NEI 00-01, Rev. 2, Section 5.2.1.2 – Probability of Spurious Actuation

- NEI 00-01, Rev. 2, "Guidance for Post-Fire Safe Shutdown Circuit Analysis," May 2009.
- Generally follows Option #1 of the Task 10 methodology in NUREG/CR-6850, EPRI TR 1011989.
- Recommends the use of spurious actuation probability point estimates from:
  - Table 2.8.3 in NRC Inspection Manual 0609, Appendix F ("FP SDP")
  - Tables 7.1 and 7.2 from EPRI Report 1006961 ("Expert Elicitation")

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS

Introduction (1) (per 6850/1011989)

- This is a Probabilistic Based Analysis
- Two methods presented
  - Expert Panel results ("Look-Up Tables")
  - Computation-based analysis ("Formulas")
- Requires knowledge about circuit design, cable type and construction, installed configuration, and component attributes
- Generally reserved for only those cases that cannot be resolved through other means

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Introduction (2)

- Caveats:
  - Our knowledge is greatly improved but uncertainties are still large
    - Very limited data for many issues
  - For this reason, implementing guidance is intended to be conservative
  - Practical implementation is challenging
  - Further analysis of existing test data and follow-on tests would be beneficial:
    - Reduce uncertainties, including conservatisms as appropriate
    - Solidify key influence factors
    - Incorporate time as a factor (FAQ 08-0051, for AC circuits only; Status: Closed)
    - Incorporate "End-Device" functional attributes and states (e.g., latching circuits vs. drop-out design)
    - Expert elicitation to produce refined spurious operation probabilities (Ongoing CY11)
  - Computation-based method (formula) is an extrapolation of existing data; validation remains to be done. Conservatism has not been established.
- Probabilities of sufficient quality to move ahead

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Introduction (3)

- Public and Peer Review Comments
  - Several questions involving interpretation of the EPRI Test Data led to extensive discussions regarding the most appropriate way to tally spurious actuation probabilities (many subtleties for implementation)
  - Team's consensus is that Expert Panel Values are, in general, somewhat conservative
  - Additional independent review of the Computational Method was solicited as a result of Peer and Public Comments
    - Review was favorable, however the team acknowledges the inevitable limitations of the methodology

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Introduction (4) – Related FAQ

- FAQ 08-0051 Hot Short Duration
  - Issue:
    - No guidance on the duration of hot shorts is provided in 6850/1011989
    - Hot shorts can produce undesirable conditions for Fire PRA components (e.g., pumps and valves)
    - The duration of a hot short is important since the affected component may be unable to perform its credited function and recovery may be delayed until the hot short is cleared
    - The clearing of the hot short may cause the component to return to its desired state or manual actions may be required to recover the equipment and its associated function
  - General approach to resolution:
    - A statistical analysis of the NEI/EPRI and CAROLFIRE test data was performed and resulted in a Weibull distribution model
    - The model predicts the probability of the duration of a spurious actuation from a hot short lasting greater than or equal to time, t, in minutes to be

      $$\mathbf{P}(T \geq t) = \exp(-\lambda t^{\beta})$$

      where, $\lambda = 0.963$ and $\beta = 0.579$,

      and $\mathbf{P}(T \geq 15 \text{ minutes}) = 0.01$
    - See A. Klein (NRR), AFPB File Memorandum, April 1, 2010, "Closure of National Fire Protection Association 805 Frequently Asked Question 08-0051 Hot Short Duration" (ML100900052) for additional details and limitations of use
  - Status:
    - Closed

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Assumptions

The following assumptions form the basis for Task 10:

- Specific cable/circuit configuration attributes are available or can be determined
- The equipment is in its normal position or operating condition at the onset of the fire
- Users of this procedure are knowledgeable and have experience with circuit design and analysis methods and probability estimating techniques
- This analysis method is applied to cables with no more than 15 conductors

