NUREG/CP-0301
Volume 1 of 2

EPRI 3002000267

Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES)-2010

Prerequisite Basic Concepts Review for NRC-RES/EPRI Fire PRA Workshops

Volume 1
Course Prerequisites

and

Module 4: Fire Human Reliability Analysis (HRA)

Based on the Joint
NRC-RES/EPRI Training Workshops
Conducted in 2010

September 27 and October 25, 2010
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ABSTRACT

The events that necessitated the Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES) training courses are presented in this document's "Introduction and Background" section, which also provides links to previous MARIAFIRES documents based on training courses conducted in 2008 (NUREG/CP-0194) (EPRI 1020621).

This is a supplement to those documents, and provides the slides and other materials used to support the enclosed video recordings of an additional first day of training that was added to the NRC-RES/EPRI Fire PRA courses conducted in 2010. The additional training was presented simultaneously in four modules: Basic Concepts of Circuit Analysis (Section 2 and Appendix A); Basic Concepts of Fire Analysis (Section 3 and Appendix B); Basic Concepts of Fire Human Reliability Assessment (HRA, Section 4 and Appendix C); and Basics of Nuclear Power Plant Probabilistic Risk Assessment (PRA, Section 5 and Appendix D).

The extra day was added because it had been observed in previous sessions that some attendees were not familiar with certain basic concepts that the course developers had assumed they would understand. This diminished the training's value to those attendees, and also delayed the progress of the whole class, which reduced the training's value to everyone.

In future years, this supplement and its video recordings will be given to all prospective students when they register for Fire PRA Workshop training. Before the first day's instruction, they will be expected to have read the short section of this supplement corresponding to the module for which they have registered (i.e., Section 2, 3, 4, or 5), to have followed the slides in the related appendix of this supplement while watching and listening to the videos for that module, and to have responded to the one-page "self assessments" presented in this supplement after the last slide of each video for that module.

Following this process will allow for more detailed instruction on the additional day, thus increasing the training's value to everyone.

Volume 2 of MARIAFIRES-2010 also contains a new module dedicated to Fire Human Reliability Analysis (HRA). This fourth module supplements the original three modules (Module 1 Fire PRA, MARIAFIRES 2008-Volume 1, Module 2 Electrical analysis MARIAFIRES 2008-Volume 2, Module 3 Fire Analysis MARIAFIRES 2008-Volume 3).

CONTENTS

ACKNOWLEDGMENTS

The authors of this report greatly appreciate the contributions made by instructors and presenters at the 2010 NRC-RES/EPRI Fire PRA Workshop. We would also like to thank the NRC audio visual team members for their efforts in video recording the hours of workshop presentations.

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LIST OF 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
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 AND BACKGROUND

The U.S. Nuclear Regulatory Commission (NRC) approved the risk-informed and performance-based alternative regulation 10 CFR 50.48(c) in July 2004, which allows licensees the option of using fire protection requirements contained in the National Fire Protection Association (NFPA) Standard 805, “Performance Based Standard for Fire Protection for Light-Water Reactor Electric Generating Plants, 2001 Edition,” with certain exceptions. To support licensees’ use of that option, the NRC’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 of the overall analysis, as well as specific recommended practices to address each key aspect of the analysis. Participants from the U.S. nuclear power industry supported demonstration analyses and provided peer review of the program. Methodological issues raised in past fire risk analyses, including the Individual Plant Examination of External Events fire analyses, are addressed to the extent allowed by the current state-of-the-art and the overall project scope. Although the primary objective of the report is to consolidate existing state-of-the-art methods, in many areas, the newly documented methods represent a significant advance over previous methods.

NUREG/CR-6850 does not constitute regulatory requirements, and 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/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 use the method correctly and to their best advantage. Accordingly, RES and EPRI conducted a joint public workshop for about 80 attendees at the EPRI NDE Center in Charlotte, NC from 14–16 June 2005. A second workshop was held the following year, in the NRC’s Two White Flint North Auditorium in Rockville, MD from 24-26 May 2006. About 130 people attended the second workshop. Based on the positive public response to these two workshops, a more detailed training class was developed by the authors of NUREG/CR-6850. Two detailed training workshops were conducted in 2007, one from 23-27 July and another from 27-30 August, both at EPRI headquarters in Palo Alto, CA. About 100 people attended each of these workshops. In 2008, two more workshops were held from 29 September through 2 October, and again from 17-20 November, in Bethesda, MD near NRC headquarters. The two workshops attracted about 170 participants, including domestic representatives from NRC headquarters and all four regional offices, the U.S. Department of Energy, the National Aeronautics and Space Administration, EPRI, NPP licensees/utilities, Nuclear Steam Supply System vendors, consulting engineering firms, and universities. Also in attendance were international representatives from Belgium, Canada, France, Japan, South Korea, Spain, and Sweden.

The material in the 2008 workshops was video recorded by members of RES's Fire Research Branch as an alternative training method for those who were unable to physically attend the training sessions. Materials supporting those videos were published in the three volumes listed (and made available) as stated below (the videos are enclosed in the published paper copies). 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.

The following URLs link to the 2008 MARIAFIRES reports:

NUREG/CP-0194, EPRI 1020621, *Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES) -2008*, Volume 1, Overall Course and Module 1: PRA/HRA
http://adamswebsearch2.nrc.gov/IDMWS/ViewDocByAccession.asp?AccessionNumber=ML101960259

NUREG/CP-0194, EPRI 1020621, *Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES) -2008*, Volume 2, Module 2: Electrical Analysis
http://adamswebsearch2.nrc.gov/IDMWS/ViewDocByAccession.asp?AccessionNumber=ML101960151

NUREG/CP-0194, EPRI 1020621, *Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES) -2008*, Volume 3, Module 3: Fire Analysis
http://adamswebsearch2.nrc.gov/IDMWS/ViewDocByAccession.asp?AccessionNumber=ML101950499

This document supplements the above three documents. It provides the slides and other materials used to support the enclosed video recordings of the additional first day of training, which was added to the MARIAFIRES courses in 2010 (i.e., it was not part of the training provided in 2008, as documented in the above three documents). The additional training was presented simultaneously in four modules: Basic Concepts of Circuit Analysis (Section 2 and Appendix A); Basic Concepts of Fire Analysis (Section 3 and Appendix B); Basic Concepts of Fire Human Reliability Assessment (HRA) (Section 4 and Appendix C); and Basics of Nuclear Power Plant Probabilistic Risk Assessment (PRA) (Section 5 and Appendix D).

The extra day was added because it had been observed in previous sessions that some attendees were not familiar with certain basic concepts that the course developers had assumed they would understand. This diminished the training's value to those attendees, and also delayed the progress of the whole class, which reduced the training's value to everyone.

In future years, this supplement and its video recordings will be given to all prospective students when they register for Fire PRA Workshop training. Before the first day's instruction, they will be expected to have read the short section of this supplement corresponding to the module for which they have registered (i.e., Section 2, 3, 4, or 5), to have followed the slides in the related appendix of this supplement while watching and listening to the videos for that module, and to have responded to the one-page "self assessments" presented in this supplement after the last slide of each video for that module (answers to the self assessment questions for all videos and all modules are provided in the back of Appendix D, starting on page D-90).

Following this process will allow for more detailed instruction on the additional day, thus increasing the training's value to everyone.

In Sections 2, 3, 4, and 5 below, the videos' contents are described and each video's duration is given. All videos lasting longer than an hour contain a slide near their midpoint suggesting that the student pause for a break.

1.1 About this text

"Methods for Applying Risk Analysis to Fire Scenarios (MARIAFIRES) – 2010, Prerequisite Basic Concepts Review for NRC-RES/EPRI Fire PRA Workshops" is a collection of the materials that were presented at a Fire PRA course provided by EPRI and NRC/RES. The training and resulting presentation materials are described in detail and represent over 24 hours of classroom instruction. The training focuses on the Fire PRA methods documented in the joint Electric Power Research Institute (EPRI)/RES publication NUREG/CR-6850 (EPRI 1011989), along with clarifications, enhancements, and additions provided in NUREG/CR-6850 Supplement 1 (EPRI 1019259), "Fire Probabilistic Risk Assessment Methods Enhancements."

The intent of this publication is to provide to the public the training materials used during the Fire PRA training. This material is not intended to be a substitute for the direct interaction provided in the Fire PRA courses, but is meant to augment that training and serve as a reference. Enthusiastic future students can use the material to become familiar with the general principles of Fire PRA prior to attending the course. Students who have already taken the course can use the material for reference. The material consists of a series of reports that document the presentations, including some speakers' notes and text. In addition, an edited version of the video recorded training session is attached to this text. This video version is intended to be viewed while simultaneously viewing the corresponding slide presentations that were delivered during the live workshop.

In providing this material, the authors hope that those who plan to attend the course can arrive more informed, those who have already attended can have a reference for future work, and those who have been unable to attend have a means to gain a more complete understanding of the intent and goals of NUREG/CR-6850 (EPRI 1011989).

2 BASIC CONCEPTS OF CIRCUIT ANALYSIS TRAINING VIDEOS

2.1 Circuit Analysis Basics, Part 1 of 4

This video's discussions include the reasoning of adding the first day to the electrical training, what subjects will be covered within the training, and circuit design. Slide 7 (page A-8) refers to a handout provided during the class, which contains eight pages of electrical circuit drawing symbols, plus one page of standard circuit component name abbreviations and one page of standard device numbers which were used as additional slides (pages A-9 through A-18). This material is in Appendix A, Part 1 of 4, pages A-2 through A-18; the video's duration is 43 minutes long.

2.2 Circuit Analysis Basics, Part 2 of 4

This video's discussions include many types of electrical drawings and how to read them, general conventions of circuits, grounded vs. ungrounded circuits, plant electrical distribution system design, plant electrical equipment, types of cables and raceways, transformers, valve operators, switchgears and relays, circuit breakers, types of electric motors, instruments, miscellaneous equipment (e.g., batteries, control panels), and types of fire-induced cable failures (e.g., shorts to ground, hot shorts). The slides are in Appendix A, Part 2 of 4, pages A-20 through A-42; the video is 1 hour and 18 minutes long, with a suggested break near its midpoint.

Note that slide 12 (page A-25) refers to the "standard device numbers" handout, which is shown and discussed on the last slide of Part 1 of 4 (page A-18) and is not further discussed in this Part 2 of 4.

Please also note that slide 29 (page A-42) is not discussed; it is shown only as a reference to the video clip and DC test photos presented in Part 4 of 4.

2.3 Circuit Analysis Basics, Part 3 of 4

This video presents a slide (picture) show of electrical equipment. The pictures were projected onto the lecture room screen and are clearly shown on the video, and are therefore not provided in this document; thus Appendix A, Part 3 of 4, contains only that video's title slide (page A-44), along with its self assessment (page A-45). The video is 52 minutes long.

2.4 Circuit Analysis Basics, Part 4 of 4

Approximately the first 15 minutes of this video are devoted to describing (and exhibiting) various electrical cable samples. The list of cables exhibited is shown on the lecture room's screen, and is clearly legible in the video; therefore, it is not separately provided in this document. The video continues by presenting the DC electrical cable test video clip and test photos that were referenced in slide 29 at the end of Part 2 of 4 (page A-42); slide 29 is also repeated in this Part 4 of 4 (page A-47). It then moves on to a presentation of 19 circuit drawings (pages A-48 through A-66), and concludes with a thorough, knowledgeable presentation of the background, history, and development of nuclear power plant fire protection regulations, e.g., such as Appendix R, which is summarized on slide 30, page A-67 (the discussion is much more detailed than the slide). These slides and circuit drawings are provided in Appendix A, Part 4 of 4, pages A-46 through A-67; the video is 1 hour and 41 minutes long, with a suggested break near its midpoint.

3 BASIC CONCEPTS OF FIRE ANALYSIS TRAINING VIDEOS

3.1 Definitions, Part 1 of 6

September presentation (video titled, "Part 1 of 6, 9/27/2010 session")

This video presents topics including the basic nature of fires, the fire triangle (fuel, oxygen, initial ignition source), materials that burn, the combustion process, flame characteristics, fire effects, fire plume, radiative heat transfer, fire propagation, heat release rate, compartment fires, and zone of influence (ZOI).

It should be noted that the video track of this recording remains frozen during the 25:14 - 25:50 time interval (part of the discussion of slide 12, page B-7), and remains unsynchronized with the audio track thereafter (i.e., during the discussion of slides 13-20, pages B-8 through B-11). However, the audio track is uninterrupted, and remains properly coordinated with the video track's indications of the slides being shown. Thus, except for possibly creating a visual distraction (which can be avoided by simply not watching the presenter), these flaws should not diminish the usefulness of the information presented.

Because of this problem, the October presentation would have been used herein instead of the September presentation. However, the October recording was incomplete; the presentation of slides 1-15 was missing, so the September presentation was the only complete video available. The slides used in this video are provided in Appendix B, "Definitions, Part 1 of 6, 9/27/2010 session," pages B-2 through B-11; the video is 36 minutes long.

October presentation (video titled, "Part 1 of 6, last 5 slides only (16-20)")

In this video, an alternate approach is used in the discussion of slides 16-20, which covers such topics as heat release rate, compartment fires, and ZOI. The slides used in this video are provided in Appendix B, "Definitions, Part 1 of 6, last 5 slides only (16-20)," pages B-13 through B-15; the video is 13 minutes long.

3.2 Fires in the Open and Fully Ventilated Fires, Part 2 of 6

This video discusses various aspects of fires that are **<u>not</u>** limited by their air supply, including heat release rate, laminar and turbulent flames, ignition of gases, ignition of liquids, ignition of solids, flame spread rates, and fire plume temperature. The slides used in this video are provided in Appendix B, "Fires in the Open and Fully Ventilated Fires, Part 2 of 6," pages B-17 through B-26; the video is 1 hour and 8 minutes long, with a suggested break near its midpoint.

3.3 Compartment Fires, Part 3 of 6

This video discusses various aspects of fires that **<u>are</u>** limited by their air supply (e.g., in compartments of nuclear power plants), such as the build-up of a hot gas/smoke layer above the fire in the upper parts of the compartment. The slides used in this video are provided in Appendix B, "Compartment Fires, Part 3 of 6," pages B-28 through B-35; the video is 45 minutes long. Note that Slide 14, page B-34, was not discussed.

3.4 Detection and Suppression, Part 4 of 6

This video discusses the typical detection and suppression features of nuclear power plants credited in Fire PRAs. Fire detection systems include prompt, smoke, heat, incipient, and delayed types. Fire suppression methods include prompt, automatic, dry-pipe/pre-action, deluge, CO2, Halon, fire brigade, and passive (e.g., fire barriers). The slides used in this video are provided in Appendix B, “Detection and Suppression, Part 4 of 6,” pages B-37 through B-45; the video is 1 hour long.

3.5 Analysis Tools, Part 5 of 6

This video’s discussions include fire modeling in a Fire PRA, how fire develops in a scenario, what damage is generated, when damage is generated, the timing of detection and suppression, the different types of fire models (hand calculations, zone models, field models, and special models), which model to choose, and verification and validation of fire models.

During the discussion of slide 8, page B-50, reference is made to the fire models presented as spreadsheets in NUREG-1805, which are available at:

http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1805/

After the discussion of the zone model MAGIC on slide 10, page B-51, another zone model (CFAST) is discussed at some length; there were no slides or handouts regarding CFAST, and although it is stated that there is a website from which it can be downloaded and used, the details were not made clear.

The slides used in this video are provided in Appendix B, “Analysis Tools, Part 5 of 6,” pages B-47 through B-55; the video is 1 hour and 16 minutes long, with a suggested break near its midpoint.

3.6 Fire Scenarios, Part 6 of 6

This video’s discussions include the set of elements representing a fire scenario, which are ignition source, intervening combustibles, targets, fire protection features, the compartment in which it occurs, and a timeline. It also describes screening and detailed analyses of a fire scenario, and explains the factors involved in scenario quantification. The slides used in this video are provided in Appendix B, “Fire Scenarios, Part 6 of 6,” pages B-57 through B-63; the video is 46 minutes long.

4 BASIC CONCEPTS OF FIRE HUMAN RELIABILITY ASSESSMENT (HRA) TRAINING VIDEOS

4.1 Principles of HRA Part 1 of 5

This section introduces the Principles of Human Reliability Analysis (HRA) module, along with discussions on the purpose and objectives of this introductory course. This section covers the definition of HRA and how HRA fits into Probabilistic Risk Assessment (PRA), including what HRA does with event tree and fault tree information. The slides corresponding to this material are located in Appendix C, pages C-2 through C-17; the video is 37 minutes long.

4.2 Principles of HRA Part 2 of 5

This section includes a discussion of what an HRA models, as well as a discussion of the ASME/ANS standard requirements for HRA. The categories of human failure events (HFEs) are identified, and other classifications of HFEs (errors of commission and errors of omission) are discussed. The slides covered are located in Appendix C, pages C-19 through C-33; the video is 52 minutes long.

4.3 Principles of HRA Part 3 of 5

This section discusses the guidance for and the keys to performing HRA and the keys to performing HRA. It covers guidance associated with HRA processes, other HRA tools or approaches, and HRA quantification methods. The keys to performing HRA are also discussed in this section. The slides covered are located in Appendix C, pages C-35 through C-51; the video is 1 hour and 14 minutes long, with a suggested break near its midpoint.

4.4 Principles of HRA Part 4 of 5

This section discusses how one can understand human error. The assertions that human error is neither random nor typically the underlying cause of a mishap are explored, as well as the assertion that human error can be predicted. The slides are located in Appendix C, pages C-53 through C-63; the video is 45 minutes long, including the part discussed below.

The last third of this video discusses a significant event detailed in a handout provided by the speaker. The essential points of the discussion are readily understandable from the video without referencing the handout, which is not provided in this document. However, full details of the event (including the fact that it occurred on June 9, 1985, at Davis Besse) are readily available online, as follows:

Working from a paper copy of this document:
www.nrc.gov; NRC LIBRARY; Document Collections; NUREG-Series Publications; Publications Prepared by NRC Staff NUREG-(nnnn); Scroll down to NUREG-1624; Appendices A through G; Appendix A, pgs. A.6-1 through A.6-5.

Working from an electronic file of this document, one can go to the last step of the above using the following URL:
http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1624/r1/sr1624r1-appa-appg.pdf

4.5 Principles of HRA Part 5 of 5

This section covers the important features of existing HRA methods, including: the Technique for Human Error Rate Prediction (THERP); the Accident Sequence Evaluation Program (ASEP); Cause-Based Decision Tree (CBDT) Method; the Human Cognitive Reliability (HCR)/Operator Reliability Experiments (ORE) Method; the Standardized Plant Analysis Risk HRA (SPAR-H) Method; and A Technique for Human Event Analysis (ATHEANA). The slides are located in Appendix C, pages C-65 through C-74; the video is 1 hour and 5 minutes long, with a suggested break near its midpoint.

5 BASICS OF NUCLEAR POWER PLANT PROBABILISTIC RISK ASSESSMENT (PRA) TRAINING VIDEOS

This video is divided into four parts. However, all of the supporting slides are presented in one continuously numbered set in Appendix D, “Materials Supporting Basics of Nuclear Power Plant Probabilistic Risk Assessment (PRA) Videos” (pages D-2 through D-88).

5.1 Basics of Nuclear Power Plant PRA Part 1 of 4

This section introduces the Basics of Nuclear Power Plant PRA module with an overview, objectives, and outline. Topics covered in this section include an introduction to the concept of “risk,” an overview of the PRA process, and a discussion of the strengths and limitations of PRA. The first of the principal steps in PRA, Initiating Event Analysis, is also covered in this section. The slides corresponding to this material are located in Appendix D, pages D-2 through D-14; the video is 1 hour and 12 minutes long, with a suggested break near its midpoint.

5.2 Basics of Nuclear Power Plant PRA (Accident Sequence Analysis) Part 2 of 4

This section covers the Accident Sequence Analysis step of the PRA. It contains a discussion on event tree model development, including the purpose of event tree analysis, the currently accepted techniques and notation for event tree construction, and the ways in which event tree logic is used to quantify PRAs. The slides corresponding to this material are located in Appendix D, pages D-16 through D-28; the video is 1 hour and 53 minutes long, with a suggested break near its midpoint.

5.3 Basics of Nuclear Power Plant PRA (Systems Analysis) Part 3 of 4

This section covers the Systems Analysis step of the PRA. It contains a discussion of fault tree model development, including an introduction to fault tree analysis terminology, Boolean algebra, and the purposes and methods of fault tree analysis. The slides corresponding to this material are located in Appendix D, pages D-30 through D-44; the video is 1 hour and 57 minutes long, including the following additional sub-part, with a suggested break near its midpoint.

The additional sub-part, “Human Reliability Analysis,” discusses HRA, including the purpose and objectives of HRA, modeling human actions, categories of human failure events in PRA, and certain HRA methods. The discussions in this sub-part are at a higher level, compared to the discussions provided in the separate HRA section (i.e., Section 4 of this document and its corresponding slides in Appendix C). The slides corresponding to this sub-part of “Part 3 of 4” are located in Appendix D, pages D-45 through D-58. Note that slides 102 (EPRI’s Cause-Based Decision Tree Method, page D-56) and 104 (the NRC’s ATHEANA HRA Method, page D-57) are not discussed in the video.

5.4 Basics of Nuclear Power Plant PRA (Data Analysis) Part 4 of 4

This section covers the Data Analysis and Accident Sequence Quantification steps of the PRA; it also includes a sub-part on the Level 2/Large Early Release Frequency (LERF) Analysis. The Data Analysis section is intended to help students understand the parameters typically modeled in PRA and how each parameter is quantified. This includes a discussion on how to quantify the initiating event frequencies and component failure rates that are needed to feed into the system fault trees and sometimes the event trees. The Accident Sequence Quantification and importance analysis section introduces the concept of plant damage states. The LERF section provides a brief introduction to accident progression analysis. The slides corresponding to this material are located in Appendix D, pages D-60 through D-88; the video is 1 hour and 41 minutes long, with a suggested break near its midpoint.

In the discussion of slides 115 and 116 (page D-65), it is suggested that NUREG/CR-6823, "Handbook of Parameter Estimation for Probabilistic Risk Assessment," is a good source of data for use in PRAs. That document is publically available at:
http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6823/

APPENDIX A: MATERIALS SUPPORTING BASIC CONCEPTS OF CIRCUIT ANALYSIS VIDEOS

EPRI/NRC-RES FIRE PRA METHODOLOGY

Circuit Analysis Basics

Part 1 of 4

D. Funk - Edan Engineering Corp.
F. Wyant - Sandia National Laboratories

Joint RES/EPRI Fire PRA Workshop
September and October 2010
Washington, DC

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

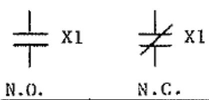
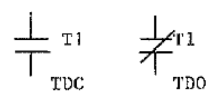
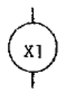
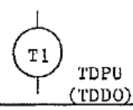
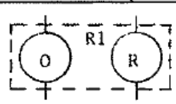
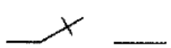
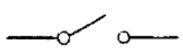
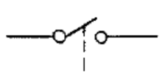
Symbol Library

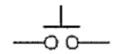
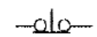
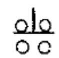
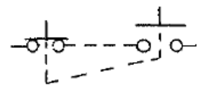
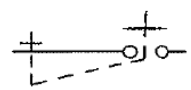
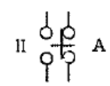
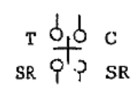
Handout

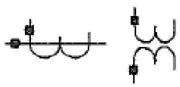
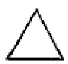
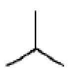
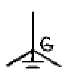
TYPICAL ELECTRICAL DRAWING SYMBOLS AND CONVENTIONS

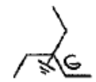
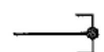
ELECTRICAL SYMBOLS

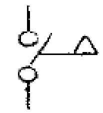
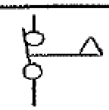
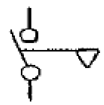
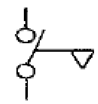
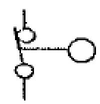
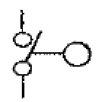
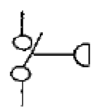
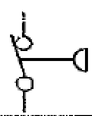
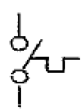
CONTACTS, SWITCHES, CONTACTORS AND RELAYS

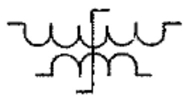
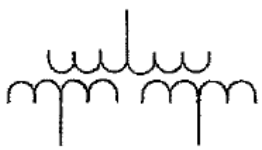
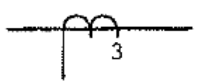
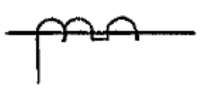
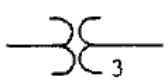
SYMBOL	DESCRIPTION
 X1 N.O. X1 N.C.	Relay contact - Shown with relay in de-energized or in reset position. (Show relay coil designation near contact.)
 T1 TDC T1 TDO	Timing Relay Contact - TDC indicates contact closes at end of timing period. TDO contact opens at end of timing period.
 X1	Coil - Relay, contactors, circuit breaker, solenoid etc. (Show device designation, X1)
 T1 TDPU (TDDO)	Coil - Timing Relay - TDPU indicates timing period starts when coil is energized. TDDO indicates timing period starts when coil is de-energized.
 O R1 R	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.

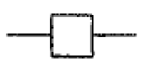
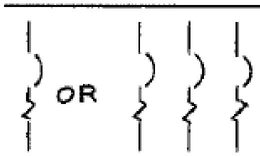
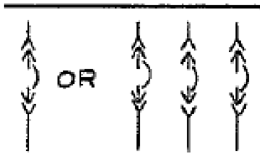
	Pushbutton - Momentary or spring return. Single Circuit (make)
	Pushbutton - Momentary or spring return. Single Circuit (break)
	Pushbutton - Momentary or spring return. Two Circuit
	Pushbutton - Maintained, two circuit
	Pushbutton - Maintained, single circuit
 H A	Selector Switch - Two position, maintained (designate position shown; i.e. A=Auto; H=Hand)
 T C SR SR	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

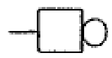
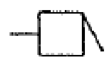
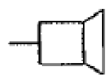
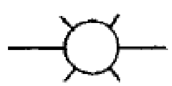
	3-phase, 3 wire zigzag, grounded neutral
	Connection to earth ground (may be plant grounding system)
	Connection to chassis or frame
	Terminal - may be added to any of the following symbols at connection points.
	Short circuit (not a fault)
	Terminal - Designates termination point of field run cables 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.
	2 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) 2

& ALARMS

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

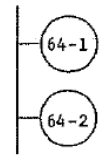
Use the following to specify color:

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

RELAYS

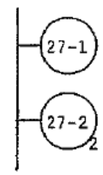
The following methods are used on drawings to identify relays:

1)



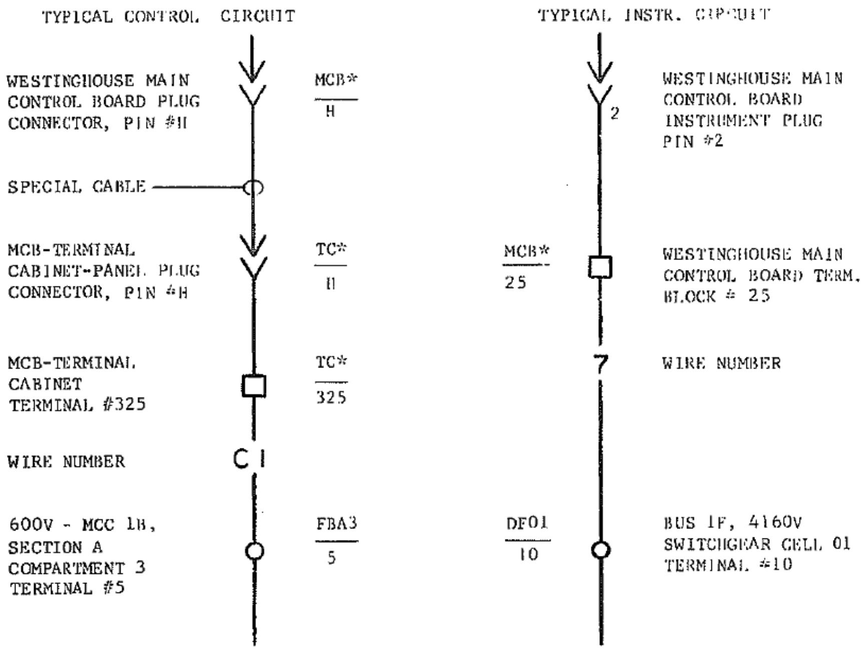
Two (2) 64 devices 64-1 and 64-2 in same cell.

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.

DIAGRAM CONNECTIONS



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

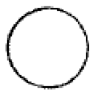
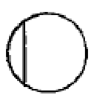
WIRE NUMBERING

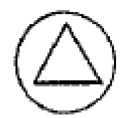
WIRE NUMBERING SYSTEM

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

Wire Number	Purpose	Wire Number	Purpose
1	A - Phase Power	4	A - Phase Potential
2	B - Phase Power		(See Notes 3 & 5)
3	C - Phase Power	5	A - Phase Current
(Note 1)	Annunciator		(See Notes 3 & 5)
N	D. C. Negative (See Note 2)	6	B - Phase Potential
P	D. C. Positive (See Note 2)		(See Notes 3 & 5)
U	115 volt A. C.-Ground Return (see Note 2)	7	B Phase Current
X	115 volt A. C. (See Note 2)		(see Notes 3 & 5)
C	Closing (See Note 2)	8	C - Phase Potential
T	Tripping (See Note. 2).		(See Notes 3 & 5)
O	Opening, MOV Only (See Note 2) 8	9	C - Phase Current
F	Instrumentation (e.g. indicator, recorder, etc; See Note 2)		(See Notes 3 & 5)
H	Computer (See Note 2)		
M	General Control (Neither tripping nor closing; See Note 2)	0	Potential (or Current) Neutral (See Notes 4 & 5)
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)		

8

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

	3-phase wye, grounded
	3-phase delta

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

ANSI/IEEE Standard Device Numbers

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

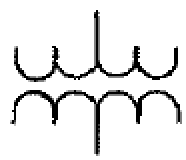
B – Bus
F – Field
G – Ground or generator
N – Neutral
T – Transformer

Self- Assessment

Circuit Analysis Basics

1. **How do you determine if a circuit is grounded?**

2. **Identify this symbol?**



a) *Relay* **b)** *Transformer* **c)** *Switch* **d)** *Generator*

3. **ANSI/IEEE Standard Device Numbers are used**
   - **a)** to standardize device components used in the design of electrical power systems.
   - **b)** to identify the functions of devices shown on a schematic diagram.
   - **c)** to denote what features a protective device supports.
   - **d)** all of the above

EPRI/NRC-RES FIRE PRA METHODOLOGY

Circuit Analysis Basics

Part 2 of 4

D. Funk - Edan Engineering Corp.
F. Wyant - Sandia National Laboratories

Joint RES/EPRI Fire PRA Workshop
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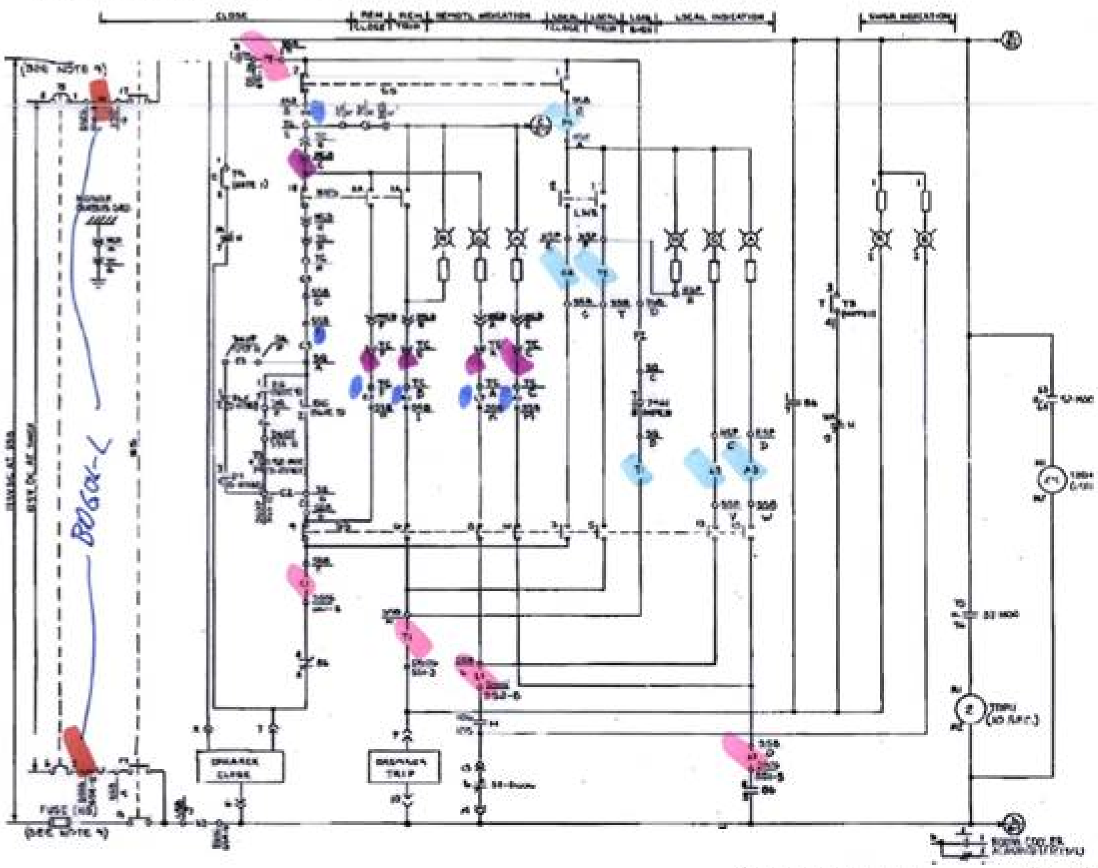
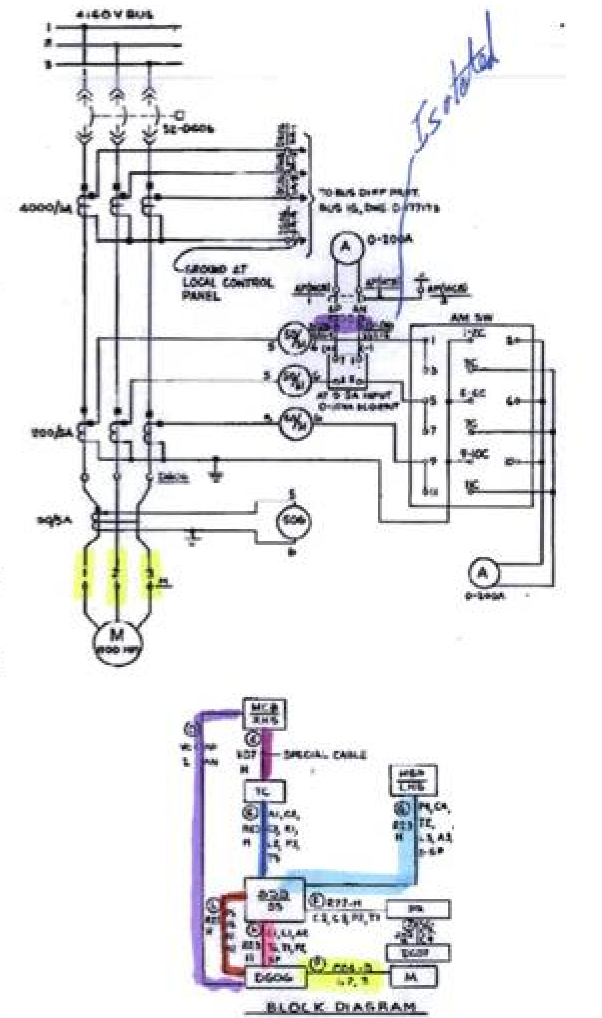
CIRCUIT ANALYSIS BASICS
Types of Drawings and How to Read Them

- 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?

CIRCUIT ANALYSIS BASICS
ANSI/IEEE Standard Device Numbers

Refer to

Standard Device Number

Handout

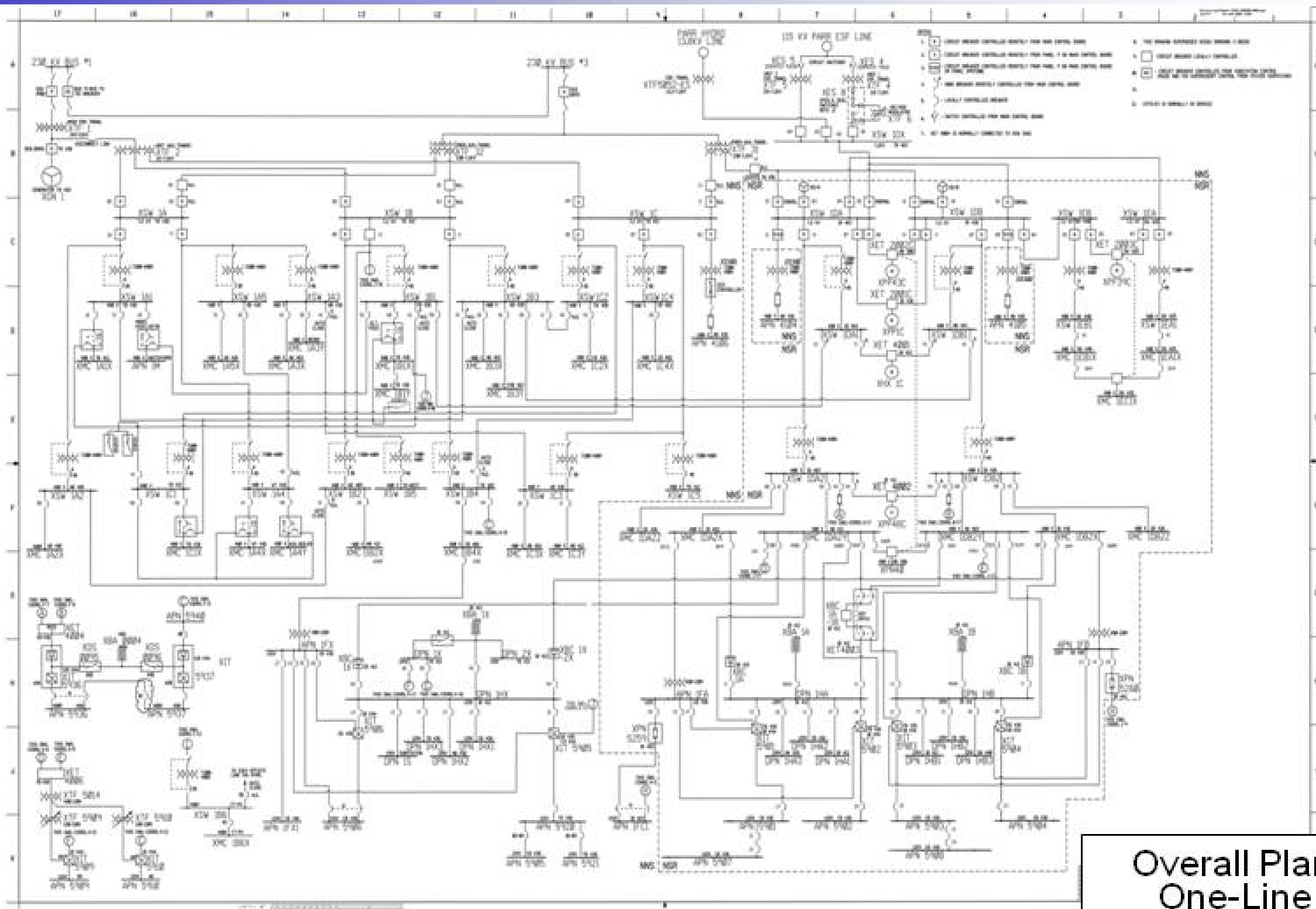
CIRCUIT ANALYSIS BASICS
Plant Electrical Distribution System Design

- 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…



Overall Plant One-Line

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

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

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

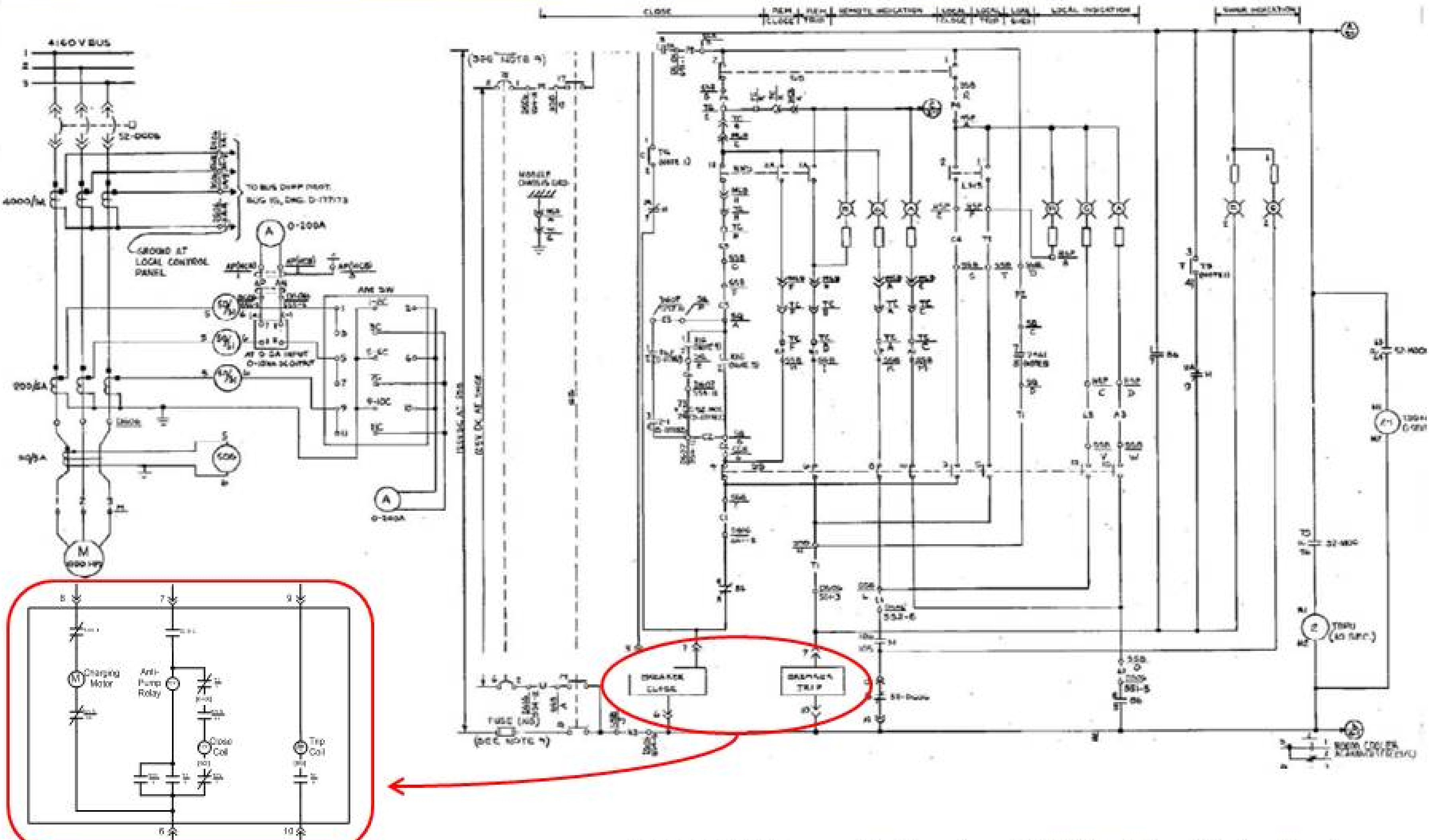
CIRCUIT ANALYSIS BASICS
Switchgear & Relays

- 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



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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

- 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]

Self- Assessment

Circuit Analysis Basics

1. **Draw the symbols used to indicate polarity in a dc circuit with a brief description?**

2. **Circuit grounding is useful to establish a common voltage potential.**
   a) *False*
   b) *True*

3. **Define the following:**

   a) *AOV -*

   b) *MOV -*

   c) *SOV -*

EPRI/NRC-RES FIRE PRA METHODOLOGY

Circuit Analysis Basics

Part 3 of 4

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Note that only this video's title screen and self assessment page are provided here, because no slildes were used during its presentation

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Self- Assessment

Circuit Analysis Basics

Best answered by listening to Electrical Videos Part 3 of 4

1. **What is a MCC?**
   - ***a)*** *Major Current Circuit*
   - ***b)*** *Motor Control Circuit*
   - ***c)*** *Major Control Center*
   - ***d)*** *Motor Control Center*

2. **Fill in the missing information, according to the speaker in the video**:

As related to power plants and motor control centers (MCCs) for analysis purposes the main items addressed are ___________________.

