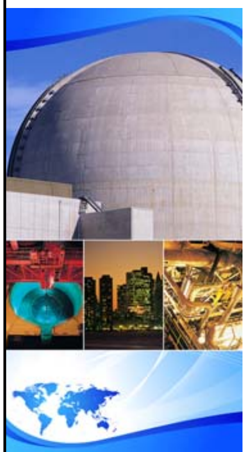


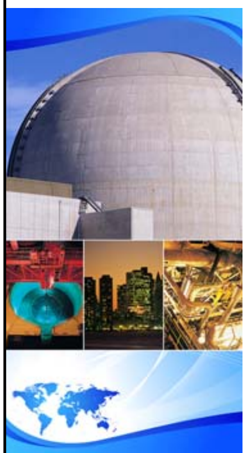
Basics of Nuclear Power Plant Probabilistic Risk Assessment

Joint RES/EPRI Fire PRA Workshop
2009
Palo Alto, CA

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

Course Objectives

- Introduce Probabilistic Risk Assessment (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
  - Large Early Release Frequency (LERF) analysis



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

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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

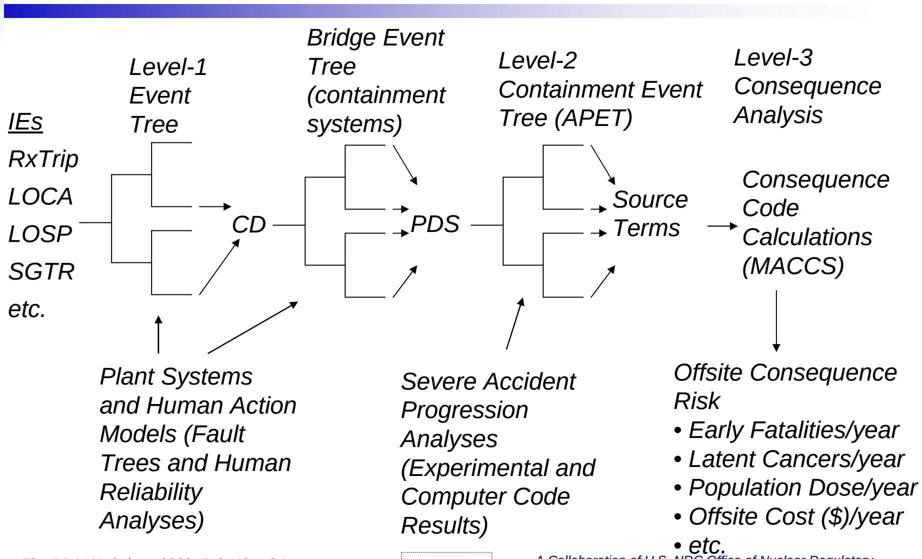
- Note: www.cdc.gov latest data (2005) 546,016 cancer deaths and 296,748,000 U.S. population, thus average individual risk ☜ (546,016 deaths/year)/296,748,000 ☜ 1.8E-03 Deaths/Person-Year

Overview of PRA Process

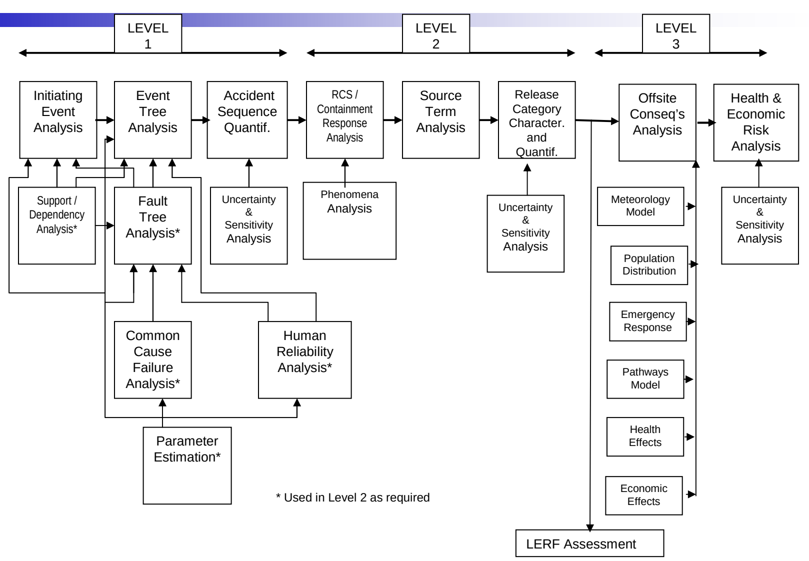
- PRAs are performed to find severe accident weaknesses and provide quantitative results to support decision-making. Three levels of PRA have evolved:

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

Overview of Level-1/2/3 PRA



Principal Steps in PRA



PRA Classification

- Internal Events – risk from accidents initiated internal to the plant
  - Includes internal flooding and fire events and loss-of-offsite power
- External Events – risk from external events
  - Includes seismic, external flooding, high winds and tornadoes, airplane crashes, lightning, hurricanes, etc.
- Full Power – accidents initiated while plant is critical 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)

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SAIC Science Applications International Corporation
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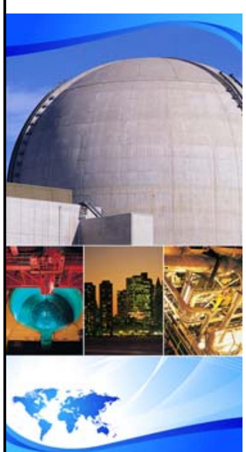