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Process

- The Task 10 procedure is subdivided into four (4) primary steps:
  - Step 1: Compile and Evaluate Prerequisite Information and Data
  - Step 2: Select Analysis Approach
  - Step 3: Perform Circuit Failure Mode Probability Analyses
  - Step 4: Generate Circuit Failure Mode Probability Reports

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Task Interfaces - Inputs

- Fire PRA Cable List (Task 3)
- Fire PRA Database (Support Task B)
- Results of Detailed Circuit Failure Analysis (Task 9)
- Specific Scenarios Identifying Affected Cables (Tasks 11 & 14)
- Cable & Circuit Configuration Attributes
- Plant Drawings

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Task Interfaces - Outputs

- Quantification of Fire Risk (Task 14)
- Post-Fire HRA (Task 12)
- Detailed Fire Scenario Quantification (Task 11)
- Circuit Failure Mode Probability Reports
- Component Work Packages (Finalized)
- Fire PRA Database & Model

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Step 1 - Compile Prerequisite Information

Ensure that prerequisite information and data are available and usable before beginning the analyses.

- Confirm completion of Detailed Circuit Analysis for components of interest
- Collect important cable and configuration attribute information:
  - Insulation
  - Number of conductors
  - Raceway types
  - Power source(s)
  - Number of Source & Target conductors (for Option #2 only)

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Step 2 - Select Analysis Approach

Decide which analysis option is best suited for conducting the evaluation.

1. Select Failure Mode Probability Estimate from Look-Up Tables
   - Grounded circuit design
   - Non-complex control circuit
   - Single component service
   - Cable configuration matches Look-Up Table categories
   - Principal failure mode of concern is Spurious Actuation
2. Calculate Probability Estimate using Formulas
   - Ungrounded or resistance-grounded circuit design
   - Complex circuit or component
   - Failure potentially affects multiple components
   - Cable configuration not easily categorized in Look-Up Tables

- Corresponding PRA Standard SRs: CF-A1

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Step 3 - Estimate Circuit Failure Mode Probabilities

Estimate Circuit Failure Mode Probabilities employing the selected method:

Option #1: Failure Mode Probability Estimate Tables

- Table 10-1, Thermoset Cables with CPTs
- Table 10-2, Thermoset Cables without CPTs
- Table 10-3, Thermoplastic Cables with CPTs
- Table 10-4, Thermoplastic Cables without CPTs
- Table 10-5, Armored or Shielded Cables

Option #2: Computational Probability Estimate Formulas

$$P_{CC} = (C_{Tot} - C_G) / [(C_{Tot} - C_G) + (2 \times C_G) + n]$$

$$CF = \{C_T \times [C_S + (0.5 / C_{Tot})]\} / C_{Tot}$$

$$P_{FM} = CF \times P_{CC}$$

- Corresponding PRA Standard SRs: CF-A1, A2
- Corresponding NEI 00-01, Rev. 2, Section: 5.2.1.2 (Option #1 only)

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Step 3 – Related FAQ

- FAQ 08-0047 Cable Dependency
  - Issue:
    - Guidance (Vol. 2, Page 10-7, Bullet 3) states that when more than one cable can cause the same spurious actuation you combine probabilities using "exclusive or" (XOR)
    - This assumes faults/effects are independent
  - General approach to resolution:
    - Consensus reached that "exclusive or" is not appropriate if faults are dependent (e.g., a common power supply for both cables)
    - Clarify treatment to determine and address dependency
  - Status:
    - Closed