EPRI/NRC-RES FIRE PRA METHODOLOGY

Circuit Analysis Basics

Part 4 of 4

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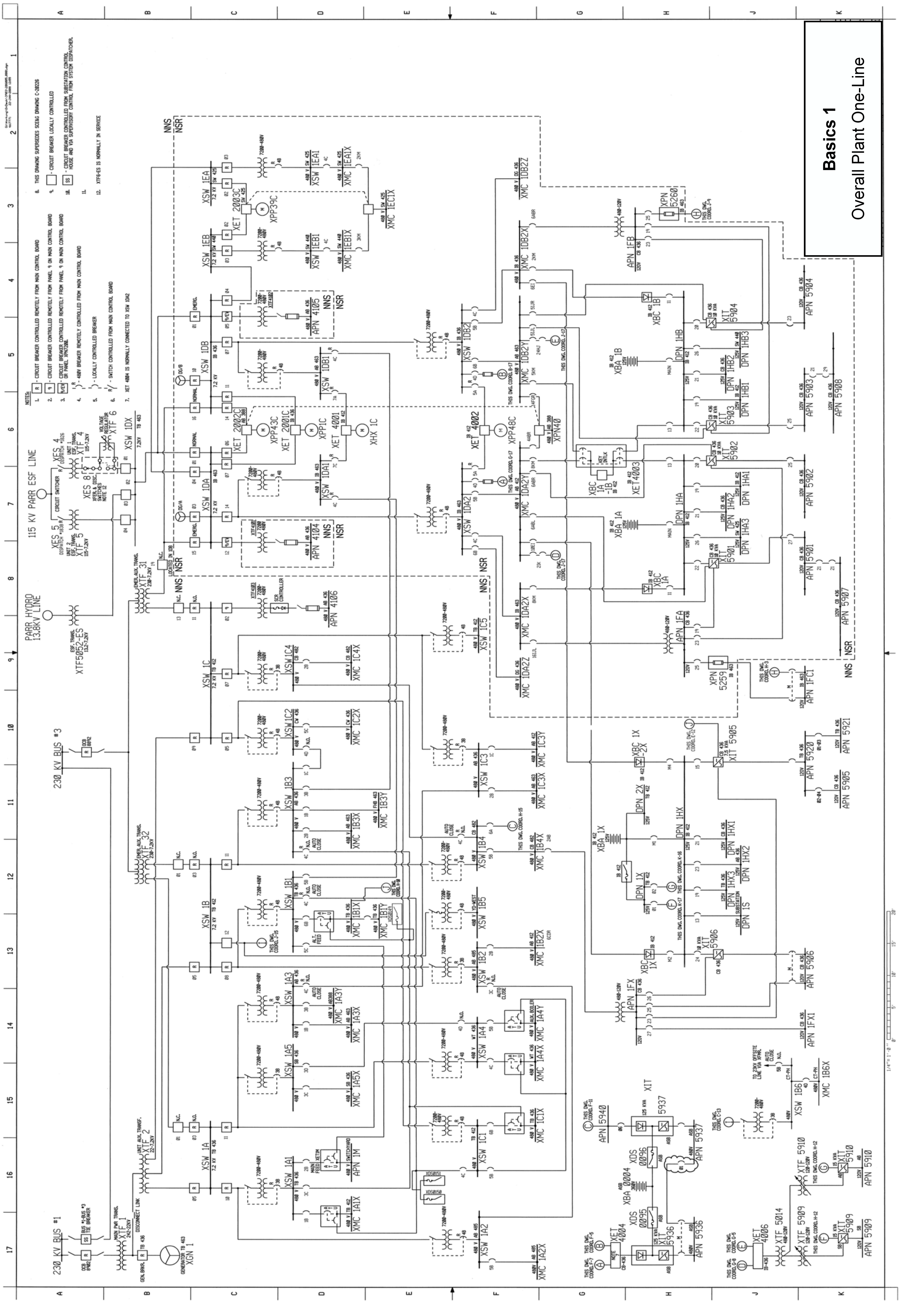
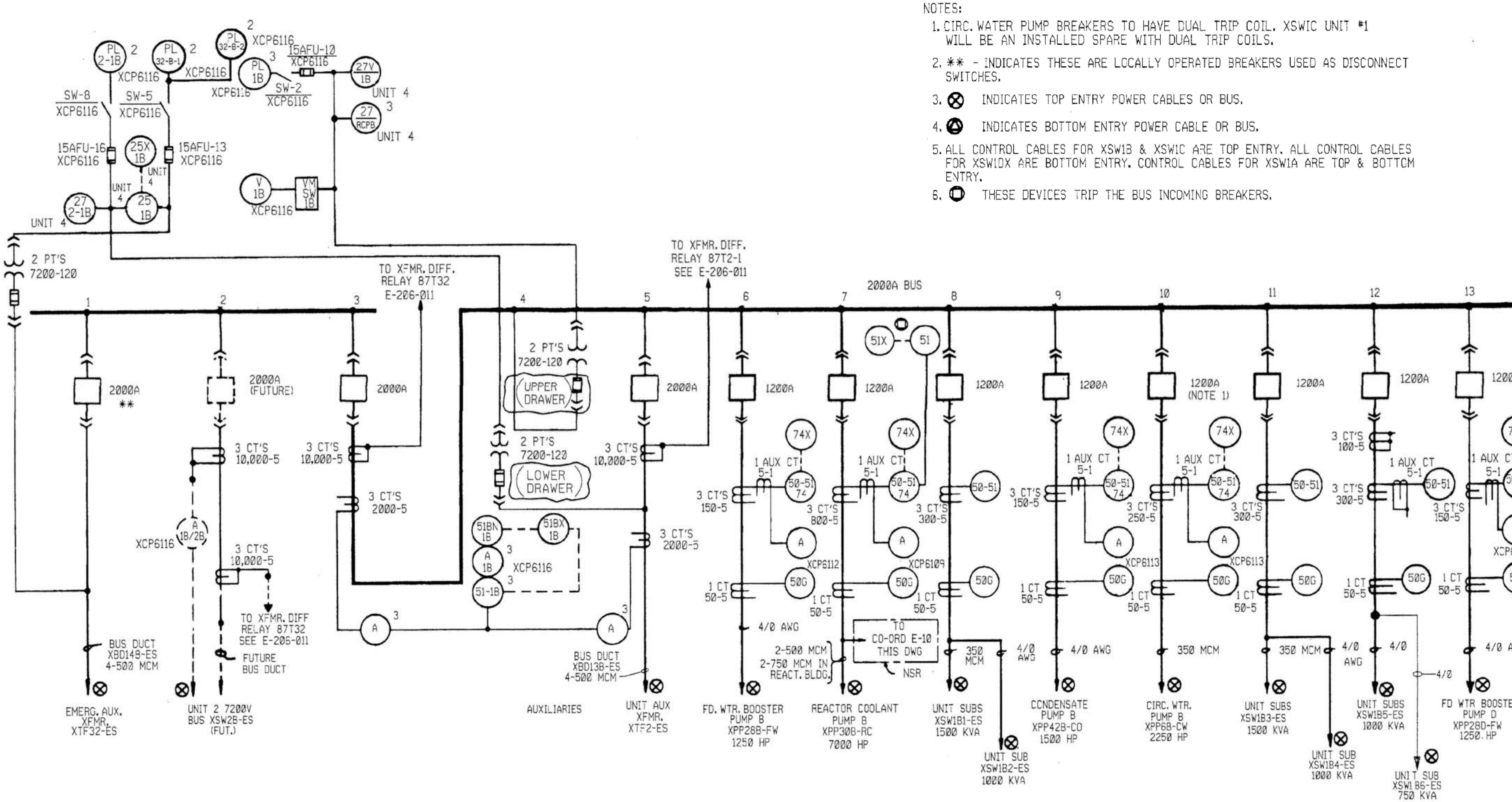
CIRCUIT ANALYSIS BASICS
Fire-Induced Cable Failures, cont…

- [Video clip & some photos from DC Tests]


Basics 1
Overall Plant One-Line

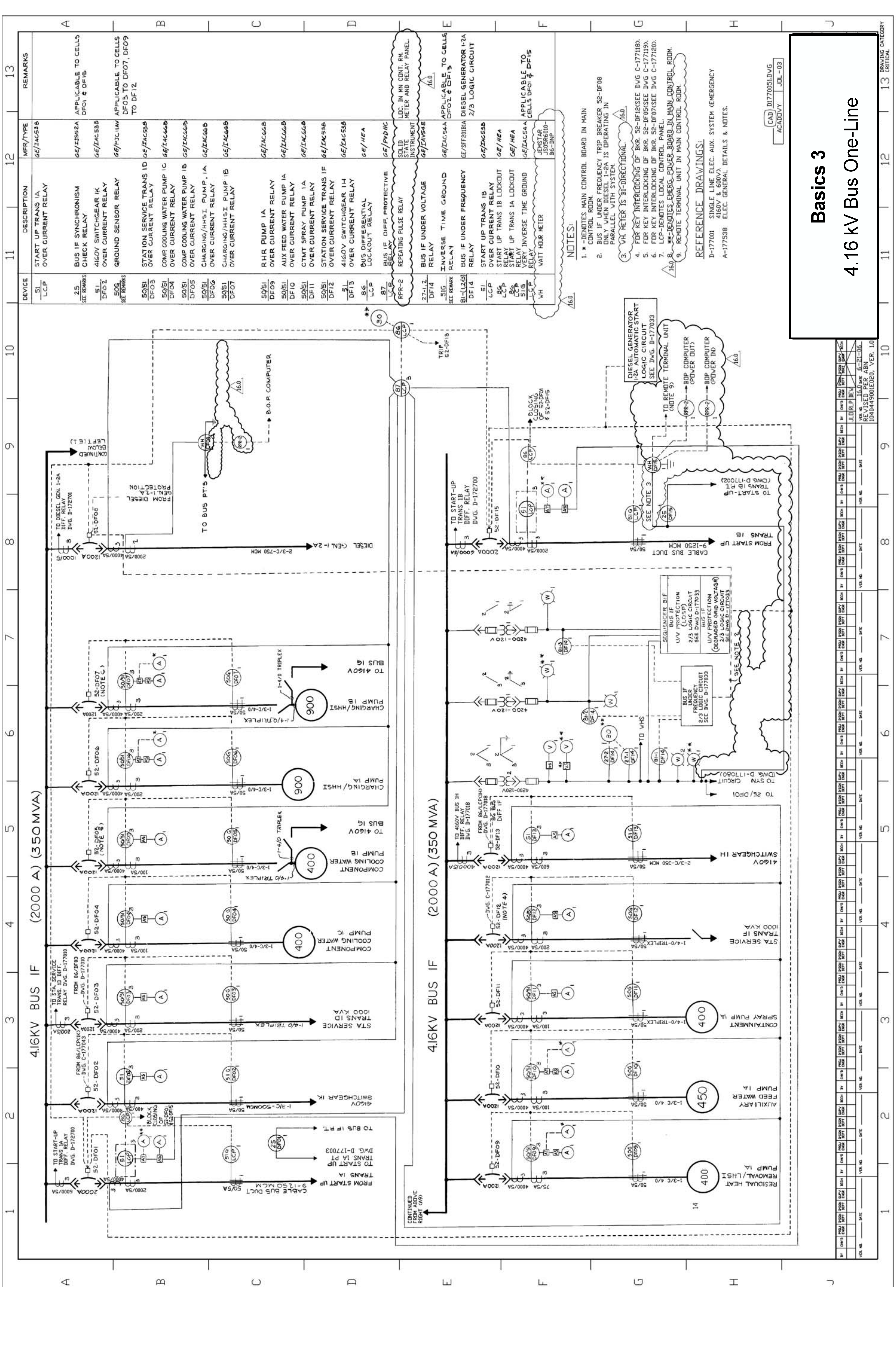
NOTES:
1. CIRC. WATER PUMP BREAKERS TO HAVE DUAL TRIP COIL. XSWIC UNIT #1 WILL BE AN INSTALLED SPARE WITH DUAL TRIP COILS.
2. ** - INDICATES THESE ARE LOCALLY OPERATED BREAKERS USED AS DISCONNECT SWITCHES.
3. ⊗ INDICATES TOP ENTRY POWER CABLES OR BUS.
4. INDICATES BOTTOM ENTRY POWER CABLE OR BUS.
5. ALL CONTROL CABLES FOR XSW1B & XSWIC ARE TOP ENTRY. ALL CONTROL CABLES FOR XSWIDX ARE BOTTOM ENTRY. CONTROL CABLES FOR XSW1A ARE TOP & BOTTCM ENTRY.
6. THESE DEVICES TRIP THE BUS INCOMING BREAKERS.

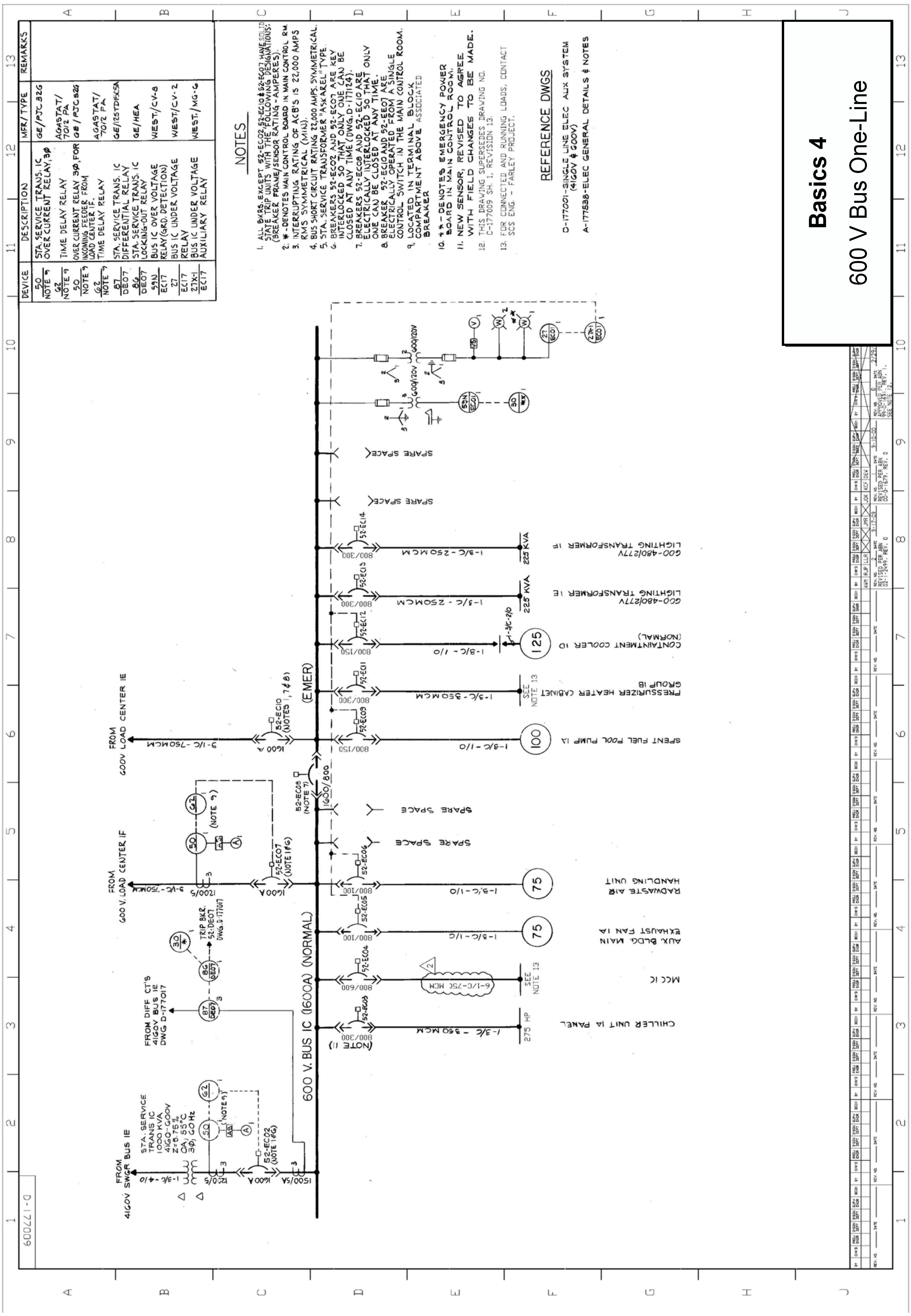


7.2 KV SWGR. BUS 1B XSW1B-ES

Basics 2

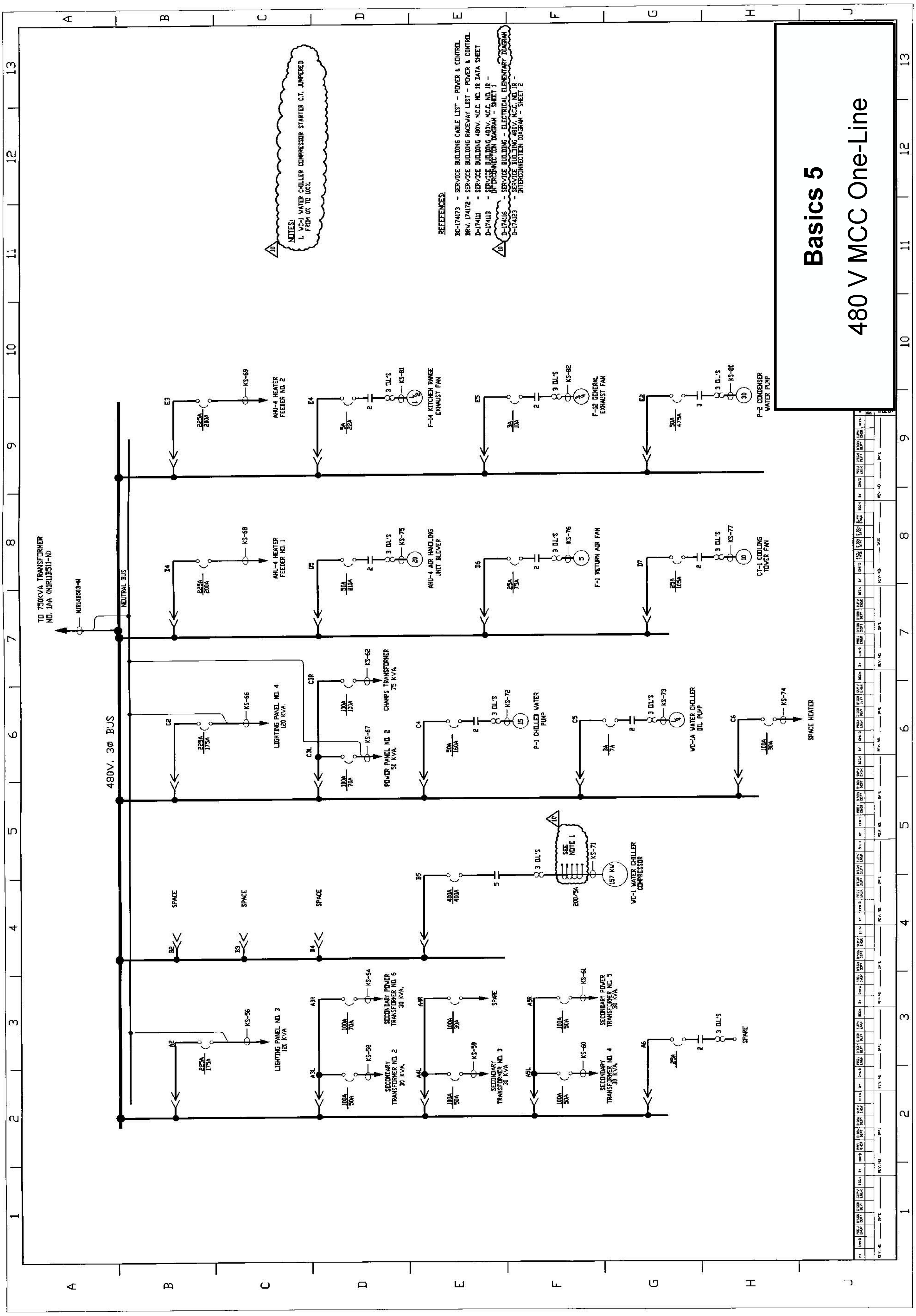
7.2 kV Bus One-Line


Basics 3
4.16 kV Bus One-Line
4.16KV BUS IF (2000 A) (350 MVA)
4.16KV BUS IF (2000 A) (350 MVA)
DEVICE
DESCRIPTION
MFR/TYPE
REMARKS
NOTES:
REFERENCE DRAWINGS:
D-177001 SINGLE LINE ELEC. AUX. SYSTEM (EMERGENCY 4160V & 600V).
A-177538 ELEC. GENERAL DETAILS & NOTES.
DRAWING CATEGORY CRITICAL

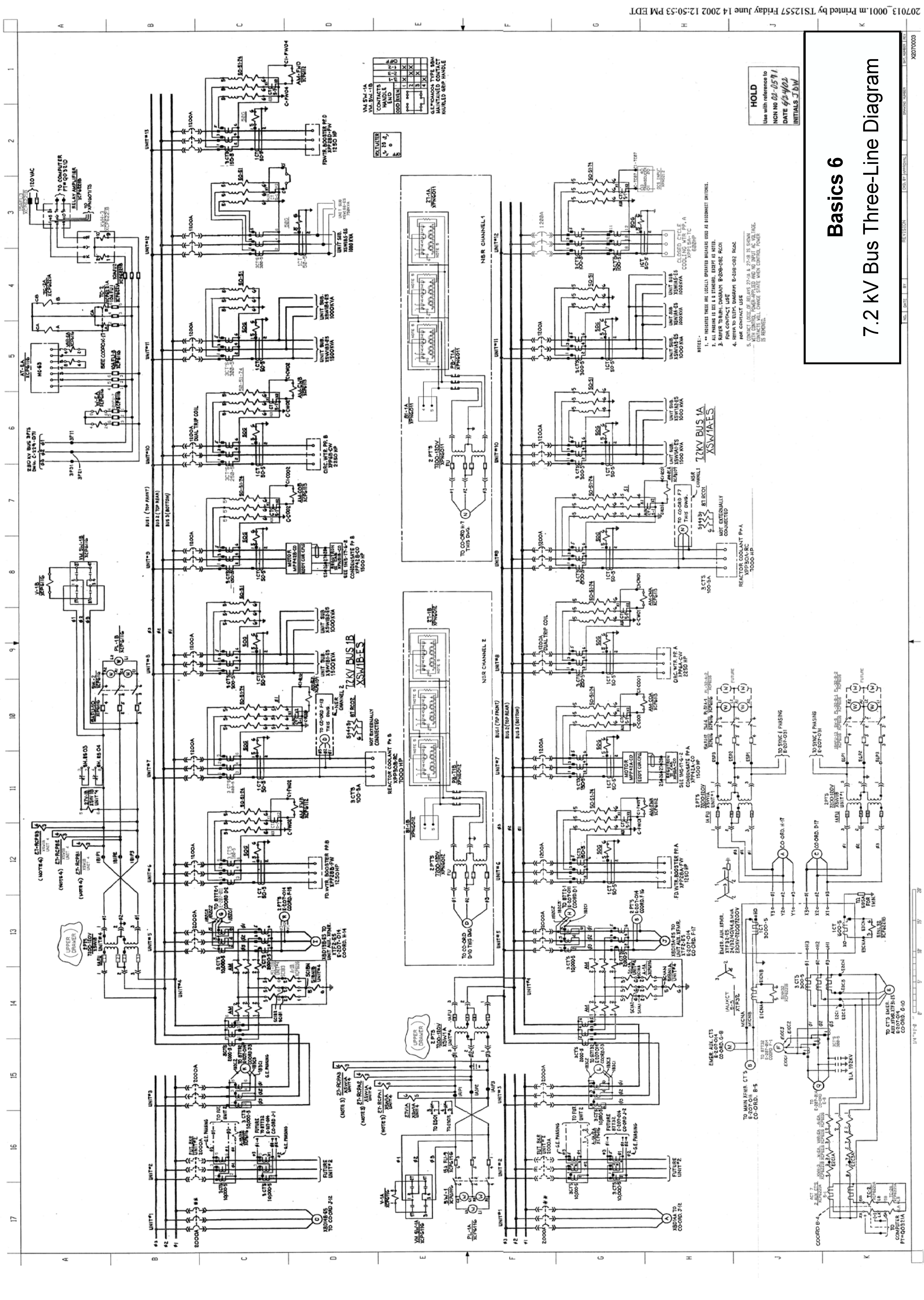


Basics 4

600 V Bus One-Line

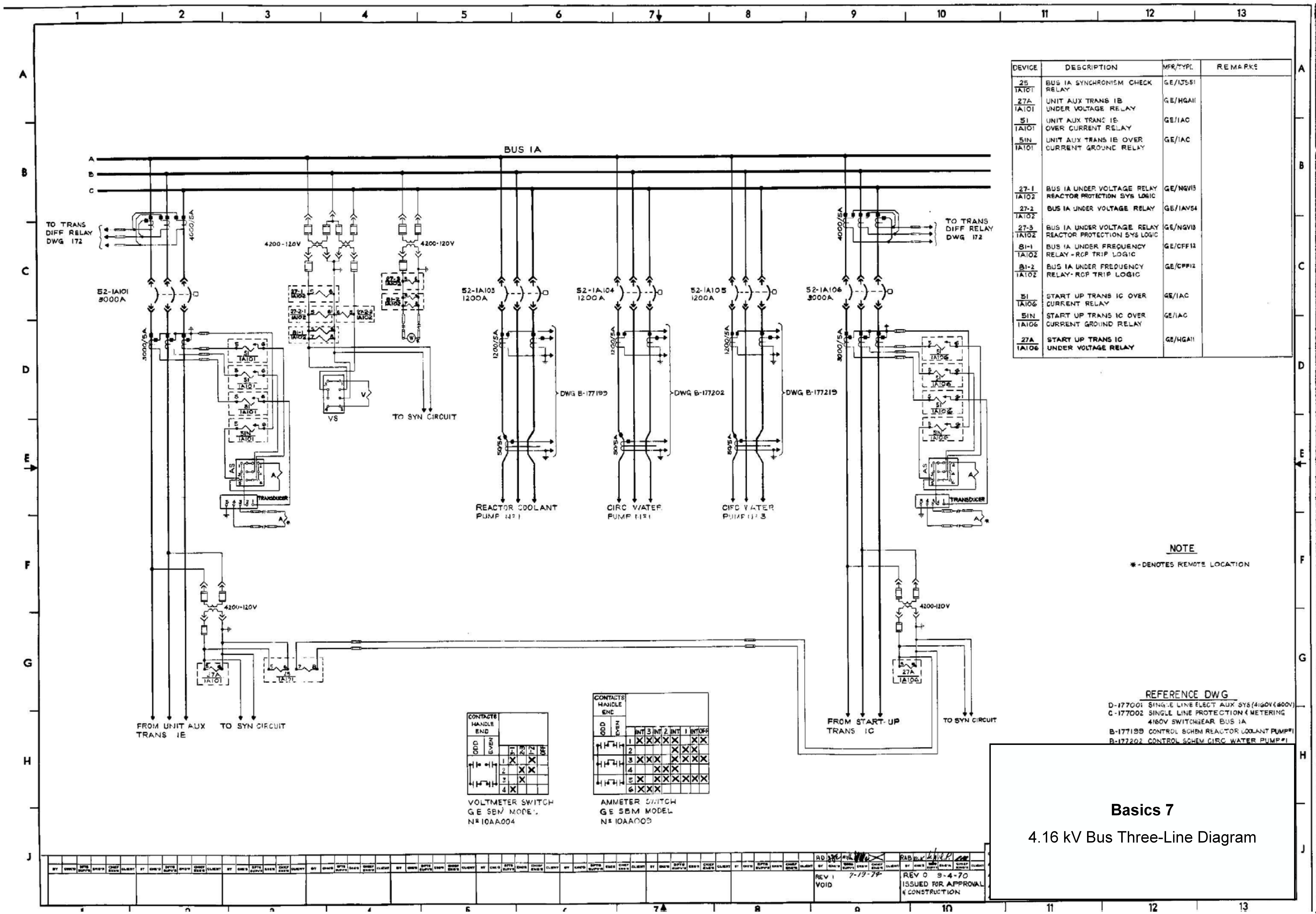


Basics 5
480 V MCC One-Line
480V. 3Ø BUS
NEUTRAL BUS
TO 750KVA TRANSFORMER NO. 1AA
NOTES:
1. WC-1 WATER CHILLER COMPRESSOR STARTER C.T. JUMPERED FROM 0% TO 100%
REFERENCES:
LIGHTING PANEL NO. 3 120 KVA
LIGHTING PANEL NO. 4 120 KVA
POWER PANEL NO. 2 50 KVA
CHAMPS TRANSFORMER 75 KVA
P-1 CHILLED WATER PUMP
WC-1A WATER CHILLER OIL PUMP
SPACE HEATER
WC-1 WATER CHILLER COMPRESSOR
AHU-4 HEATER FEEDER NO. 1
AHU-4 HEATER FEEDER NO. 2
AHU-4 AIR HANDLING UNIT BLOWER
F-1 RETURN AIR FAN
CT-1 COOLING TOWER FAN
F-14 KITCHEN RANGE EXHAUST FAN
F-12 GENERAL EXHAUST FAN
P-2 CONDENSER WATER PUMP
SPACE
SPARE



Basics 6

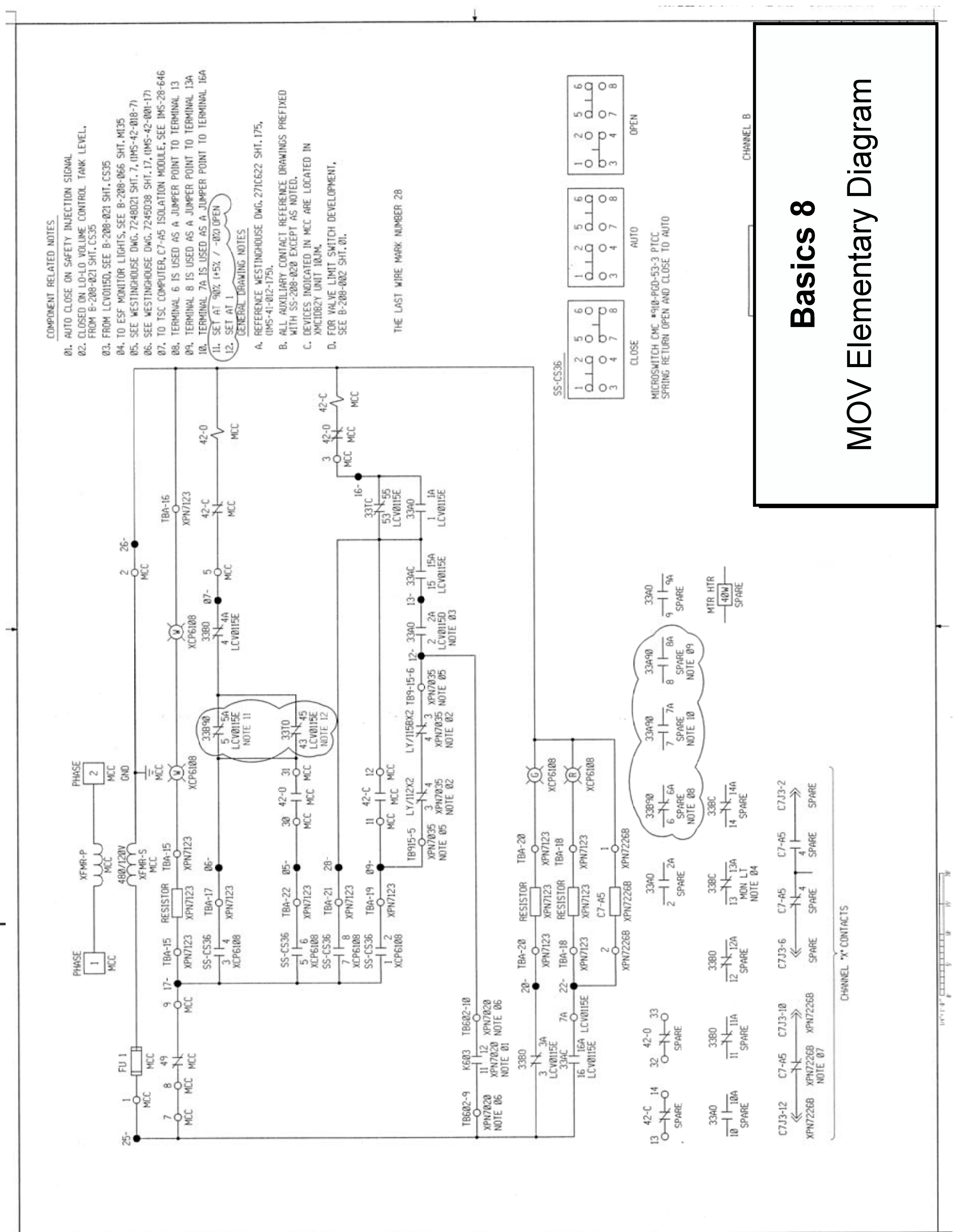
7.2 kV Bus Three-Line Diagram

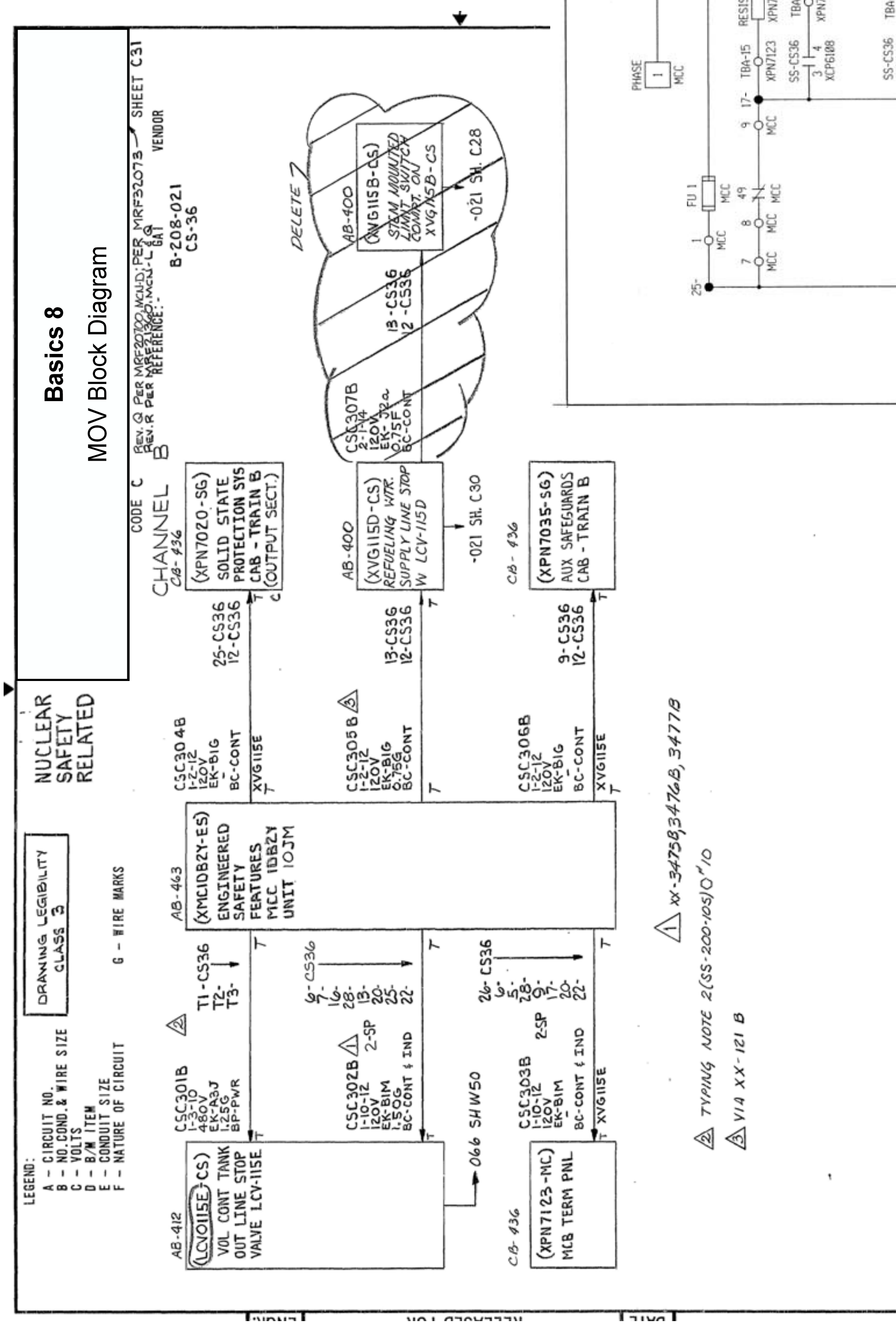


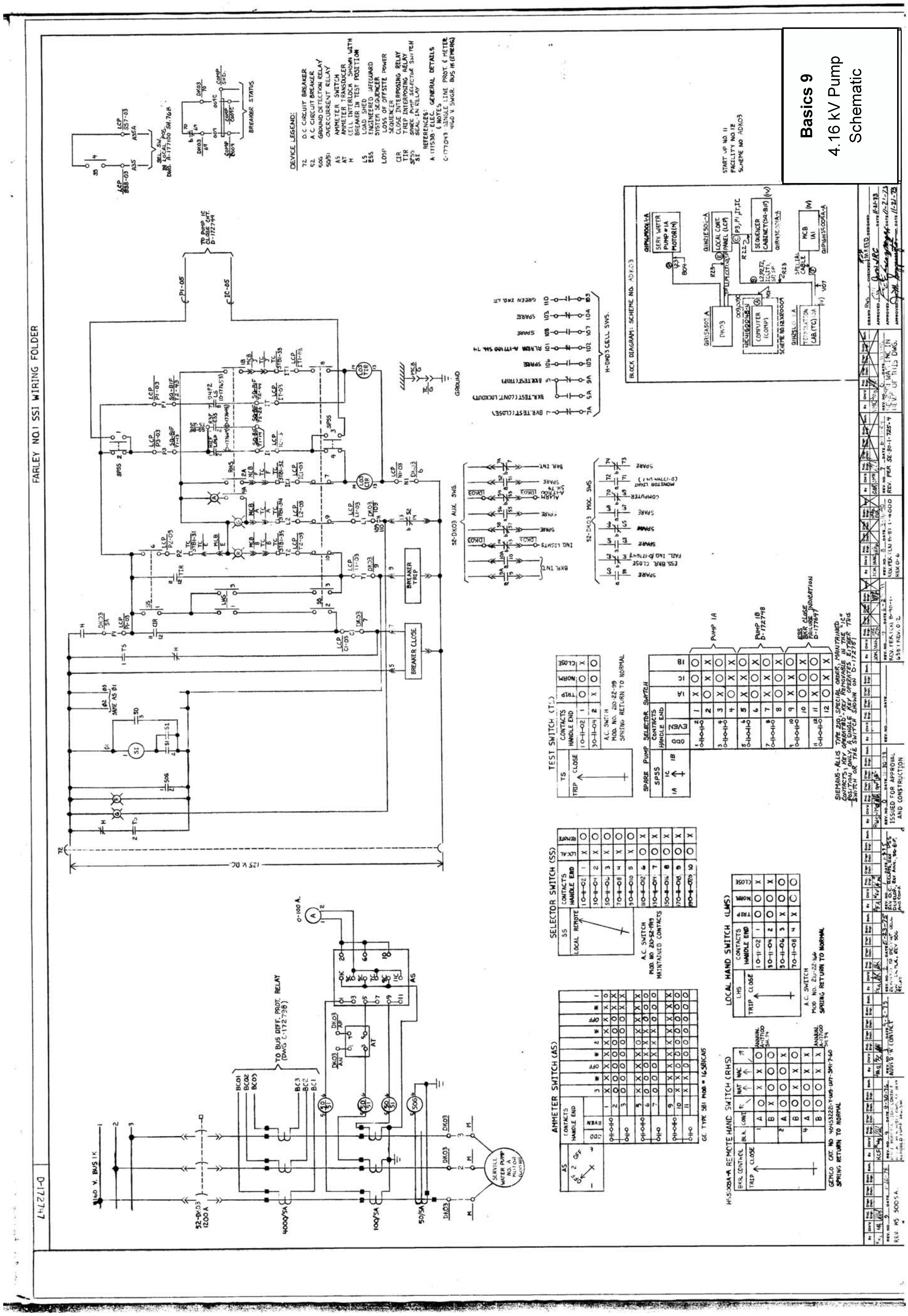
DEVICE	DESCRIPTION	MFR/TYPE	REMARKS
25 / 1A101	BUS 1A SYNCHRONISM CHECK RELAY	GE/IJS51	
27A / 1A101	UNIT AUX TRANS 1B UNDER VOLTAGE RELAY	GE/HGA11	
51 / 1A101	UNIT AUX TRANS 1B OVER CURRENT RELAY	GE/IAC	
51N / 1A101	UNIT AUX TRANS 1B OVER CURRENT GROUND RELAY	GE/IAC	
27-1 / 1A102	BUS 1A UNDER VOLTAGE RELAY REACTOR PROTECTION SYS LOGIC	GE/NGV13	
27-2 / 1A102	BUS 1A UNDER VOLTAGE RELAY	GE/IAV54	
27-3 / 1A102	BUS 1A UNDER VOLTAGE RELAY REACTOR PROTECTION SYS LOGIC	GE/NGV13	
81-1 / 1A102	BUS 1A UNDER FREQUENCY RELAY - RCP TRIP LOGIC	GE/CFF12	
81-2 / 1A102	BUS 1A UNDER FREQUENCY RELAY - RCP TRIP LOGIC	GE/CFF12	
51 / 1A106	START UP TRANS 1C OVER CURRENT RELAY	GE/IAC	
51N / 1A106	START UP TRANS 1C OVER CURRENT GROUND RELAY	GE/IAC	
27A / 1A106	START UP TRANS 1C UNDER VOLTAGE RELAY	GE/HGA11	