Initiating Event Analysis

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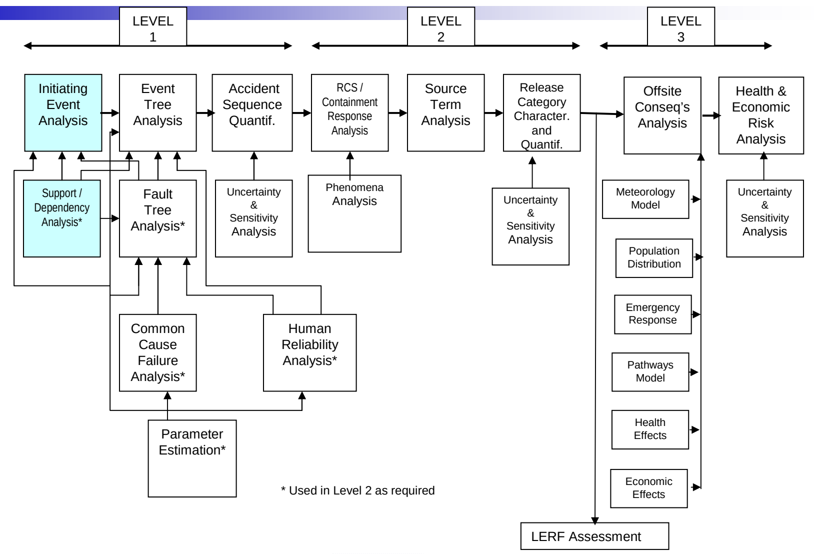
Principal Steps in PRA



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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

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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 (ISLOCAs)
  - 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 breaks vs. stuck-open relief valves), 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 light-water reactors (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/ANS 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 ventilation and cooling)
  - 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 (Power Conversion System 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

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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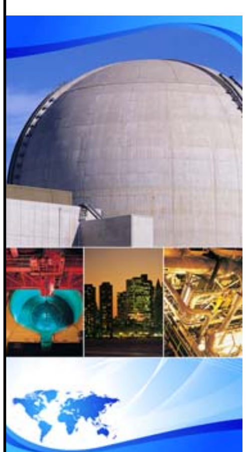

Event Tree Analysis

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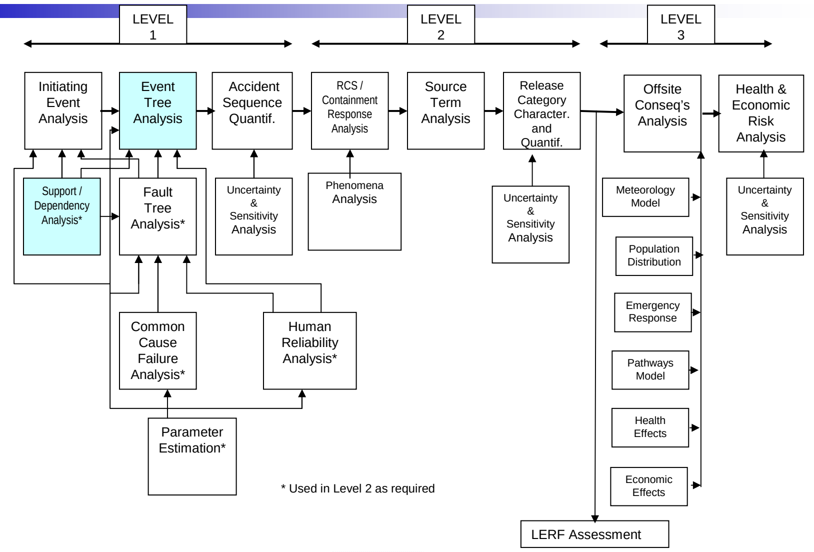
Principal Steps in PRA



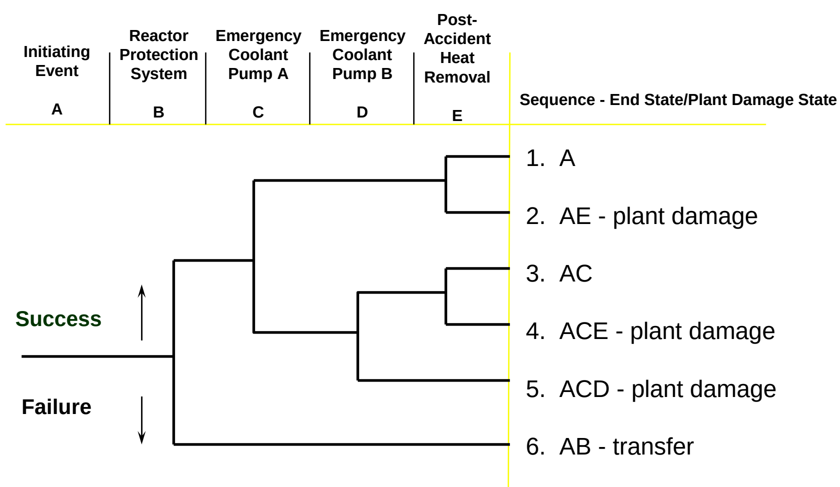
Event Tree Analysis

- Purpose: Students will learn purposes & techniques of event tree 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 damage
  - Containment OK
  - Containment failed
  - Containment vented
- Extent of operator recovery