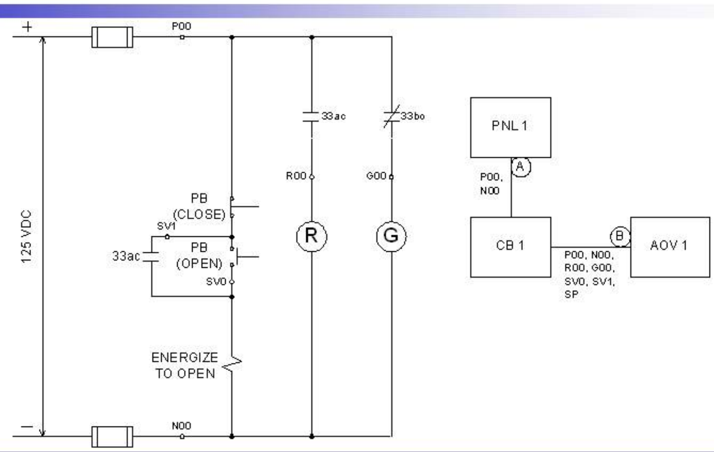
CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Step 4 - Generate Failure Mode Probability Reports

- Enter results into the Fire PRA Database

- Generate Circuit Failure Mode Probability Reports
  - Listing the Probability Estimates for the Circuit Failure Modes of Concern for Each Component of Interest by Plant Area (Compartment, Fire Area, Fire Zone, etc.)

- Corresponding PRA Standard SRs: CF-B1

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Example – Simple AOV/SOV Control Circuit



QUESTION: What is the *probability* that damage to Cable B will result in spurious opening of the AOV?

See next slide→

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Example – Step 1: Prerequisite Information

- Detailed circuit analysis completed & documented? ***Yes***

Cable	+125 VDC Hot Probe	-125 VDC Reference Ground Probe
A	LOP-FB	LOP-FB
B	LOP-FB, EI-HS, SO-HS	LOP-FB, LOC

- Collect important cable and configuration data:
  - Cable insulation? ***Thermoset***
  - Number of conductors? ***Seven***
  - Raceway type? ***Tray***
  - Power source? ***Ungrounded DC bus (no CPT)***
  - Number of source & target conductors? ***3 sources, 1 target***

See next slide→

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Example – Step 2: Select Analysis Approach

- Option #1: Failure Mode Probability Tables
  - Grounded circuit design? ***No***
  - Control circuit cable? ***Yes***
  - Single component circuit? ***Yes***
  - Known cable configuration? ***Yes***
  - Spurious actuation concern? ***Yes***
- Option #2: Computational Probability Estimate
  - Ungrounded circuit? ***Yes***
  - Complex circuit/component? ***No***
  - Multiple component circuit? ***No***
  - Cable configuration not categorized? ***No***

For this example, we'll show both methods

See next slide→

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Example – Step 3: Perform Analysis (1)

- Option #1:
  - Which Table to Use? ***Table 10-2, Thermoset Cable without CPT***

Raceway Type	Description of Hot Short	Best Estimate	High Confidence Range
Tray	M/C Intra-cable 1/C Inter-cable M/C → 1/C Inter-cable M/C → M/C Inter-cable	0.60 0.40 0.20 0.02 – 0.1	0.20 – 1.0 0.1 – 0.60 0.1 – 0.40
Conduit	M/C Intra-cable 1/C Inter-cable M/C → 1/C Inter-cable M/C → M/C Inter-cable	0.15 0.1 0.05 0.01 – 0.02	0.05 – 0.25 0.025 – 0.15 0.025 – 0.1

  - SO Probability Estimate, **P** = <u>0.62</u> (0.60 + 0.06 – 0.60*0.06)

See next slide→

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS

Example – Step 3: Perform Analysis (2)

- Option #2:
  - Calculate probability of a conductor-to-conductor short:

$$P_{CC} = (C_{Tot} - C_G) / [(C_{Tot} - C_G) + (2 * C_G)]$$

$$P_{CC} = (7 - 1) / [(7 - 1) + (2 * 1)]$$

$$P_{CC} = 6 / [6 + 2]$$

$$P_{CC} = 0.75$$

  - Determine cable configuration factor:

$$CF_{SO} = \{C_T * [C_S + (0.5 / C_{Tot})]\} / C_{Tot}$$

$$CF_{SO} = \{1 * [3 + (0.5 / 7)]\} / 7$$

$$CF_{SO} = 3.071 / 7$$

$$CF_{SO} = 0.44$$

  - Probability of spurious actuation, $\mathbf{P}_{SO}$ = 0.75 * 0.44 = <u>0.33</u>