Basics 7

4.16 kV Bus Three-Line Diagram


Basics 8
MOV Elementary Diagram

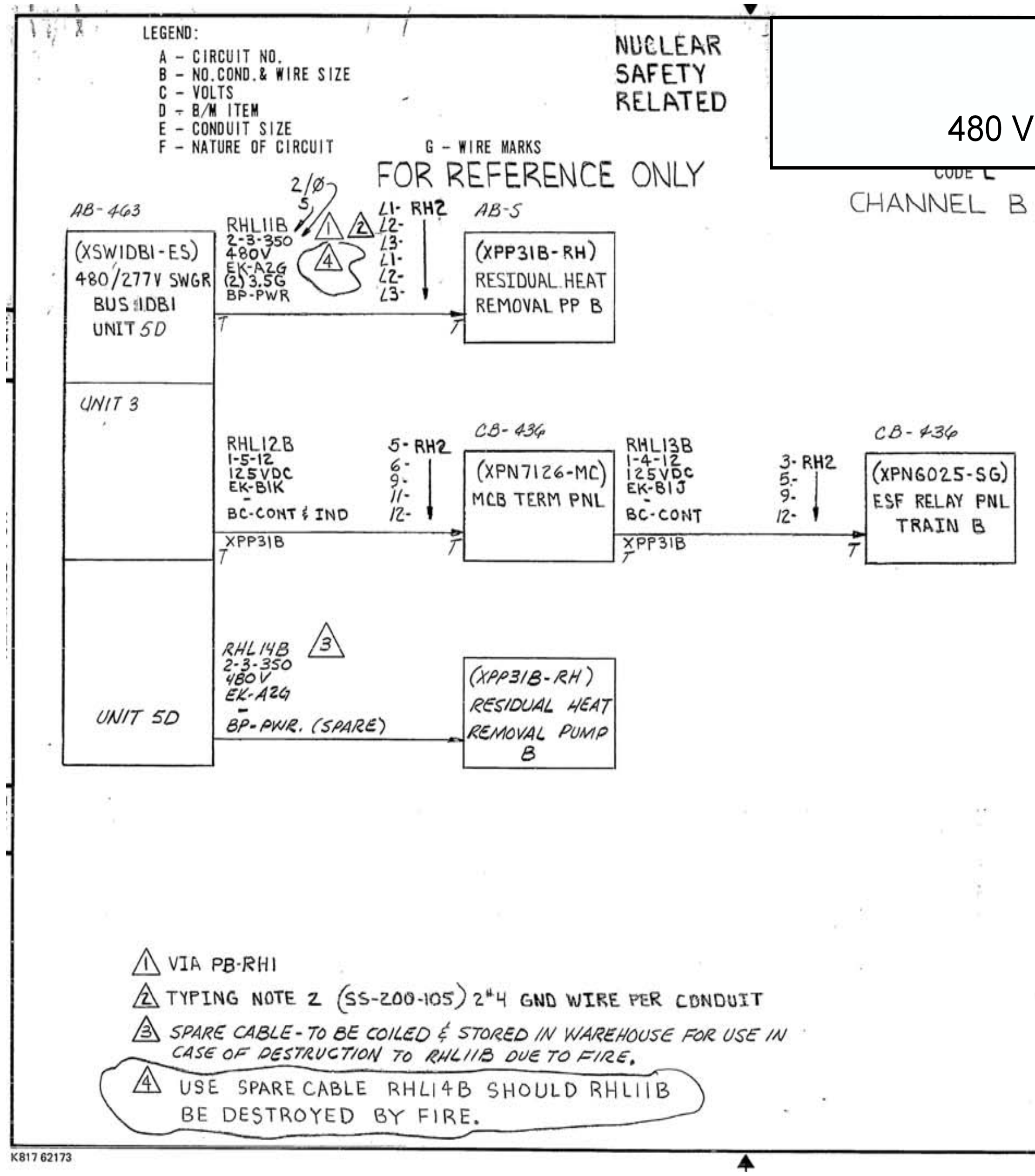

Basics 8
MOV Block Diagram

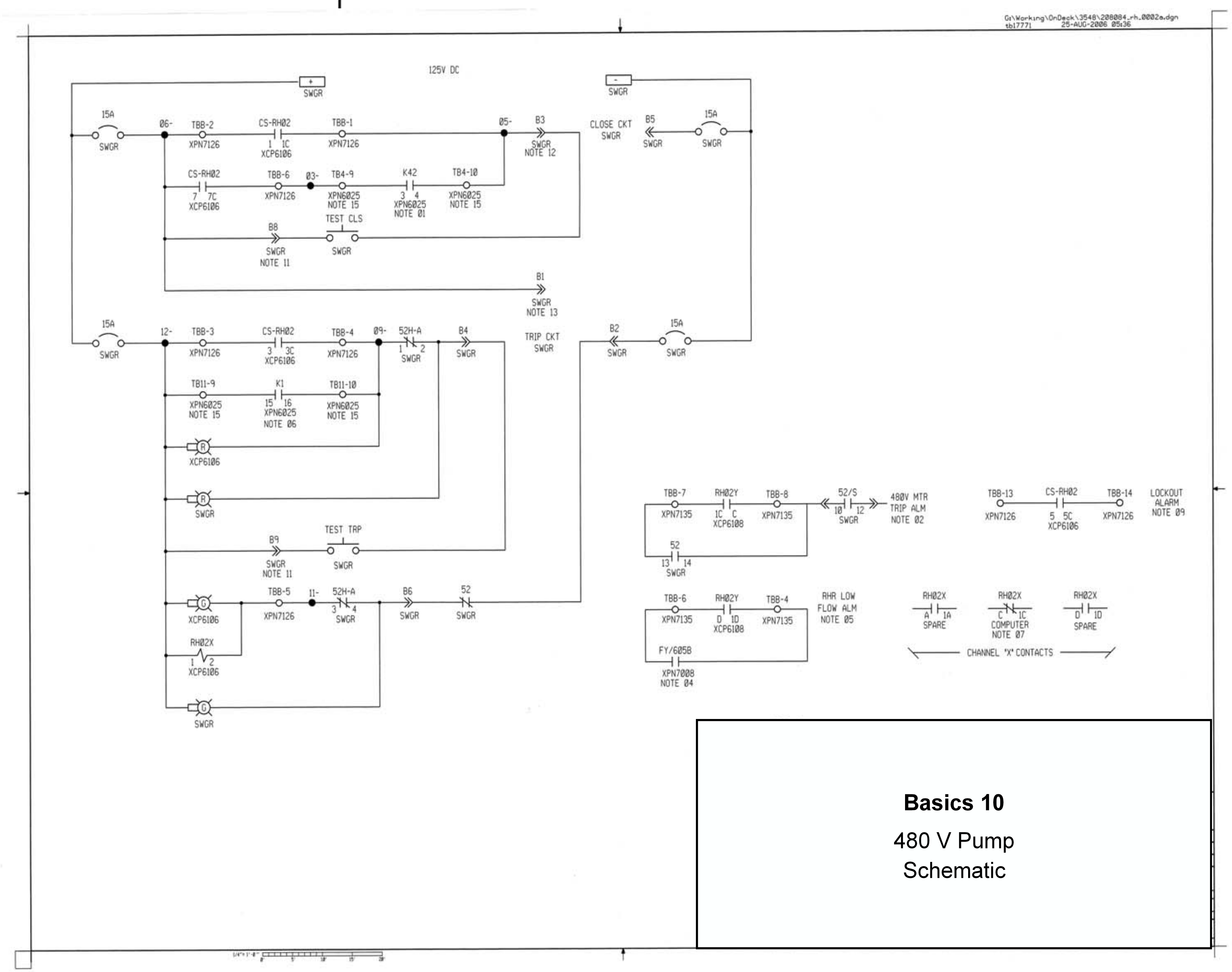


Basics 9
4.16 kV Pump Schematic

Basics 10

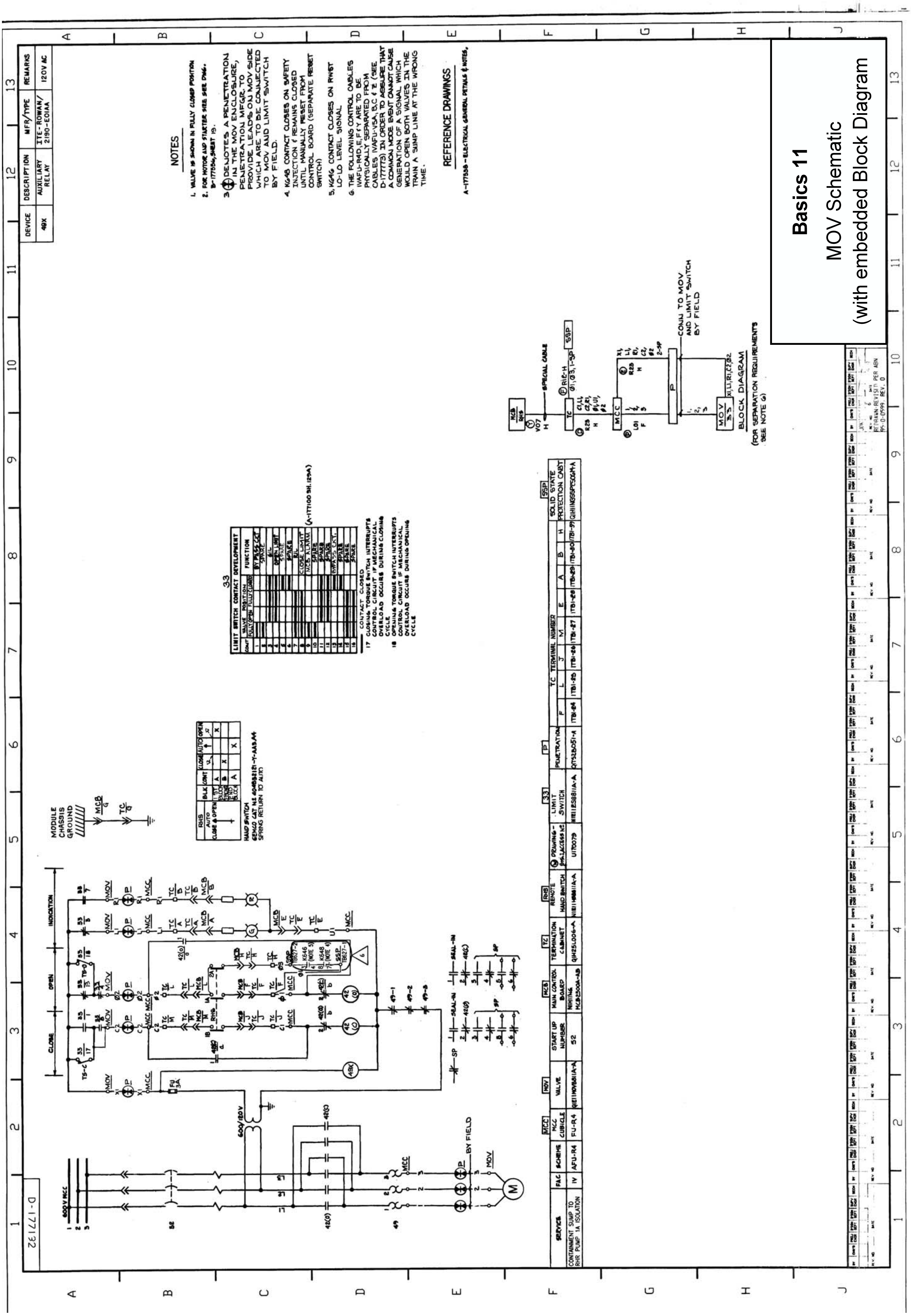
480 V Pump Block Diagram



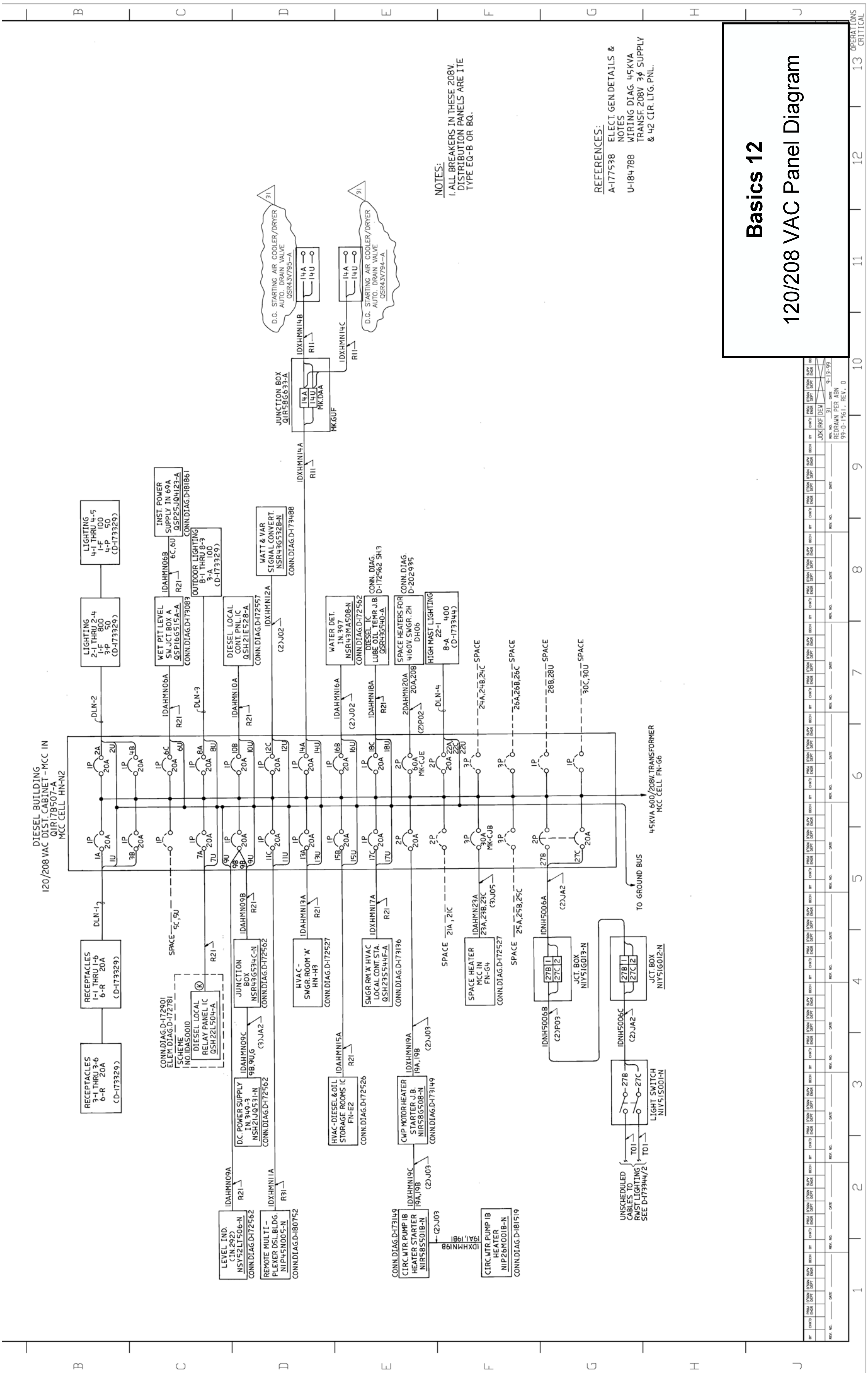


Basics 10

480 V Pump Schematic



Basics 11
MOV Schematic
(with embedded Block Diagram)



Basics 12
120/208 VAC Panel Diagram
DIESEL BUILDING
120/208 VAC DIST. CABINET-MCC IN
QIR17B507-A
MCC CELL HN-N2
NOTES:
1. ALL BREAKERS IN THESE 208V DISTRIBUTION PANELS ARE ITE TYPE EQ-B OR BQ.
REFERENCES:
A-177538 ELECT. GEN. DETAILS & NOTES
U-184788 WIRING DIAG. 45KVA TRANSF. 208V 3ϕ SUPPLY & 42 CIR. LTG. PNL.
45KVA 600/208V TRANSFORMER MCC CELL FN-G6
TO GROUND BUS
OPERATIONS CRITICAL

NOTES:

1. BREAKERS SHOWN IN THE 'OPEN' POSITION
2. COILS SHOWN IN THE 'DE-ENERGIZED' STATE.
3. PRESSURE SWITCHES, FLOW SWITCHES, ETC. SHOWN IN THE 'OFF-SHELF' POSITION.
4. THE COMPLETE WIRE MARK IS THE WIRE MARK SHOWN PLUS THE SYSTEM SHEET NUMBER (e.g. 1-ES09, 2-ES09, ETC.)
5. VALVES SHOWN IN THE 'CLOSED' POSITION (EXCEPT AS NOTED).
6. GAI-ERAC NO.'S WILL BE USED TO IDENTIFY EQUIPMENT LOCATION WHERE APPLICABLE. SEE EQUIPMENT LIST FOR GAI-ERAC DESIGNATION
7. ALL AUX. RELAYS WILL BE 'CUTLER-HAMMER' TYPE M-600V AS SHOWN ON B-208-002 SHT. 19. EXCEPT AS NOTED ON ELEM. DIAGRAM'S
8. DROPPING RESISTORS FOR 'CMC' LIGHT MODULES ON MCB SHALL BE AS FOLLOWS:
   a) 125VDC CIRCUITS - 1950 OHMS FOR SINGLE LAMP; 1600 OHMS FOR TWO LAMPS IN SERIES
   b) 120VAC CIRCUITS - 1750 OHMS FOR SINGLE LAMP; 1400 OHMS FOR TWO LAMPS IN SERIES
9. INSTRUMENTATION SETPOINTS SHOWN ON THIS SERIES DRAWINGS ARE FOR INFORMATION ONLY. THE SETPOINT DATABASE/LIST SHALL BE CHECKED TO VERIFY INSTRUMENT SETPOINTS LISTED ON THESE DRAWINGS.

LIMIT SWITCH DEVELOPMENT - ROTORK OPERATOR

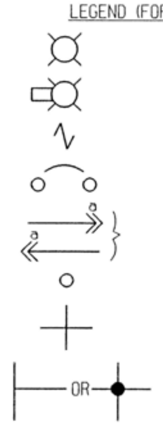
SWITCH	CONTACT	OPEN	INTERMEDIATE	CLOSED
OT/LS	24-25			
CT/LS	26-27			
OAS1	15-16			
CAS1	6-7			
OAS2	17-18			
CAS2	8-9			

ADD-ON-PAK 1 SWITCH OPERATION

SWITCH	CONTACT	OPEN	INTERMEDIATE	CLOSED
IAS1	10-11			
IAS2	12-13			
IAS3	19-20			
IAS4	21-22			
IAS5	28-29			
IAS6	30-31			

ADD-ON-PAK SWITCHES CAN BE SET AT VALVE FULL OPEN, FULL CLOSED, OR ANY POSITION IN BETWEEN

LEGEND (FOR COMPUTER GENERATED DRAWINGS)

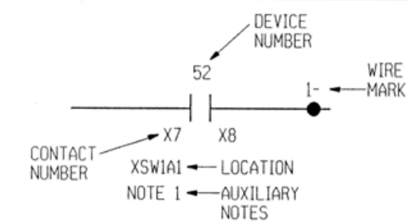


INDICATING LIGHT
INDICATING LIGHT WITH RESISTOR
COIL/SOLENOID VALVE
BREAKER
BREAK IN CIRCUIT SHOWING CONTINUATION ON ANOTHER LINE
EQUIPMENT TERMINAL [TERMINAL NUMBER ABOVE / LOCATION BELOW
INDICATES NO CONNECTION
OR INDICATES CONNECTION

ABBREVIATIONS

ABBREVIATIONS	DEFINITIONS
AL	ALARM
BLU	BLUE
B.O.	BLACK OUT
COMPT	COMPUTER
CONT	CONTROL
DFTD	DEFEATED
GRN	GREEN
INTERLK	INTERLOCK
MON AL 2	MONITOR LIGHT ALARM GROUP 2
MON LT 2	MONITOR LIGHT GROUP 2
REM	REMOTE
T.C.	TORQUE SWITCH TO STOP VALVE CLOSING
T.O.	TORQUE SWITCH TO STOP VALVE OPENING
WH	WESTINGHOUSE
WHT	WHITE
YEL	YELLOW

DEVICE IDENTIFICATION (COMPUTER DRAWINGS)



LIMIT SWITCH DEVELOPMENT FOR AIR OPERATED VALVES AND DAMPERS

	LIMIT SWITCH	DEVICE POSITION FULL CLOSE		FULL OPEN
SWITCH ACTUATED	33bc			
	33bc			
DEVICE CLOSED	33ac			
	33ac			
SWITCH ACTUATED	33ao			
	33ao			
DEVICE OPEN	33bo			
	33bo			

NOTE: 33 CONTACTS SHOWN FOR DEVICE FULL CLOSED

LIMIT SWITCH DEVELOPMENT - LIMITORQUE OPER.

ROTOR	POSITION SWITCH	CONT	VALVE POSITION FULL CLOSE		FULL OPEN
1	33AO	1			
	33AO	2			
	33BO	3			
	33BO	4			
2	33BC	5			
	33BC	6			
	33AC	7			
	33AC	8			
3	33AO	9			
	33AO	10			
	33BO	11			
	33BO	12			
4	33BC	13			
	33BC	14			
	33AC	15			
	33AC	16			
		17	CLOSING TORQUE SWITCH INTERRUPTS CONTROL CIRCUIT IF MECHANICAL OVERLOAD OCCURS DURING CLOSING CYCLE OR FULLY CLOSED VALVE		
		18	OPENING TORQUE SWITCH INTERRUPTS CONTROL CIRCUIT IF MECHANICAL OVERLOAD OCCURS DURING OPENING CYCLE OR FULLY OPENED VALVE		

NOTES: LIMIT SWITCH DEVELOPMENT- LIMITORQUE OPER.

1. INTERMEDIATE POSITIONS ARE EXPRESSED IN PERCENTAGE OF FULL OPEN. EX. 33A05 CONTACT ACTUATES WHEN THE VALVE IS 5% OPEN.
2. THE TOLERANCE FOR ROTOR 2 CONTACTS SET AT 25% OPEN IS ± 2.5%.
3. LIMITORQUE VALVES STROKED OPEN TO A POSITION OF ≥90% ARE CONSIDERED 'FULLY OPEN' WITH THE EXCEPTION OF XVG2802A & B-MS, WHICH MUST BE STROKED OPEN TO 95%. THE BASIS FOR THIS STATEMENT IS NUCLEAR ENGINEERING LETTER CGSS-20371, DATED 11/9/87.

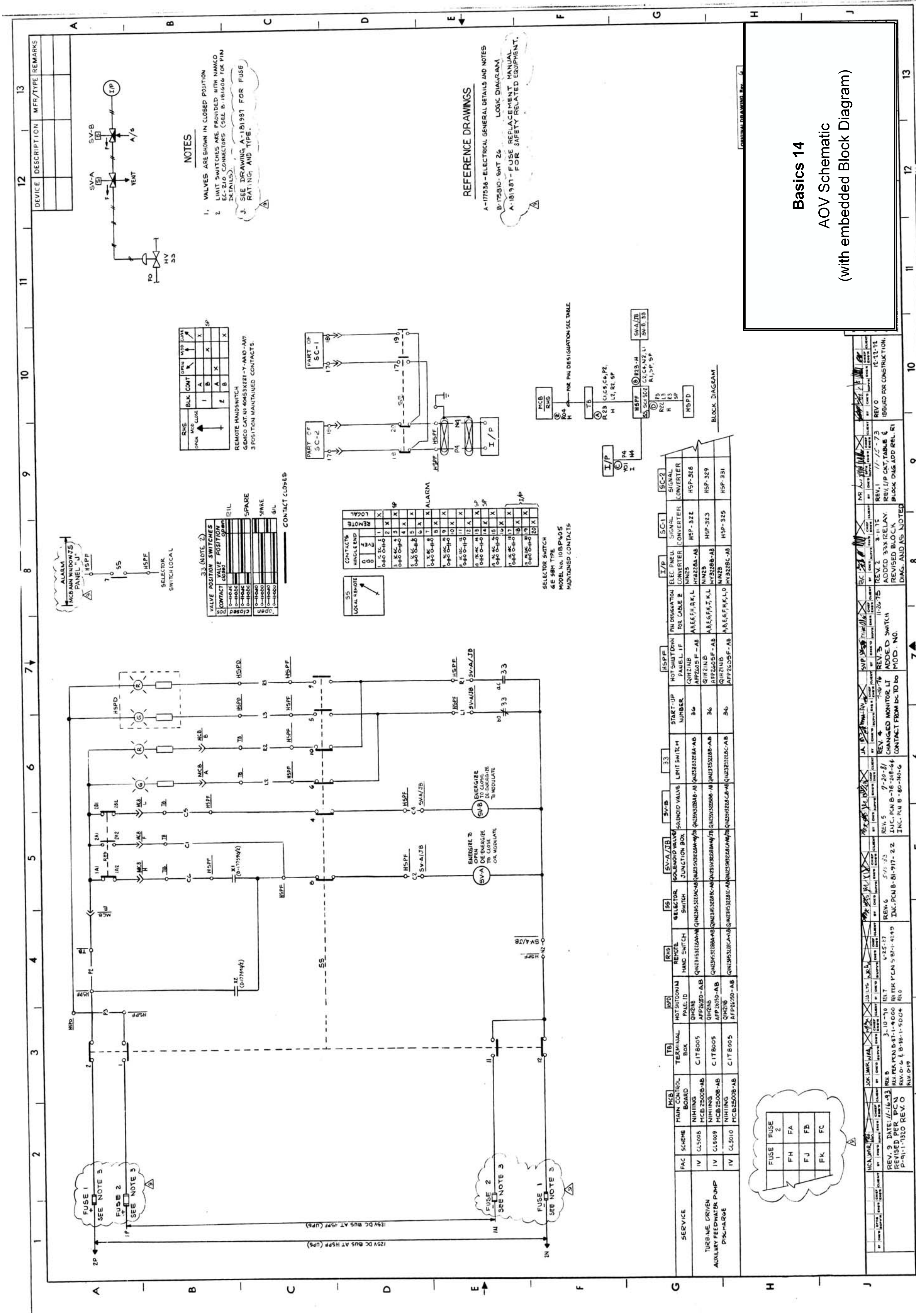
ESSENTIAL

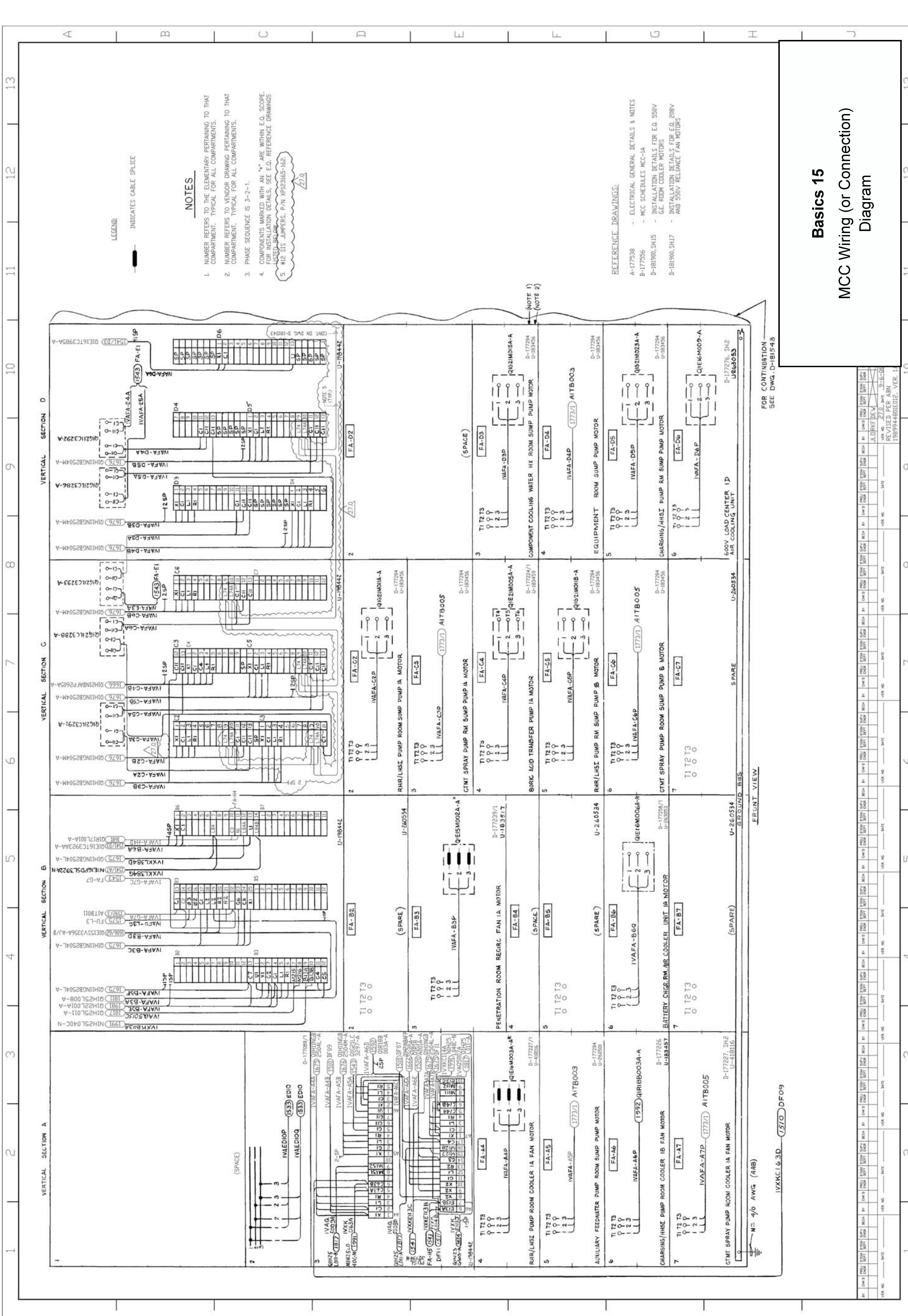
DRAWING LEGIBILITY

Basics 13

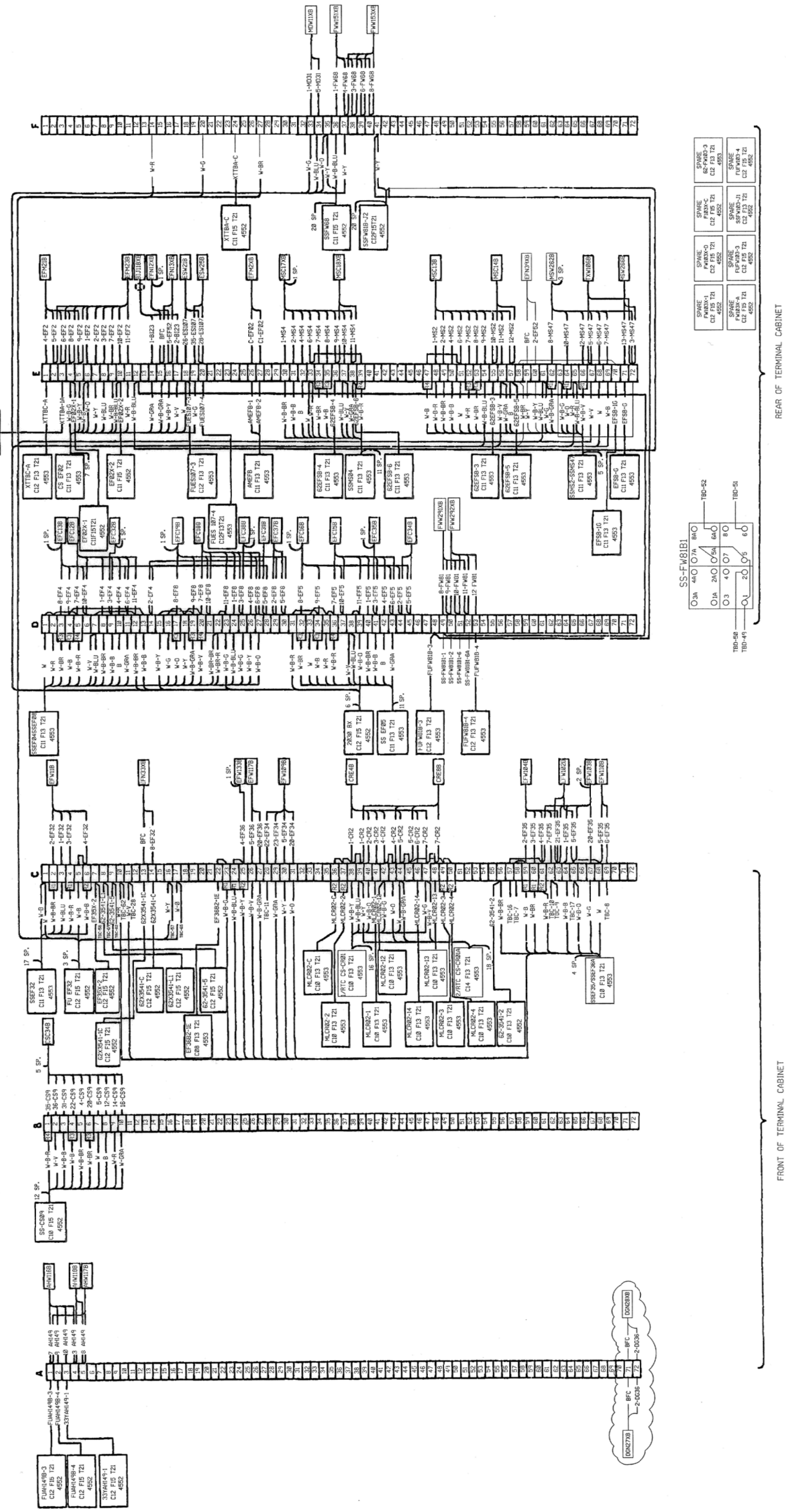
Valve Limit Switch Legend

208002_xx_0001


Basics 14
AOV Schematic
(with embedded Block Diagram)
NOTES
REFERENCE DRAWINGS
BLOCK DIAGRAM

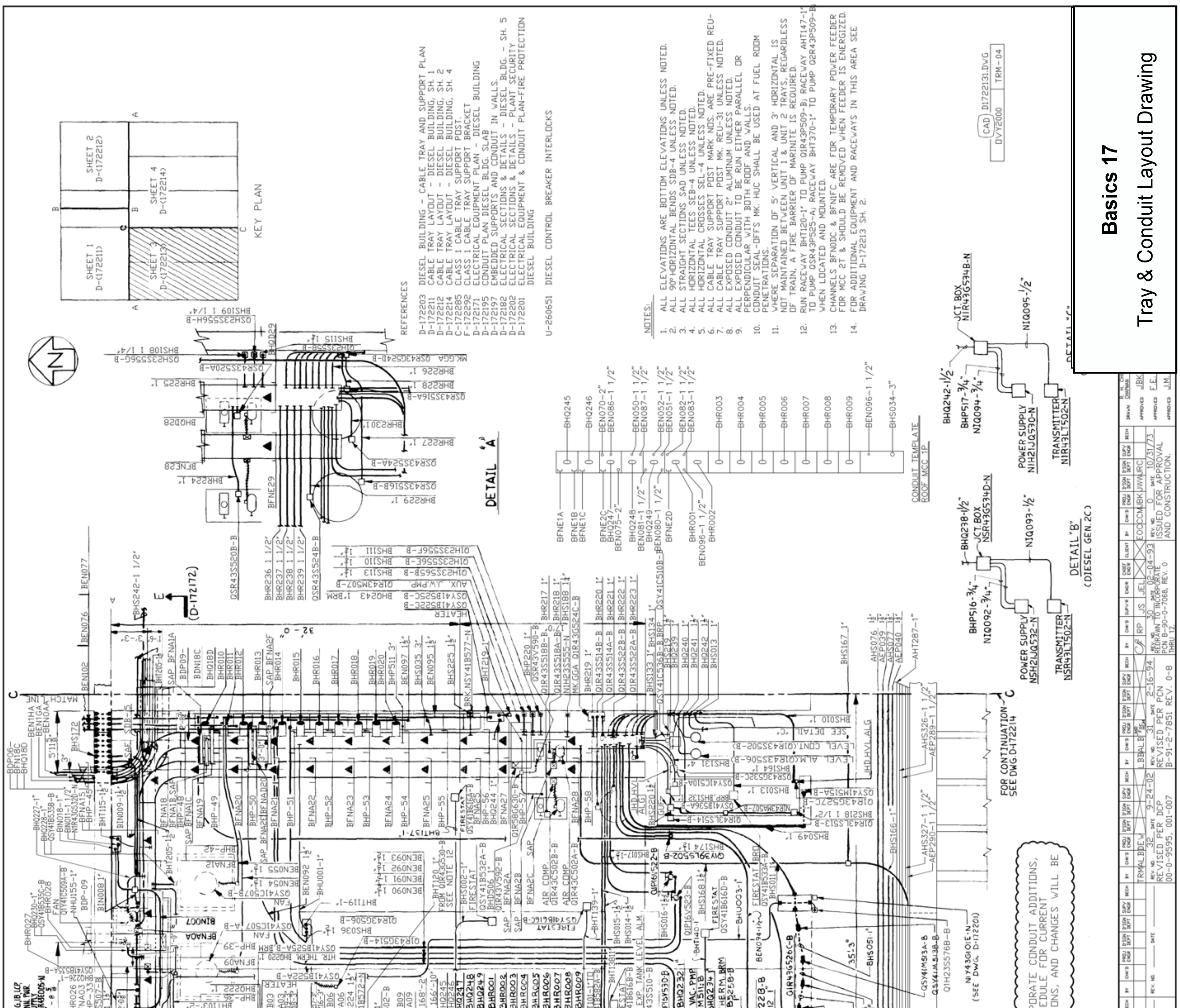


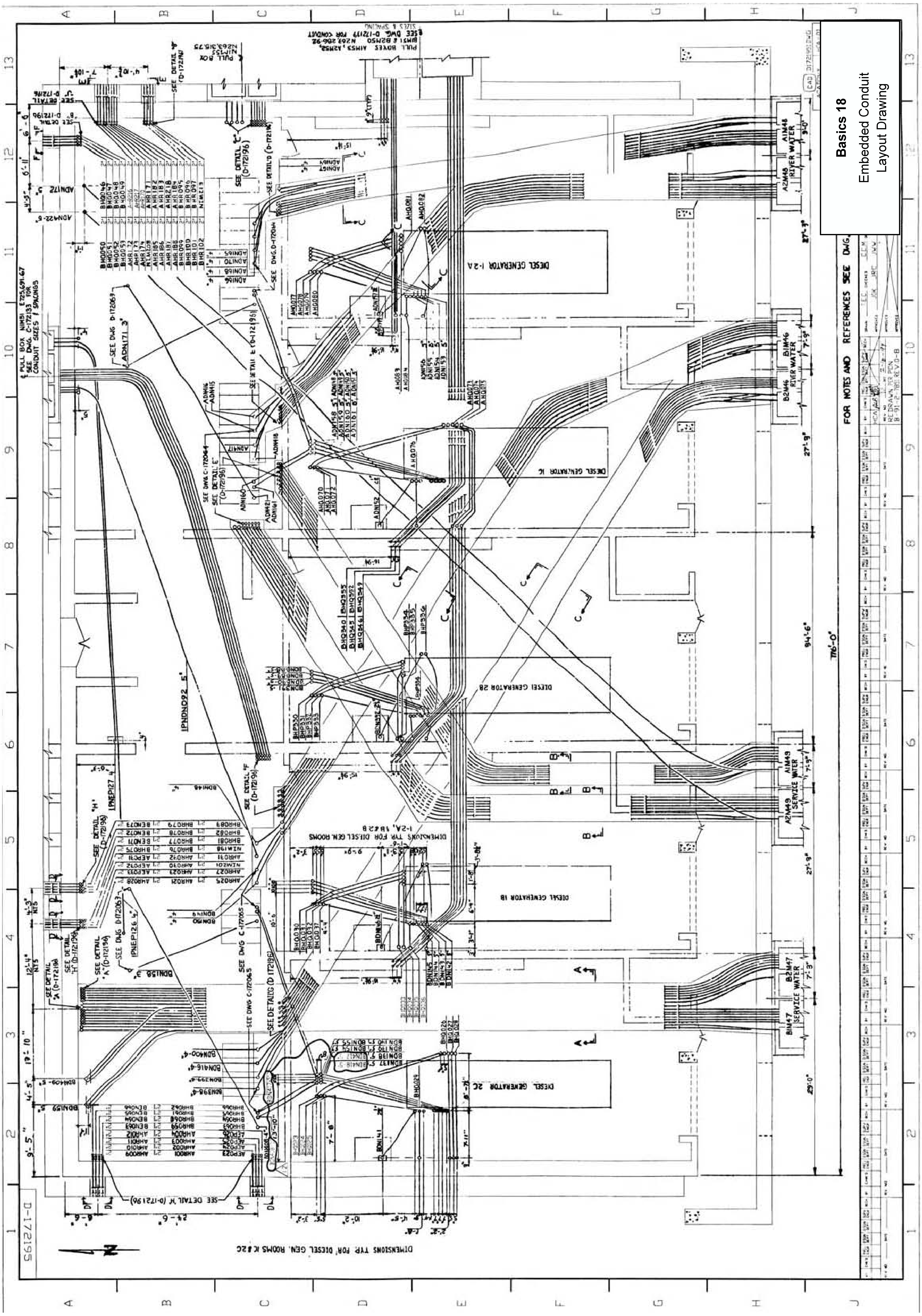
Basics 15
MCC Wiring (or Connection) Diagram

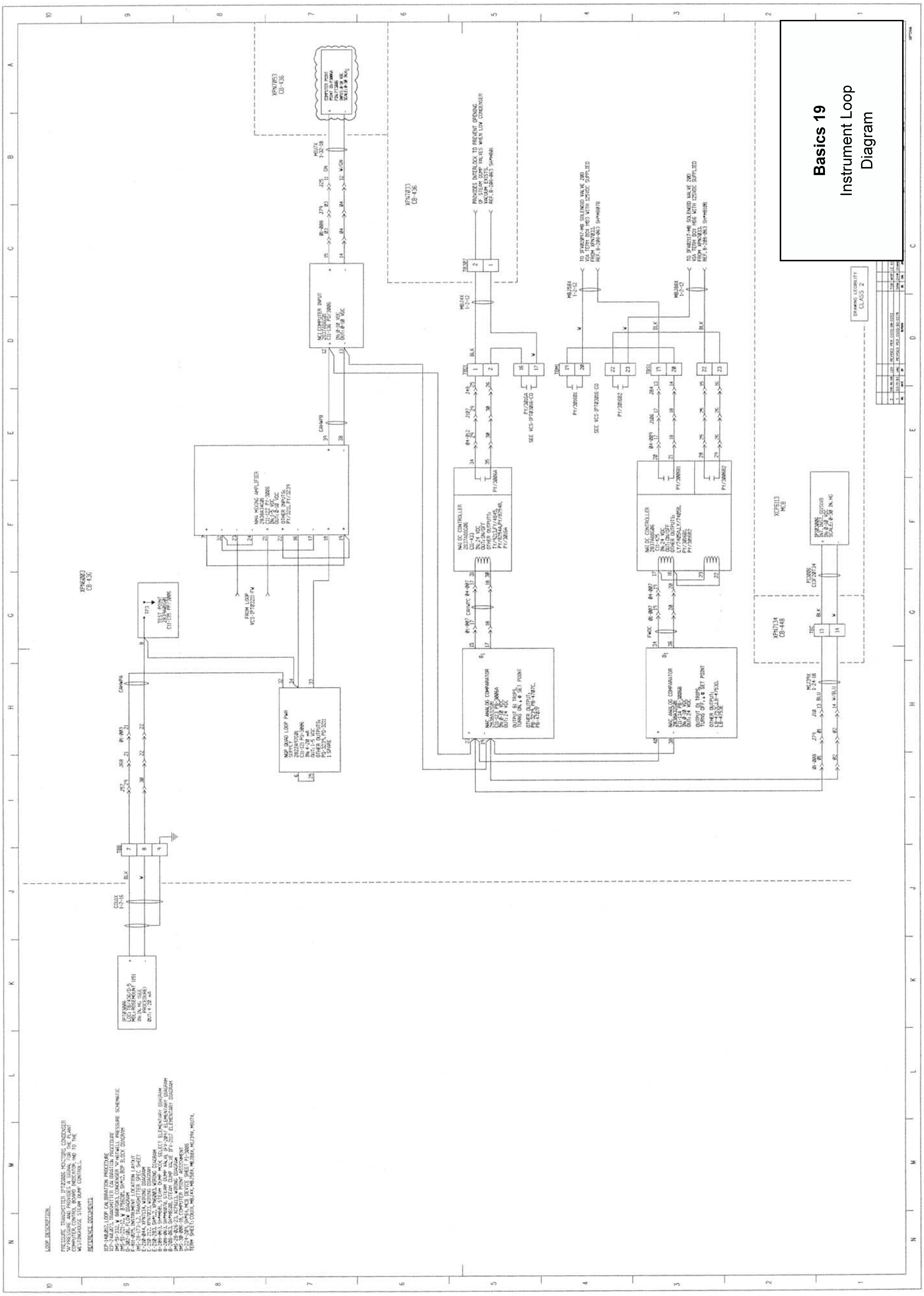


Basics 16

Terminal Cabinet Wiring (or Connection) Diagram


Basics 17
Tray & Conduit Layout Drawing


Basics 18
Embedded Conduit
Layout Drawing



Basics 19
Instrument Loop Diagram

CIRCUIT ANALYSIS BASICS
Evolution of Fire Protection Circuit Analysis

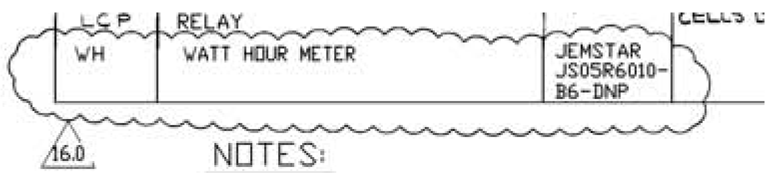
- Appendix R – the early years
- Appendix R – the later years
- Appendix R – redux
- Early Generation Fire PRA
- Cable Fire Tests
- Operator Manual Actions
- NFPA 805
- EPRI 1011989 - NUREG/CR-6850 & Next Generation Fire PRA
- Multiple Spurious Operations (MSO)
- 10 CFR 50.48(c) – RIPB voluntary alternative 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

Self- Assessment

Circuit Analysis Basics

1. **Name the two polymer classifications of electrical cable insulation/jacket material.**

2. **What do the clouds on the drawings represent?**



a) The most important information on the drawing
b) Circuit breakers
c) Changes to the drawing
d) Where to refer for additional information

3. **Which publication is considered the "PRA Standard"?**
   a) *Appendix R*
   b) *NFPA 805*
   c) *10 CFR 50.48(c)*
   d) *ASME/ANS RA-Sa-2009*

APPENDIX B: MATERIALS SUPPORTING BASIC CONCEPTS OF FIRE ANALYSIS VIDEOS

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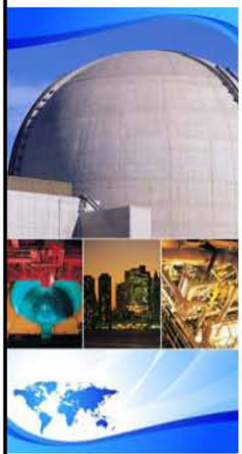


EPRI/NRC-RES FIRE PRA METHODOLOGY

Definitions

Part 1 of 6, 9/27/2010 session. Parts 2-6 are from the 10/25/2010 session

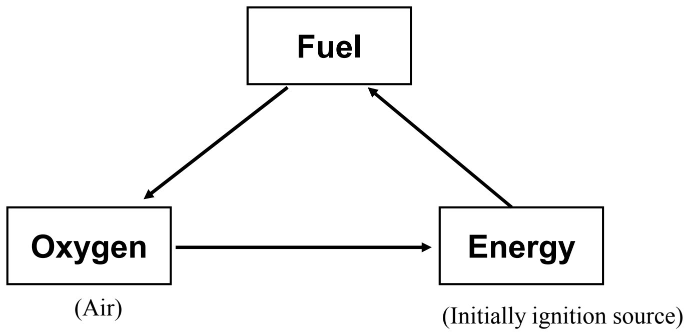
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

What is a Fire?