Critical Safety Functions

Example safety functions for core & containment

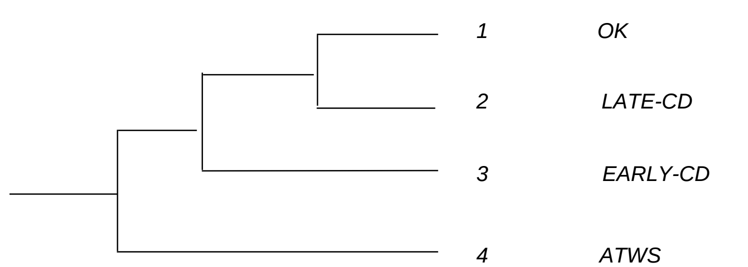
- Reactor subcriticality
- Reactor coolant system overpressure protection
- Early core heat removal
- Late core heat removal
- Containment pressure suppression
- Containment heat removal
- Containment integrity

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 best-estimate, 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)

PWR Mitigating Systems

Function	Systems
Reactivity Control	Reactor Protection System (RPS)
RCS Overpressure Protection	Safety valves, Pressurizer power-operated relief valves (PORV)
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)

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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*

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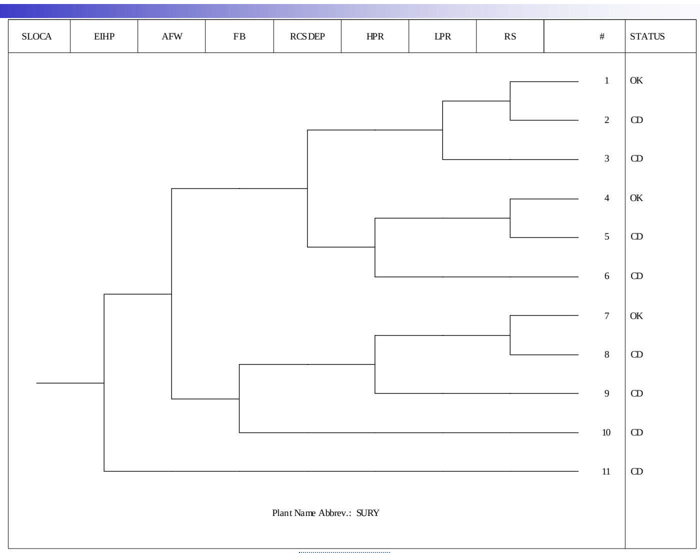
System-Level Event Tree Development

- 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 mitigating systems 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 trees for development
- Each path of an event tree represents a potential scenario
- Each potential scenario results in either plant success or core damage (or a particular end state of interest)

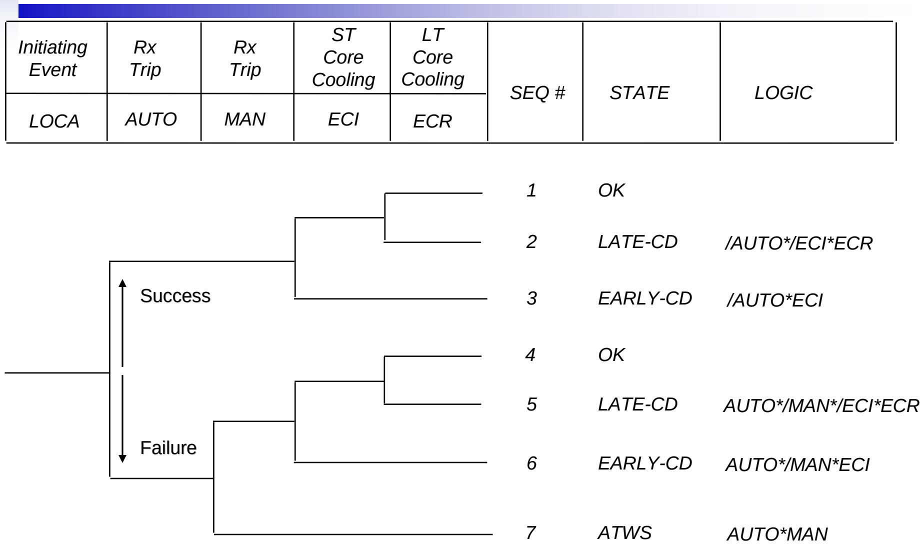
Small LOCA Event Tree from Surry SDP Notebook



Event Tree Reduction and Simplification

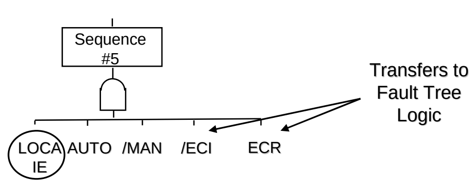
- Single transient event tree can be drawn with specific IE dependencies included at the fault tree level
- Event tree structure can often be simplified by reordering top events
  - Example – Placing ADS before LPCI and CS on a BWR transient event tree
- Event tree development can be stopped if a partial 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)

System Level Event Tree Determines Sequence Logic



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 Reactor Coolant System or RCS (e.g., pressure, integrity)
  - Status of water inventories (e.g., injected into Reactor Pressure Vessel?)