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS

Example – Step 4: Failure Mode Probability Report

Failure Code	Estimated Probability (Calculated)	Estimated Probability (From Table 10-2)
SO-HS	0.33	0.62

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Recommended Step-by-Step Process for Task 10 Analyses

1. Determine appropriate option for estimating failure mode probability:
   a) Grounded circuit?
   b) Simple circuit design?
   c) Single affected component?
   d) Cable configuration compatible with an Expert Table (Ref. EPRI TR 1011989 – NUREG/CR-6850, Vol. 2, Tables 10-1 through 10-5)?
   e) Spurious actuation is failure mode of concern?

- If all answers (a through e) are "**Yes**," then use appropriate Look-Up Table values – Option #1
- If all answers are "**No**," then use formula method – Option #2
- If answers are a mix of "Yes" and "No," then use best engineering judgment for the specific cable/circuit being analyzed to select the appropriate option.

2. If multiple cables for equipment can result in the same failure mode, then logically combine the probability values (XOR)
   a) If the multiple cables can also fail such that power to the circuit is cut off, then only use the highest probability value determined for the cable set (Ref. FAQ 08-0047)

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS
Questions

Any Questions?

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS

Mapping HLRs & SRs for the CF technical element to NUREG/CR-6850, EPRI TR 1011989

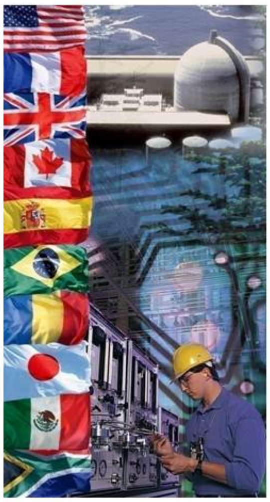
Technical Element	HLR	SR	6850/1011989 Sections that cover SR	Comments
CF	A	The Fire PRA shall determine the applicable conditional probability of the cable and circuit failure mode(s) that would cause equipment functional failure and/or undesired spurious operation based on the credited function of the equipment in the Fire PRA.		
		1	10.5.2, 10.5.3	
		2	10.5.3	
	B	The Fire PRA shall document the development of the elements above in a manner that facilitates Fire PRA applications, upgrades, and peer review.		
		1	9.5.3, 10.5.3	Also covered in "Detailed Circuit Failure Analysis" chapter

CIRCUIT FAILURE MODE LIKELIHOOD ANALYSIS

Mapping NEI 00-01, Rev. 2, Risk Significance Analysis to NUREG/CR-6850, EPRI TR 1011989

NEI 00-01, Rev. 2, Section	NEI 00-01 – Probability of Spurious Actuation	6850/1011989 Sections that cover step	Comments
5 – Risk Signifi-cance Analysis	5.2.1.2	10.5.3	NEI 00-01, Rev. 2, only recommends use of tables to determine spurious actuation probability estimates. NUREG/CR-6850, EPRI TR 1011989 also offers formula method.