- Fire is an exothermic chemical reaction involving a fuel and oxygen in the air
  - Requires presence of:
    - Material that can burn, the fuel
    - Oxygen (air)
    - Energy (initial ignition source)
  - Ignition source can be a spark, short in an electrical device, etc.

What is a Fire?

- Fire Triangle



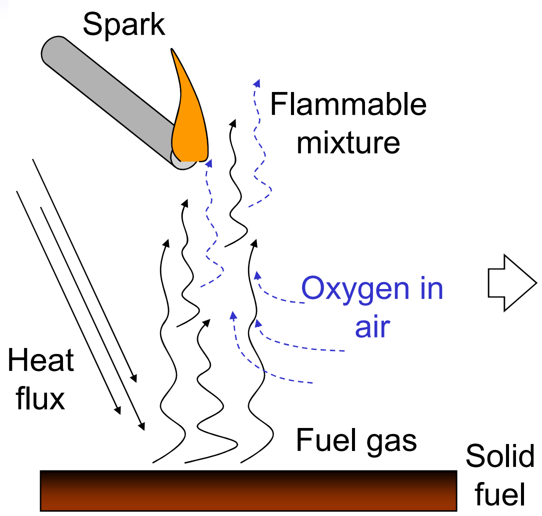
Materials that May Burn

- Materials that can burn are generally categorized by:
  - Ease of ignition (ignition temperature or flash point)
    - Flammable materials (e.g., gasoline)
    - Combustible materials (e.g., wood, high ignition temperature oils, and diesel fuel)
  - State
    - Solid (wood, electrical cable insulation)
    - Liquid (diesel fuel)
    - Gaseous (hydrogen)

Combustion Process

- Combustion process involves . . .
  - An ignition source comes into contact and heats up the material
  - Material vaporizes and mixes up with the oxygen in the air and ignites
  - Exothermic reaction generates additional energy that heats the material, that vaporizes more, that reacts with the air, etc.
  - Flame is the zone where chemical reaction is taking place

What is Fire?



Flame Characteristics

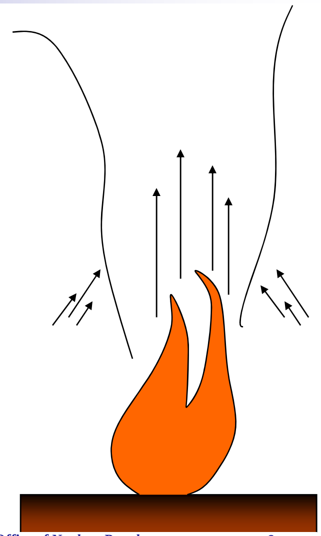
- Flame characteristics
  - Flame color depends on the material burning
  - Most flames are visible to the naked eye
  - Flame temperature can range from 1,500°F to 3,500°F – For example . . .
    - Laminar flames ~ 3,500 °F, e.g., a candle flame
    - Turbulent flames ~ 1,500 °F, e.g., a fire place

Effects of a Fire

- A fire generates heat, smoke and combustion products
  - Heat is the main adverse effect of concern in a nuclear power plant
  - Heat generated by the fire is transferred by radiation and convection
  - Products of combustion include soot and other species such as HCL, etc.
    - Smoke and soot can adversely affect equipment
    - Smoke can be a hindrance to plant operators

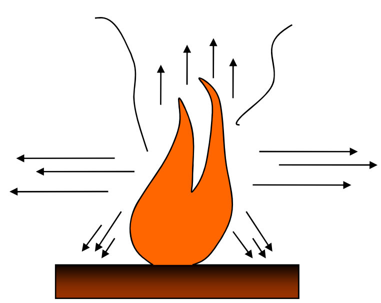
Fire Plume

- A fire plume . . .
  - Draws fresh air from the surroundings
  - A part of the air gets used in the flame
  - Air drawn above the flames gets heated up
  - The hot gases rise and envelope items above the fire with very hot gases
  - Hot gases transfer the larger portion of the energy generated by a fire by convection



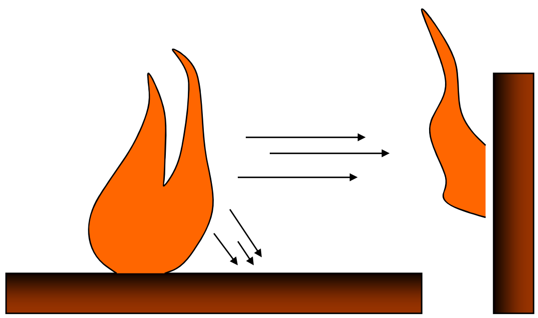
Radiative Heat of a Fire

- Radiative heat from a fire is emanated from the flame in all directions
  - A part of the radiative heat evaporates the fuel to continue the combustion process



Flame Spread and Fire Propagation

- Flame spread is a series of ignitions that can lead to fire propagation to adjacent or nearby items



Definitions

- Pyrolisis – Breakdown of the molecules of a solid material from exposure to heat into gaseous molecules that combust in the flame.
- Spontaneous Ignition – Ignition of a combustible or flammable material without an ignition source, which is generally done by raising material temperature above its auto-ignition temperature.
- Smoldering – A slow combustion process without visible flames that occurs in a porous solid fuel (e.g., burning of charcoal brickets or wood in a fire pit). Generally occurs because of limited oxygen access to the burning surfaces. It can generate large quantity of carbon monoxide which is lethal if inhaled.

Definitions

- Fire Plume - A fire plume is a buoyant column of hot air rising above the base of a fire
- Flame - A flame is the visible (light-emitting) part of a fire. It is caused by an exothermic reaction taking place in a thin zone where fuel vapors and oxygen in the air meet.

Definitions

- Diffusion Flame – The flame of a burning material (liquid or solid) where the combustion process occurs at the interface where vaporized fuel comes into contact with the oxygen in the air (e.g., flame on top of a candle or the wood in a fireplace.)
- Pre-mixed Flame –The flame of burning gaseous material that is mixed with air upstream of the flame (e.g., the flame of a gas range or gas fired furnace)
- Laminar Flame – A flame with laminar flow of gases (e.g. typical candle flame). Most flames greater than 1 ft tall demonstrate turbulent (non-laminar) behavior because of increased gas velocities caused by increased heat.

Definitions

- Conduction – Heat transfer between two adjacent stationary media through the interface between them (e.g., putting your hand on a cold surface)
- Convection – Heat transfer between a moving fluid and a solid or liquid material (e.g., blowing over a hot food to cool it down)
- Radiation – Heat transfer through open space via electromagnetic energy between two materials of different temperatures that are within line of sight of each other (e.g., infra-red radiation from a very hot material).

Definitions

- Mass Loss Rate (Burning Rate) – The rate of mass loss of a burning material in a fire. It is commonly expressed in terms of mass per unit area per unit time (e.g., 10 g per cm^2 per second).
- Heat Release Rate (HRR) – The energy release per unit time from a combustible material (kW)
- Heat Flux – Heat transferred expressed per unit time per unit area (kW/m^2). Its is a good measure of fire hazard.

Definitions

- Heat Release Rate Profile – The heat release rate as a function of time.
  - Example . . .

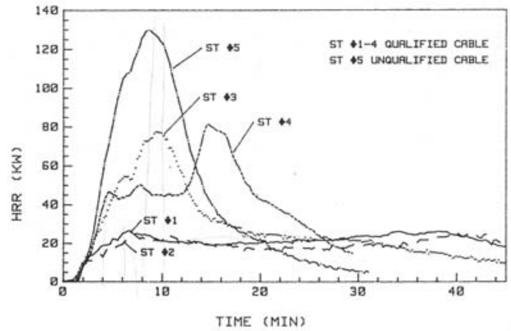


Figure 8. Heat Release Rate Plots for Scoping Tests #1 through 5

Definitions

- Fire in the Open – A fire event where heat generated from the fire is limited by the surface burning rate of the material. In other words sufficient air is always available for the fire.
- Compartment Fire – A fire inside a compartment, which may be affected by:
  - Oxygen availability
  - Feedback form compartment boundaries

Definitions

- Upper and Lower Flammability –Concentration of a flammable gas in air in a pre-mixed flame that can sustain combustion. If the mixture is close to lower flammability limit, it is too lean. If the mixture is close to the upper flammability limit, it is too fuel rich.
- Fire Modeling vs. Fire Analysis Tasks – Fire modeling is the analytical process of estimating the behavior of a fire event in terms of the heat flux impinging material near the fire and behavior of those materials as a result of that.

Definitions

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

Self- Assessment

Fire PRA Methodology

1. **A fire requires the presence of : ______________________, ______________________,**

and ____________________ to burn?

2. **What is the *main* adverse effect of concern in a nuclear power plant regarding the effects of fire?**

   a) Oxygen levels **b)** *Combustion products* **c)** *Heat* **d)** *Smoke*

3. **Heat Flux is the amount of heat transferred expressed in units of (kW).**
   - **a)** True
   - **b)** False

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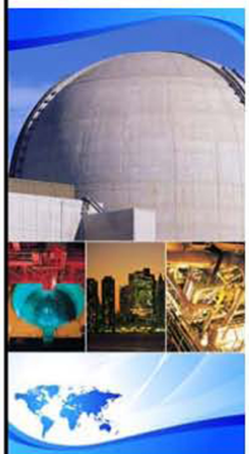

EPRI/NRC-RES FIRE PRA METHODOLOGY

Definitions

Part 1 of 6, last 5 slides only (16-20), by S. Nowlen in the Oct. 2010 session

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

Definitions

- Mass Loss Rate (Burning Rate) – The rate of mass loss of a burning material in a fire. It is commonly expressed in terms of mass per unit area per unit time (e.g., 10 g per cm^2 per second).
- Heat Release Rate (HRR) – The energy release per unit time from a combustible material (kW)
- Heat Flux – Heat transferred expressed per unit time per unit area (kW/m^2). Its is a good measure of fire hazard.

Definitions

- Heat Release Rate Profile – The heat release rate as a function of time.
  - Example . . .

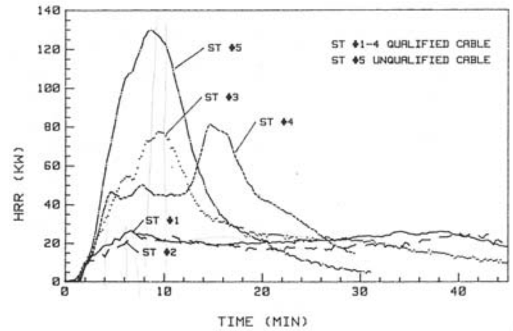

Figure 8. Heat Release Rate Plots for Scoping Tests #1 through 5

Definitions

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  - Feedback form compartment boundaries

Definitions

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

Definitions

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

Self- Assessment

Fire PRA Methodology

Best answered by listening to Fire Video Part 1 of 6, last 5 slides only

1. **The Heat Release Rate (HRR) of a fire has a time dependent behavior which typically has three phases:**
   a)

   b)

   c)

2. **An oxygen limited fire is considered?**
   a) *A fire in the open*
   b) *A compartment fire*
   c) *A fuel limited fire*
   d) *A fire plume*

3. **Calculation of the Zone of Influence (ZOI) is dependent upon the fire, target and orientation.**
   a) True
   b) False

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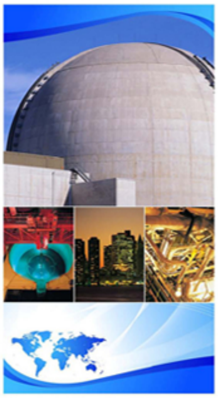


EPRI/NRC-RES FIRE PRA METHODOLOGY

Fires in the Open and Fully Ventilated Fires

Part 2 of 6

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

Fire in the Open

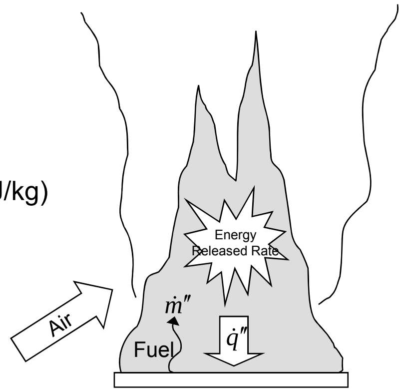
- A fire event where heat generated from the fire is limited by the surface burning rate of the material.
- Sufficient air is always available for the fire.
- Generates hot gases and radiative heat

Heat Release Rate

- The heat release rate from a fire can be estimated using the following equation:

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

  - $\dot{m}''$ is the burning mass flux
  - ΔHc is the heat of combustion (kJ/kg)
  - A is the burning area (m2)

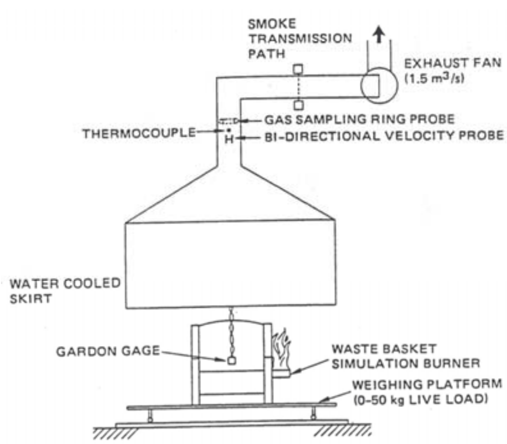


Heat Release Rate

- Can be estimated experimentally using oxygen consumption calorimeters

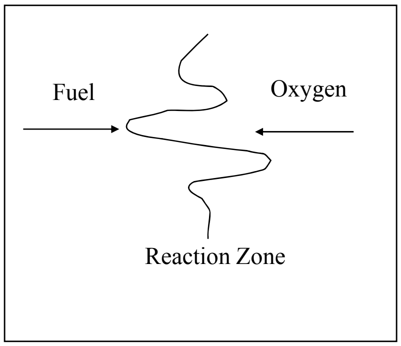
$$\dot{Q} = \dot{m}_{O_2} \cdot \Delta H_c (kJ / kg_{O_2})$$

  - ΔH_c = 13.1 kJ/kg$_{O2}$



Flames

- Laminar
- Turbulent



Ignition of Gases

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

Ignition of Liquids

- For a liquid to ignite, it must first evaporate sufficiently to form a flammable mixture in the presence of a pilot.
  - This occurs at a liquid temperature called a flash-point temperature.
  - In general, this can be called the piloted ignition temperature and the term carries over to solids.
  - The flash-point is the temperature at which the amount of liquid evaporated from the surface achieves the lower flammable limit.

- If no pilot is present, the mixture must be heated to the auto-ignition temperature.

- Auto-ignition temperature of gases is above its boiling point.

Ignition of Solids

- Solids do not vaporize like liquids when heated. They form gaseous decomposition compounds leaving behind possible char in a process called pyrolysis.

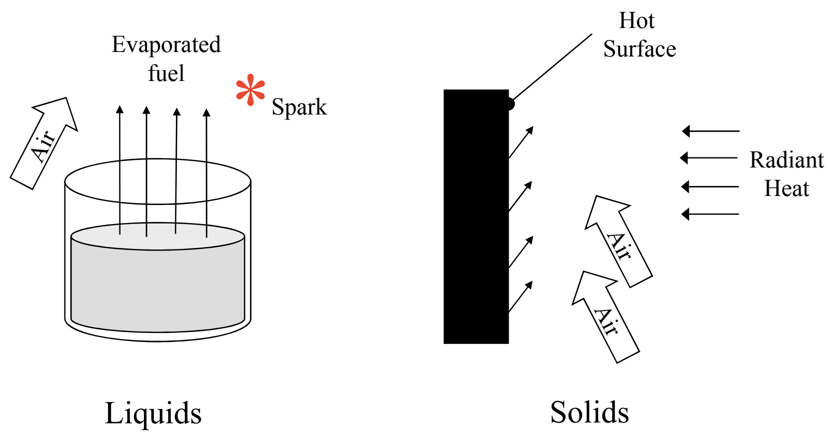
- At some point, the gases ignite by piloted ignition or auto-ignition.

- Typically, piloted ignition temperatures for solids range from 250°C (~480°F) to 450°C(~840°F).

- Auto-ignition temperatures can exceed 500°C (~930°F).
  - For a given material, these temperatures are not constants and can change with the nature of heating.
  - For practical purposes, a (piloted) ignition temperature (T_{ig}) may be treated as a property of a combustible solid.

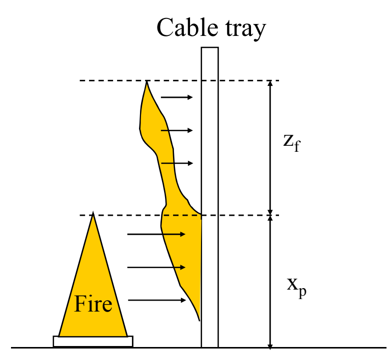
- We shall consider thin (less than ~1 mm) and thick solids to have different time responses to ignition when exposed to impinging heat flux

Ignition



Flame Spread

- Motion of vaporization front at the ignition temperature for solids and liquids



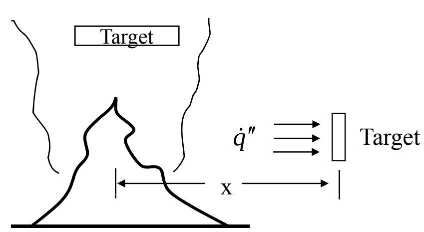
Typical Flame Spread Rates

- It is very difficult to compute flame spread rate because formulas are not completely available, rates may not be steady, and fuel properties are not generally available. Nevertheless, we can estimate approximate magnitudes for spread rates based on the type of system. These estimates are listed below:

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

Zone of Influence

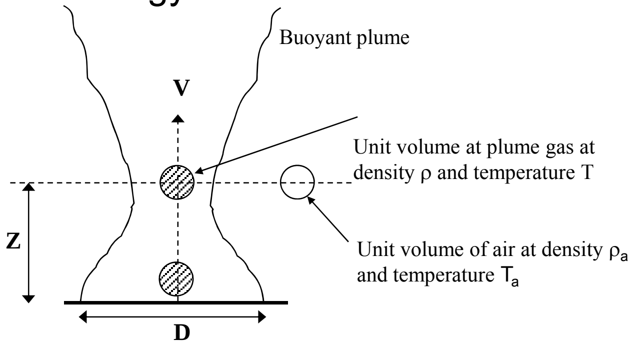
- Regions nearby the fire where damage is expected. For fires in the open:
  - Flame Radiation



  - Convection inside the fire plume

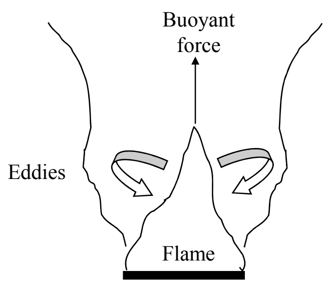
Buoyant Flow

- Temperature rise gives a decrease in density
- Potential energy converted into kinetic energy



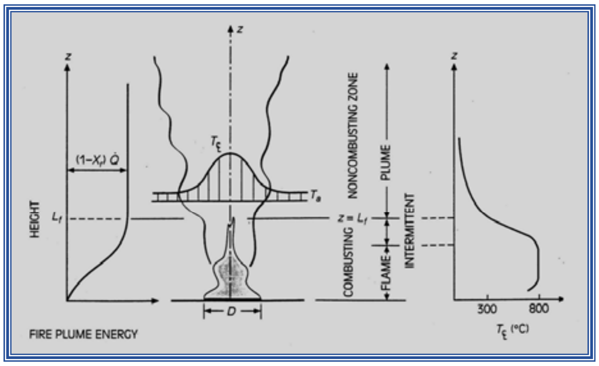
Turbulent Entrainment

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

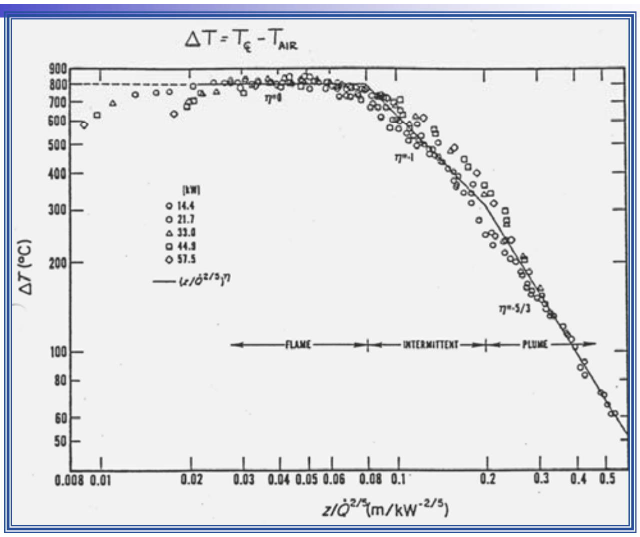


Turbulent Fire Plume

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



Fire Plume Temperature Along the Centerline



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

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

Heskdestad's Flame Height Correlation

Input

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

Result

L - Flame height [m]	1.5

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

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

Heskestad's Plume Temperature Correlation

Input

T_{amb} - Ambient temperature [C]	20
Q_f - HRR [kW]	250
F_e - Fire elevation [m]	0
H_p - Target Elevation [m]	3.7
z_0 - Fire Diameter [m]	1

Result

T_{pl} - Plume Temp [C]	328

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

- Flame Radiation: Point Source Model

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

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

Example Case - Zone-of-Influence Calculation

Radiation Heat Flux

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

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

Self- Assessment

Fire PRA Methodology

1. **With a spark or small flame present, ignition is based on whether the gaseous fuel concentration is between the ______________________ and ________________________ flammability limits.**

2. **Entrainment is air drawn into the fire plume by upward movement of the buoyant plume?**

   a) *True*
   b) *False*

3. **Match the type of ignition to corresponding characteristics.**

   a) Ignition of gases
   b) Ignition of liquids
   c) Ignition of solids

____ Must first evaporate sufficiently to form a flammable mixture in the presence of a pilot.

____ 250°C (480°F) to 450°C (840°F) is the typical piloted ignition temperature range.

____ The fuel-air mixture is said to be flammable if a flame will propagate in this mixture.

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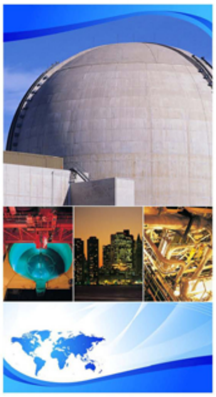


EPRI/NRC-RES FIRE PRA METHODOLOGY

Compartment Fires

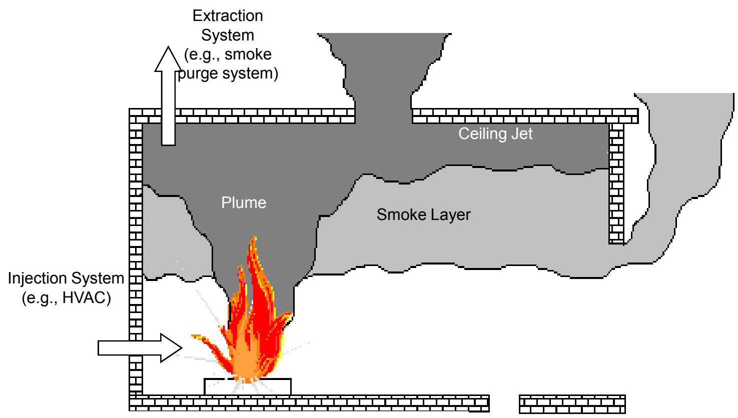
Part 3 of 6

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

Outline

- Enclosure fire dynamics – qualitative description
- Pressure profiles and vent flows
- The hot gas layer
- Heat transfer
- Combustion products

Qualitative Description



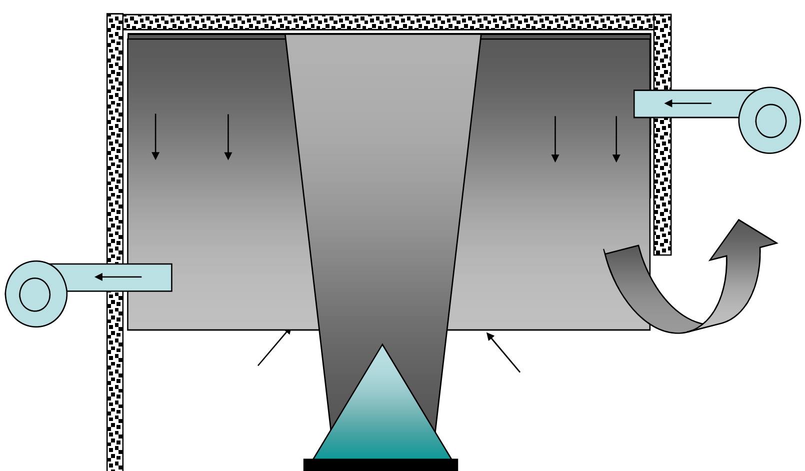
Phases in a Compartment Fire

- Ignition: Process that produces an exothermic reaction
  - Piloted or spontaneous
  - Accompanying process can be flaming or smoldering combustion
- Growth
  - Can occur at different rates depending on type of fuel, interactions with surroundings, and access to oxygen
- Hot gas layer buildup and room heatup
- Flashover: Rapid transition to a state of total surface involvement of combustible materials within an enclosure
  - Temperatures between 500°C (930°F) to 600°C (1,110°F), or
  - Heat fluxes between 15 kW/m2 to 20 kW/m2

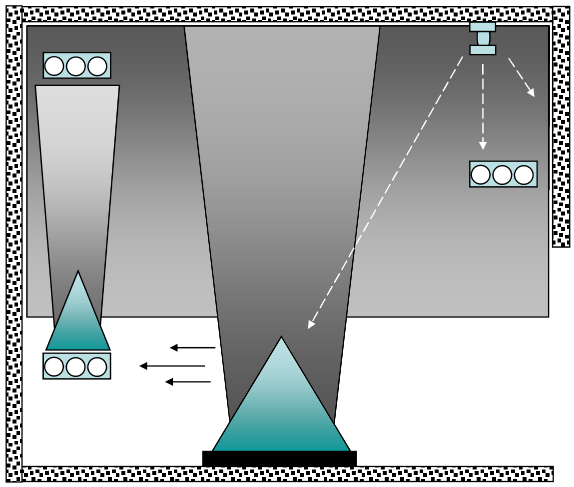
Phases in a Compartment Fire

- Fully developed fire: The energy released in the enclosure is at its greatest level and is very often limited by the available oxygen
  - Gas temperatures between 700°C (1,300°F) and 1200°C (2,200°F)
- Decay: Fuel becomes consumed
  - Hazard indicators (temperature and heat fluxes) start to decrease
- Other terminology may include
  - Pre-flashover fire
    - Focus on life safety and sensitive targets
    - In NPP, cables damage at 218°C (424°F) for thermoplastic cables and 330°C (626°F) for thermoset cables
  - Post-flashover fire:
    - Focus in structural stability and safety of firefighters

Compartment Fires



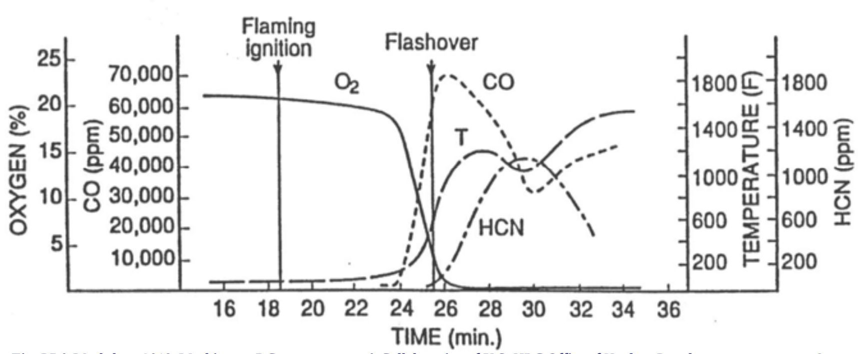
Compartment Fires



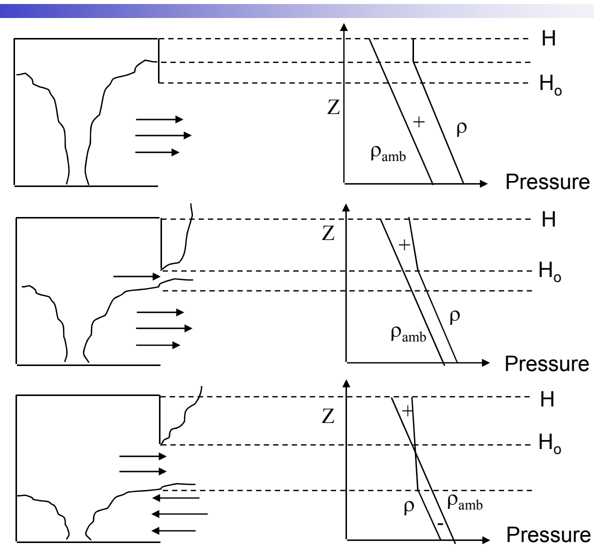
Sense of Scale

Room: 12 x 18 x 8 ft. high; open doorway

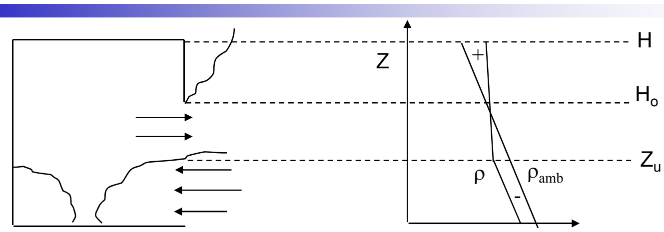
Data at 5.5 ft. height



Pressure Profiles & Vent Flows



Pressure Profiles & Vent Flows



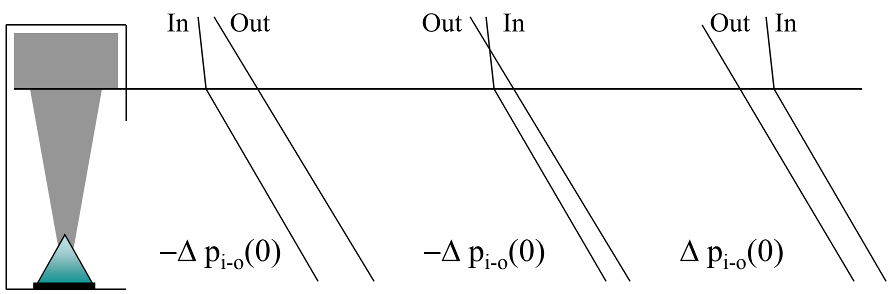
$$P_i(h) = P_i(0) - \rho_o gZu - \rho_u g(h - Zu)$$ **Inside Profile**

$$P_o(h) = P_o(0) - \rho_o gh$$ **Outside Profile**

$$\Delta P_{i-o}(h) = \Delta P_i(0) + \rho_o g(h - Zu) + \rho_u g(Zu - h)$$ **ΔP Profile**

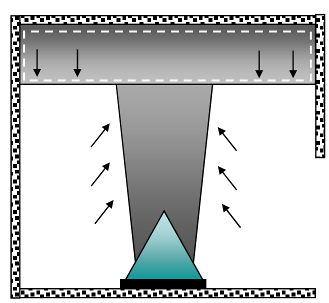
Pressure Profiles & Vent Flows

Under Pressurized | **Normal** | **Over Pressurized**



Smoke Layer

- Accumulation of hot gases in the upper part of the room
- Mass: entrainment (~90%) and combustion products (~10%)
- Volume: entrainment, combustion products, and expansion due to energy added
- Temperature rise: expansion generates a larger volume than corresponding mass resulting in lower gas densities.
- Conservation of mass and energy



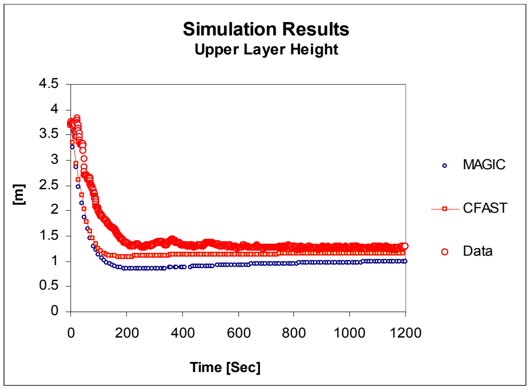
Smoke Layer

Room size:

- 22 x 7 x 3.7 m

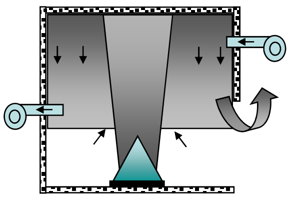
Fire: ~1 MW

Door: 2 x 2 m



Smoke Layer

- Conservation of Mass
  - Rate of change of mass in the control volume
    - Accumulation
  - Mass flow through the control surface
    - Plume flow
    - Supply and exhaust systems
    - Flow through doors and windows

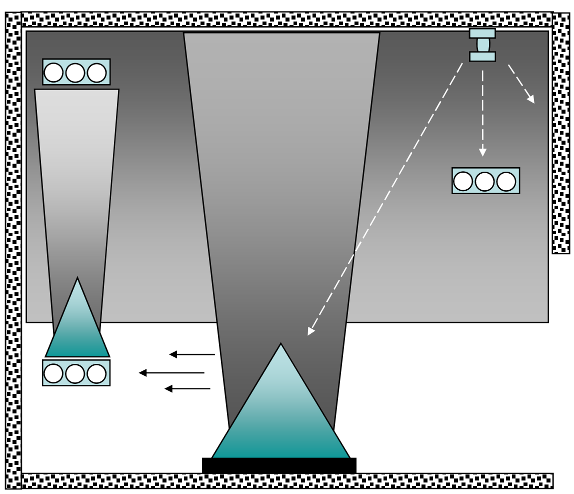


Heat Transfer

- To walls
  - Convection and radiation
  - Conduction losses
- To targets
  - Convection and radiation
- Heat losses
  - Conduction through walls
  - Convection and radiation through openings and vents

Heat Transfer

- Conduction
- Convection
- Radiation



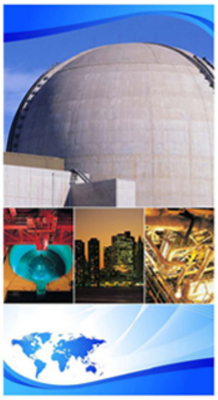
Self- Assessment

Fire PRA Methodology

1. **_________________________ is used to calculate the temperature inside a cable.**

2. **Hot Gas Layer (HGL) changes as a function of ________________ .**
   a) *Time*
   b) Area
   c) Distance
   d) Height

3. **Name the phases in a compartment fire:**
   a)
   b)
   c)
   d)
   e)
   f)



EPRI/NRC-RES FIRE PRA METHODOLOGY

Detection and Suppression

Part 4 of 6

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

Objectives

- Fire PRA credits fire detection and suppression features when appropriate
- The objective of this presentation is to briefly describe typical detection and suppression features that are credited

Fire Detection

- Typical fire detection features credited in the Fire PRA
  - Prompt detection
  - Smoke detection
  - Heat detection
  - Incipient detection
  - Delayed detection

Prompt Detection

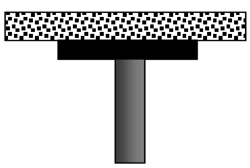
- Continuous fire watch
- Hotwork fire watch
- Continuously manned rooms, e.g., the control room

Smoke Detection

- Spot type smoke detectors
  - Ionization detection
  - Optical density detection
- Generally, smoke particles move into the chamber for the device to actuate
- Needs power (generally line and backup battery)

Heat Detection

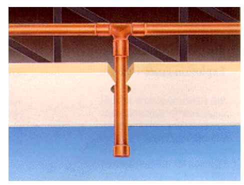
- Heat detectors
  - Detection devices
  - Sprinkler heads
  - Linear heat detectors



- Generally characterized by a response time index and an activation temperature
  - Response Time Index (RTI): a parameter describing how fast the device responds to the surrounding gas temperature
  - Activation Temperature: the temperature at which the detection device actuates

Incipient Detection

- Examples include air sampling systems
- Typically used where conventional fire detectors can't provide sufficiently rapid response.
- The objective is for plant personnel to prevent potential fire impacts



Delayed Detection

- Roving fire watch
- Plant personnel
- Control room indication
  - The control room receives a process alarm and dispatches an operator to inspect the situation.

Fire Suppression

- Fire can be suppressed by:
  - Cooling down the burning fuel and adjacent items – example: water spray
  - Removing oxygen – example: CO_2
  - Separating burning surface from impinging heat flux from the flame – example: Foam

Fire Suppression

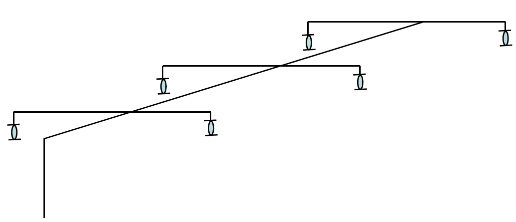
- Prompt suppression
- Automatic sprinklers
- Dry-Pipe/Pre-action sprinklers
- Deluge systems
- CO2: Automatic or Manual
- Halon: Automatic or Manual
- Fire brigade

Prompt Suppression

- Hotwork fire watch
- Some of the operators are generally trained in the use of portable extinguishers

Automatic Sprinklers

- Fusible links at the nozzles
- Water readily available
- Full room coverage, localized, in trays, etc.