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 Emergency Core Cooling System (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

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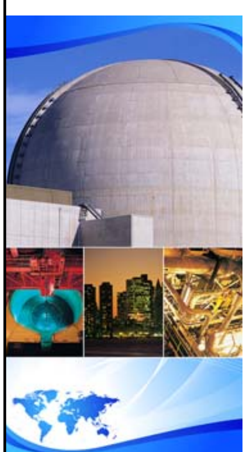

Fault Tree Analysis

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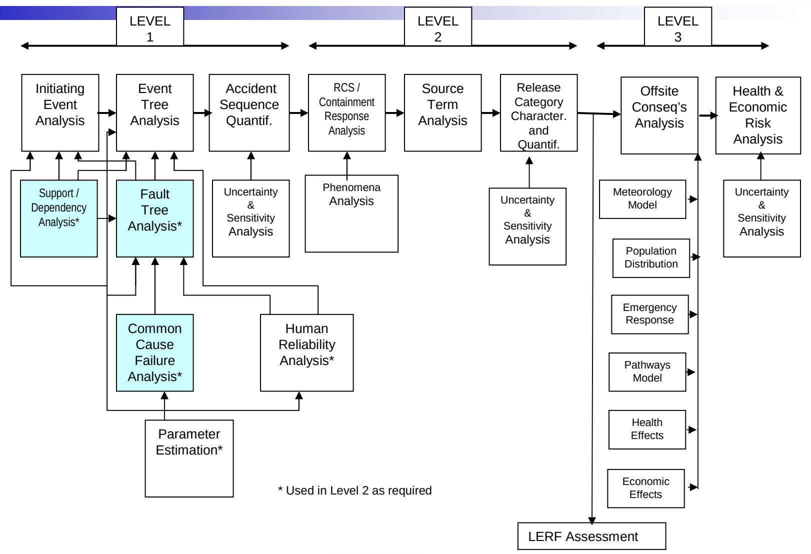
Principal Steps in PRA



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

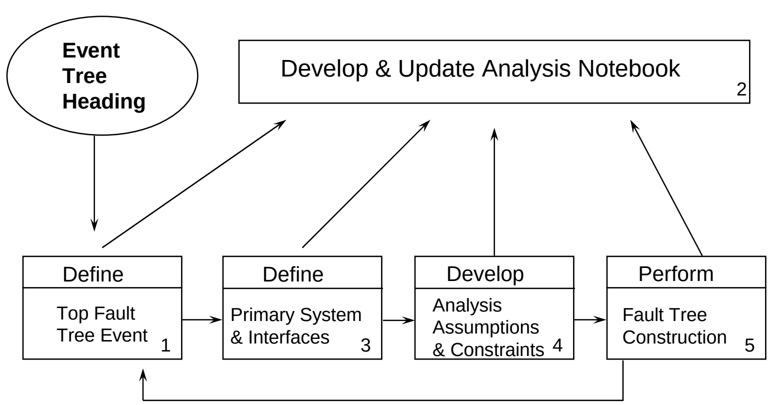
Fault Trees

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

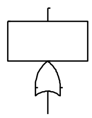
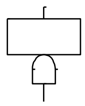
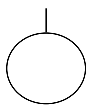
Fault Trees (cont.)

- Fault trees are graphic model of the various parallel and sequential combination of faults that will result in the occurrence of an undesired (top) event.
- Fault tree development moves from the top event to the basic faults which can cause it.
- Fault tree consists of gates which serve to permit or inhibit the passage of faults logic up 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.

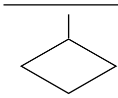
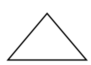
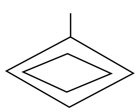
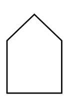
Fault Tree Development Process



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.

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
  - Unavailable because of Test or Maintenance
  - Fail to Open/Close/Operate
  - Definitions not always consistent among PRAs
    - e.g., transition from start phase to run phase can be defined differently

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, failure of actuation circuits can be included as a contributor to a component failing to start (FTS) and failure of room cooling can be included as a failure mode of a component failing to run (FTR)

Active Components Require "Support"

- Signal needed to "actuate" component
  - Safety Injection Signal starts pump or opens valve
- 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 systems in a BWR share common suction valve from Condensate Storage Tank)
    - 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 Reactor Water Storage Tank 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