4.5 Support Task B – Fire PRA Database



EPRI/NRC-RES FIRE PRA METHODOLOGY

Support Task B - Fire PRA Database

Dan Funk – Kleinsorg Group
Gabriel Taylor – U.S. NRC
Office of Nuclear Regulatory Research

Joint RES/EPRI Fire PRA Training Workshop
Bethesda, MD, July and September 2012

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

FIRE PRA DATABASE
Purpose & Scope

- Identify Required Database Functionality
- Assess Capability of Existing Systems
- Implement Structured Process to Obtain the Required Database Capability
- New Software and Data Management Tools are Finding Their Way Into the Market

Fire PRA Workshop, 2012, Bethesda, MD
Support Task B - Fire PRA Database

Slide 2

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FIRE PRA DATABASE
Introduction

- Task is Distinctly Different from Other Tasks

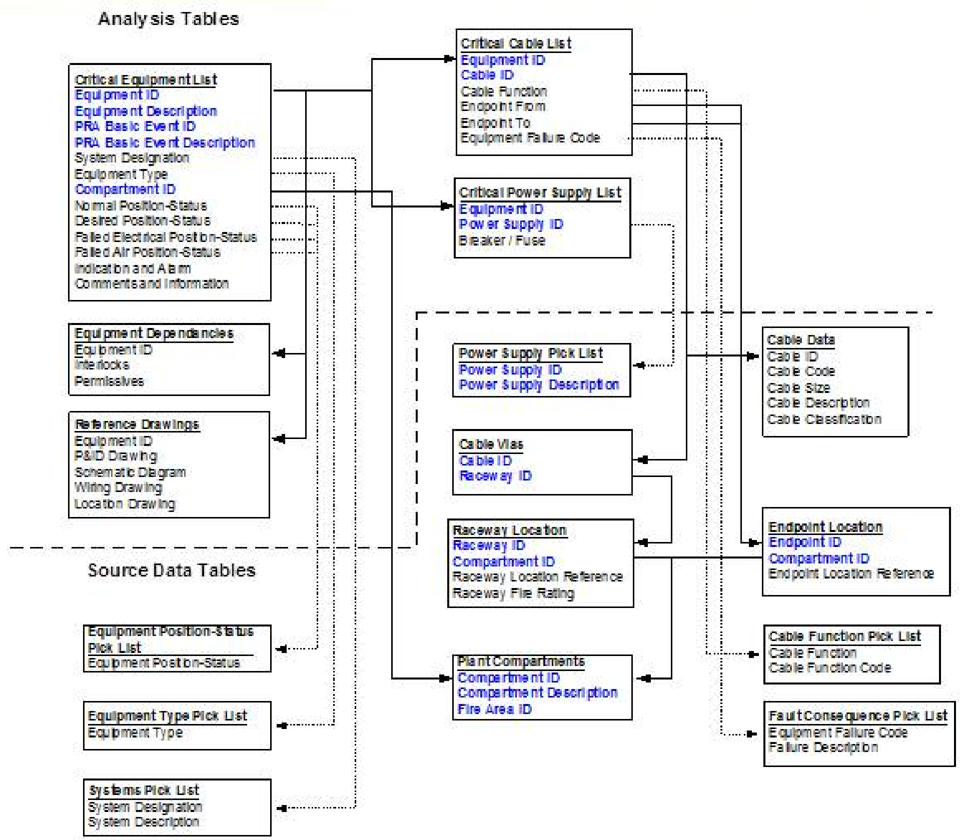
- Essential Element of PRA
  - Proposed methods require manipulation and correlation of large amounts of data
  - Must be efficient and user friendly for effective implementation
  - Manual analysis not practical