Dry-Pipe/Pre-Action Sprinklers

- Sprinkler pipes are maintained dry (upstream shutoff valve keeps the water away from sprinkler heads)
- A smoke detection system opens the shutoff valve that fills the pipes (turns the system into a wet system)
- Sprinkler heads need to open from exposure to heat from the fire.

Deluge Sprinklers

- Pipes are maintained dry
- All sprinkler heads are open
- A smoke or heat detection system signals the main shutoff valve open
- All sprinklers discharge at the same time upon opening of the shutoff valve
- Generally used for protecting large liquid filled transformers and high fire hazard areas

Carbon Dioxide

- CO_2 gas is used to displace oxygen from the fire.
- Automatic CO_2- Suppression agent is generally released after smoke detection and a life safety alarm and delay time
- Manual CO_2- Requires an operator or fire brigade personnel to activate the system after smoke detection
- Must maintain proper suppression agent concentration for a soak time
- Life safety considerations

Halon

- Automatic Halon- Suppression agent is generally released after smoke detection and a life safety alarm and delay time
- Manual Halon- Requires an operator or fire brigade personnel to activate the system after smoke detection
- Must maintain proper suppression agent concentration for a soak time
- Not being manufactured any more and existing ones are being phased out because of environmental considerations

Fire Brigade

- Credited in most fire scenarios
- Typically characterized by the response time and time to start suppression activities in each room
- Typically use portable extinguishers (gaseous) first, followed by water (fire hose) if needed
- Typically plants maintain a professional brigade or operators/plant personnel are trained in fire fighting techniques

Passive Fire Protection

- Passive fire protection refers to fixed features put in place for reducing or preventing fire propagation.

- Such features include coatings, cable tray barriers, fire stops, self-closing dampers, penetration seals, self-closing doors, and fire-rated walls.

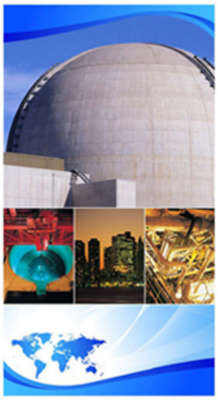
Self- Assessment

Fire PRA Methodology

1. **Name typical fire detection methods credited in Fire PRA:**
   - **a)**
   - **b)**
   - **c)**
   - **d)**
   - **e)**

2. **Explain how smoke detectors differ from heat detectors.**

3. **Name typical fire suppression methods credited in Fire PRA:**
   - **a)**
   - **b)**
   - **c)**
   - **d)**
   - **e)**
   - **f)**



EPRI/NRC-RES FIRE PRA METHODOLOGY

Analysis Tools

Part 5 of 6

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

Analysis Tools: Outline

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

Five Steps of Fire Modeling

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

Fire Modeling

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

Capabilities

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

Fire Models

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

Hand Calculations

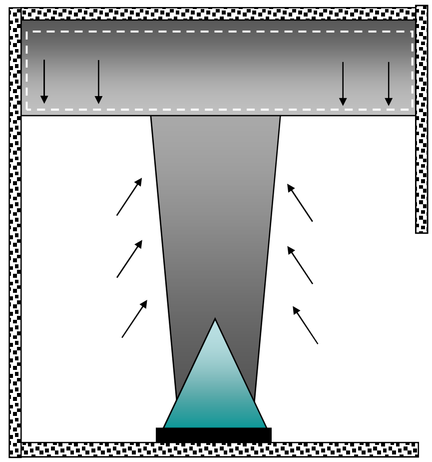
- Heat release rate, flame height and flame radiation
- Fire plume velocity, temperature heat flux, and entrainment
- Ceiling jet velocity, temperature, and heat flux
- Overall room temperature
- Target temperature, and time to target damage

Example of Hand Calcs: FDT's

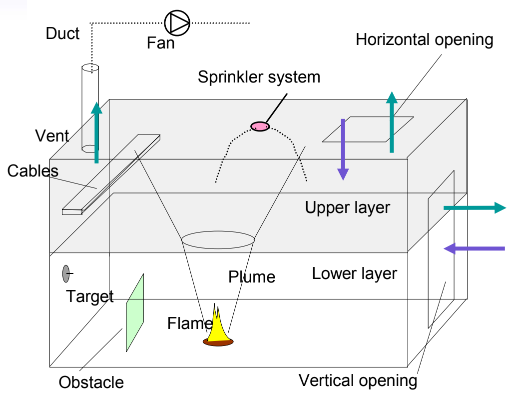
- **FDTs** are a series of Microsoft Excel® spreadsheets issued with **NUREG-1805, "Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program**."
- The primary goal of FDTs was to be a training tool to teach NRC Fire Protection Inspectors.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

Zone Models

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



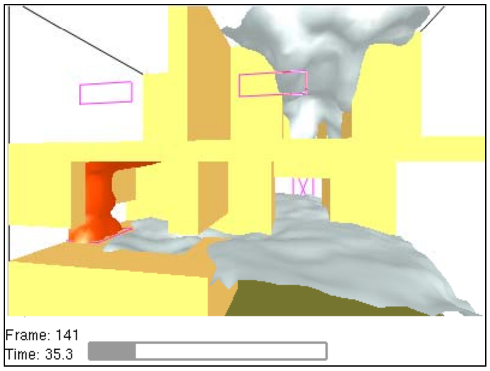
Example of a Zone Model: MAGIC



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

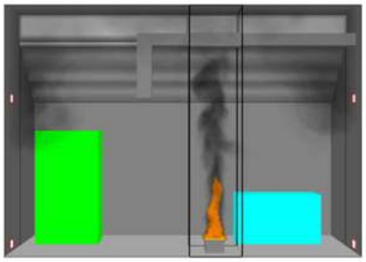
Field Models

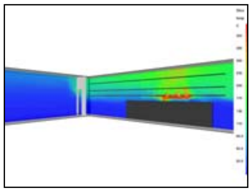
- Solve a simplified form of the Navier Stokes equations for low velocity flows
- Calculation time in the order of hours, days or weeks
- May help in modeling complex geometries

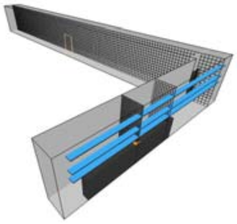


Example of Field Model: FDS

- Fire Dynamics Simulator
- Developed and maintained by NIST







Special Models

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

Which Model to Choose

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

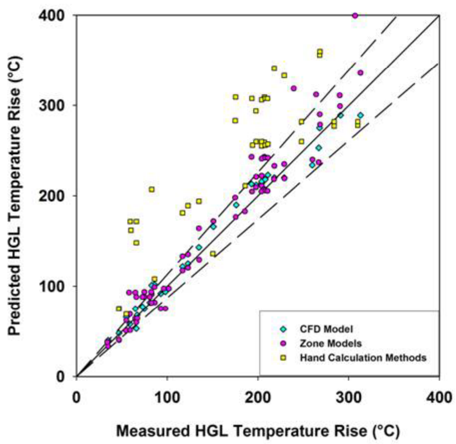
Verification and Validation

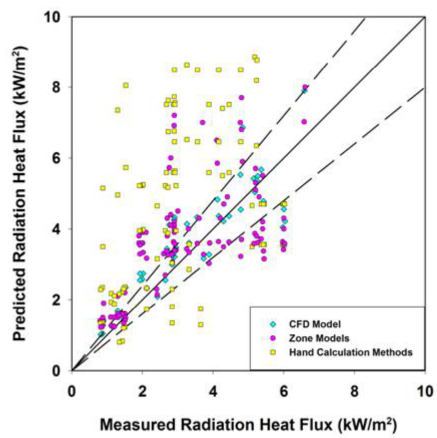
- ***Verification:*** the process of determining that the implementation of a calculation method accurately represents the developer’s conceptual description of the calculation method and the solution to the calculation method. *Is the Math right?*
- ***Validation:*** the process of determining the degree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

Verification and Validation

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

Verification and Validation





Fire PRA Workshop, 2010, Washington DC
Introduction to Fire Analysis

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

17

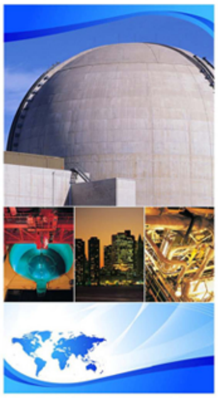
Self- Assessment

Fire PRA Methodology

1. **What are the steps of PRA fire modeling:**
   - **a)**
   - **b)**
   - **c)**
   - **d)**
   - **e)**

2. **Define fire modeling?**

3. **Name the different types of fire models discussed in the materials:**
   - **a)**
   - **b)**
   - **c)**
   - **d)**



EPRI/NRC-RES FIRE PRA METHODOLOGY

Fire Scenarios

Part 6 of 6

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

Fire Scenario

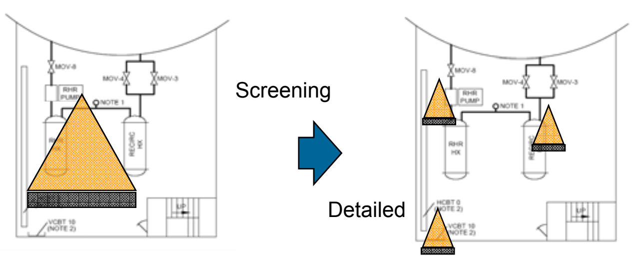
- A set of elements representing a fire event:
  - The ignition source, e.g., electrical cabinets, pumps
  - Intervening combustibles, e.g., cables
  - Targets, e.g., power, instrumentation or control cables
  - Fire protection features, e.g., automatic sprinklers
  - The compartment where the fire is located
  - A time line

Fire Scenario Time Line

1. Starts with a specific ignition source
2. Fire growth involving the affected fuel,
3. Heat transfer from the fire to other items within the zone of influence,
4. Damage of the affected items (e.g., cables and equipment items),
5. Propagation of the fire to other materials,
6. Detection of the fire (Note: this step could occur right after #2, or even #1 if there is very early warning smoke detection present)
7. Automatic initiation of suppression systems of the area,
8. Fire brigade response,
9. Successful fire extinguishment.

Fire Scenario - *Level of Detail*

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



Fire Scenario *Initial Screening Stage*

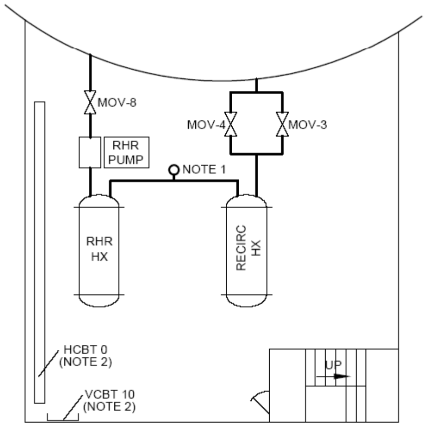
- In the initial stages of screening, fire scenarios are defined in terms of compartments and loss of all items within each compartment.
  - Assumes all items fail in the worst failure mode
  - Detection and suppression occur after the worst damage takes place
  - Fire does not propagate to adjacent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

Detailed Scenario Identification Process

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

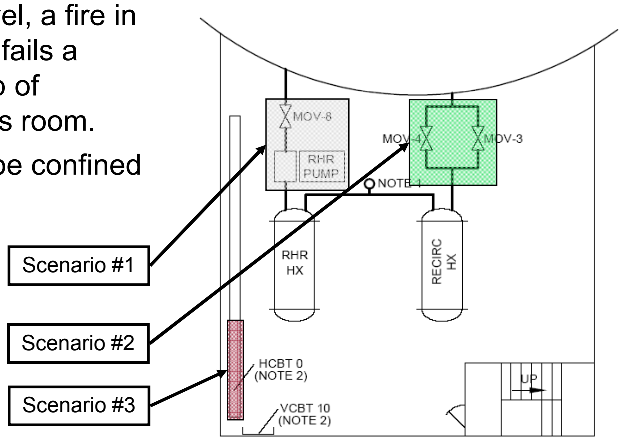
Example – Screening Level

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



Example – Detailed Analysis

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



Select and Describe Fire Scenarios

- Selection of fire scenarios:
  - How many fire scenarios are enough to demonstrate the objective?
  - Which scenarios are the appropriate ones?
- Selecting scenarios is dependent on the objectives of the fire risk quantification
  - Fire conditions that are actually modeled
  - Represent a complete set of fire conditions relevant to the objectives
- Selection of scenarios is dependent on the hazard characteristics of the area
  - Combustibles, layouts, fire protection
- The fire scenario should challenge the conditions being considered
  - Can the fire cause damage? vs. Which fire can cause damage?

Select and Describe Fire Scenarios

1. Scenarios should have an ignition source and at least one target or other measurable objectives
2. Consider the range of possible intervening combustibles
3. Scenarios should capture targets as well as fire's ability to ignite or damage them
4. Include in the scenario any fire protection system (active or passive) that may influence the outcome of the event

Select and Describe Fire Scenarios

5. Sometimes, multiple ignition sources or targets can be combined into one scenario
6. Sketch the scenario on a compartment layout drawing and try to qualitatively describe the conditions that a fire might generate. After the analysis, compare this qualitative prediction with the modeling results.
7. Do not neglect the importance of details such as ceiling obstructions, soffits, open or close doors, etc.

Scenario Quantification

- Ignition frequency: fire frequency for the postulated ignition source
- Apportioning factor: probability that the ignition occurs in a specific ignition source or plant location
- Severity factor: probability that the fire is severe enough to generate the postulated damage
- Non suppression probability: probability of failing to suppress the fire
- Circuit failure probability: probability that the affected circuits will generate the postulated equipment impact
- Conditional core damage probability

$$CDF = \lambda \cdot W \cdot SF \cdot P_{ns} \cdot P_{cf} \cdot CCDP$$

Scenario Quantification

- A fire in a specific plant location
  - That is severe enough
    - That is unsuppressed
      - That generates the postulated circuit failure mode
        - That prevents safe shutdown

$$\lambda_{is} = \lambda_g \cdot W \cdot 1 \cdot 1 \cdot 1$$

$$\lambda_{is} = \lambda_g \cdot W_{is} \cdot SF \cdot 1 \cdot 1$$

$$\lambda_{is} = \lambda_g \cdot W_{is} \cdot SF \cdot P_{ns} \cdot 1$$

$$\lambda_{is} = \lambda_g \cdot W_{is} \cdot SF \cdot P_{ns} \cdot P_{cf}$$

$$\lambda_{CDF} = \lambda_{is} \cdot ccdp$$

Self- Assessment

Fire PRA Methodology

1. **In the video, Part 6 of 6, the speaker states, "*Timeline is key to analyzing risk assessment*".**
   a) *True*
   b) *False*

2. **In ___________________ , at any level of detail, a fire scenario represents a collection of more detailed scenarios.**
   a) *screening*
   b) *practice*
   c) *processing*
   d) *principle*

3. **In your own words, explain Core Damage Frequency (CDF) in scenario quantification.**

APPENDIX C: MATERIALS SUPPORTING BASIC CONCEPTS OF FIRE HUMAN RELIABILITY ASSESSMENT (HRA) TRAINING VIDEOS

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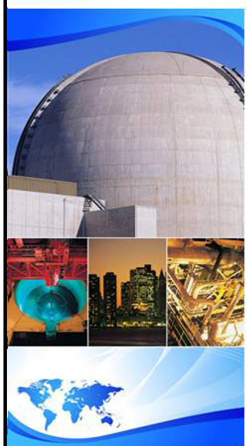
SAIC Science Applications International Corporation
From Science to Solutions



Principles of Human Reliability Analysis (HRA)

Part 1 of 5

Joint RES/EPRI Fire PRA Workshop
September and October 2010
Washington, DC

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

Course Objectives

- Introduce Human Reliability Analysis (HRA), in the context of PRA for nuclear power plants.
- Provide students with a basic understanding of HRA:
  - What is HRA?
  - Where does HRA fit into PRA?
  - What does HRA model?
  - Is there a standard for performing HRA?
  - What guidance is there for performing HRA?
  - What are the keys to performing HRA?
  - How can we understand human error?
  - What are the important features of existing HRA methods?
  - What are the HRA concerns or issues for fire PRA?

Course Outline

- **What is HRA?**
- Where does HRA fit into PRA?
- What does HRA model?
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- How can we understand human error?
- What are the important features of existing HRA methods?
- What are the HRA concerns or issues for fire PRA?
- Any final questions?

Human Reliability Analysis (HRA) ….

Is generally defined as:

- A **structured approach** used to **identify** potential human failure events (HFEs) and to systematically **estimate the probability** of those errors using data, models, or expert judgment

Is developed because:

- **PRA reflects the as-built, as-operated plant**
- **HRA is needed to model the "as-operated" portion (and cross-cuts many PRA tasks and products)**

Produces:

- Identified and defined human failure events (HFEs)
- Qualitative evaluation of factors influencing human errors and successes
- Human error probabilities (HEPs) for each HFE

HRA …. (continued)

- Requires inputs from many technical disciplines, e.g.,:
  - PRA
  - Plant design & behavior
  - Engineering (e.g., thermal hydraulics)
  - Plant operations
  - Procedures & how they are used
  - Ergonomics of monitoring & control interfaces (both inside & outside control room)
  - Cognitive & behavioral science
  - Etc., etc., etc.
- Is performed by:
  - A multi-disciplinary team

Course Outline

- What is HRA?
- **Where does HRA fit into PRA?**
- What does HRA model?
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- How can we understand human error?
- What are the important features of existing HRA methods?
- What are the HRA concerns or issues for fire PRA?
- Any final questions?

SRL2

Overview of PRA Process

- PRAs are performed to find severe accident weaknesses and provide quantitative results to support decision-making. Three levels of PRA have evolved:

Level	An Assessment of:	Result
1	Plant accident initiators and systems'/operators' response	Core damage frequency & contributors
2	Reactor core melt, and frequency and modes of containment failure	Categorization & frequencies of containment releases
3	Public health consequences	Estimation of public & economic risks

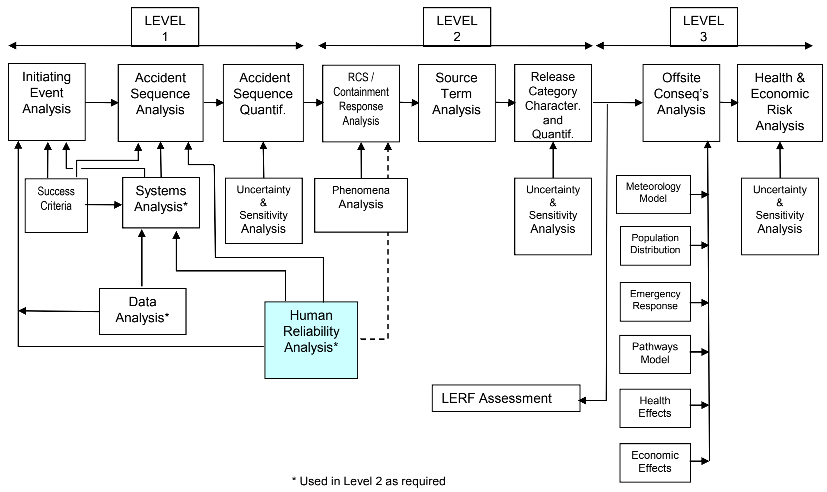
PRA Classification

- Internal Hazards – risk from accidents initiated internal to the plant
  - Includes internal events, internal flooding and internal fire events
- External Hazards – risk from external events
  - Includes seismic, external flooding, high winds and tornadoes, airplane crashes, lightning, hurricanes, etc.
- At-Power – accidents initiated while plant is critical and producing power (operating at >X%* power)
- Low Power and Shutdown (LP/SD) – accidents initiated while plant is <X%* power or shutdown
  - Shutdown includes hot and cold shutdown, mid-loop operations, refueling

**X is usually plant-specific. The separation between full and low power is determined by evolutions during increases and decreases in power.*

SRL3

Principal Steps in PRA



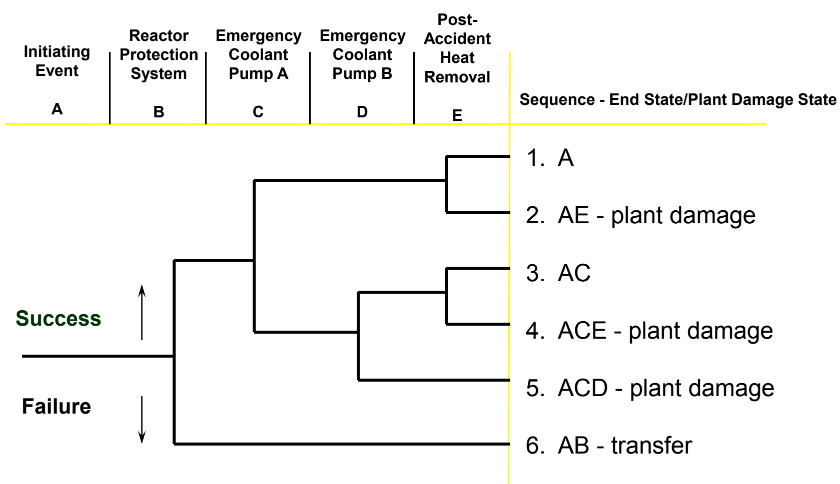
HRA modeling in Event Trees (ETs)

Human Events in Event Trees

Nature of event trees:

- Typically used to model the response to an initiating event
- Features:
  - Generally, a unique system-level event tree is developed for each initiating event group
  - Identifies systems/functions required for mitigation
  - Identifies operator actions required for mitigation
  - Identifies event sequence progression
  - End-to-end traceability of accident sequences leading to bad outcome
- Primary use
  - Identification of accident sequences which result in some outcome of interest (usually core damage and/or containment failure)
  - Basis for accident sequence quantification

Simple Event Tree



System-Level Event Tree Development

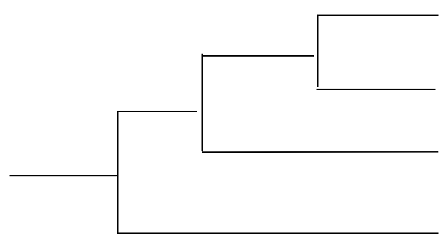
- A system-level event tree consists of an initiating event (one per tree), followed by a number of headings (top events), and sequences of events defined by success or failure of the top events
- Top events represent the systems, components, and/or human actions required to mitigate the initiating event
- To the extent possible, top events are ordered in the time-related sequence in which they would occur
  - Selection of top events and ordering reflect emergency procedures
- Each node (or branch point) below a top event represents the success or failure of the respective top event
  - Logic is typically binary
    - Downward branch – failure of top event
    - Upward branch – success of top event
  - Logic can have more than two branches, with each branch representing a specific status of the top event

System-Level Event Tree Development (Continued)

- Dependencies among systems (to prevent core damage) are identified
  - Support systems can be included as top events to account for significant dependencies (e.g., diesel generator failure in station blackout event tree)
- Timing of important events (e.g., physical conditions leading to system failure) determined from thermal-hydraulic (T-H) calculations
- Branches can be pruned logically to remove unnecessary combinations of system successes and failures
  - This minimizes the total number of sequences that will be generated and eliminates illogical sequences
- Branches can transfer to other event trees for development
- Each path of an event tree represents a potential scenario
- Each potential scenario results in either prevention of core damage or onset of core damage (or a particular end state of interest)

Functional Event Tree

Initiating Event	Reactor Trip	Short term core cooling	Long term core cooling	SEQ #	STATE
IE	RX-TR	ST-CC	LT-CC		



SEQ #	STATE
1	OK
2	LATE-CD
3	EARLY-CD
4	ATWS

Critical Safety Functions

Example safety functions for core & containment

- Reactor subcriticality
- Reactor coolant system overpressure protection
- Early core heat removal
- Late core heat removal
- Containment pressure suppression
- Containment heat removal
- Containment integrity

Example BWR Mitigating Systems

Function	Systems
Reactivity Control	Reactor Protection System, Standby Liquid Control, Alternate Rod Insertion
RCS Overpressure Protection	Safety/Relief Valves
Coolant Injection	High Pressure Coolant Injection, High Pressure Core Spray, Reactor Core Isolation Cooling, Low Pressure Core Spray, Low Pressure Coolant Injection (RHR) Alternate Systems- Control Rod Drive Hydraulic System, Condensate, Service Water, Firewater
Decay Heat Removal	Power Conversion System, Residual Heat Removal (RHR) modes (Shutdown Cooling, Containment Spray, Suppression Pool Cooling)

Example PWR Mitigating Systems

Function	Systems
Reactivity Control	Reactor Protection System (RPS)
RCS Overpressure Protection	Safety valves, pressurizer Power-Operated Relief Valves (PORVs)
Coolant Injection	Accumulators, High Pressure Safety Injection (HPSI), Chemical Volume and Control System (CVCS), Low Pressure Safety Injection (LPSI), High Pressure Recirculation (may require LPSI)
Decay Heat Removal	Power Conversion System (PCS), Auxiliary Feedwater (AFW), Residual Heat Removal (RHR), Feed and Bleed (PORV + HPSI)

System Success Criteria

- Identify systems which can perform each function
- Often include if the system is automatically or manually actuated.
- Identify minimum complement of equipment necessary to perform function (often based on thermal/hydraulic calculations, source of uncertainty)
  - Calculations often realistic, rather than conservative
- May credit non-safety-related equipment where feasible

Example Success Criteria

IE	*Reactor Trip*	*Short Term Core Cooling*	*Long Term Core Cooling*
Transient	*Auto Rx Trip or Man. Rx Trip*	*PCS or 1 of 3 AFW or 1 of 2 PORVs & 1 of 2 ECI*	*PCS or 1 of 3 AFW or 1 of 2 PORVs & 1 of 2 ECR*
Medium or Large LOCA	*Auto Rx Trip or Man. Rx Trip*	*1 of 2 ECI*	*1 of 2 ECR*

What does HRA do with ET information?

For example, the HRA analyst:

- From initiating event and subsequent top events on ET:
  - Identifies the procedures and procedure path that lead to successful mitigation of the initiating event
- From success criteria:
  - Determines what defines an operator failure (e.g., fewer pumps started than needed, actions performed too late in time)
- From plant behavior timing provided by T-H calculations:
  - Determines what plant parameters, alarms, and other indications are available to help operators:
    - understand the plant state (initially and as the accident progresses)
    - use procedures appropriately to respond to specific accident sequence

What does HRA do with ET information? (continued)

- From the various branches on the event tree (combined with success criteria and timing information):
  - Identifies (or confirms) what operator actions, if failed, could result in "down" branches and certain plant damage states (alone or in combination with system failures)
  - Identifies what specific operator actions (e.g., fails to start HPI Train A pump, turns off Safety Injection) would result in a "down" branch
  - Identifies what procedure paths might be plausibly taken that would result in operator failures
  - Identifies what plant information (or missing information) might cause operators to take inappropriate procedure paths
- These inputs also can be as factors influencing the selection of screening values for human failure events.

HRA modeling in Fault Trees

Human Events in Fault Trees

Characteristics of fault trees:

- Deductive analysis (event trees are inductive)
- Start with undesired event definition
- Used to estimate system failure probability
- Explicitly model multiple failures
- Identify ways by which a system can fail
- Models can be used to find:
  - System "weaknesses"
  - System failure probability
  - Interrelationships between fault events

Fault Trees (cont.)

- Fault trees are graphic models depicting the various paths of combinations of faults that will result in the occurrence of the undesired top event.
- Fault tree development moves from the top event to the basic event (or faults) which can cause it.
- Fault tree consists of gates to develop the fault logic in the tree.
- Different types of gates are used to show the relationship of the input events to the higher output event.
- Fault tree analysis requires thorough knowledge of how the system operates and is maintained.

Specific Failure Modes Modeled for Each Component

- Each component associated with a specific set of failure modes/mechanisms determined by:
  - Type of component
    - E.g., Motor-driven pump, air-operated valve
  - Normal/Standby state
    - Normally not running (standby), normally open
  - Failed/Safe state
    - Failed if not running, or success requires valve to stay open

Typical Component Failure Modes

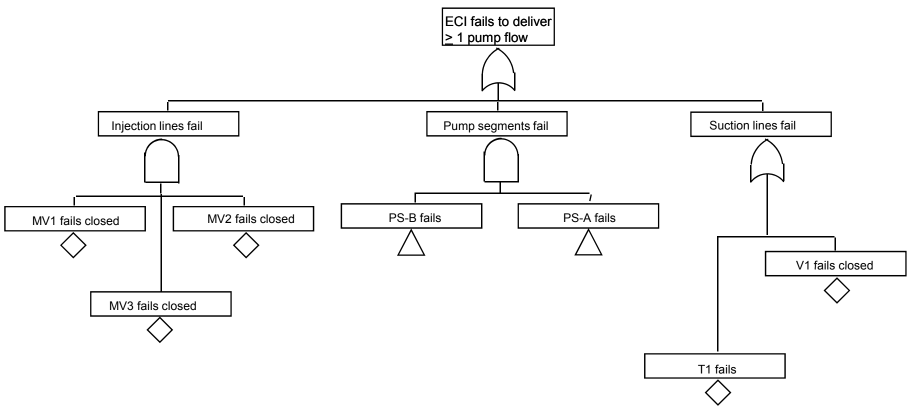
- Active Components
  - Fail to Start*
  - Fail to Run*
  - Fail to Open/Close/Operate*
- Additional "failure mode" is component is unavailable because it is out for test or maintenance

* Operator "error of commission" – suppresses actuation or operation, or turns off

Active Components Require "Support"

- Signal needed to "actuate" component
  - Safety Injection Signal starts pump or opens valve
- If system is a "standby" system, operator action may be needed to actuate
- Support systems might be required for component to function
  - AC and/or DC power
  - Service water or component water cooling
  - Room cooling

Simplified Fault Tree for Failure of Emergency Coolant Injection (ECI)



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Principles of HRA

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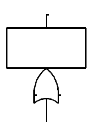
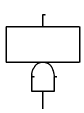
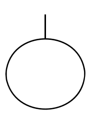
Fault Tree Symbols

Symbol		Description
	"OR" Gate	Logic gate providing a representation of the Boolean union of input events. The output will occur if at least one of the inputs occur.
	"AND" Gate	Logic gate providing a representation of the Boolean intersection of input events. The output will occur if all of the inputs occur.
	Basic Event	A basic component fault which requires no further development. Consistent with level of resolution in databases of component faults.

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What does HRA do with FT information?

- From the top events & types of equipment modeled in the fault tree:
  - Identify & define any human failure events (HFEs) that could result in system, train, or component failures (e.g., starting, actuating, opening/closing)
- From review of procedures & other documents related to testing & maintenance:
  - Identify & define operator failures to restore systems, trains, or components following testing or maintenance
  - Determine the frequency of testing & preventive maintenance
  - Determine what post-testing & post-maintenance checks are performed
- These inputs also can be used in selecting appropriate screening values for HFEs.

Self- Assessment

Human Reliability Analysis (HRA) Basics

1. **What is HRA?**

2. **List the three main products of an HRA:**

   -
   -
   -

3. **True or False**

   In terms of PRA Classification, a seismic event is an example of an Internal Hazard.

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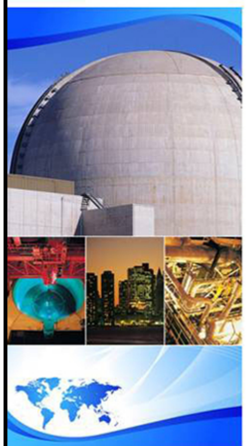

Principles of Human Reliability Analysis (HRA)

Part 2 of 5

Joint RES/EPRI Fire PRA Workshop
September and October 2010
Washington, DC

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

Course Outline

- What is HRA?
- Where does HRA fit into PRA?
- **What does HRA model?**
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- How can we understand human error?
- What are the important features of existing HRA methods?
- What are the HRA concerns or issues for fire PRA?
- Any final questions?

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Principles of HRA

Slide 32

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Human Reliability Analysis

- Starts with the basic premise that the humans can be represented as either:
  - A component of a system, or
  - A failure mode of a system or component.
- Identifies and quantifies the ways in which human actions initiate, propagate, or terminate fault & accident sequences.
- Human actions with both positive and negative impacts are considered in striving for realism.
- A difficult task in a PRA since the HRA analyst needs to understand the plant hardware response, the operator response, the accident progression modeled in the PRA.

Human Reliability Analysis Objectives

Ensure that the **impacts of plant personnel** actions are reflected in the assessment of risk in such a way that:

a) both **pre-initiating event and post-initiating event** activities, including those modeled in support system initiating event fault trees, are addressed.

b) logic model elements are defined to represent the effect of such personnel actions on **system availability**/unavailability and on **accident sequence** development.

c) plant-specific and scenario-specific factors are accounted for, including those factors that influence either what activities are of interest or human performance.

d) human performance issues are addressed in an integral way so that **issues of dependency are captured**.

Ref. ASME RA-Sa-2009

Categories of Human Failure Events in PRA

- Operator actions can occur throughout the accident sequence:
  - Before the initiating event (i.e., pre-initiator)
  - As a cause of the initiating event
  - After the initiating event (i.e., post-initiator)

Categories of Human Failure Events: Pre-Initiator HFEs

- Sometimes called "latent errors" because they are not revealed until there is a demand for the affected system (after the initiating event).
- Examples:
  - Failure to restore valve lineup following routine system testing
  - Failure to rack-in pump breaker in following preventive maintenance
  - Mis-calibration of instrument strings
- Most frequently relevant outside main control room
- Some of these failures are captured in equipment failure data.
- For HRA, the focus is on equipment being left misaligned, unavailable, or not working exactly right (accounting for post-test/post-maintenance verification).

Categories of Human Failure Events: Initiating-Event Related

- Operator actions can contribute to the occurrence of or **cause initiating events** (i.e., human-induced initiators)
- In PRAs, such events are most often
  - Included implicitly in the data used to quantify initiating event frequencies, and
  - Therefore not modeled explicitly in the PRA
- Operator actions can be particularly relevant for operating conditions other than power operation
  - Human-caused initiating events can have unique effects (e.g., causing drain-down of reactor or RCS during shutdown)
  - Actions that cause initiating events may also have implications for subsequent human response (i.e., dependence can be important)

Categories Of Human Failure Events: Post-Initiator HFEs

- **Post-initiator HFEs** account for failures associated with response to an initiating event
- Typically reflect failure to take necessary action (in main control room or locally)
  - Failure to initiate function of manually-actuated system
  - Failure to back up an automatic action
  - Failure to recover from other system failures
    - Reconfigure system to overcome failures (e.g., align electrical bus to alternative feed)
    - Make use of an alternative system (e.g., align fire water to provide pump cooling)
- Most often reflect failure to take actions called for by procedures

Other Classifications of Human Failure Events

- Another way to classify human failure events (HFEs) from the perspective of the PRA is:
  - Error of omission (EOO)
  - Error of commission (EOC)
- Errors of omission (EOOs):
  - *A human failure event resulting from a failure to take a required action, leading to an unchanged or inappropriately changed and degraded plant state.*
  - Examples:
    - Failure to start auxiliary feedwater system
    - Failure to block automatic depressurization system signals

Other Classifications of HFEs (continued)

- Errors of commission (EOCs):
  - *A human failure event resulting from a well-intended but inappropriate, overt action that, when taken, leads to a change in the plant and results in a degraded plant state.*
  - Often, these events represent "good" operating practice, but applied to the wrong situation (especially, when understanding the situation is difficult).
  - Examples:
    - Prematurely terminating safety injection (because operators think SI is not needed; but for the specific situation, SI is needed).

Other Classifications of HFEs (continued)

- Pre-initiator HFEs can be either EOOs or EOCs:
  - These HFEs usually represent failures in execution (i.e., failures to accomplish the critical steps; these steps are typically already decided so no decision-making is required).
  - Execution failures are often caused by inattention (or over-attention) failures
  - Examples:
    - Inattention: Skipped steps (especially, following interruptions or other distractions)
    - Over-attention: Repeated or reversed steps

Other Classifications of HFEs (continued)

- Most post-initiator HFEs that are modeled are EOOs:
  - These HFEs can represent either failures in execution or cognitive failures (such as failures in diagnosis of the plant condition or decision-making regarding procedure use for a particular situation).
  - Most PRAs ***only include*** EOOs; however, EOCs have been involved in many significant accidents, both in nuclear power industry & others.
  - Later, we'll see that the fire PRA methodology for NFPA-805 requires that certain EOCs be addressed.

Course Outline

- What is HRA?
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Standard for HRA?

- NRC's Regulatory Guide 1.200 provides staff position for one approach in determining the technical adequacy of a PRA to support a risk-informed activity
- The staff position, in determining technical adequacy, defines a technically acceptable base PRA
- For each technical element (e.g., HRA)
  - Defines the necessary attributes and characteristics of at technically acceptable HRFA
  - Allows use of a standard in conjunction with a peer review to demonstrate conformance with staff position
  - Endorses ASME/ANS standard and NEI peer review guidance (with some exceptions)

Standard for HRA? (continued)

- RG 1.200 specifies what is needed in a technically acceptable PRA/HRA
- ASME/ANS PRA standard defines requirements*
  - Specifies **what** you need to do.
- These standard requirements have been established to ensure PRA quality commensurate with the type of PRA application and/or regulatory decision

*The use of the word “Requirements” is Standard language and is not meant to imply any regulatory requirement

Standard for HRA? (continued)

- The standard provides two levels of technical requirements:
  - High level requirements (HLRs)
  - Supporting requirements (SRs)
- The HLRs provide the minimum requirements for a technically acceptable baseline PRA. The HLRs are defined in general terms and reflect the diversity of approaches and accommodate future technological innovations.
- The SRs define the requirements needed to accomplish each HLR

Standard for HRA? (continued)

- In defining the SRs, the standard recognizes that, depending on the application, the level of detail, the level of plant specificity and the level of realism can vary
- Three capability categories are defined, and the degree to which each is met increases from Category I to Category III
- Each SR is defined to a different "Capability Category"
- A PRA, even the HRA element can be a mixture of capability categories.

Standard for HRA? (continued)

- Capability Category I:
  - Scope and level of detail are sufficient to identify relative importance of contributors down to system or train level.
  - Generic data and models are sufficient except when unique design or operational features need to be addressed.
  - Departures from realism have moderate impact on results.
- Capability Category II:
  - Scope and level of detail are sufficient to identify relative importance of significant contributors down to component level, including human actions.
  - Plant-specific data and models are used for significant contributors.
  - Departures from realism have small impact on results.

Standard for HRA? (continued)

- Capability Category III:
  - Scope and level of detail are sufficient to identify relative importance of contributors down to component level, including human actions.
  - Plant-specific data and models are used for all contributors.
  - Departures from realism have negligible impact on results.

Objective HRA Technical Element in ASME/ANS PRA Standard

The objective of the human reliability element of the PRA is to ensure that the impacts of plant personnel actions are reflected in the assessment of risk in such a way that:

- Both pre-initiating event & post-initiating event activities addressed
- Logic model elements are defined to represent the effect of such personnel actions
- Plant-specific and scenario-specific factors are accounted for
- Human performance issues are addressed in an integral way so that issues of dependency are captured

PRA Standard Requirements for HRA

ASME HRA **High Level Requirements** Compared

Pre-Initiator	Post Initiator
A – Identify HFEs	E – Identify HFEs
B – Screen HFEs	
C – Define HFEs	F – Define HFEs
D – Assess HEPs	G – Assess HEPs
	H – Recovery HFEs
I – Document HFEs/HEPs	

ASME/ANS Standard Post-Initiator HRA High Level Requirements (HLRs)

- Examples of High Level Requirements (HLRs) for post-initiator HFEs:

HLR-HR-E

A systematic review of the relevant procedures shall be used to identify the set of operator responses required for each of the accident sequences

HLR-HR-F

Human failure events shall be defined that represent the impact of not properly performing the required responses, consistent with the structure and level of detail of the accident sequences.

ASME/ANS Standard Post-Initiator HRA High Level Requirements

- Examples (continued):

HLR-HR-G

The assessment of the probabilities of the post-initiator HFEs shall be performed using a well defined and self-consistent process that addresses the plant-specific and scenario-specific influences on human performance, and addresses potential dependencies between human failure events in the same accident sequence.

HLR-HR-H

Recovery actions (at the cutset or scenario level) shall be modeled only if it has been demonstrated that the action is plausible and feasible for those scenarios to which they are applied. Estimates of probabilities of failure shall address dependency on prior human failures in the scenario

ASME/ANS Standard Pre- and Post-Initiator HRA High Level Requirements

- Examples (continued):

HLR-HR-I

The HRA shall be documented consistent with the applicable supporting requirements (HLR-HR-I).

ASME/ANS Standard Post-Initiator HRA Supporting Level Requirements (SLRs)

- Examples of Supporting Level Requirements (SLRs) for post-initiator HFEs:

SLR-HR-E1

When identifying the key human response actions review (a) the plant-specific emergency operating procedures, and other relevant procedures (e.g., AOPs, annunciator response procedures) in the context of the accident scenarios (b) system operation such that an understanding of how the system(s) and the human interfaces with the system is obtained. (All Capability Categories)

ASME/ANS Standard Post-Initiator HRA Supporting Level Requirements (SLRs)

- Examples (continued):

SLR-HR-G1

Capability Category I: Use conservative estimates (e.g., screening values) for the HEPs of the HFEs in accident sequences that survive initial quantification.

Capability Category II: Perform detailed analyses for the estimation of HEPs for significant HFEs. Use screening values for HEPs for non-significant human failure basic events.

Capability Category III: Perform detailed analyses for the estimation of human failure basic events.

ASME/ANS Standard Post-Initiator HRA Supporting Level Requirements (SLRs)

- Examples (continued):

SLR-G6

Check the consistency of the post-initiator HEP quantifications. Review the HFEs and their final HEPs relative to each other to check their reasonableness given the scenario context, plant history, procedures, operational practices, and experience. (All Capability Categories)

ASME/ANS Standard: Supporting and Fire HRA-Specific Requirements

- The standard is for an at-power Level 1/LERF PRA for both internal and external hazards
- The requirements in the PRA standard for internal events provide the requirements for the base PRA model
- The other hazards (e.g., internal fires) build upon the base PRA model for internal events
- In general, the HRA requirements (both HLRs and SRs) for internal events apply to the other hazards (e.g., fire, seismic).
- The Fire HRA Track presented this week will identify HLRs and SRs specifically applicable in performing fire HRA/PRA.

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Self- Assessment

Human Reliability Analysis (HRA) Basics

1. **Pre-initiator human failure events are sometimes referred to as _________ ___________ because they are not revealed until there is a demand for the affected system.**

2. **A PRA in which generic data and models are used and the scope and level of detail are sufficient to identify relative importance of <u>contributors</u> down to <u>system</u> or <u>train</u> level would meet ________________ ____________________ , according to the ASME/ANS PRA standard.**

3. **A human failure event resulting from a well intended but inappropriate, overt action that, when taken leads to a change in the plant and results in a degraded plant state is called a(n) ______________ _____________ .**

   a) Error of Commission
   b) Pre initiator
   c) Error of Omission
   d) Human error

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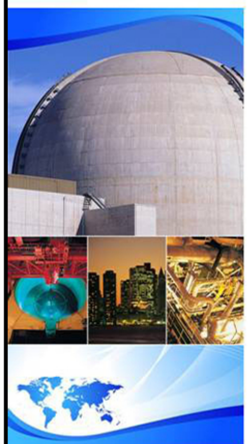

Principles of Human Reliability Analysis (HRA)

Part 3 of 5

Joint RES/EPRI Fire PRA Workshop
September and October 2010
Washington, DC

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

HRA Guidance – How To….