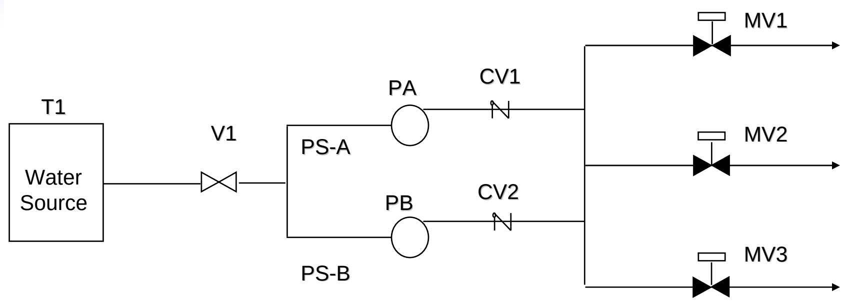
Common Cause Failure Mechanisms

- 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

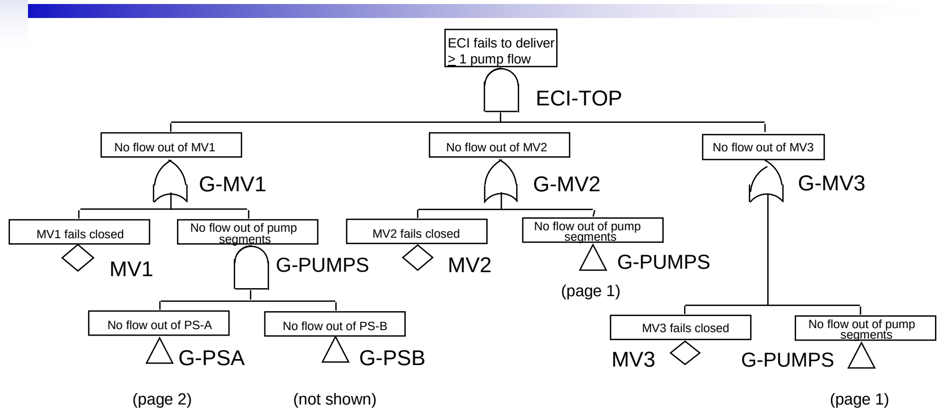
Example – Emergency Coolant Injection (ECI) System



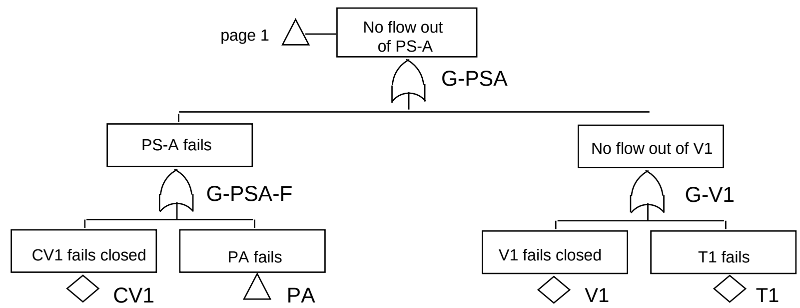
***Success Criteria**: Flow from any one pump through any one MV*

T_ tank
V_ manual valve, normally open
PS-_ pipe segment
P_ pump
CV_ check valve
MV_ motor-operated valve, normally closed

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



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



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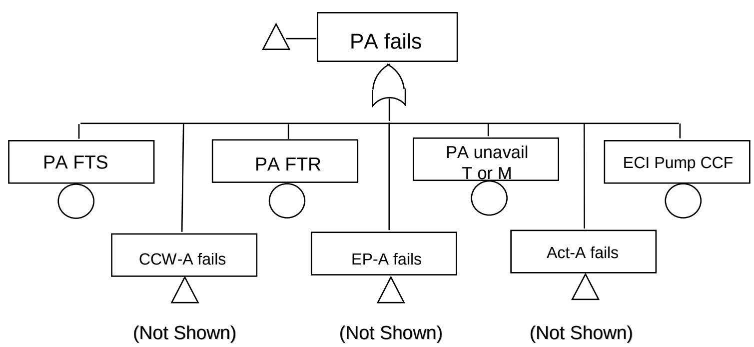
ECI System Fault Tree – “Sink to Source Method” (page 3)



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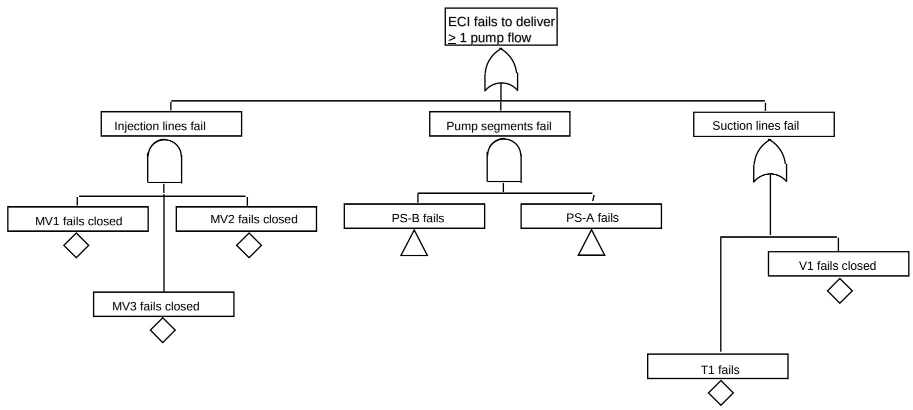
ECI System Fault Tree - Block Diagram Method



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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

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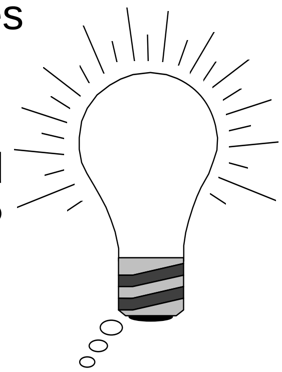
Minimal Cutset

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 test & maintenance unavailability can result in illegal cutsets
- Putting recovery in fault tree might give optimistic results
- Logic loops

Results

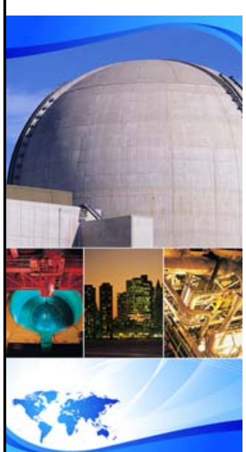
- Sanity checks on cut sets
  - Symmetry
    - If Train-A failures appear, do Train-B failures also appear?
  - Completeness
    - Are all redundant trains/systems really failed?
    - Are failure modes accounted for at component level?
  - Realism
    - Do cut sets make sense (i.e., Train-A out for 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?