FIRE PRA DATABASE
Step 1.1 - Database Functional Criteria

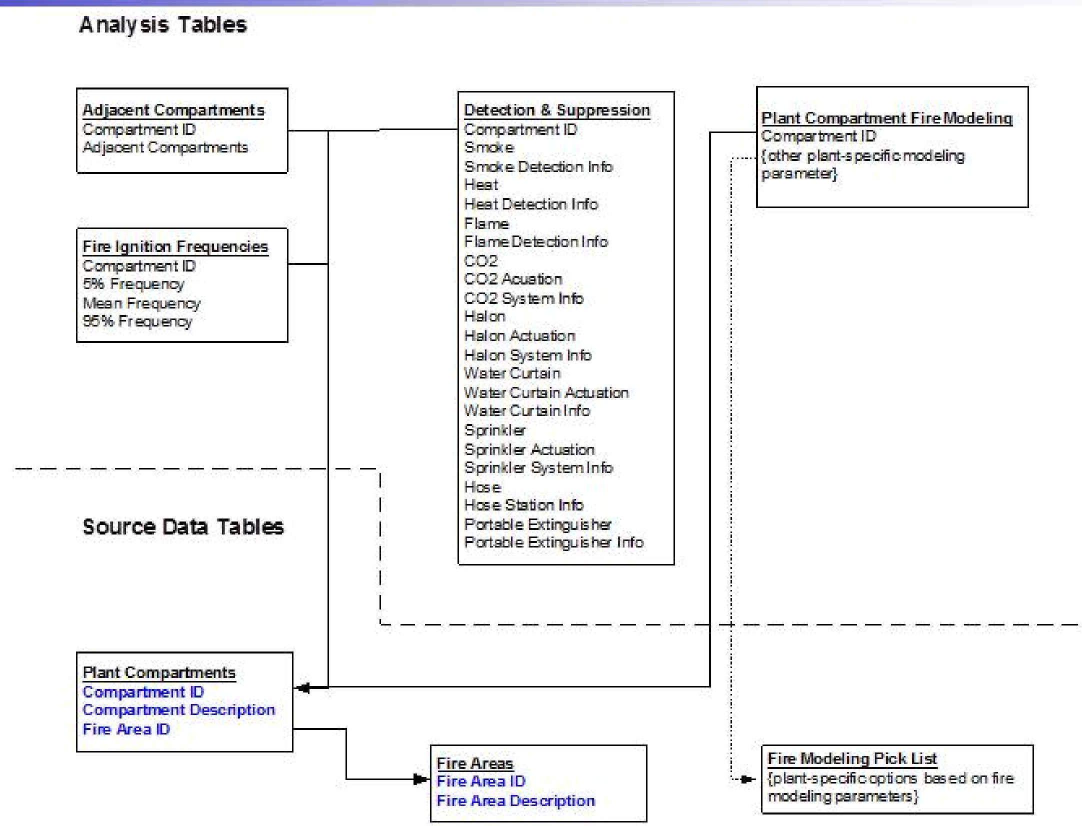
- Data Input Criteria
  - In what shape and format is existing data?
  - How and who will entered and control data?
  - Will data be shared by separate groups? If so, who can change data?

- Data Output Criteria
  - Define required output reports
  - Define sort and query options
  - Establish electronic data transfer requirements

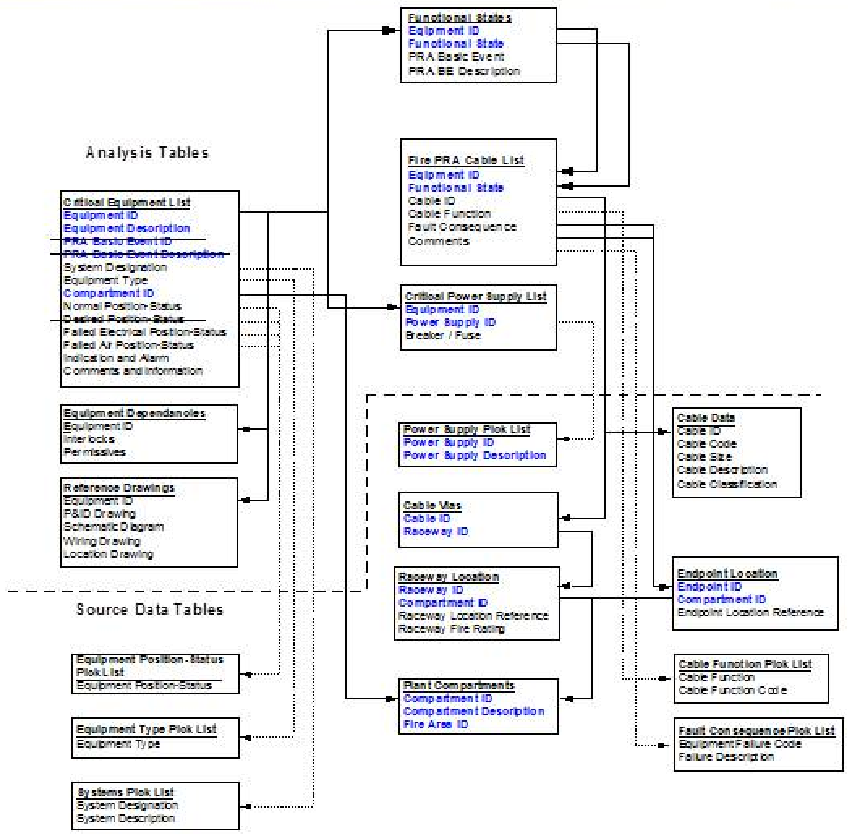
FIRE PRA DATABASE
Step 1.2 - Database Structure (Example A)