- From our last presentation:
  - The standard specifies **what** you need to do.
  - Guidance, on the other hand, is a description of **how-to** do something…..
- In this presentation, we will discuss three different types of HRA guidance associated with:
  1. HRA processes
  2. Other HRA tools or approaches
  3. HRA quantification methods

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Principles of HRA

Slide 60

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HRA Processes – How to….

- An HRA process is a prescribed set of steps for **how to** perform an HRA.
- Usually, an HRA process explicitly identifies steps that are also products of HRA, i.e.,
  1. Identification and definition of human failure events (HFEs),
  2. Quantification of each HFE (i.e., assignment of human error probabilities (HEPs)),
  3. Qualitative analysis that supports #1 and #2, and
  4. Documentation of all of the above.

HRA Processes – How to…. (continued)

- Not many HRA processes have been published.
- Usually, the HRA process provides both:
  1. Steps for **how to** perform HRA, and
  2. **How to** perform the steps.
- Two examples of published HRA processes are:
  – EPRI's " SHARP1 – A Revised Systematic Human Action Reliability Procedure," EPRI TR-101711, December 1992
  – NRC's "Good Practices for Implementing Human Reliability analysis (HRA)," NUREG-1792, April 2005

HRA Processes – How to…. (continued)

- SHARP1:
  - Written to provide a "user-friendly tool" for utilities in preparing Individual Plant Examinations (IPEs) back in the early 1990s.
  - Written to enhance the original SHARP, developed in 1984, to:
    - Address review comments
    - Incorporate the experience and insight gained in intervening years
  - Described as a "framework…for incorporating human interactions into PRA…" with emphasis on the iterative nature of the process.
  - Structured in "stages" to provide additional guidance for systematically integrating HRA into the overall plant logic model of the PRA.
  - Describes and compares selected HRA methods for quantification.
  - Includes four case studies.

HRA Processes – How to…. (continued)

- SHARP1 describes how to formulate a project team to perform HRA.
- SHARP1 is organized into four "stages" to define clearly the interactions with major PRA tasks:
  - Stage 1: Human Interaction Event Definition and Integration into Plant Logic Model
  - Stage 2: Human Interaction Event Quantification
  - Stage 3: Recovery Analysis
  - Stage 4: Internal Review
- The original 7 steps in SHARP still apply (but are captured within these four stages).

HRA Processes – How to…. (continued)

- SHARP1 uses three broad categories of human interactions:
  - Type A: Pre-initiating event interactions
  - Type B: Initiating event interactions
  - Type C: Post-initiating event interactions
    - CP: Actions dictated by operating procedures and modeled as essential parts of the plant logic model
    - CR: Recovery actions
- SHARP1 emphasizes the importance of dependencies between human interactions (especially with respect to premature screening of important interactions) and defines four classes of dependencies.

HRA Processes – How to…. (continued)

- SHARP1 provides detailed guidance on **how to** define and place HFEs into the plant logic model, including:
  - example event trees and fault trees
  - comparisons of procedure steps with what an HFE represents
  - detailed accounts for four case studies
- SHARP1 provides some discussion of influence and/or performance shaping factors, but there is no particular emphasis on this topic.
- Qualitative HRA is not explicitly identified or discussed, but is incorporated into different "stages"

HRA Processes – How to…. (continued)

- NRC's "Good Practices for HRA":
  - Written to establish "good practices" for performing HRA and to assess the quality of HRA, when it is reviewed.
  - Are generic in nature; not tied to any specific methods or tools.
  - Written to support implementation of RG 1.200 for Level 1 and limited Level 2 internal event, at-power PRAs (using direct links between elements of "good practices" and RG 1.200).
  - Consequently, written ultimately to address issues related to PRA quality and associated needs for confidence in PRA results used to support regulatory decision-making.
  - Developed using the experience of NRC staff and its contractors, including lessons learned from developing HRA methods, performing HRAs, and reviewing HRAs.

HRA Processes – How to…. (continued)

- NRC's "Good Practices" (GPs) address the following:
  - HRA team formation and overall guidance (2 GPs), e.g.,
    - Should use a multidisciplinary team
    - Should perform field observations
  - Pre-initiator HFEs (15 GPs), e.g.,
    - In identifying HFEs, should review procedures for all routine testing and maintenance
    - In quantifying HFEs, it is acceptable to use screening values if: a) the HEPs are clearly overestimates and b) dependencies among multiple HFEs are conservatively accounted for.
    - In quantifying HFEs, should account for the most relevant plant- and activity-specific performance shaping factors (PSFs).

HRA Processes – How to…. (continued)

- NRC's "Good Practices" (GPs) address (continued):
  - Post-initiator HFEs (17 GPs), e.g.,
    - In identifying HFEs, should review post-initiator related procedures and training.
    - In modeling (a.k.a., defining) HFEs, should define such that they are plant- and accident sequence-specific.
    - In quantifying HFEs, should address both diagnosis and response execution failures.
    - In adding recovery actions, should consider a number of aspects (e.g., whether cues will be clear and timely, whether there is sufficient time available, whether sufficient crew resources exist)
  - Errors of commission (2 GPs), e.g.,
    - Recommend to identify and model potentially important EOCs.

HRA Processes – How to…. (continued)

- NRC's "Good Practices" (GPs) address (continued):
  - HRA documentation (1 GP), i.e.,
    - Should allow a knowledgeable reviewer to understand the analysis enough that it could be approximately reproduced and the same resulting conclusion reached.
- Does not explicitly address human-induced initiating events, but GPs for pre-initiator HFEs and post-initiator HFEs also should apply to HFEs that induce initiating events.

HRA Processes – How to…. (continued)

- Neither SHARP1 nor NRC's "Good Practices" specify or dictate:
  – Which HRA method should be used to perform HRA quantification
  – Any specific HRA tools or approaches for performing HFE identification and definition, and qualitative analysis
- In fact, often an HRA method does not:
  – Provide an accompanying and explicit HRA process for applying that specific method, and/or
  – Specify which (or that any) HRA process (e.g., SHARP) should be used to apply the specific method.
- Consequently, it usually is up to the HRA analyst to decide on selecting and applying an explicit HRA process to follow.

HRA Processes – How to…. (continued)

- However, there are a few HRA quantification methods that provide a specific HRA process.
- Examples of such methods:
  – THERP (NUREG/CR-1278)
  – ATHEANA (NUREG-1624, Rev. 1)
  – Fire HRA Guidelines (draft NUREG-1921/EPRI TR 1019196)
- For both ATHEANA and the Fire HRA Guidelines, the HRA process steps include explicit guidance for certain steps or use of HRA tools, such as:
  – Approaches for identifying HFEs (e.g., EOCs)
  – Approaches or techniques for doing certain aspects of qualitative HRA (e.g., determining if an operator action is feasible and, therefore, suitable to be included in PRA)

Course Outline

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- Any final questions?

What are the keys to performing HRA?

<u>The</u> key is to….

What are the keys to performing HRA?

…understand the problem.

What are the keys to performing HRA?

- Why do you need to "understand the problem"?
  - To be able to identify, define, and model (i.e., place appropriately in the plant logic model) HFEs such that they are consistent with, for example:
    - the specific accident sequence
    - associated plant procedures and operations
    - expected plant behavior and indications
    - engineering calculations that support the requirements for successful accident mitigation
    - consequences that are risk-significant

What are the keys to performing HRA?

- Why do you need to “understand the problem”? (continued)
  - To appropriately select an HRA quantification method to (usually) indirectly represent how operators are expected to behave, based on, for example:
    - their procedures and training,
    - plant-specific (and maybe even crew-specific) styles for responding to accidents,
    - plant-specific operating experience
    - general understanding of human error, behavior and cognitive science, human factors and ergonomics
    - knowledge of HRA methods and their underlying bases
  - To support and justify the HFEs and their quantification.

What are the keys to performing HRA?

- How do you develop this understanding?
  - Perform an appropriately thorough **qualitative analysis**, performed **iteratively** and **repeatedly** throughout the entire HRA process until the final HRA quantification is done.
- How do you know when are you done?
  - Usually, one or more of the following has occurred:
    - The accident sequence analyst tells you that you should move on to a new problem/HFE (that is more risk-significant).
    - Your deadline has arrived.
    - Your money is spent.

What are the keys to performing HRA?

- Increasingly, the HRA/PRA recognizes the importance of HRA qualitative analysis.
- More focus on qualitative analysis is appearing in recent or upcoming HRA/PRA guidance, e.g.,
  - Joint EPRI/NRC-RES Fire HRA guidance (draft NUREG-1921/EPRI TR 1019196)
  - ATHEANA (NUREG-1624, Rev. 1)
  - EPRI's HRA Calculator
- This emphasis is supported or based on recent studies such as:
  - "International HRA Empirical Study – Phase 1 Report" (NUREG/IA-0216, Volume 1, 2009)

What are the keys to performing HRA?

An important key to building an understanding of the problem is…

What are the keys to performing HRA?

context.

What are the keys to performing HRA?

- Context has long been recognized as important, e.g.,
  - SHARP1 (1992) discusses the importance of addressing human interactions for plant-specific and accident sequence-specific scenarios.
- However, a commonly held belief, still evident in popular accounts of incidents and reflected in how some people regard what new technologies ought to accomplish, is:
  - If we could just eliminate the human, we'd never have any problems.
- This corresponds with the so-called "blame culture" or "human-as-a-hazard" view

What are the keys to performing HRA?

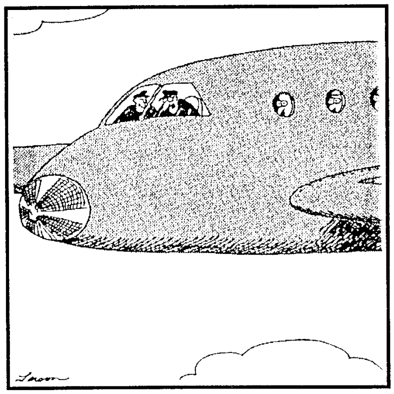
- Of course, the "human" here is the one on the "sharp end," i.e., the last one to "touch" any equipment or try to respond to an accident.
- But, humans also are involved in design, planning, inspection, testing, manufacturing, software development, etc., etc., etc.

- Let's look at some everyday examples of what humans on the "sharp end" have to contend with.

What are the keys to performing HRA?

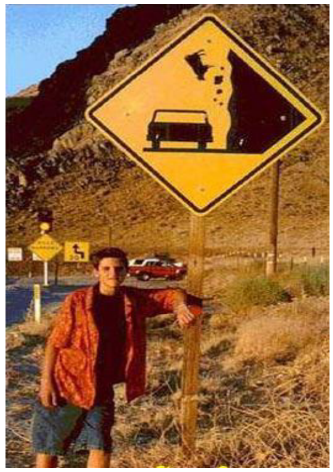
What are the keys to performing HRA?

What are the keys to performing HRA?



"The fuel light's on, Frank! We're all going to die!...We're all going to die!..Wait, wait...Oh, my mistake - that's the intercom light."

What are the keys to performing HRA?



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Slide 87

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What are the keys to performing HRA?

- Recent research on human error and human actions involved in serious accidents has contributed to building a new perspective on the role of humans in technology and the role of context.
- Examples of research/researchers include:
  - James Reason, Human Error, 1990, Managing the Risks of Organizational Accidents, 1997, The Human Contribution: Unsafe Acts, Accidents and Heroic Recoveries, 2008.
  - Donald R. Norman, The Design of Everyday Things, 1988.
  - E. M. Roth & R.J. Mumaw, An Empirical Investigation of Operator Performance in Cognitively Demanding Simulated Emergencies, NUREG/CR-6208, 1994.
  - Others, such as: Eric Hollnagel, David Woods, Micah Endsley

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What are the keys to performing HRA?

- Some of the key messages from this body of research are:
  - The operator is often "set-up" for failure …
    - …by prior events, pre-existing conditions, failed or misleading information, unusual and unfamiliar plant conditions and configurations, procedures that don't match the situation, and so on.
  - But, he doesn't always fail…
    - …"[E]ven the best [trouble-shooters] have bad days. It is my impression that the very best trouble-shooters get it right about half the time. The rest of us do much worse." (Reason, *The Human Contribution*, page 66)
  - So, he's the "last line of defense" …
    - …after all other previous designs and plans have failed.

What are the keys to performing HRA?

Suggestions for some practical exercises on context

1. You want a book off the shelf in your living room. You even go to the living room to get the book. However, after you return to your home office, you discover that you never got the book.
2. You have a doctor's appointment. Despite reminding yourself of the location for the doctor's office while you drive away from home, you end up at your children's school instead.
3. You drive yourself to work every day on the same route, you have a good driving record, and you drive defensively. Somehow, you end up in a collision with another vehicle.

All unlikely, right? Now, think about how the context might "cause" you to make one of these mistakes.

What are the keys to performing HRA?

Suggestions for some practical exercises on context

1. In Reason's *Human Error*, the context was an interruption, namely knocking a bunch of books off the shelf. After picking up all the books, you forget why you were there in the first place.
2. I've done this. I got distracted by thinking about a work problem and/or was focused on the radio music. My "automatic pilot" kicked in and, instead of stopping at the doctor's office (~1 mile before the turnoff to the school), I did what I usually do 2x per day – drove to the school.
3. This one is easy (i.e., lot of options for added context).
   - Potential distractions, e.g.: Call coming in on the cell phone, passengers in car (*Bring Your Child to Work Day*?), etc.
   - Added challenges, e.g.: Rain/ice/snow, fogged or iced up windows, road construction.
   - Unexpected equipment problems, e.g.: "Fuel low" light comes on, run out of windshield washer fluid.

Self- Assessment

Human Reliability Analysis (HRA) Basics

1. **In terms of keys to performing HRA, an important key to building an understanding of the problem is __________ .**

2. **List two examples of published HRA processes:**
    -
    -

3. **Explain the "blame culture" or "human-as-a-hazard" view**

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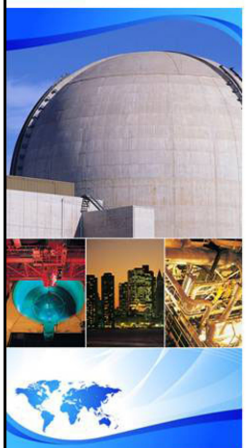

Principles of Human Reliability Analysis (HRA)

Part 4 of 5

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Principles of HRA

Slide 92

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How can we understand human error?

Lesson 1:

How can we understand human error?

Human error is <u>not</u> random.

How can we understand human error?

- But, why does human error seem random?
- Remember our exercise about context?
  - How many different possible contexts would you estimate can influence your everyday life?
  - For the actions typically addressed by HRA, the range of contexts has been constrained to:
    - Existing, licensed and operating nuclear power plants (NPPs)
    - NPP accidents represented in Level 1, at-power, internal events PRA
    - Actions taken by licensed operators
    - Operator actions taken (mostly) in the control room (that has been extensively designed and redesigned, reviewed and re-reviewed)
    - Operator actions that are addressed by Emergency Operating Procedures (EOPs) (that have been validated and demonstrated with decades of experience)
    - Operator actions that are adequately trained
    - Etc., etc., etc.

How can we understand human error?

Lesson 2:

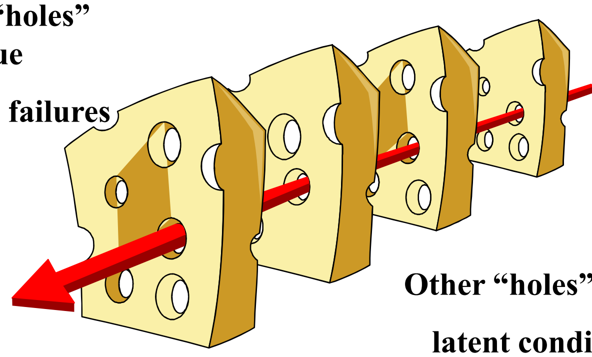
How can we understand human error?

Human error is not the "cause" of a mishap.

How can we understand human error?

- Remember….
  - **The operator is often "set-up" for failure …**
  - **And, the operator is on the "sharp-end" (i.e., simply the last one to touch "the problem").**
- To illustrate this concept, here is Reason's Swiss Cheese model of event causation (1990 & 1997)

The 'Swiss Cheese' Model of Event Causation



Successive layers of defenses, barriers, & safeguards

How can we understand human error?

Lesson 3:

How can we understand human error?

Human error can be predicted.

Human error can be predicted because…

- People's behavior is almost always rational
  - adaptive – i.e., goals are achieved
  - satisficing – i.e., best under the circumstances
- People's actions will tend to be
  - practical
    - people do what "works"
  - economical
    - people act so as to conserve resources

- And, in the case of NPPs, we have lots of rules and regulations to follow that are taken seriously.

Human error can be predicted because…

- People follow familiar paths
  - Maximize use of habits (good *and* bad)
  - Minimize ‘cognitive strain’
- People use ‘rapid pattern-matching’ to detect and interpret faults and errors
  - Very effective at detecting most problems, but
  - Not very effective at detecting our own errors
- People also use…
  – “shortcuts, heuristics, and expectation-driven actions.”
  – efficiency-thoroughness trade-offs

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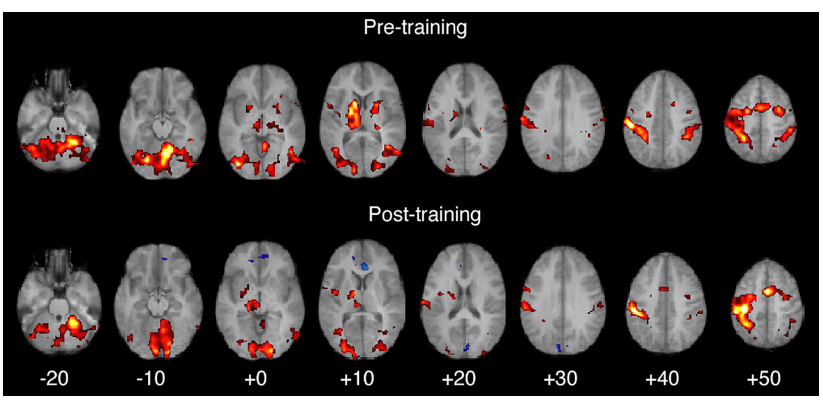
Practiced actions become ‘automatic’…



…whether we want them to or not.

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How can we understand human error?

Lesson 4:

How can we understand human error?

By combining Lessons #1 through #3…

How can we understand human error?

Human errors are not isolated breakdowns, but rather are the result of the same processes that allow a system's normal functioning.

How can we understand human error?

- But, what can we **use** to predict human error and/or behavior?
  1. Classifications, categories, types, etc.:
     - Errors of omission and commission
     - Slips/lapses, mistakes, and circumventions
     - Skill-, rule-, and knowledge-based errors
  2. Behavior models, e.g.,
     - Information processing models, such as:
       - Detection
       - Situation assessment
       - Response planning
       - Response execution
- Which one do you use?
  - **Depends** on a variety of factors but, especially, the type of operation or action being modeled.
  - May even be helpful if more than one way of classifying an action is used.

How can we understand human error?

- And, the HRA analyst further develops his understanding and ability to predict operator actions by addressing…
  - The context for the operator action

- The context includes both:
  1. Plant/facility conditions, configuration, and behavior, and
  2. Operator behavior influencing factors (sometimes called "performance shaping factors" (PSFs), performance influencing factors (PIFs), or driving factors)

How can we understand human error?

- Performance shaping factors usually capture important aspects of, for example:
  - Time available (often not defined as a PSF, but a **<u>very</u>** important factor)
  - Procedures
  - Operator training
  - Human-machine interfaces
  - Action cues and other indications
  - Crew staffing and organization
  - Crew communication
- The important aspects of these factors can change with the plant/facility, NPP operation, operator action and location, etc.

How can we understand human error?

- What else can an HRA analyst use or do?
  1. Classification schemes…. (already mentioned)
  2. Behavior models…. (already mentioned)
  3. Compare among different HRA quantification methods and/or approaches (e.g., HRA processes) that…
     - Use different classification and categorization schemes
     - Emphasize different PSFs, driving factors, or other elements of context
     - Represent (usually by implication only) different…
       - types of operator actions and associated possible failures or errors
       - models of behavior
       - "snapshots" of how NPPs are designed and operated

How can we understand human error?

- So, it's important for an HRA analyst to do his best to
  - "Understand the problem" by understanding the context, operator actions and potential failures or errors, etc. (i.e., perform some HRA qualitative analysis)
  - Match "the problem" to the HRA method that best represents the critical aspects of "the problem
- In other words, HRA method selection is important and should be done after you have some "understanding of the problem," including the likely operator actions and potential operator failures ("errors").
- In the next presentation topic, we'll summarize some of the important features of existing HRA methods.

Self- Assessment

Human Reliability Analysis (HRA) Basics

1. **What can we use to predict human error and/or behavior?**

   a)

   b)

2. **It is important for an HRA analyst to do his/her best to "understand the problem" by understanding the _________________ , operator actions and potential failures or errors.**

3. **True or False**
   Human error cannot be predicted.

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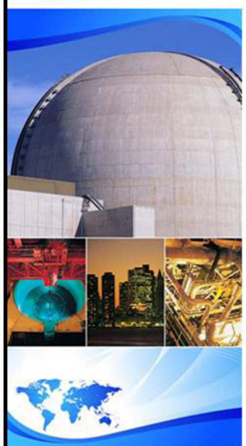

Principles of Human Reliability Analysis (HRA)

Part 5 of 5

Joint RES/EPRI Fire PRA Workshop
September and October 2010
Washington, DC

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Course Outline

- What is HRA?
- Where does HRA fit into PRA?
- What does HRA model?
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- How can we understand human error?
- **What are the important features of existing HRA methods?**
- What are the HRA concerns or issues for fire PRA?
- Any final questions?

What are the important features of existing HRA methods?

- Attempt to reflect the following characteristics:
  - plant behavior and conditions
  - timing of events and the occurrence of human action cues
  - parameter indications used by the operators and changes in those parameters as the scenario proceeds
  - time available and locations necessary to implement the human actions
  - equipment available for use by the operators based on the sequence
  - environmental conditions under which the decision to act must be made and the actual response must be performed
  - degree of training, guidance, and procedure applicability

What are the important features of existing HRA methods?

- Common US HRA methods:
  - Technique for Human Error Rate Prediction (THERP)
  - Accident Sequence Evaluation Program (ASEP) HRA Procedure
    - Simplification from THERP
  - Cause-Based Decision Tree (CBDT) Method
  - Human Cognitive Reliability (HCR)/Operator Reliability Experiments (ORE) Method
  - Standardized Plant Analysis Risk HRA (SPAR-H) Method
  - A Technique for Human Event Analysis (ATHEANA)

What are the important features of existing HRA methods?

- Overall, many HRA methods have been developed:
  - THERP (published in 1983) was the first; developed to support first nuclear power plant PRA effort (WASH-1400 [1975])..
  - Many methods were developed in the 1990s to support a growing number of PRA studies (e.g., IPEs).
  - In the 2000s, HRA method development continued with a focus on cognitive/decision-making.
  - So-called “second-generation” methods were developed in the 2000s, trying to capture advances in behavior and cognitive science, etc.
- In general, each HRA method represents (usually, implicitly):
  1. A perspective on human error (e.g., what performance shaping factors are important), and
  2. A snapshot in time (with respect plant design, operations, etc.).

What are the important features of existing HRA methods?

- To-date, the principal focus to HRA methods development has been on supporting Level 1, at-power, internal events PRA.
- However, existing HRA methods have been applied to other kinds of problems:
  - Low power and shutdown HRA/PRA for nuclear power plants (e.g., NUREG/CR-6144 and NUREG/CR-6145).
  - NASA PRAs for space shuttle
  - DOE's license application for Yucca Mountain waste repository
- In some cases, these applications have explicitly expanded or adapted existing HRA methods (in recognition that the method is not being applied exactly as intended)
- And, there have been other cases….

THERP: Technique for Human Error Rate Prediction (NUREG/CR-1278, 1983)

- This is the most extensively documented and the most widely used (and misused) HRA technique. The handbook has four main sections:
  - Basic concepts.
  - Method for analysis and quantification of human performance.
  - Human performance models and HEPs.
  - Tables of HEPs and examples.
- Simplified version developed as "Accident Sequence Evaluation Program Human Reliability Analysis Procedure" in NUREG/CR-4772, 1987
  - Referred to as "ASEP"

THERP (continued)

- THERP:
  - Is applicable to pre- and post-Initiator HFEs
  - Provides a cognitive model based on time reliability correlations (TRCs)
- THERP models **execution errors** using task analysis, e.g.,
  - Tasks are reviewed to identify critical steps
  - Each critical step has two failure modes
    - Error of omission
    - Error/s of commission
  - HFE can be represented in a HRA event tree
- THERP provides human error probabilities in Chapter 20 tables
  - Intended to be assigned as "branch" probabilities in HRA event tree
  - Limited number of PSFs used to adjust HEPs
  - Recovery and dependencies are addressed

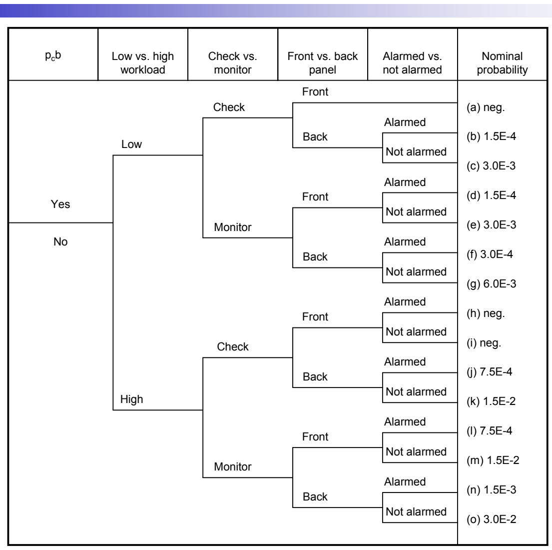
Caused Based Decision Tree (CBDT) Method (EPRI)

- CBDT consists of a series of decision trees to address potential causes of errors, produces HEPs based on those decisions.
- Half of the decision trees involve the man-machine cue interface:
  - Availability of relevant indications (location, accuracy, reliability of indications)
  - Attention to indications (workload, monitoring requirements, relevant alarms)
  - Data errors (location on panel, quality of display, interpersonal communications)
  - Misleading data (cues may not match procedure, need for training in cue recognition, etc.)

CBDT (continued)

- Half of the decision trees involve the man-procedure interface:
  - Procedure format (visibility and salience of instructions, place-keeping aids)
  - Instructional clarity (standardized vocabulary, completeness of information, training provided)
  - Instructional complexity (avoid use of "not" statements, or complex use of "and" & "or" terms, etc.)
  - Potential for deliberate violations (unquestioning belief in instructional adequacy, lack of awareness of availability and consequences of alternatives, etc.)
- For time-critical actions, the CBDT is supplemented by a time-reliability correlation

Example CBDT decision-tree: data not attended to



EPRI HRA Calculator

- Software tool
- Uses SHARP1 as the HRA framework/HRA process
- Post-initiator HFE methods:
  - For diagnosis, uses CBDT (decision trees) and/or HCR/ORE (time based correlation)
  - For execution, THERP for manipulation
- Pre-Initiator HFE methods:
  - Uses THERP and ASEP to quantify pre-initiator HFEs

ATHEANA

- Provides an HRA process, an approach for identifying and defining HFEs (especially for EOCs), an HRA quantification method, and a knowledge-base (including analyzed events and psychological literature)
- Provides a structured search for problem scenarios and unsafe actions
- Focuses on the <u>error-forcing context</u>
- Uses the knowledge of domain experts (e.g., operators, pilots, operator trainers)

ATHEANA (continued)

- Links plant conditions, performance shaping factors (PSFs) and human error mechanisms
- Consideration of dependencies across scenarios
- Attempts to address PSFs holistically (considers potential interactions)
- Structured search for problem scenarios and unsafe actions

Course Outline

- What is HRA?
- Where does HRA fit into PRA?
- What does HRA model?
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- How can we understand human error?
- What are the important features of existing HRA methods?
- **What are the HRA concerns or issues for fire PRA?**
- Any final questions?

What are the HRA concerns or issues for fire PRA?

What are the HRA concerns or issues for fire PRA?

- Actually, there are some different issues for fire HRA, such as:
  - New HFEs to identify, e.g.,
    - Fire response operator actions in fire procedures
  - Errors of Commission (EOCs) to identify and define, e.g.,
    - Per the Standard, the possibility that operators respond to spurious indications as if they are “real” must be considered.
    - Is there a way to limit the number of EOCs modeled in the fire PRA?
  - New environmental hazards to model as performance shaping factors (PSFs), e.g.:
    - Fire effects of smoke, heat, and toxic gases on operators
    - Impact of breathing apparatus and protective gear on operator performance, including communications
  - More challenging contexts, e.g.,
    - Potentially wide variations in size, location, and duration of fires and their effects on plant systems and functions

What are the HRA concerns or issues for fire PRA?

- Some different issues for fire HRA: (continued)
  - Different types of decisions, e.g.,
    - Operator judgment on whether to abandon the control room
  - Other PSFs or influencing factors, e.g.,
    - Design of ex-control room equipment control locations and alternate shutdown panels
- But, this, and more, will be addressed in the Fire HRA track, starting tomorrow.

Course Outline

- What is HRA?
- Where does HRA fit into PRA?
- What does HRA model?
- Is there a standard for performing HRA?
- What guidance is there for performing HRA?
- What are the keys to performing HRA?
- How can we understand human error?
- What are the important features of existing HRA methods?
- What are the HRA concerns or issues for fire PRA?
- **Any final questions?**

Self- Assessment

Human Reliability Analysis (HRA) Basics

Match the HRA methods with the descriptions below:

1. ATHEANA	a. most extensively documented and the most widely used HRA technique, models execution errors using task analysis
2. CBDT	b. An approach for identifying and defining HFEs, quantification method that makes use of expert elicitation and focuses on error-forcing context
3. THERP	c. method developed by the NRC as a simple method to evaluate the contribution made by operators to events. Commonly used in significance determination process (SDP) evaluations
4. SPAR-H	d. consists of a series of decision trees to address potential causes of errors, produces HEPs based on those decisions

APPENDIX D: MATERIALS SUPPORTING BASICS OF NUCLEAR POWER PLANT PROBABILISTIC RISK ASSESSMENT (PRA) TRAINING VIDEOS

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Basics of Nuclear Power Plant Probabilistic Risk Assessment

Part 1 of 4

Joint RES/EPRI Fire PRA Workshop
September and October, 2010
Washington DC

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Course Objectives

- Introduce PRA modeling and analysis methods applied to nuclear power plants
  - Initiating event identification
  - Event tree and fault tree model development
  - Human reliability analysis
  - Data analysis
  - Accident sequence quantification
  - LERF analysis

Course Outline

1. Overview of PRA
2. Initiating Event Analysis
3. Event Tree Analysis
4. Fault tree Analysis
5. Human Reliability Analysis
6. Data Analysis
7. Accident Sequence Quantification
8. LERF Analysis

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Overview of PRA

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What is Risk?

- Arises from a “Danger” or “Hazard”
- Always associated with undesired event
- Involves both:
  - likelihood of undesired event
  - severity (magnitude) of the consequences

Risk Definition

- Risk - the frequency with which a given consequence occurs

$$\text{Risk}\left[\frac{\text{Consequence Magnitude}}{\text{Unit of Time}}\right] =$$

$$\text{Frequency}\left[\frac{\text{Events}}{\text{Unit of Time}}\right] \times \text{Consequences}\left[\frac{\text{Magnitude}}{\text{Event}}\right]$$

Risk Example: Death Due to Accidents

- Societal Risk = 93,000 accidental-deaths/year

  (based on Center for Disease Control actuarial data)
- Average Individual Risk

  = (93,000 Deaths/Year)/250,000,000 Total U.S. Pop.

  = 3.7E-04 Deaths/Person-Year

  ≈ 1/2700 Deaths/Person-Year
- In any given year, approximately 1 out of every 2,700 people in the entire U.S. population will suffer an accidental death

- Note: www.cdc.gov latest data (2005) 117,809 unintentional deaths and 296,748,000 U.S. population, thus average individual risk ≈ (117,809 deaths/year)/296,748,000 ≈ 4E-04 Deaths/Person-Year

Risk Example: Death Due to Cancer

- Societal Risk = 538,000 cancer-deaths/year

  (based on Center for Disease Control actuarial data)
- Average Individual Risk

  = (538,000 Cancer-Deaths/Year)/250,000,000 Total U.S. Pop.

  = 2.2E-03 Cancer-Deaths/Person-Year

  ≈ 1/460 Cancer-Deaths/Person-Year
- In any given year, approximately 1 person out of every 460 people in the entire U.S. population will die from cancer

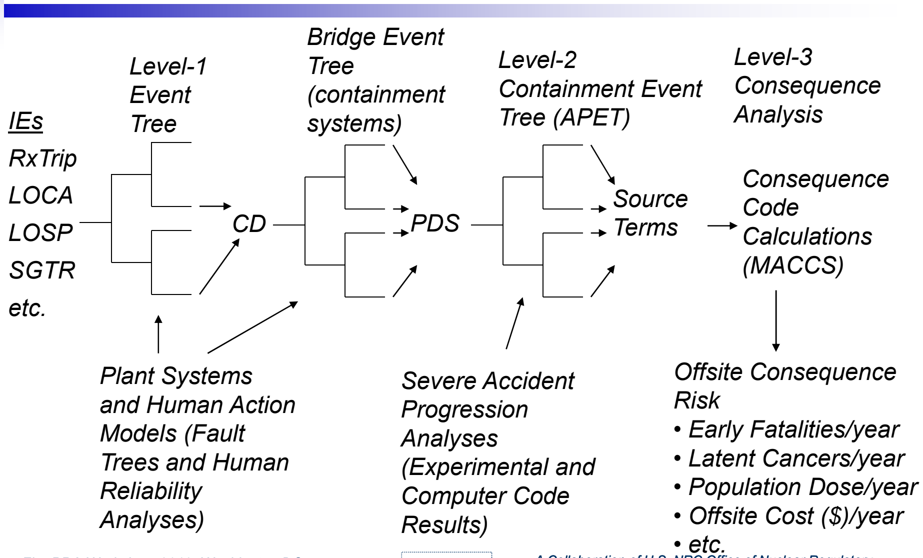
- Note: www.cdc.gov latest data (2005) 546,016 cancer deaths and 296,748,000 U.S. population, thus average individual risk ≈ (546,016 deaths/year)/296,748,000 ≈ 1.8E-03 Deaths/Person-Year

Overview of PRA Process

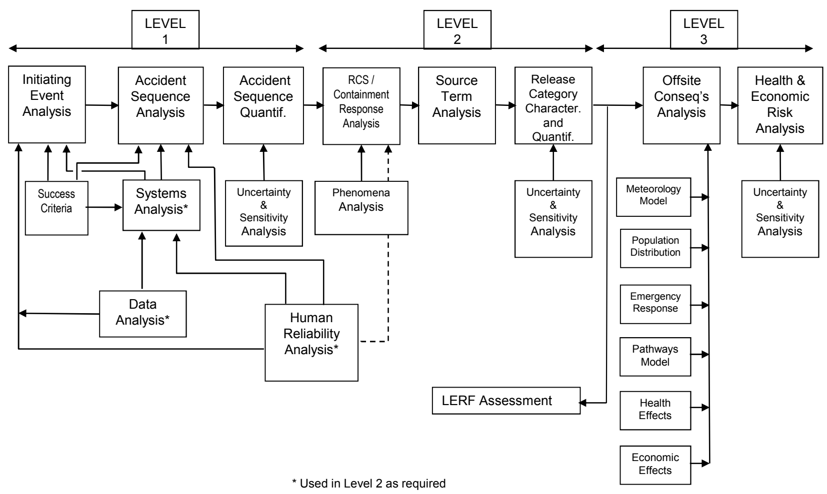
- PRAs are performed to find severe accident weaknesses and provide quantitative results to support decision-making. Three levels of PRA have evolved:

Level	An Assessment of:	Result
1	Plant accident initiators and systems'/operators' response	Core damage frequency & contributors
2	Frequency and modes of containment failure	Categorization & frequencies of containment releases
3	Public health consequences	Estimation of public & economic risks

Overview of Level-1/2/3 PRA



Principal Steps in PRA



PRA Classification

- Internal Hazards – risk from accidents initiated internal to the plant
  - Includes internal events, internal flooding and internal fire events
- External Hazards – risk from external events
  - Includes seismic, external flooding, high winds and tornadoes, airplane crashes, lightning, hurricanes, etc.
- At-Power – accidents initiated while plant is critical and producing power (operating at >X%* power)
- Low Power and Shutdown (LP/SD) – accidents initiated while plant is <X%* power or shutdown
  - Shutdown includes hot and cold shutdown, mid-loop operations, refueling

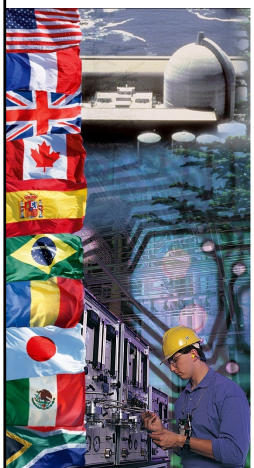
**X is usually plant-specific. The separation between full and low power is determined by evolutions during increases and decreases in power*

Specific Strengths of PRA

- Rigorous, systematic analysis tool
- Information integration (multidisciplinary)
- Allows consideration of complex interactions
- Develops qualitative design insights
- Develops quantitative measures for decision making
- Provides a structure for sensitivity studies
- Explicitly highlights and treats principal sources of uncertainty

Principal Limitations of PRA

- Inadequacy of available data
- Lack of understanding of physical processes
- High sensitivity of results to assumptions
- Constraints on modeling effort (limited resources)
  - simplifying assumptions
  - truncation of results during quantification
- PRA is typically a snapshot in time
  - this limitation may be addressed by having a "living" PRA
    - plant changes (e.g., hardware, procedures and operating practices) reflected in PRA model
    - temporary system configuration changes (e.g., out of service for maintenance) reflected in PRA model
- Lack of completeness (e.g., human errors of commission typically not considered)



Initiating Event Analysis

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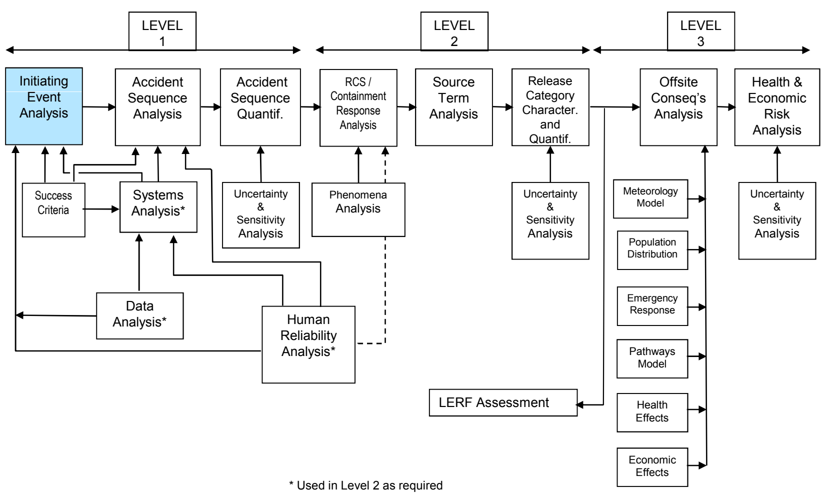
Principal Steps in PRA



* Used in Level 2 as required

Initiating Event Analysis

- Purpose: Students will learn what is an initiating event (IE), how to identify them, and group them into categories for further analysis.

Objectives:
  - Understand the relationship between initiating event identification and other PRA elements
  - Identify the types of initiating events typically considered in a PRA
  - Become familiar with various ways to identify initiating events
  - Understand how initiating events are grouped
- References:
  - NUREG/CR-2300, NUREG/CR-5750, NUREG/CR-3862, NUREG/CR-4550, Volume 1

Initiating Events

- Definition – Any potential occurrence that could disrupt plant operations to a degree that a reactor trip or plant shutdown is required. Initiating events are quantified in terms of their frequency of occurrence (i.e., number of events per calendar year of operation)
- Can occur while reactor is at full power, low power, or shutdown
  - Focus of this session is on IEs during full power operation
- Can be internal to the plant or caused by external events
  - Focus of this session is on internal IEs
- Basic categories of internal IEs:
  - transients (initiated by failures in the balance of plant or nuclear steam supply)
  - loss-of-coolant accidents (LOCAs) in reactor coolant system
  - interfacing system LOCAs
  - LOCA outside of containment
  - special transients (generally support system initiators)

Role of Initiating Events in PRA

- Identifying initiating events is the first step in the development of accident sequences
- Accident sequences can be conceptually thought of as a combination of:
  - an initiating event, which triggers a series of plant and/or operator responses, and
  - A combination of success and/or failure of the plant system and/or operator response that result in a core damage state
- Initiating event identification is an iterative process that requires feedback from other PRA elements
  - system analysis
  - review of plant experience and data

Initiating Event Analysis

- Collect information on actual plant trips
- Identify other abnormal occurrences that could cause a plant trip or require a shutdown
- Identify the plant response to these initiators including the functions and associated systems that can be used to mitigate these events
- Grouping IEs into categories based on their impact on mitigating systems
- Quantify the frequency of each IE category (Included later in Data Analysis session)

Comprehensive Engineering Evaluation

- Review historical events (reactor trips, shutdowns, system failures)
- Discrete spectrum of LOCA sizes considered based on location of breaks (e.g., in vs. out of containment, steam vs. liquid), components (e.g., pipe vs. SORV), and available mitigation systems
- Review comprehensive list of possible transient initiators based on existing lists (see for example NUREG/CR-3862) and from Safety Analysis Report
- Review list of initiating event groups modeled in other PRAs and adapt based on plant-specific information – typical approach for existing LWRs
- Feedback provided from other PRA taks

Sources of Data for Identifying IEs

- Plant-specific sources:
  - Licensee Event Reports
  - Scram reports
  - Abnormal, System Operation, and Emergency Procedures
  - Plant Logs
  - Safety Analysis Report (SAR)
  - System descriptions
- Generic sources:
  - NUREG/CR-3862
  - NUREG/CR-4550, Volume 1
  - NUREG/CR-5750
  - Other PRAs

Criteria for Eliminating IEs

- Some IEs may not have to modeled because:
  - Frequency is very low (e.g., <1E-7/ry)
    - ASME PRA Standard exclude ISLOCAs , containment bypass, vessel rupture from this criteria
  - Frequency is low (<1E-6/ry) and at least two trains of mitigating systems are not affected by the IE
  - Effect is slow, easily identified, and recoverable before plant operation is adversely affected (e.g., loss of control room HVAC)
  - Effect does not cause an automatic scram or an administrative demand for shutdown (e.g., waste treatment failure)

Initiating Event Grouping

- For each identified initiating event:
  - Identify the safety functions required to prevent core damage and containment failure
  - Identify the plant systems that can provide the required safety functions
- Group initiating events into categories that require the same or similar plant response
- This is an iterative process, closely associated with event tree construction. It ensures the following:
  - All functionally distinct accident sequences will be included
  - Overlapping of similar accident sequences will be prevented
  - A single event tree can be used for all IEs in a category

Example Initiating Events (PWR) from NUREG/CR-5750

Category	Initiating Event	Mean Frequency (per critical year)
B	Loss of offsite power	4.6E-2
L	Loss of condenser	0.12
P	Loss of feedwater	8.5E-2
Q	General transient (PCs available)	1.2
F	Steam generator tube rupture	7.0E-3
	ATWS	8.4E-6
G7	Large LOCA	5E-6
G6	Medium LOCA	4E-5
G3	Small LOCA	5E-4

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PRA/HRA Overview

Slide 25

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Example Initiating Events (PWR) from NUREG/CR-5750 (cont.)