ELECTRIC POWER RESEARCH INSTITUTE

Sandia National Laboratories

Curtiss Wright Flow Control Company SCIENTECH

SAIC Science Applications International Corporation



Human Reliability Analysis

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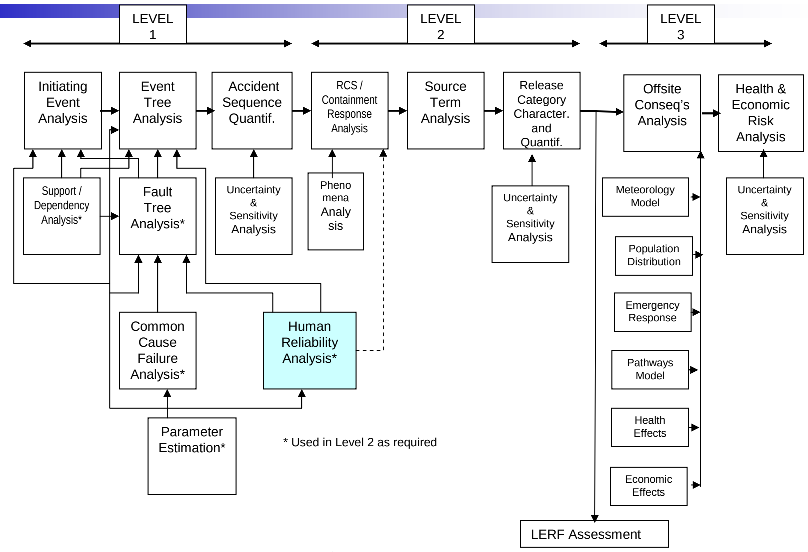
Principal Steps in PRA



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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

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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 are, in effect, components of the system.
  - Thus, Nuclear Power Plants and the systems which comprise them are "Man-Machine Systems."
- 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
  - Subject to the greatest uncertainties.

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 Emergency Operating Procedures)
  - 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

Identification & Definition:
- taxonomies
- context from event trees
- error producing conditions
- cognitive error
- errors of commission

Qualitative:
- Context from event trees & fault trees
- generic error models
- performance shaping factors

Quantification:
- data availability
- databases
- simulation
- empirical approaches

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.

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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 Operations-- 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

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Identification & Definition Process (cont.)

- PRA model identifies component/system/function failures
- HRA requires **definition** of supporting information, such as:
  - for post-initiating events, 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 Emergency Operating Procedures (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 conditions
  - 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

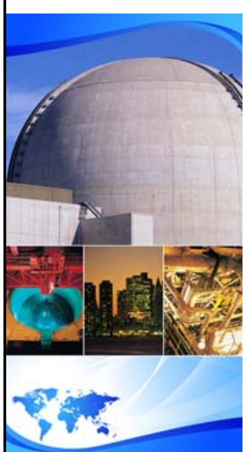
Dependencies

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.



Data Analysis

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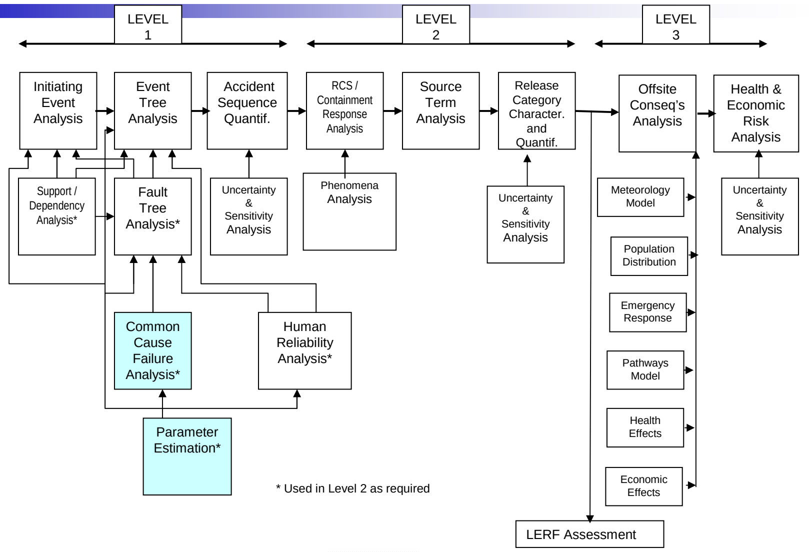
Principal Steps in PRA



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.
  - Fail to Run (FTR) – failures while operating and operating time
  - Fail to Start/Fail to Open (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

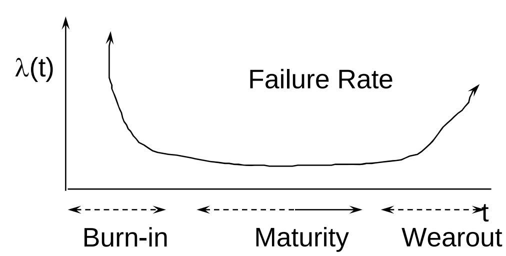
- Environment
  - Radioactivity
  - Temperature
  - Corrosive environment
- Design deficiency
- Manufacturing error
- Test or Maintenance error
- Operational error

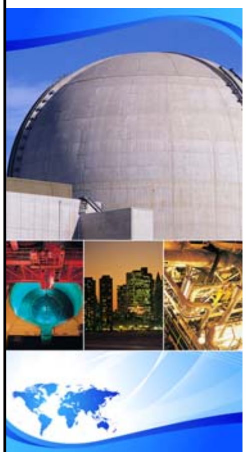
Limitations of CCF Modeling

- 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 diverse 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) = λ(t)
  - “Bathtub” curve