FIRE PRA DATABASE
Step 1.2 - Database Structure (Example A)



FIRE PRA DATABASE
Step 1.2 - Database Structure (Example B)



FIRE PRA DATABASE
Step 2 - Database Platform

- Decide on Platform for Database
  - Existing system
  - New stand alone system
  - Upgrade existing system
  - Combination of existing and new
- Vendors are Responding to the Call for New and Improved Software Functionality
  - Highly integrated solutions are emerging as the standard for NFPA 805 plants
  - Seamless link to Fire PRA software is just now emerging as a viable production tool

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Support Task B - Fire PRA Database

Slide 8

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FIRE PRA DATABASE
Step 3 - Database Augmentation Plan

- Augmentation Plan is Based on the Results of Step 2
- Formalize Process for Upgrades/Changes
- Determine Necessary Resources
  - This effort can innocently affect many plant organizations
  - The cost, resources, schedule, training, procedural changes and overall impact of major software changes **ALWAYS** seems to be underestimated
- Involve IS/IT Department from the Beginning

FIRE PRA DATABASE
Step 4 – Implement Database Upgrades

- Have a Clear Plan **BEFORE** Beginning any Significant Work
- Consider Long-Term Maintainability
- Plan for De-bugging and Test Runs
- Do Not Overlook Data Integrity and Configuration Control Features
- Determine All Affected Users and Involve Them Early
- The Days of "Rogue" PRA Databases are Gone!

Questions?

4.6 Fire PRA Circuit Analysis Summary

ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

Science Applications International Corporation

EPRI/NRC-RES FIRE PRA METHODOLOGY

Fire PRA Circuit Analysis Summary

Dan Funk – Kleinsorg Group
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CIRCUIT ANALYSIS SUMMARY
Topics

- Circuit Analysis “Big Picture” Road Map
- Interface with Fire PRA Group
- Circuit Analysis Strategy & Implementation
- Key Considerations & Factors
- Relationship to Appendix R & NFPA 805
- Lessons Learned

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Fire PRA Circuit Analysis Summary
Slide 2
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CIRCUIT ANALYSIS SUMMARY
Circuit Analysis Road Map

- Task 3 / 9A
  - Fire PRA Cable Selection
  - Circuit Analysis (Part A): Design Attributes
- Task 9B / 10
  - Circuit Analysis (Part B): Configuration Attributes
  - Circuit Failure Mode Likelihood Analysis
- Support Task B – Fire PRA Database

Remember – You cannot work in a vacuum! You must interface continuously with all team members!