Category	Initiating Event	Mean Frequency (per critical year)
G2	Stuck-open relief valve	5.0E-3
K1	High energy line break outside containment	1.0E-2
C1+C2	Loss of vital medium or low voltage ac bus	2.3E-2
C3	Loss of vital dc bus	2.1E-3
D	Loss of instrument or control air	9.6E-3
E1	Loss of service water	9.7E-4

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PRA/HRA Overview

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Self- Assessment

Probabilistic Risk Assessment (PRA) Basics

1. Why are Probabilistic Risk Assessments performed?

2. List three reasons why there are limitations of PRA:

-
-
-

3. An initiating event is

a) A high level representation of a vital safety function.
b) Any potential occurrence that could disrupt plant operations to a degree that a reactor trip or plant shutdown is required.
c) A graphical model depicting the various fault paths that will result in the occurrence of an undesired event.
d) all of the above

Basics of Nuclear Power Plant Probabilistic Risk Assessment

Part 2 of 4

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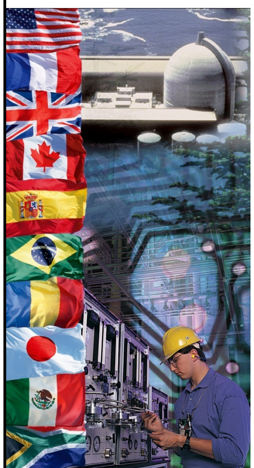
Sandia National Laboratories

Curtiss Wright Flow Control Company SCIENTECH

EPRI ELECTRIC POWER RESEARCH INSTITUTE

SAIC Science Applications International Corporation



Accident Sequence Analysis

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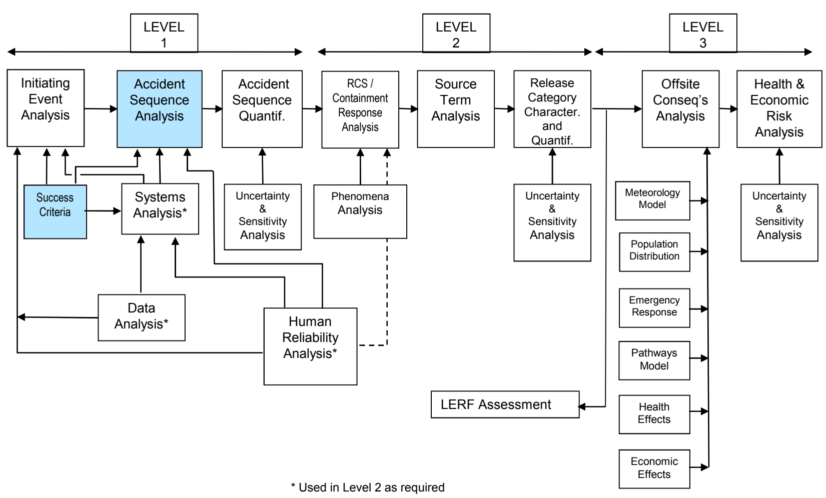
Principal Steps in PRA



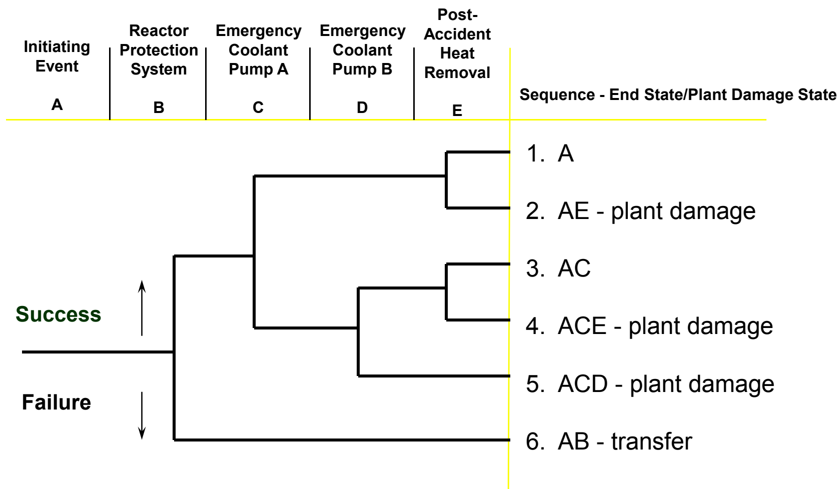
Accident Sequence Analysis

- Purpose: Students will learn purposes & techniques of accident sequence (event) analysis. Students will be exposed to the concept of accident sequences and learn how event tree analysis is related to the identification and quantification of dominant accident sequences.
- Objectives:
  - Understand purposes of event tree analysis
  - Understand currently accepted techniques and notation for event tree construction
  - Understand purposes and techniques of accident sequence identification
  - Understand how to simplify event trees
  - Understand how event tree logic is used to quantify PRAs
- References: NUREG/CR-2300, NUREG/CR-2728

Event Trees

- Typically used to model the response to an initiating event
- Features:
  - Generally, one system-level event tree for each initiating event group is developed
  - Identifies systems/functions required for mitigation
  - Identifies operator actions required for mitigation
  - Identifies event sequence progression
  - End-to-end traceability of accident sequences leading to bad outcome
- Primary use
  - Identification of accident sequences which result in some outcome of interest (usually core damage and/or containment failure)
  - Basis for accident sequence quantification

Simple Event Tree



Required Information

- Knowledge of accident initiators
- Thermal-hydraulic response during accidents
- Knowledge of mitigating systems (frontline and support) operation
- Know the dependencies between systems
- Identify any limitations on component operations
- Knowledge of procedures (system, abnormal, and emergency)

Principal Steps in Event Tree Development

- Determine boundaries of analysis
- Define critical plant safety functions available to mitigate each initiating event
- Generate functional event tree (optional)
  - Event tree heading - order & development
  - Sequence delineation
- Determine systems available to perform each critical plant safety function
- Determine success criteria for each system for performing each critical plant safety function
- Generate system-level event tree
  - Event tree heading - order & development
  - Sequence delineation

Determining Boundaries

- Mission time
  - Sufficient to reach stable state (generally 24 hours)
- Dependencies among safety functions and systems
  - Includes shared components, support systems, operator actions, and physical processes
- End States (describe the condition of both the core and containment)
  - Core OK
  - Core vulnerable
  - Core damage
  - Containment OK
  - Containment failed
  - Containment vented
- Extent of operator recovery

Critical Safety Functions

Example safety functions for core & containment

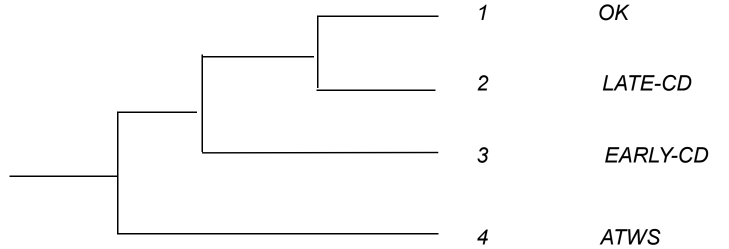
- Reactor subcriticality
- Reactor coolant system overpressure protection
- Early core heat removal
- Late core heat removal
- Containment pressure suppression
- Containment heat removal
- Containment integrity

Functional Event Tree

- High-level representation of vital safety functions required to mitigate abnormal event
  - Generic response of the plant to achieve safe and stable condition
- One functional event tree for transients and one for LOCAs
- Guides the development of more detailed system-level event tree model
- Generation of functional event trees not necessary; system-level event trees are the critical models
  - Could be useful for advanced reactor PRAs

Functional Event Tree

Initiating Event	Reactor Trip	Short term core cooling	Long term core cooling	SEQ #	STATE
IE	RX-TR	ST-CC	LT-CC		



System Success Criteria

- Identify systems which can perform each function
- Often includes if the system is automatically or manually actuated.
- Identify minimum complement of equipment necessary to perform function (often based on thermal/hydraulic calculations, source of uncertainty)
  - Calculations often realistic, rather than conservative
- May credit non-safety-related equipment where feasible

BWR Mitigating Systems

Function	Systems
Reactivity Control	Reactor Protection System, Standby Liquid Control, Alternate Rod Insertion
RCS Overpressure Protection	Safety/Relief Valves
Coolant Injection	High Pressure Coolant Injection, High Pressure Core Spray, Reactor Core Isolation Cooling, Low Pressure Core Spray, Low Pressure Coolant Injection (RHR) Alternate Systems- Control Rod Drive Hydraulic System, Condensate, Service Water, Firewater
Decay Heat Removal	Power Conversion System, Residual Heat Removal (RHR) modes (Shutdown Cooling, Containment Spray, Suppression Pool Cooling)

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Slide 39

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PWR Mitigating Systems

Function	Systems
Reactivity Control	Reactor Protection System
RCS Overpressure Protection	Safety valves, Pressurizer power-operated relief valves (PORV)
Coolant Injection	Accumulators, High Pressure Safety Injection, Chemical Volume and Control System, Low Pressure Safety Injection (LPSI), High Pressure Recirculation (may require LPSI)
Decay Heat Removal	Power Conversion System (main feedwater), Auxiliary Feedwater, Residual Heat Removal (RHR), Feed and Bleed (PORV + HPSI)

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Example Success Criteria

IE	Reactor Trip	Short Term Core Cooling	Long Term Core Cooling
Transient	*Auto Rx Trip or Man. Rx Trip*	*PCS or 1 of 3 AFW or 1 of 2 PORVs & 1 of 2 ECI*	*PCS or 1 of 3 AFW or 1 of 2 PORVs & 1 of 2 ECR*
Medium or Large LOCA	*Auto Rx Trip or Man. Rx Trip*	*1 of 2 ECI*	*1 of 2 ECR*

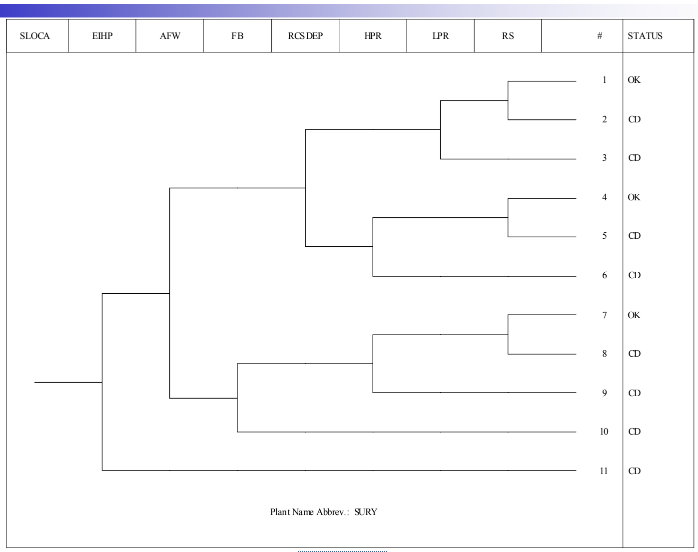
System-Level Event Tree Development

- A system-level event tree consists of an initiating event (one per tree), followed by a number of headings (top events), and a sequence of events representing the success or failure of the top events
- Top events represent the systems, components, and/or human actions required to mitigate the initiating event
- To the extent possible, top events are ordered in the time-related sequence in which they would occur
  - Selection of top events and ordering reflect emergency procedures
- Each node (or branch point) below a top event represents the success or failure of the respective top event
  - Logic is typically binary
    - Downward branch – failure of top event
    - Upward branch – success of top event
  - Logic can have more than two branches, with each branch representing a specific status of the top event

System-Level Event Tree Development (Continued)

- Dependencies among systems(needed to prevent core damage) are identified
  - Support systems can be included as top events to account for significant dependencies (e.g., diesel generator failure in station blackout event tree)
- Timing of important events (e.g., physical conditions leading to system failure) determined from thermal-hydraulic calculations
- Branches can be pruned logically (i.e., branch points for specific nodes removed) to remove unnecessary combinations of system success criteria requirements
  - This minimizes the total number of sequences that will be generated and eliminates illogical sequences
- Branches can transfer to other event tress for development
- Each path of an event tree represents a potential scenario
- Each potential scenario results in either prevention of core damage or onset of core damage (or a particular end state of interest)

Small LOCA Event Tree from Surry SDP Notebook



Event Tree Reduction and Simplification

- Single transient event tree can be drawn with specific IE dependencies included at the fault tree level
- Event tree structure can often be simplified by reordering top events
  - Example – Placing ADS before LPCI and CS on a BWR transient event tree
- Event tree development can be stopped if a partial sequence frequency at a branch point can be shown to be very small
- If at any branch point, the delineated sequences are identical to those in delineated in another event tree, the accident sequence can be transferred to that event tree (e.g., SORV sequences transferred to LOCA trees)
- Separate secondary event trees can be drawn for certain branches to simplify the analysis (e.g., ATWS tree)

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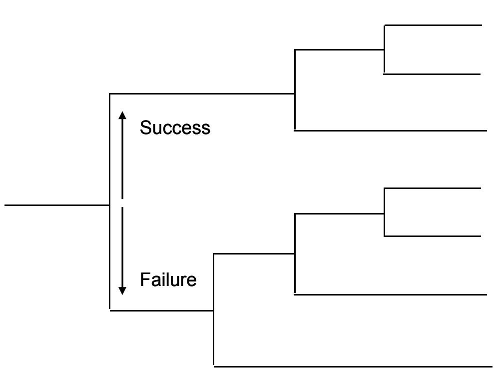
System Level Event Tree Determines Sequence Logic

Initiating Event	*Rx Trip*	*Rx Trip*	*ST Core Cooling*	*LT Core Cooling*	*SEQ #*	*STATE*	*LOGIC*
LOCA	*AUTO*	*MAN*	*ECI*	*ECR*			



SEQ #	*STATE*	*LOGIC*
1	*OK*	
2	*LATE-CD*	*/AUTO*/ECI*ECR*
3	*EARLY-CD*	*/AUTO*ECI*
4	*OK*	
5	*LATE-CD*	*AUTO*/MAN*/ECI*ECR*
6	*EARLY-CD*	*AUTO*/MAN*ECI*
7	*ATWS*	*AUTO*MAN*

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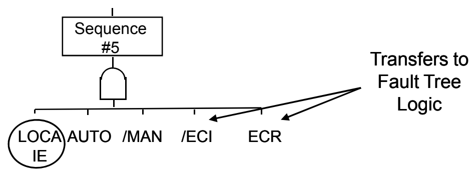
Sequence Logic Used to Combine System Fault Trees into Accident Sequence Models

- System fault trees (or cut sets) are combined, using Boolean algebra, to generate core damage accident sequence models.
  - – CD seq. #5 = LOCA * AUTO * /MAN * /ECI * ECR



Sequence Cut Sets Generated From Sequence Logic

- Sequence cut sets generated by combining system fault trees (or cut sets) comprised by sequence logic
  - – Cut sets can be generated from sequence #5 “Fault Tree”
    - Sequence #5 cut sets = (LOCA) * (AUTO cut sets) * (/MAN cut sets) * (/ECI cut sets) * (ECR cut sets)
    - Or, to simplify the calculation (via “delete term”)
      - – Sequence #5 cut sets ≈ (LOCA) * (AUTO cut sets) * (ECR cut sets) - any cut sets that contain MAN + ECI cut sets are deleted

Plant Damage State (PDS)

- Core Damage (CD) designation for end state not sufficient to support Level 2 analysis
  - Need details of core damage phenomena to accurately model challenge to containment integrity
- PDS relates core damage accident sequence to:
  - Status of plant systems (e.g., AC power operable?)
  - Status of RCS (e.g., pressure, integrity)
  - Status of water inventories (e.g., injected into RPV?)

Example Category Definitions for PDS Indicators

1. Status of RCS at onset of Core Damage

T	no break (transient)
A	large LOCA (6" to 29")
S1	medium LOCA (2" to 6")
S2	small LOCA (1/2" to 2")
S3	very small LOCA (less than 1/2")
G	steam generator tube rupture with SG integrity
H	steam generator tube rupture without SG integrity
V	interfacing LOCA

2. Status of ECCS

I	operated in injection only
B	operated in injection, now operating in recirculation
R	not operating, but recoverable
N	not operating and not recoverable
L	LPI available in injection and recirculation of RCS pressure reduced

3. Status of Containment Heat Removal Capability

Y	operating or operable if/when needed
R	not operating, but recoverable
N	never operated, not recoverable

Self- Assessment

Probabilistic Risk Assessment (PRA) Basics

1. **What is the primary use of an event tree?**

2. **Event trees are typically used to model the response to an _____________ ___________ .**

3. **What are the principal steps in event tree development?**

   a)

   b)

   c)

   d)

   e)

   f)

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From Science to Solutions

Basics of Nuclear Power Plant Probabilistic Risk Assessment

Part 3 of 4

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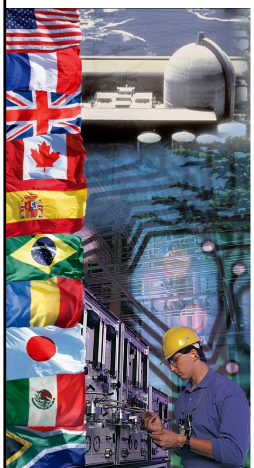

Systems Analysis

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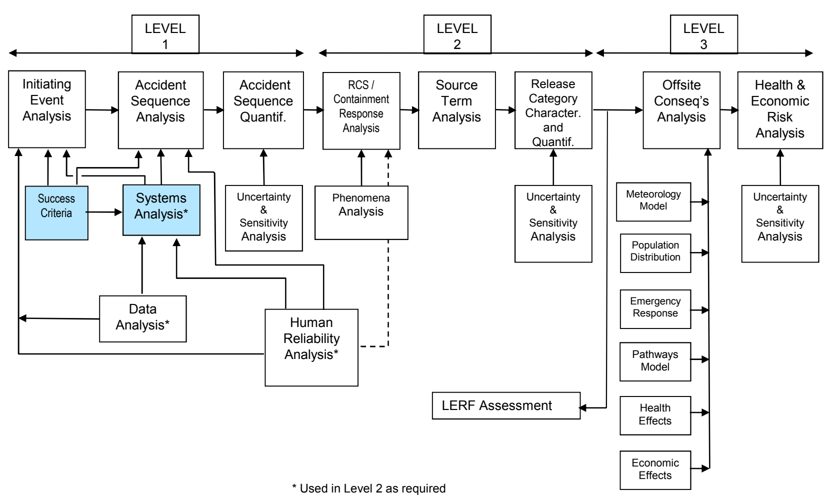
Principal Steps in PRA



* Used in Level 2 as required

Systems (Fault Tree) Analysis

- **Purpose:** Students will learn purposes & techniques of fault tree analysis. Students will learn how appropriate level of detail for a fault tree analysis is established. Students will become familiar with terminology, notation, and symbology employed in fault tree analysis. In addition, a discussion of applicable component failure modes relative to the postulation of fault events will be presented.
- **Objectives:**
  - Demonstrate a working knowledge of terminology, notation, and symbology of fault tree analysis
  - Demonstrate a knowledge of purposes & methods of fault tree analysis
  - Demonstrate a knowledge of the purposes and methods of fault tree reduction
- **References:**
  - NUREG-0492, Fault Tree Handbook
  - NUREG/CR-2300, PRA Procedures Guide
  - NUREG-1489, NRC Uses of PRA

Fault Tree Analysis Definition

*"An analytical technique, whereby an **undesired state** of the system is specified (usually a state that is critical from a safety standpoint), and the system is then analyzed **in the context of its environment and operation** to find all **credible** ways in which the undesired event can occur."*

NUREG-0492

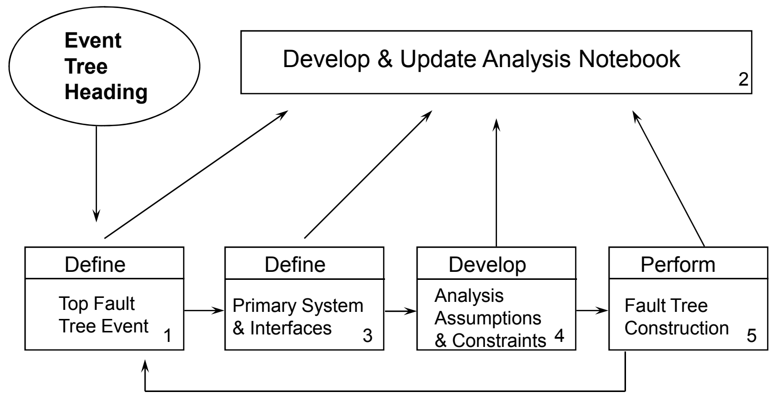
Fault Trees

- Deductive analysis (event trees are inductive)
- Starts with undesired event definition
- Used to estimate system failure probability
- Explicitly models multiple failures
- Identify ways in which a system can fail
- Models can be used to find:
  - System "weaknesses"
  - System failure probability
  - Interrelationships between fault events

Fault Trees (cont.)

- Fault trees are graphic models depicting the various fault paths that will result in the occurrence of an undesired (top) event.
- Fault tree development moves from the top event to the basic events (or faults) which can cause it.
- Fault tree use gates to develop the fault logic in the tree.
- Different types of gates are used to show the relationship of the input events to the higher output event.
- Fault tree analysis requires thorough knowledge of how the system operates and is maintained.

Fault Tree Development Process



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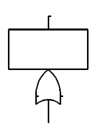
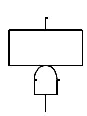
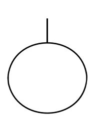
Fault Tree Symbols

Symbol		Description
	"OR" Gate	Logic gate providing a representation of the Boolean union of input events. The output will occur if at least one of the inputs occur.
	"AND" Gate	Logic gate providing a representation of the Boolean intersection of input events. The output will occur if all of the inputs occur.
	Basic Event	A basic component fault which requires no further development. Consistent with level of resolution in databases of component faults.

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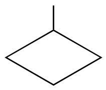
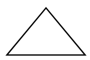
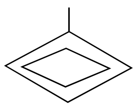
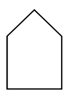
Fault Tree Symbols (cont.)

Symbol		Description
	Undeveloped Event	A fault event whose development is limited due to insufficient consequence or lack of additional detailed information
	Transfer Gate	A transfer symbol to connect various portions of the fault tree
	Undeveloped Transfer Event	A fault event for which a detailed development is provided as a separate fault tree and a numerical value is derived
	House Event	Used as a trigger event for logic structure changes within the fault tree. Used to impose boundary conditions on FT. Used to model changes in plant system status.

Event and Gate Naming Scheme

- A consistent use of an event naming scheme is required to obtain correct results
- Example naming scheme: XXX-YYY-ZZ-AAAA
- Where:
  - XXX is the system identifier (e.g., HPI)
  - YYY is the event and component type (e.g., MOV)
  - ZZ is the failure mode identifier (e.g., FS)
  - AAAAA is a plant component descriptor
- A gate naming scheme should also be developed and utilized - XXXaaa
  - XXX is the system identifier (e.g., HPI)
  - aaa is the gate number

Specific Failure Modes Modeled for Each Component

- Each component associated with a specific set of failure modes/mechanisms determined by:
  - Type of component
    - E.g., Motor-driven pump, air-operated valve
  - Normal/Standby state
    - Normally not running (standby), normally open
  - Failed/Safe state
    - Failed if not running, or success requires valve to stay open

Typical Component Failure Modes

- Active Components
  - Fail to Start
  - Fail to Run
  - Fail to Open/Close/Operate
  - Unavailability
    - Test or Maintenance Outage

Typical Component Failure Modes (cont.)

- Passive Components (Not always modeled in PRAs)
  - Rupture
  - Plugging (e.g., strainers/orifice)
  - Fail to Remain Open/Closed (e.g., manual valve)
  - Short (cables)

Component Boundaries

- Typically include all items unique to a specific component, e.g.,
  - Drivers for EDGs, MDPs, MOVs, AOVs, etc.
  - Circuit breakers for pump/valve motors
  - Need to be consistent with how data was collected
    - That is, should individual piece parts be modeled explicitly or implicitly
    - For example, actuation circuits (FTS) or room cooling (FTR)

Active Components Require "Support"

- Signal needed to "actuate" component
  - Safety Injection Signal starts pump or opens valve
  - Operator action may be needed to actuate
- Support systems might be required for component to function
  - AC and/or DC power
  - Service water or component water cooling
  - Room cooling

Definition of Dependent Failures

- Three general types of dependent failures:
  - Certain initiating events (e.g., fires, floods, earthquakes, service water loss) cause failure of multiple components
  - Intersystem dependencies including:
    - Functional dependencies (e.g., dependence on AC power)
    - Shared-equipment dependencies (e.g., HPCI and RCIC share common suction valve from CST)
    - Human interaction dependencies (e.g., maintenance error that disables separate systems such as leaving a manual valve closed in the common suction header from the RWST to multiple ECCS system trains)
  - Inter-component dependencies (e.g., design defect exists in multiple similar valves)
- The first two types are captured by event tree and fault tree modeling; the third type is known as common cause failure (i.e., the residual dependencies not explicitly modeled) and is treated parametrically

Common Cause Failures (CCFs)

- Conditions which may result in failure of more than one component, subsystem, or system
- Concerns:
  - Defeats redundancy and/or diversity
  - Data suggest high probability of occurrence relative to multiple independent failures

Common Cause Failure Mechanisms

- Environment
  - Radioactivity
  - Temperature
  - Corrosive environment
- Design deficiency
- Manufacturing error
- Test or Maintenance error
- Operational error

Two Common Fault Tree Construction Approaches

- "Sink to source"
  - Start with system output (i.e., system sink)
  - Modularize system into a set of pipe segments (i.e., group of components in series)
  - Follow reverse flow-path of system developing fault tree model as the system is traced
- Block diagram-based
  - Modularize system into a set of subsystem blocks
  - Develop high-level fault tree logic based on subsystem block logic (i.e., blocks configured in series or parallel)
  - Expand logic for each block

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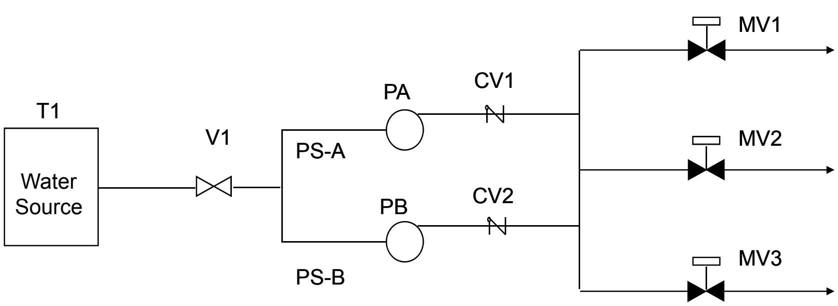
Example - ECI



Success Criteria*: Flow from any one pump through any one MV*
T_ tank
V_ manual valve, normally open
PS-_ pipe segment
P_ pump
CV_ check valve
MV_ motor-operated valve, normally closed

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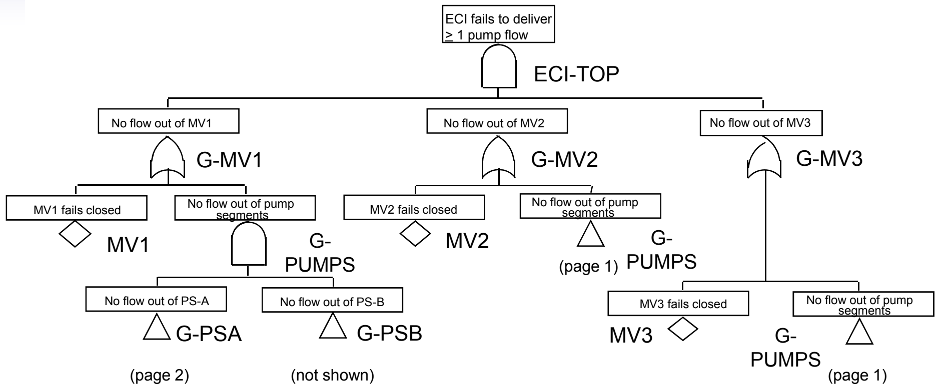
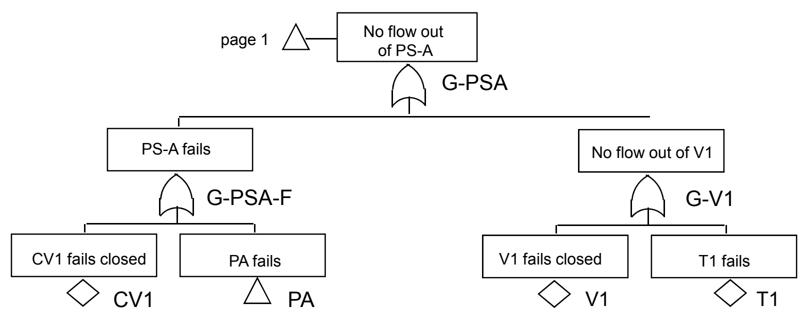
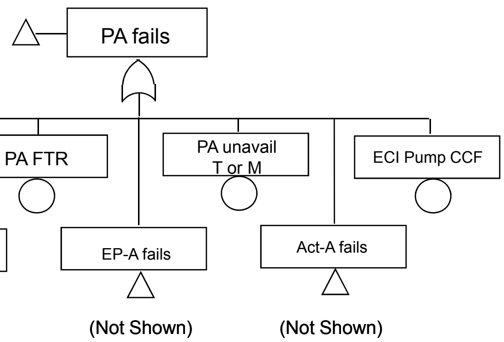
ECI System Fault Tree – "Sink to Source Method" (page 1)



ECI System Fault Tree – "Sink to Source Method" (page 2)



ECI System Fault Tree – “Sink to Source Method” (page 3)



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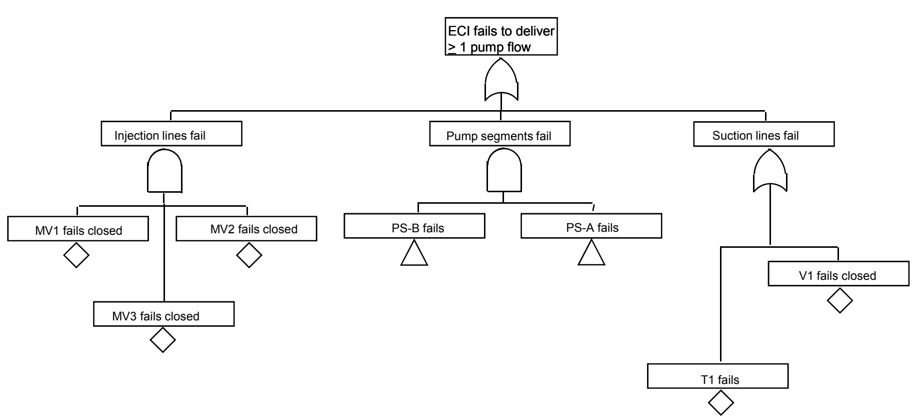
ECI System Fault Tree - Block Diagram Method



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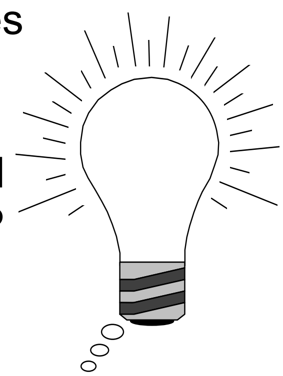
Boolean Fault Tree Reduction

- Express fault tree logic as Boolean equation
- Apply rules of Boolean algebra to reduce terms
- Results in reduced form of Boolean equation

Minimal Cutset

A group of basic event failures (component failures and/or human errors) that are ***collectively necessary*** and ***sufficient*** to cause the TOP event to occur.



Fault Tree Pitfalls

- Inconsistent or unclear basic event names
  - X*X = X, so if X is called X1 in one place and X2 in another place, incorrect results are obtained
- Missing dependencies or failure mechanisms
  - An issue of completeness
- Unrealistic assumptions
  - Availability of redundant equipment
  - Credit for multiple independent operator actions
  - Violation of plant LCO
- Modeling T&M unavailability can result in illegal cutsets
- Putting recovery in FT might give optimistic results
- Logic loops

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Results

- Sanity checks on cut sets
  - Symmetry
    - If Train-A failures appear, do Train-B failures also appear?
  - Completeness
    - Are all redundant trains/systems really failed?
    - Are failure modes accounted for at component level?
  - Realism
    - Do cut sets make sense (i.e., Train-A out for T&M ANDed with Train-B out for T&M)?
  - Predictive Capability
    - If system model predicts total system failure once in 100 system demands, is plant operating experience consistent with this?

Fire PRA Workshop, 2010, Washington DC
PRA/HRA Overview

Slide 78

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

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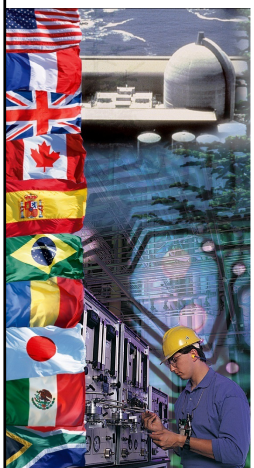
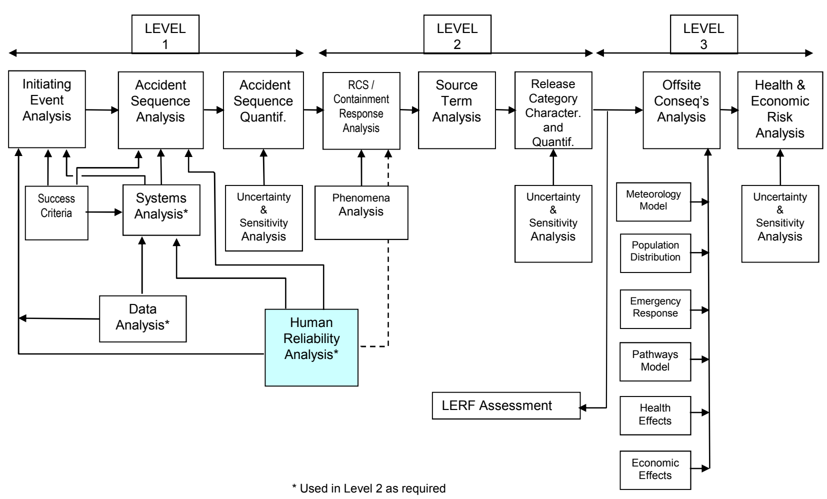


Human Reliability Analysis

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

Principal Steps in PRA



* Used in Level 2 as required

Human Reliability Analysis

Purpose: This session will provide a generalized, high-level introduction to the topic of human reliability and human reliability analysis in the context of PRA.

Objectives: Provide students with an understanding of:
- The goals of HRA and important concepts and issues
- The basic steps of the HRA process in the context of PRA
- Basic aspects of selected HRA methods

HRA Purpose

Why Develop a HRA?
- **PRA reflects the as-built, as-operated plant**
  - **HRA models the "as-operated" portion**

Definition of HRA
- A **structured approach** used to **identify** potential human failure events (HFEs) and to systematically **estimate the probability** of those errors using data, models, or expert judgment

HRA Produces
- Qualitative evaluation of the factors impacting human errors and successes
- Human error probabilities (HEPs)

Human Reliability Analysis

- Starts with the basic premise that the humans can be represented as either:.
  - A component of a system, or
  - A failure mode of a system or component.
- Identifies and quantifies the ways in which human actions initiate, propagate, or terminate fault & accident sequences.
- Human actions with both positive and negative impacts are considered in striving for realism.
- A difficult task in a PRA since need to understand the plant hardware response, the operator response, and the accident progression modeled in the PRA.

Human Reliability Analysis Objectives

Ensure that the **impacts of plant personnel** actions are reflected in the assessment of risk in such a way that:

a) both **pre-initiating event and post-initiating event** activities, including those modeled in support system initiating event fault trees, are addressed.

b) logic model elements are defined to represent the effect of such personnel actions on **system availability**/unavailability and on **accident sequence** development.

c) plant-specific and scenario-specific factors are accounted for, including those factors that influence either what activities are of interest or human performance.

d) human performance issues are addressed in an integral way so that **issues of dependency are captured**.

Ref: ASME RA-Sb-2005

Modeling of Human Actions

- Human Reliability Analysis provides a structured modeling process
- HRA **process steps**:
  - – Identification & Definition
    - Human interaction identified, then defined for use in the PRA as a Human Failure Event (HFE)
    - Includes HFE categorization as to the type of action
  - – Qualitative analysis of context & performance shaping factors
  - – Quantification of Human Error Probability (HEP)
  - – Dependency
  - – Documentation

PRA Standard Requirements for HRA

ASME HRA **High Level Requirements** Compared

Pre-Initiator	Post Initiator
A – Identify HFEs	E – Identify HFEs
B – Screen HFEs	<blank>
C – Define HFEs	F – Define HFEs
D – Assess HEPs	G – Assess HEPs
<blank>	H – Recovery HFEs
I – Document HFEs/HEPs	

Categories Of Human Failure Events in PRA

- Operator actions can occur throughout the accident sequence
  - **Pre-initiator errors** (latent errors, unrevealed) occur before the initiating event.
    - May occur in or out of the main control room
    - Failure to restore from test/maintenance
    - Miscalibration
    - Often captured in equipment failure data
    - For HRA the focus is on equipment being left unavailable or not working exactly right.
  - Operator actions contribute or **cause initiating events**
    - Usually implicitly included in the data used to quantify initiating event frequencies.

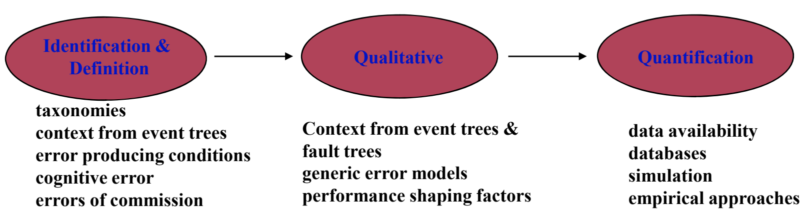
Categories Of Human Failure Events in PRA (cont'd)

- **Post-initiator errors** occur after reactor trip. Examples:
  - Operation of components that have failed to operate automatically, or require manual operation.
  - "Event Tree top event" operator actions modeled in the event trees (e.g., failure to depressurize the RCS in accordance with the EOPs)
  - Recovery actions for hardware failures (example - aligning an alternate cooling system, subject to available time)
  - Recovery actions following crew failures (example - providing cooling late after an earlier operator action failed)
  - Operation of components from the control room or locally.

Categorization & Definition of Human Failure Events in PRA (cont'd)

- Additional "category", error of commission or aggravating errors of commission, typically out of scope of most PRA models.
  - Makes the plant response worse than not taking an action at all
- Within each operator action, there are generally, two types of error:
  - Diagnostic error (cognition) – failure of detection, diagnosis, or decision-making
  - Execution error (manipulation) – failure to accomplish the critical steps, once they have been decided, typically due to the following error modes.
    - Errors of omission (EOO, or Skip) -- Failure to perform a required action or step, e.g., failure to monitor tank level
    - Errors of commission (EOC, or Slip) -- Action performed incorrectly or wrong action performed, e.g., opened the wrong valve, or turned the wrong switch.

Human Reliability Analysis is the Combination of Three Basic Steps



From about 1980 on, some 38 different HRA methods have been developed - almost all centered on quantification.

There is no universally accepted HRA method (to date).

The context of the operator action comes directly from the event trees and fault trees although some techniques have recently ventured beyond.

Identification & Definition Process

- **Identify** Human Failure Events (HFEs) to be considered in plant models.
  - Based on PRA event trees, fault trees, & procedures.
    - Includes front line systems & support systems.
  - Often done in conjunction with the PRA modelers (Qualitative screening)
  - Normal Plant Ops-- Identify potential errors involving miscalibration or failure to restore equipment by observing test and maintenance, reviewing relevant procedures and plant practices
    - Guidelines for pre-initiator qualitative screening
  - Post-Trip Conditions-- Determine potential errors in diagnosing and manipulating equipment in response to various accident situations

Identification & Definition Process (cont.)

- PRA model identifies component/system/function failures
- HRA requires **definition** of supporting information, such as:
  - <u>for post-initiating events</u>, the cues being used, timing and the emergency operating procedure(s) being used.
- ATHEANA – identify the "base case" for accident scenario
  - Expected scenario – including operator expectations for the scenario
  - Sequence and timing of plant behavior – behavior of plant parameters
  - Key operator actions

Identification Process (cont'd)

- Review emergency operating procedures to identify potential human errors
- Flow chart the EOPs to identify critical decision points and relevant cues for actions
- If possible, do early observations of simulator exercises
- List human actions that could affect course of events (qualitative screening)

Qualitative Analysis

- **Context**, a set of plant conditions based on the PRA model
  - Initiating event & event tree sequence
    - includes preceding hardware & operator successes/failures
  - Cues, Procedure, Time window
- Qualitatively examine factors that could influence performance (**Performance Shaping Factors, PSFs**) such as
  - Training/experience
  - Clarity of cues
  - Task complexity
  - Environmental cond.
  - Human-machine interface
  - Management and organizational factors
  - Scenario timing
  - Workload
  - Crew dynamics
  - Accessibility
- Note ATHEANA models "Error Forcing Context" consisting of plant context & scenario-specific factors that would influence operator response.

Performance Shaping Factors (PSFs)

- Are people-, task-, environmental-centered influences which could affect performance.
- Most HRA modeling techniques allow the analyst to account for PSFs during their quantification procedure.
- PSFs can Positively or Negatively impact human error probabilities
- PSFs are identified and evaluated in the human reliability task analysis

Quantifying the Human Error Probability

- Quantifying is the process of
  - selecting an HRA method then
  - calculating the Human Error Probability for a HFE
    - based on the qualitative assessment and
    - based on the context definition.
- The calculation steps depend on the methodology being used.
- Data sources – the input data for the calculations typically comes operator talk-throughs &/or simulations, while some methods the data comes from databanks or expert judgment.
- The result is typically called a Human Error Probability or HEP

Levels of Precision

- Conservative (screening) level useful for determining which human errors are the most significant contributors to overall system error
- Those found to be potentially significant contributors can be profitably analyzed in greater detail (which often lowers the HEP)

Screening

- Too many HFEs to do detailed quantification?
  - Trying to reduce level of effort, resources
  - Used during IPE era for initial model development
- ASME PRA Standard
  - Pre-initiators: screening pre-initiators is addressed in High Level Requirement HLR-HR-B
  - Post-initiators: screening is not addressed explicitly as a High Level Requirement
    - Supporting requirement HR-G1 limits the PRA to Capability Category I if conservative/screening HEPs used.
- Thus, screening is more appropriate to Fire PRA.