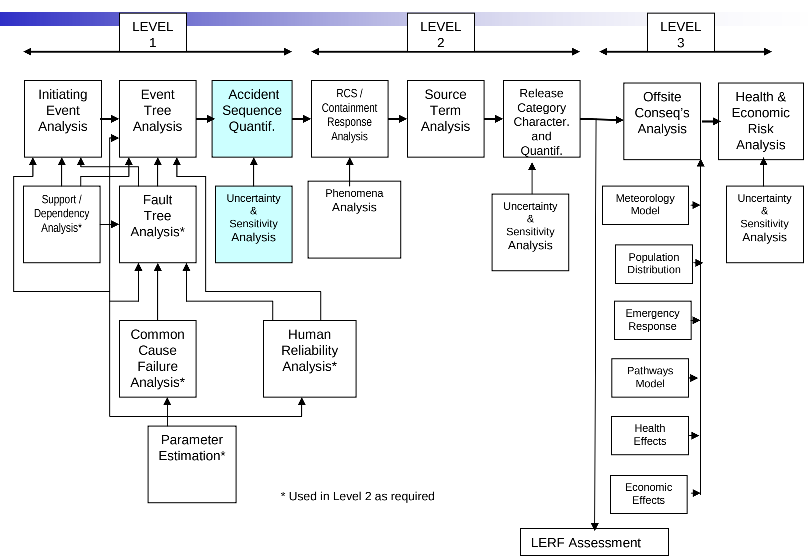




Accident Sequence Quantification

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

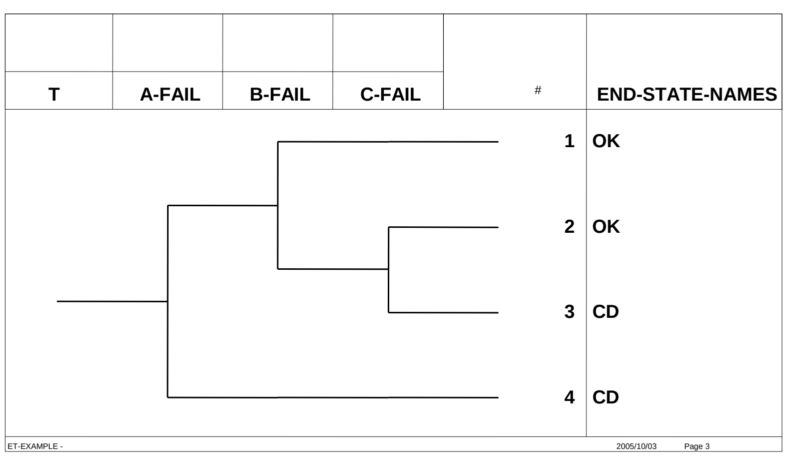
Prerequisites for Generating and Quantifying Accident Sequence Cut Sets

- 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)

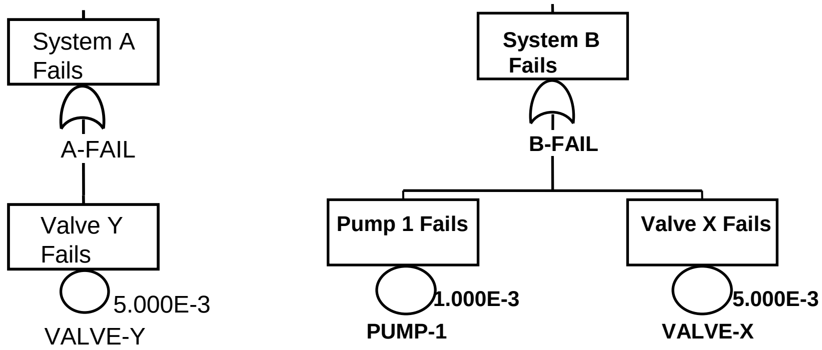
Accident Sequence Quantification (Fault-Tree Linking Approach)

- 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

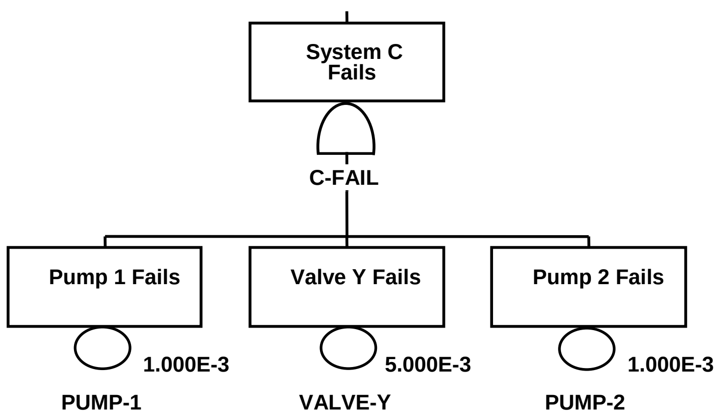
Example Event Tree



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

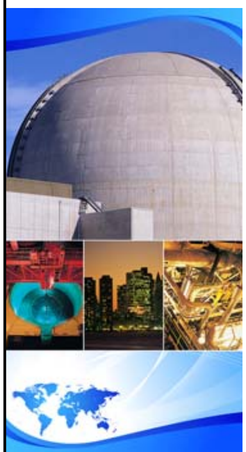
- Cut sets for individual sequence or groups of sequences (e.g., by initiator or total plant model) exist
- Failure probabilities for each basic event, including distribution and correlation information (for those events that are uncertain or are modeled as having uncertainty)
- Frequencies for each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