CIRCUIT ANALYSIS SUMMARY
Interface with Fire PRA Group

- Coordination with Task 2 (Component Section) is essential – MUST understand the EXACT functionality credited for each component
- Essential that Fire PRA and NFPA-805 data be fully integrated

  Note: The subtleties of aligning Fire PRA and traditional Appendix R / NFPA-805 data is more complex than originally anticipated. This primarily shows up in Component Selection (Task 2), but has major ramifications to the circuit analysis
- Existing Appendix R Circuit Analysis is **NOT** as useful as originally envisioned

CIRCUIT ANALYSIS SUMMARY
Interface with Fire PRA Group (continued)

- Be forewarned…the PRA process is iterative and the components / function states will change (i.e., you will redo some analyses)

- Do not expect the PRA analysts to fully understand the various nuances with the circuit analysis for any given functional state – you will need to question them on inherent assumptions with the Basic Events

  Example: What automatic functions are inherently credited for a given Basic Event? Is the automatic function really required for the Fire Scenario?

CIRCUIT ANALYSIS SUMMARY
Strategy and Implementation

- Each Circuit Analysis task represents a refined level of detail (i.e., graded approach)
- Level-of-effort for the electrical work is a key driver for project scope, schedule, and resources
  - High programmatic risk if not carefully controlled
  - Analysis and routing of all cables can be a large resource sink with minimal overall benefit
  - Concerns validated by most projects
- Important to screen out obvious "Not Required" cables during the initial cable selection process (Task 9A), with refinement driven by quantitative screening (Task 9B)

CIRCUIT ANALYSIS SUMMARY
Strategy and Implementation (continued)

- Circuit Analysis (including cable tracing) can consume 40%-70% of overall budget
- Circuit Analysis scope **MUST** be a primary consideration during project planning
- Qualified and experienced circuit analysts must be integral members of the PRA team
- Evaluation, coordination, and integration with Appendix R must occur early and must be rigorous
- Long-term strategy for data configuration control – especially if sharing data with Appendix R / NFPA 805

CIRCUIT ANALYSIS SUMMARY
Key Considerations & Factors

- Circuit Analysis remains a technically and logistically challenging area
  - Practical aspects of dealing with an integrated data set
  - Practical approach for dealing with MSOs
  - Circuit Analysis is more complex and difficult than analyses performed under Appendix R
- Availability, quality, and format of cable data
- Availability of electrical engineering support
  - Circuit Analysis is a developed expertise
  - Do not expect to be a proficient analyst based on a simple introductory course

CIRCUIT ANALYSIS SUMMARY
Key Considerations & Factors (continued)

- Usability of Appendix R circuit analysis data
  - Not as useful as originally envisioned
  - Automated tools are essential
  - Functional state analysis is critical – overly conservative cable selection will not work for Fire PRA
  - Many plants are finding that circuit analysis re-baseline is necessary to support upgraded Fire PRA and NFPA-805 projects
- User-friendliness of electrical drawings

CIRCUIT ANALYSIS SUMMARY
Relationship to Appendix R & NFPA 805

- Practical aspects of dealing with an integrated data set
- Practical approach for dealing with MSOs
- Implication of these Advances: Circuit Analysis is more complex and difficult than analyses performed under Appendix R

CIRCUIT ANALYSIS SUMMARY
Lessons Learned

- Do not underestimate scope
- Ensure proper resources are committed to project
- Doable but **MUST** work smart
- Do not "broad brush" interface with Appendix R – have a detailed plan before starting
- Interface between PRA and Electrical groups is typically poor
- Develop project procedures – but don't get carried away
- Compilation and management of large volume of data
  - Automated tools imperative for efficient process
  - Long-term configuration management often overlooked until very end of the project

CIRCUIT ANALYSIS SUMMARY
Lessons Learned (continued)

- NFPA 805 projects assume too much about the ability of the Fire PRA model to answer specific Appendix R questions
- Resolution of VFDRs via the FRE process is complicated and challenging to get right…to a large degree the consistency of the circuit analysis determines how well the process goes

NRC FORM 335 (12-2010) NRCMD 3.7

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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.

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