Detailed Quantification

- Point at which you bring all the information you have about each event
  - PSFs, descriptions of plant conditions given the sequence
  - Results from observing simulator exercises
  - Talk-throughs with operators/trainers
  - Dependencies
- Quantification Methods
  - Major problem is that none of the methods handle all this information very well
- Assign HEPs to each event in the models

HRA Methods

- Attempt to reflect the following characteristics:
  - plant behavior and conditions
  - timing of events and the occurrence of human action cues
  - parameter indications used by the operators and changes in those parameters as the scenario proceeds
  - time available and locations necessary to implement the human actions
  - equipment available for use by the operators based on the sequence
  - environmental conditions under which the decision to act must be made and the actual response must be performed
  - degree of training, guidance, and procedure applicability

Common HRA Methodologies in the USA

- Technique for Human Error Rate Prediction (THERP)
- Accident Sequence Evaluation Program (ASEP) HRA Procedure

- Cause-Based Decision Tree (CBDT) Method
- Human Cognitive Reliability (HCR)/Operator Reliability Experiments (ORE) Method

- Standardized Plant Analysis Risk HRA (SPAR-H) Method
- A Technique for Human Event Analysis (ATHEANA)

Caused Based Decision Tree (CBDT) Method (EPRI)

Series of decision trees address potential causes of errors, produces HEPs based on those decisions.

- Half of the decision trees involve the man-machine cue interface:
  - Availability of relevant indications (location, accuracy, reliability of indications);
  - Attention to indications (workload, monitoring requirements, relevant alarms);
  - Data errors (location on panel, quality of display, interpersonal communications);
  - Misleading data (cues match procedure, training in cue recognition, etc.);
- Half of the decision trees involve the man-procedure interface:
  - Procedure format (visibility and salience of instructions, place-keeping aids);
  - Instructional clarity (standardized vocabulary, completeness of information, training provided);
  - Instructional complexity (use of "not" statements, complex use of "and" & "or" terms, etc.); and
  - Potential for deliberate violations (belief in instructional adequacy, availability and consequences of alternatives, etc.).
- For time-critical actions, the CBDT is supplemented by a time reliability correlation

EPRI HRA Calculator

- Software tool
- Uses SHARP1 as the HRA framework
- Post-initiator HFE methods:
  - For diagnosis, uses CBDT (decision trees) and/or HCR/ORE (time based correlation)
  - For execution, THERP for manipulation
- Pre-Initiator HFE methods:
  - Uses THERP and ASEP to quantify pre-initiator HFEs

ATHEANA

- Experience-based (uses knowledge of domain experts, e.g., operators, pilots, trainers,etc.)
- Focuses on the error-forcing context
- Links plant conditions, performance shaping factors (PSFs) and human error mechanisms
- Consideration of dependencies across scenarios
- Attempts to address PSFs holistically (considers potential interactions)
- Structured search for problem scenarios and unsafe actions

Dependencies

Dependency refers to the extent to which failure or success of one action will influence the failure or success of a subsequent action.

1) Human interaction depends on the accident scenario, including the type of initiating event
2) Dependencies between multiple human actions modeled within the accident scenario,
3) Human interactions performed during testing or maintenance can defeat system redundancy,
4) Multiple human interactions modeled as a single human interaction may involve significant dependencies. (from SHARP1)

HRA Process Summary

- Human Reliability Analysis provides a structured modeling process
- Human Interactions are incorporated as Human Failure Events in a PRA, **identification & definition** finds the HFEs
- Post-initiator operator actions consist of:
  - **Qualitative analysis** of Context and Performance Shaping Factors
    - Operator action must be feasible (for example, sufficient time, sufficient staff, sufficient cues, access to the area)
  - Then **Quantitative assessment (using an HRA method)**
    - Includes dependency evaluation
- Two Parts of the Each Human Failure Event (HFE)
  - Operator must recognize the need/demand for the action (**cognition**) AND
  - Operator must take steps (**execution**) to complete the actions.

Self- Assessment

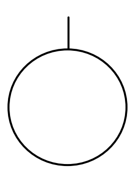
Probabilistic Risk Assessment (PRA) Basics

1. An analytical technique, whereby an **undesired state** of the system is specified (usually a state that is critical from a safety standpoint), and the system is then analyzed **in the context of its environment and operation** to find all **credible** ways in which the undesired event can occur.
   - **a)** Event sequence
   - **b)** Response analysis
   - **c)** Accident sequence
   - **d)** Fault tree analysis

2. **Fault trees use ______________ to develop the fault logic in the tree.**

3. **Write the name and give a description of the symbol below:**

Name:



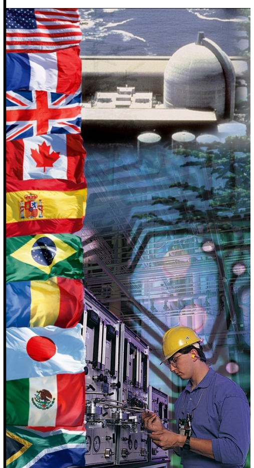
Description:

Basics of Nuclear Power Plant Probabilistic Risk Assessment

Part 4 of 4

Joint RES/EPRI Fire PRA Workshop
September and October, 2010
Washington DC

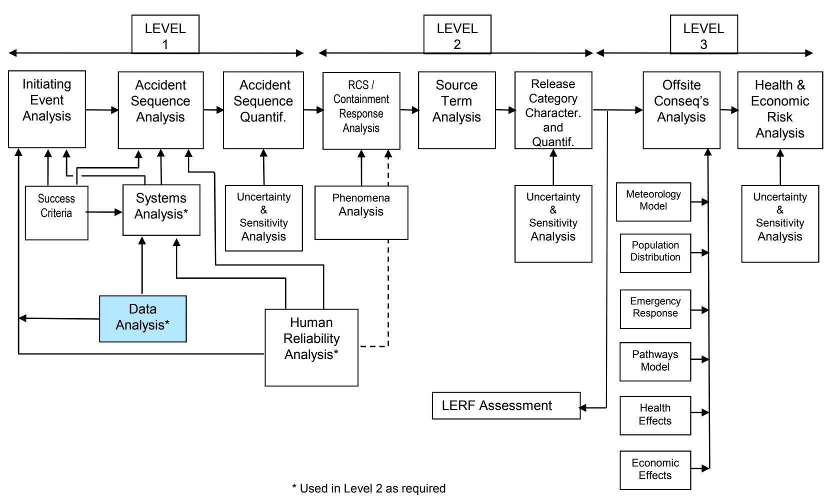
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)



Data Analysis

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

Principal Steps in PRA



* Used in Level 2 as required

Data Analysis

- Purpose: Students will be introduced to sources of initiating event data; and hardware data and equipment failure modes, including common cause failure, that are modeled in PRAs.

- Objectives: Students will be able to:
  - Understand parameters typically modeled in PRA and how each is quantified.
  - Understand what is meant by the terms
    - Generic data
    - Plant-specific data
    - Bayesian updating
  - Describe what is meant by common-cause failure, why it is important, and how it is included in PRA

PRA Parameters

- Initiating Event Frequencies
- Basic Event Probabilities
  - Hardware
    - component reliability (fail to start/run/operate/etc.)
    - component unavailability (due to test or maintenance)
  - Common Cause Failures
  - Human Errors (discussed in previous session)

Categories of Data

- Two basic categories of data: plant-specific and generic
- Some guidance on the use of each category:
  - Not feasible or necessary to collect plant-specific data for all components in a PRA (extremely reliable components may have no failures)
  - Some generic data sources are non-conservative (e.g., LERS do not report all failures)
  - Inclusion of plant-specific data lends credibility to the PRA
  - Inclusion of plant-specific data allows comparison of plant equipment performance to industry averages
- Should use plant-specific data whenever possible, as dictated by the availability of relevant information

Boundary Conditions and Modeling Assumptions Affect Form of Data

- Clear understanding of component boundaries and missions needed to accurately use raw data or generic failure rates. For example:
  - Do motor driven components include circuit breakers? (Are CB faults included in component failure rate?)
- Failure mode being modeled also impacts type and form of data needed to quantify the PRA.
  - FTR – failures while operating and operating time
  - FTS/FTO – failures and demands (successes)

Data Sources for Parameter Estimation

- Generic data
- Plant-specific data
- Bayesian updated data
  - Prior distribution
  - Updated estimate

Generic Data Issues

- Key issue is whether data is applicable for the specific plant being analyzed
  - Most generic component data is mid-1980s or earlier vintage
  - Some IE frequencies known to have decreased over the last decade
    - Frequencies updated in NUREG/CRs 5750 and 5496
  - Criteria for judging data applicability not well defined (do not forget important engineering considerations that could affect data applicability)
  - ASME PRA Standard requirements

Plant-Specific Data Sources

- Licensee Event Reports (LERs)
  - Can also be source of generic data
- Post-trip SCRAM analysis reports
- Maintenance reports and work orders
- System engineer files
- Control room logs
- Monthly operating status reports
- Test surveillance procedures

Plant-Specific Data Issues

- Combining data from different sources can result in:
  - double counting of the same failure events
  - inconsistent component boundaries
  - inconsistent definition of "failure"
- Plant-specific data is typically very limited
  - small statistical sample size
- Inaccuracy and non-uniformity of reporting
  - LER reporting rule changes
- Difficulty in interpreting "raw" failure data
  - administratively declared inoperable, does not necessarily equate to a "PRA" failure

Bayesian Methods Employed to Generate Uncertainty Distributions

- Two motivations for using Bayesian techniques
  - Generate probability distributions (classical methods generally only produce uncertainty intervals, not pdf's)
  - Compensate for sparse data (e.g., no failures)
- In effect, Bayesian techniques combine an initial estimate (prior) with plant-specific data (likelihood function) to produce a final estimate (posterior)
- However, Bayesian techniques rely on (and incorporate) subjective judgement
  - different options for choice of prior distribution (i.e., the starting point in a Bayesian calculation)

Common Cause Failures (CCFs)

- Conditions which may result in failure of more than one component, subsystem, or system
- Common cause failures are important since they:
  - Defeats redundancy and/or diversity
  - Data suggest high probability of occurrence relative to multiple independent failures

Common Cause Failure Mechanisms

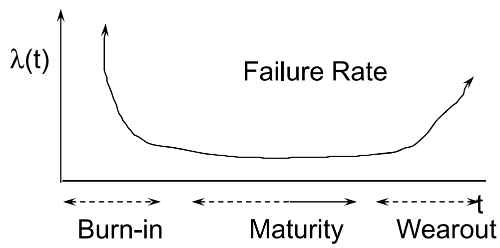
- Environment
  - Radioactivity
  - Temperature
  - Corrosive environment
- Design deficiency
- Manufacturing error
- Test or Maintenance error
- Operational error

Limitations of CCF Modeling

- Limited data, hence generic data often used
  - Applicability issue for specific plant
- Screening values may be used
  - Potential to skew the results
- Not typically modeled across systems since data is collected/analyzed for individual systems
- Not typically modeled for divers components (e.g., motor-driven pump/turbine-driven pump)
- Causes not explicitly modeled (i.e., each failure mechanism not explicitly modeled)

Component Data Not Truly Time Independent

- PRAs typically assume time-independence of component failure rates
  - One of the assumptions for a Poisson process (i.e., failures in time)
- However, experience has shown aging of equipment does occur
  - Failure rate (λ) = $\lambda(t)$
  - "Bathtub" curve



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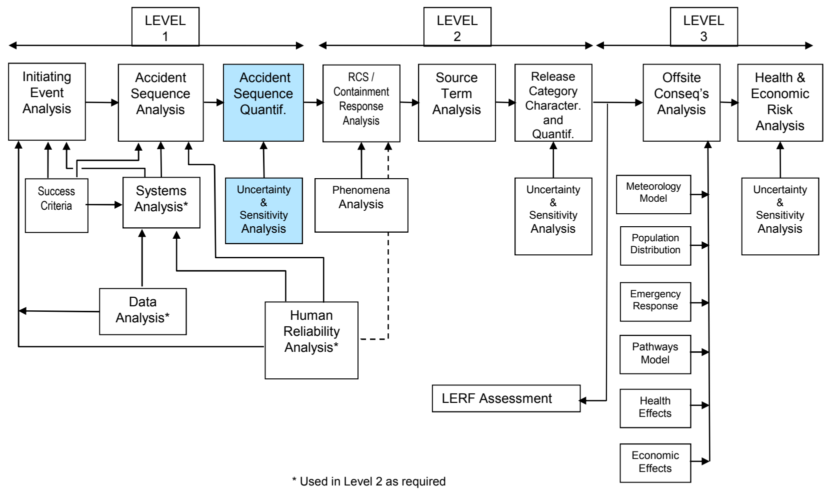
Accident Sequence Quantification

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

Principal Steps in PRA



Purpose and Objectives

- Purpose
  - Present elements of accident sequence quantification and importance analysis and introduce concept of plant damage states
- Objectives
  - Become familiar with the:
    - process of generating and quantifying cut sets
    - different importance measures typically calculated in a PRA
    - impact of correlation of data on quantification results
    - definition of plant damage states

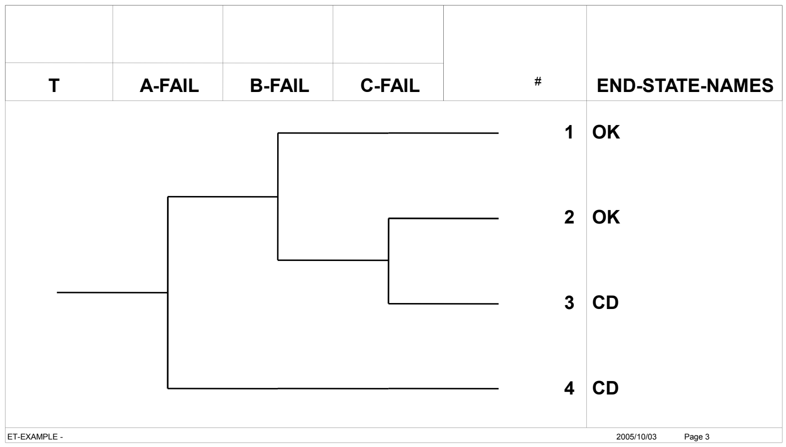
Prerequisites for Generating and Quantifying Accident Sequence Cut Sets

- Initiating events and frequencies
- Event trees to define accident sequences
- Fault trees and Boolean expressions for all systems (front line and support)
- Data (component failures and human errors)

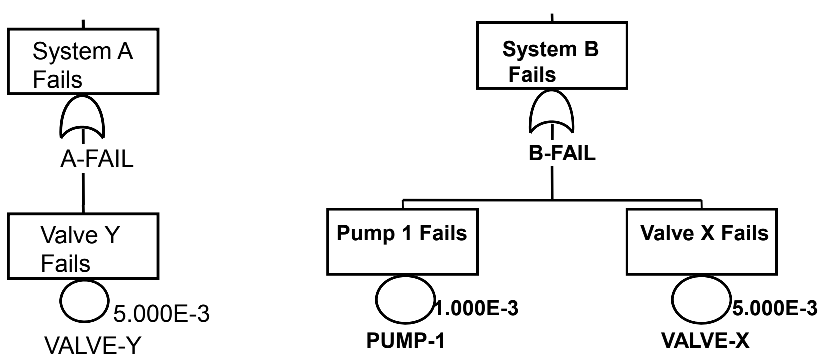
Accident Sequence Quantification (Fault-Tree Linking Approach)

- Link fault tree models on a sequence level using event trees (i.e., generate sequence logic)
- Generate minimal cut sets (Boolean reduction) for each sequence
- Quantify sequence minimal cut sets with data
- Eliminate inappropriate cut sets, add operator recovery actions, and requantify
- Determine dominant accident sequences
- Perform sensitivity, importance, and uncertainty analysis

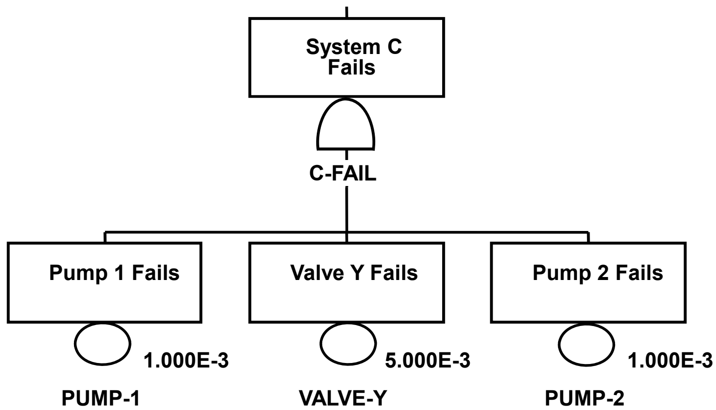
Example Event Tree



Example Fault Trees



Example Fault Trees (Concluded)



Generating Sequence Logic

- Fault trees are linked using sequence logic from event trees. From the example event tree two sequences are generated:
  - Sequence # 3: T * /A-FAIL * B-FAIL * C-FAIL
  - Sequence #4: T * A-FAIL

Generate Minimal Cut Sets for Each Sequence

- A ***cut set*** is a combination of events that cause the sequence to occur
- A minimal cut set is the smallest combination of events that causes to sequence to occur
- Cut sets are generated by "ANDing" together the failed top event fault trees, and then, if necessary, eliminating (i.e., deleting) those cut sets that contain failures that would prevent successful (i.e., complemented) top events from occurring. This process of elimination is called *Delete Term*
- Each cut set represents a failure scenario that must be "ORed" together with all other cut sets for the sequence when calculating the total frequency of the sequence

Sequence Cut Set Generation Example

- Sequence #3 logic is T * /A-FAIL * B-FAIL * C-FAIL
- ANDing failed top events yields

B-FAIL * C-FAIL = (PUMP-1 + VALVE-X) * (PUMP-1 * VALVE-Y * PUMP-2)

= (PUMP-1 * PUMP-1 * VALVE-Y * PUMP-2) + (VALVE-X * PUMP-1 * VALVE-Y * PUMP-2)

= (PUMP-1 * VALVE-Y * PUMP-2) + (VALVE-X * PUMP-1 * VALVE-Y * PUMP-2)

= PUMP-1 * VALVE-Y * PUMP-2

- Using Delete Term to remove cut sets with events that would fail top event A-FAILS (i.e., VALVE-Y) results in the elimination of all cut sets
- Sequence #4 logic is T * A-FAIL, resulting in the cut set T *VALVE-Y

Eliminating “Inappropriate” Cut Sets

- When solving fault trees to generate sequence cut sets it is likely that “inappropriate” cut sets will be generated
- “Inappropriate” cut sets are those containing *invalid* combinations of events. An example would be:
  - … SYS-A-TRAIN-1-TEST * SYS-A-TRAIN-2-TEST ….
- Typically eliminated by searching for combinations of invalid events and then deleting the cut sets containing those combinations

Adding “Recovery Actions” to Cut Sets

- Cut sets are examined to determine whether the function associated with a failed event can be restored; thus “recovering” from the loss of function
- If the function associated with an event can be restored, then a “Recovery Action” is ANDed to the cut set to represent this restoration
- The probability assigned to the “Recovery Action” will be the probability that the operators fail to perform the action or actions necessary to restore the lost function
- Probabilities are derived either from data (e.g., recovery of off-site power) or from human reliability analysis (e.g., manually opening an alternate flow path given the primary flow path is failed)

Dominant Accident Sequences (Examples)

Surry (NUREG-1150)

Seq	Description	% CDF	Cum
1	Station Blackout (SBO) - Batt Depl.	26.0	26.0
2	SBO - RCP Seal LOCA	13.1	39.1
3	SBO - AFW Failure	11.6	50.7
4	SBO - RCP Seal LOCA	8.2	58.9
5	SBO - Stuck Open PORV	5.4	64.3
6	Medium LOCA - Recirc Failure	4.2	68.5
7	Interfacing LOCA	4.0	72.5
8	SGTR - No Depress - SG Integ'ty Fails	3.5	76.0
9	Loss of MFW/AFW - Feed & Bleed Fail	2.4	78.4
10	Medium LOCA - Injection Failure	2.1	80.5
11	ATWS - Unfavorable Mod. Temp Coeff.	2.0	82.5
12	Large LOCA - Recirculation Failure	1.8	84.3
13	Medium LOCA - Injection Failure	1.7	86.0
14	SBO - AFW Failure	1.6	87.6
15	Large LOCA - Accumulator Failure	1.6	89.2
16	ATWS - Emergency Boration Failure	1.6	90.8
17	Very Small LOCA - Injection Failure	1.5	92.3
18	Small LOCA - Injection Failure	1.1	93.4
19	SBO - Battery Depletion	1.1	94.5
20	SBO - Stuck Open PORV	0.8	95.3

Grand Gulf (NUREG-1150)

Seq	Description	% CDF	Cum
1	Station Blackout (SBO) With HPCS And RCIC Failure	89.0	89.0
2	SBO With One SORV, HPCS And RCIC Failure	4.0	93.0
3	ATWS - RPS Mechanical Failure With MSIVs Closed, Operator Fails To Initiate SLC, HPCS Fails And Operator Fails To Depressurize	3.0	96.0

Importance Measures for Basic Events

- Provide a quantitative perspective on risk and sensitivity of risk to changes in input values
- Three are encountered most commonly:
  - Fussell-Vesely (F-V)
  - Birnbaum
  - Risk Reduction (RR)
  - Risk Increase (RI) or Risk Achievement (RA)

Importance Measures
(Layman Definitions)

- Risk Achievement Worth (RAW)
  - Relative risk increase assuming failure
- Risk Reduction Worth (RRW)
  - Relative risk reduction assuming perfect performance
- Fussell-Vesely (F-V)
  - Fractional reduction in risk assuming perfect performance
- Birnbaum
  - Difference in risk between perfect performance and assumed failure

Importance Measures
(Mathematical Definitions)

R = Baseline Risk

R(1) = Risk with the element always failed or unavailable

R(0) = Risk with the element always successful

RAW = R(1)/R or R(1) - R

RRW = R/R(0) or R - R(0)

F-V = [R-R(0)]/R

Birnbaum = R(1) – R(0)

Uncertainty Must be Addressed in PRA

- Uncertainty arises from many sources:
  - Inability to specify initial and boundary conditions precisely
    - Cannot specify result with deterministic model
    - Instead, use probabilistic models (e.g., tossing a coin)
  - Sparse data on initiating events, component failures, and human errors
  - Lack of understanding of phenomena
  - Modeling assumptions (e.g., success criteria)
  - Modeling limitations (e.g., inability to model errors of commission)
  - Incompleteness (e.g., failure to identify system failure mode)

PRAs Identify Two Types of Uncertainty

- Distinction between aleatory and epistemic uncertainty:
  - "Aleatory" from the Latin Alea (dice), of or relating to random or stochastic phenomena. Also called "random uncertainty or variability."
  - "Epistemic" of, relating to, or involving knowledge; cognitive. [From Greek episteme, knowledge]. Also called "state-of-knowledge uncertainty."

Aleatory Uncertainty

- Variability in or lack of precise knowledge about underlying conditions makes events unpredictable. Such events are modeled as being probabilistic in nature. In PRAs, these include initiating events, component failures, and human errors.
- For example, PRAs model initiating events as a Poisson process, similar to the decay of radioactive atoms
- Poisson process characterized by frequency of initiating event, usually denoted by parameter λ

Epistemic Uncertainty

- Value of λ is not known precisely
- Could model uncertainty in estimate of λ using statistical confidence interval
  - Can't propagate confidence intervals through PRA models
  - Can't interpret confidence intervals as probability statements about value of λ
- PRAs model lack of knowledge about value of λ by assigning (usually subjectively) a probability distribution to λ
  - Probability distribution for λ can be generated using Bayesian methods.

Types of Epistemic Uncertainties

- Parameter uncertainty
- Modeling uncertainty
  - System success criteria
  - Accident progression phenomenology
  - Health effects models (linear versus nonlinear, threshold versus non-threshold dose-response model)
- Completeness
  - Complex errors of commission
  - Design and construction errors
  - Unexpected failure modes and system interactions
  - All modes of operation not modeled

Addressing Epistemic Uncertainties

- Parameter uncertainty addressed by propagating parameter uncertainty distributions through model
- Modeling uncertainty usually addressed through sensitivity studies
  - Research ongoing to examine more formal approaches
- Completeness addressed through comparison with other studies and peer review
  - Some issues (e.g., design errors) are simply acknowledged as limitations
  - Other issues (e.g., errors of commission) are topics of ongoing research

Prerequisites for Performing a Parameter Uncertainty Analysis

- Cut sets for individual sequence or groups of sequences (e.g., by initiator or total plant model) exist
- Failure probabilities for each basic event, including distribution and correlation information (for those events that are uncertain or are modeled as having uncertainty)
- Frequencies for each initiating event, including distribution information

Performing A Parameter Uncertainty Analysis

- Select cut sets
- Select sampling strategy
  - Monte Carlo: simple random sampling process/technique
  - Latin Hypercube: stratified sampling process/technique
- Select number of observations (i.e., number of times a variable's distribution will be sampled)
- Perform calculation

Correlation: Effect on Results

- Correlating data produces wider uncertainty in results
  - Without correlating a randomly selected high value will usually be combined with randomly selected lower values (and vice versa), producing an averaging effect
    - Reducing calculated uncertainty in the result
  - Mean value of probability distributions that are skewed right (e.g. lognormal, commonly used in PRA) is increased when uncertainty is increased

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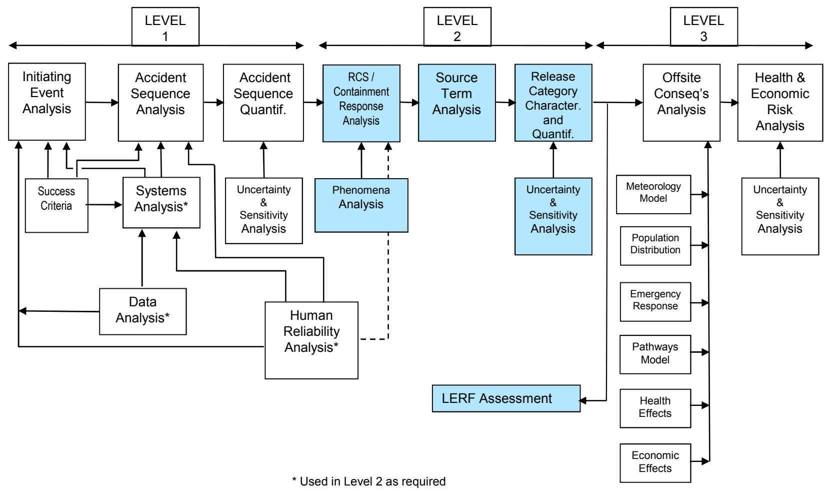
SAIC Science Applications International Corporation From Science to Solutions™

LEVEL 2/LERF Analysis

Principal Steps in PRA



Purpose and Objectives

- Purpose: Students receive a brief introduction to accident progression (Level 2 PRA).
- Objectives: At the conclusion of this topic, students will be able to:
  - List primary elements which comprise accident phenomenology
  - Explain how accident progression analysis is related to full PRA
  - Explain general factors involved in containment response
- Reference: NUREG/CR-2300, NUREG-1489 (App. C)

Level 2 PRA Risk Measures

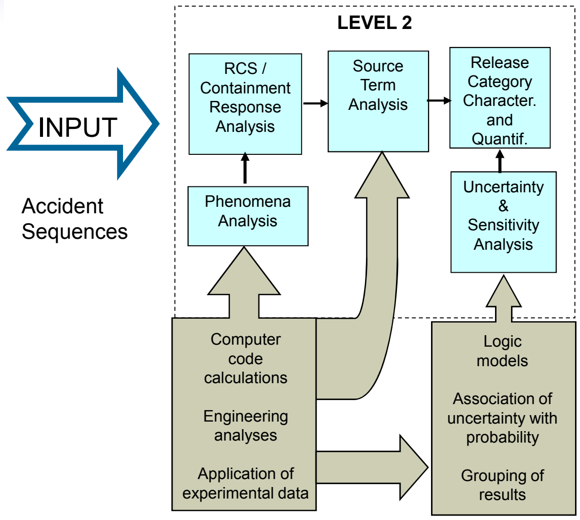
- Current NRC emphasis on LERF
  - Risk-informed Decision-Making for Currently Operating Reactors
  - Broader view expected for new reactors
- Some discussion of alternative risk acceptance criteria
  - Goals for frequency of various release magnitudes
  - Release often expressed in units of activity (not health consequences)
- Full-scope Level 2 offers Complete Characterization of Releases to Environment
  - Frequency of large/small, early/late releases

LERF Definition

- A LERF definition is provided in the PSA Applications Guide:

  Large, Early Release: A radioactive release from the containment which is both large and early. Large is defined as involving the rapid, unscrubbed release of airborne aerosol fission products to the environment. Early is defined as occurring before the effective implementation of the off-site emergency response and protective actions.

Level 2 PRA is a Systematic Evaluation of Plant Response to Core Damage Sequences



OUTPUT

Deterministic:

- Reactor transient
- Containment response
- Core damage progression
- Fission product inventory released to environment

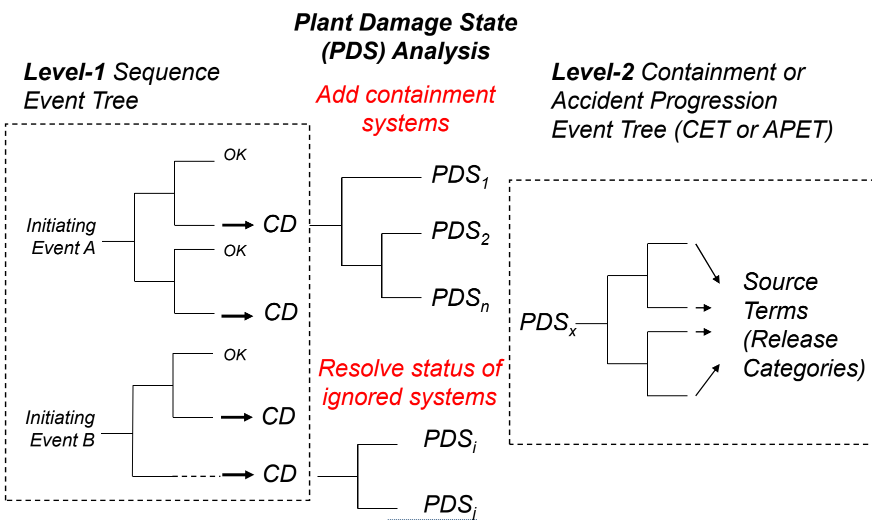
Probabilistic:

- Relative likelihood of (confidence in) alternative responses for each sequence
- Frequency of fission product release categories

Some Subtle Features of the Level 2 PRA Process

- Level 2 Requires More Information than a Level 1 PRA Generates
  - Containment safeguards systems not usually needed to determine 'core damage'
  - Level 1 event trees built from success criteria can ignore status of front-line systems that influence extent of core damage
- Event Trees Create Very Large Number of Scenarios to Evaluate
  - Grouping of similar scenarios is a practical necessity
- Quantification Involves Considerable Subjective Judgment
  - Uncertainty, Sensitivity and Uncertainty in Uncertainty

Additional Work is Often Required to Link Level 1 Results to Level 2



Fire PRA Workshop, 2010, Washington DC
PRA/HRA Overview

Slide 155

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

Major Tasks:

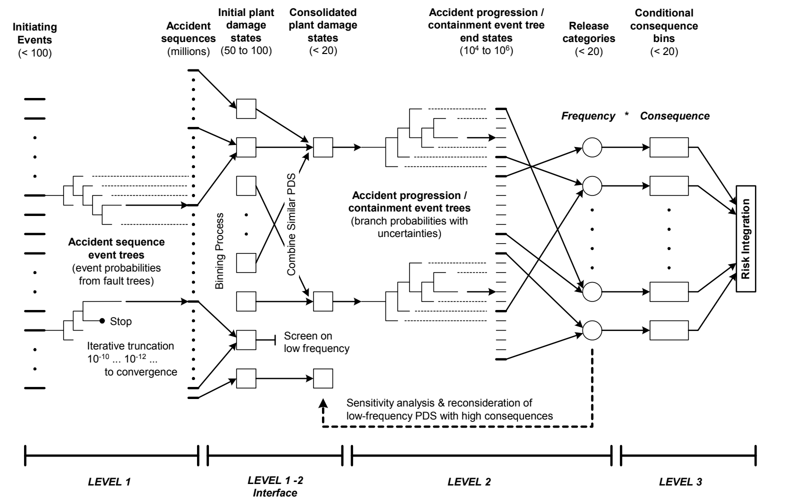
- Plant Damage State (PDS) Analysis
  - Link to Level 1
- Deterministic Assessments of Plant Response to Severe Accidents
  - Containment performance assessment
  - Accident progression & source term analysis
- Probabilistic Treatment of Epistemic Uncertainties
  - Account for phenomena not treated by computer codes
  - Characterize relative probability of alternative outcomes for uncertain events
- Couple Frequency with Radiological Release
  - Link to Level 3

Fire PRA Workshop, 2010, Washington DC
PRA/HRA Overview

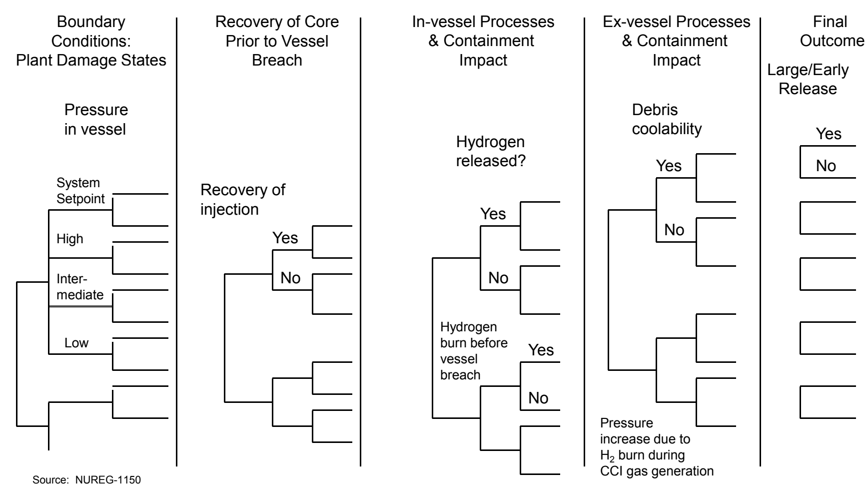
Slide 156

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

Typical Steps in Level 2 Probabilistic Model



Schematic of Accident Progression Event Tree



Source: NUREG-1150

Accident Progression Analysis

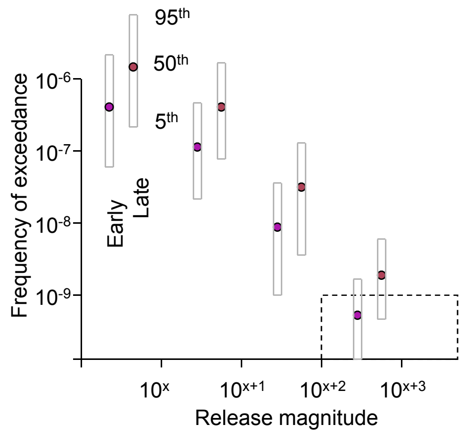
- There are 4 major steps in Accident Progression Analysis
  - 1. Develop the Accident Progression Event Trees (APETs)
  - 2. Perform structural analysis of containment
  - 3. Quantify APET issues
  - 4. Group APET sequences into accident progression bins

Containment Response

- How does the containment system deal with physical conditions resulting from the accident?
  - Pressure
  - Heat sources
  - Fission products
  - Steam and water
  - Hydrogen
  - Other non-condensables

Full Scope Level 2 PRA: Wide Range of Possible Releases of Accidental Releases to Environment

- Characterization of Releases to the Environment of all Types
  - Large/Small
  - Early/Late
  - Energetic/Protracted
  - Elevated/Ground level
- Frequency of Each Type Describes Full Spectrum of Releases Associated with Core Damage Events



Self- Assessment

Probabilistic Risk Assessment (PRA) Basics

1. **Define the following:**
    - **Cut set –**
    - **Minimal cut set –**

2. **Bayesian techniques combine an initial estimate (called a ___________________) with plant-specific data (likelihood function) to produce a final estimate (called a ______________).**

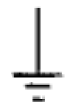
3. **What is the difference between aleatory and epistemic uncertainty?**

APPENDIX E: ANSWERS TO SELF ASSESSMENT

Answers to Self- Assessment

Circuit Analysis Basics

Electrical Videos (Part 1 of 4):

1. *A grounded circuit includes the earth ground symbol* 
2. *b*
3. *d*

Electrical Videos (Part 2 of 4):

1. **+** *, indicates positive polarity* **-** *, indicates negative polarity*
2. *b*
3. *a) Air Operated Valve b) Motor Operated Valve c) Solenoid Valve*

Electrical Videos (Part 3 of 4):

1. *d*
2. *Motor Operated Valves (MOVs)*

Electrical Videos (Part 4 of 4):

1. *Thermoset and Thermoplastic*
2. *c*
3. *d*

Answers to Self- Assessment

Fire PRA Methodology

Fire Videos (Part 1 of 6):

1. *Fuel, oxygen, and energy*
2. *c*
3. *b, correct unit is* kW/m^2

Fire Videos (Part 1 of 6, last 5 slides):

1. *Growth, steady burn, decay*
2. *b*
3. *a*

Fire Videos (Part 2 of 6):

1. *upper and lower*
2. *a*
3. *b, c, a*

Fire Videos (Part 3 of 6):

1. *Conduction*
2. *a*
3. *a) ignition b) growth c) HGL build-up d) flashover e) fully developed fire f) decay*

Fire Videos (Part 4 of 6):

1. *a) prompt b) smoke c) heat d) incipient e) delayed*
2. *Smoke detectors measure the particulates that enter the chamber of the device; whereas, heat detectors measure temperature increases.*
3. *a) prompt b) automatic sprinklers c) dry-Pipe/pre-action sprinklers d) deluge systems e) CO2 auto & manual f) halon g)fire brigade*

Fire Videos (Part 5 of 6):

1. *a) define modeling objectives b) select and describe fire scenarios c) select the appropriate model(s) d) run/apply the model e) interpret modeling results*
2. *Fire modeling is an approach for predicting various aspects of fire generated conditions*
3. *a) hand calculations b) zone models c) field models d) special models*

Fire Videos (Part 6 of 6):

1. *a*
2. *d*
3. *Can be explained based on the information presented on Slide #12 and Slide #13*

Answers to Self- Assessment

Human Reliability Analysis (HRA) Basics

HRA Videos (Part 1 of 5):

1. *Human Reliability Analysis (HRA) is a structured approach used to identify potential human failure events and to systematically estimate the probability of those errors using data, models, or expert judgment.*
2.
   - *Human Failure Events (HFE)*
   - *Qualitative evaluation or analysis of factors influencing human errors and successes*
   - *Human Error Probabilities (HEP) for each HFE*
3. *False, a seismic event is an External Hazard*

HRA Videos (Part 2 of 5):

1. *latent errors*
2. *Capability Category I*
3. *a*

HRA Videos (Part 3 of 5):

1. *context*
2.
   - *EPRI's SHARP1 – A Revised Systematic Human Action Reliability Procedure, EPRI TR-101711*
   - *NRC's Good Practices for Implementing Human Reliability Analysis (HRA), NUREG-1792*
3. *The "blame culture" or "human-as-a-hazard" view is a commonly held belief by some that: If we could just eliminate the human, we'd never have any problems.*

HRA Videos (Part 4 of 5):

1.
    - ***a)*** *Classifications, categories, types, etc…*
        - *Errors of omission and commission*
    - ***b)*** *Behavior models*
        - *Information processing models, such as: detection, situation assessment, etc…*

2. *context*
3. *False, because human error is not random.*

HRA Videos (Part 5 of 5):

1. *B*
2. *D*
3. *A*
4. *C*

Answers to Self- Assessment

Probabilistic Risk Assessment (PRA) Basics

PRA Videos (Part 1 of 4):

1. *PRAs are performed to find severe accident weaknesses and provide quantitative results to support decision-making.*
2. *Several limitations, refer to Slide #14*
3. *b*

PRA Videos (Part 2 of 4):

1. *Identification of accident sequences which result in some outcome of interest (usually core damage and/or containment failure); and basis for accident sequence quantification*
2. *initiating event*
3.
    a. *Determine boundaries of analysis*
    b. *Define critical plant safety functions available to mitigate each initiating event*
    c. *Determine systems available to perform each critical plant safety function*
    d. *Determine success criteria for each system for performing each critical plant safety function*
    e. *Generate system-level event tree*
    f. *Generate functional event tree (optional)*

PRA Videos (Part 3 of 4):

1. *d*
2. *gates*
3. ***Name**: Basic Event*

    ***Description**: a basic component fault which requires no further development. Consistent with level of resolution in databases of component faults.*

PRA Videos (Part 4 of 4):

1.
    a. *A cut set is a combination of events that cause the sequence to occur*
    b. *A minimal cut set is the smallest combination of events that causes two sequences to occur*
2. *prior , posterior*
3. *Refer to Slide #140*

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The U.S. Nuclear Regulatory Commission (NRC) approved the risk-informed and performance-based alternative regulation 10 CFR 50.48(c) in July, 2004, which allows licensees the option of using fire protection requirements contained in the National Fire Protection Association (NFPA) Standard 805, "Performance Based Standard for Fire Protection for Light-Water Reactor Electric Generating Plants, 2001 Edition," with certain exceptions. To support licensees' use of that option, the NRC and the Electric Power Research Institute (EPRI) jointly issued NUREG/CR-6850 (EPRI 1011989) "Fire PRA Methodology for Nuclear Power Facilities," in September 2005. That report documents the state-of-the-art methods, tools, and data for conducting a fire Probabilistic Risk Assessment (PRA) in a commercial nuclear power plant (NPP) application. Since the release of NUREG/CR-6850 in 2005, the NRC-RES and EPRI have conducted a number of joint public workshops to provide training in the use of the methodologies and tools contained in the document. The workshops have attracted both domestic and international attendees. The material in this NUREG/CP was recorded during the first day of each of two week-long workshops conducted in 2010, during which certain fundamental, basic principles were discussed that are prerequisite for the remaining days of the workshops. It was adapted by the NRC-RES Fire Research Branch (FRB) members for use by persons before they attend future workshops, in lieu of the basic discussions previously conducted on the workshops' first day - this will allow the first day of future workshops to be used to cover more advanced material. This report can also serve as a refresher for those who attended one or more previous training sessions.

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