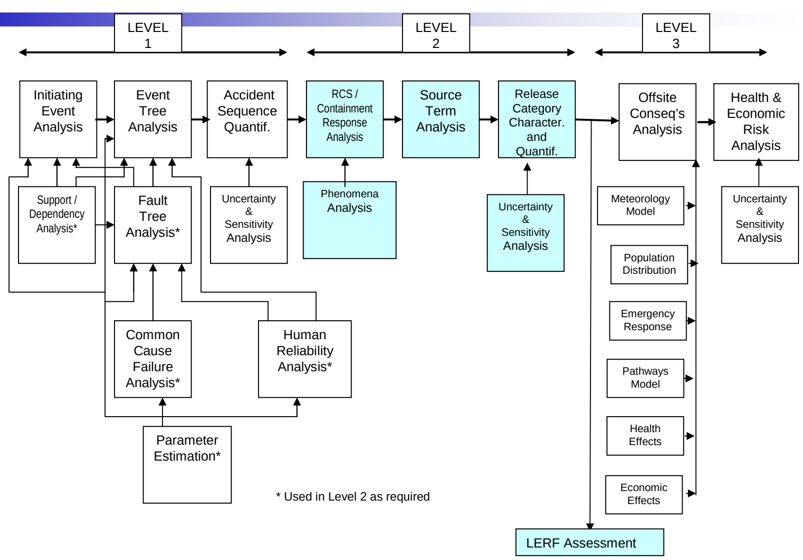
- Correlating data produces wider uncertainty in results
  - Without correlating a randomly selected high value will usually be combined with randomly selected lower values (and vice versa), producing an averaging effect
    - Reducing calculated uncertainty in the result
  - Mean value of probability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



LEVEL 2/LERF Analysis

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: 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

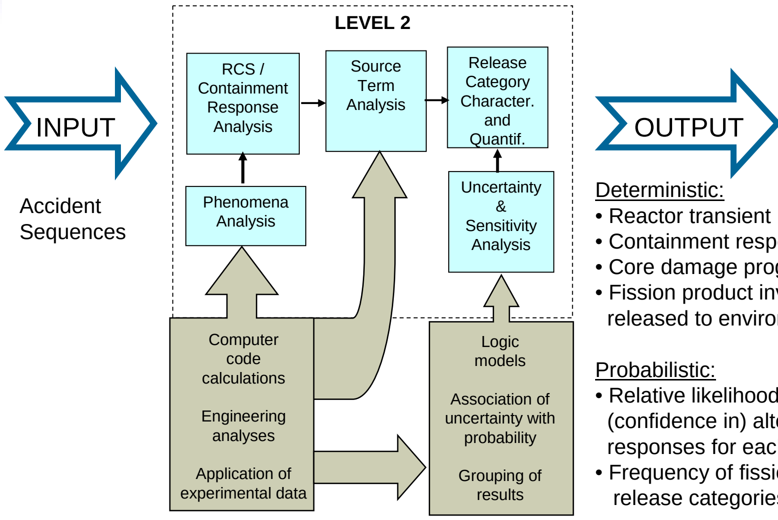
- Current NRC emphasis on LERF
  - Risk-informed Decision-Making for Currently Operating Reactors
  - Broader view expected for new reactors
- Some discussion of alternative risk acceptance criteria
  - Goals for frequency of various release magnitudes
  - Release often expressed in units of activity (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



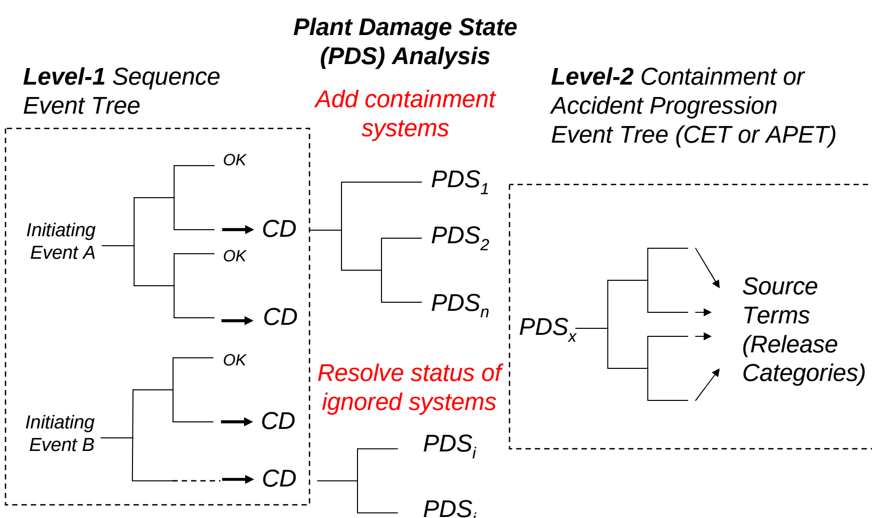
Deterministic:
- Reactor transient
- Containment response
- Core damage progression
- Fission product inventory released to environment

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 <u>extent of</u> 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

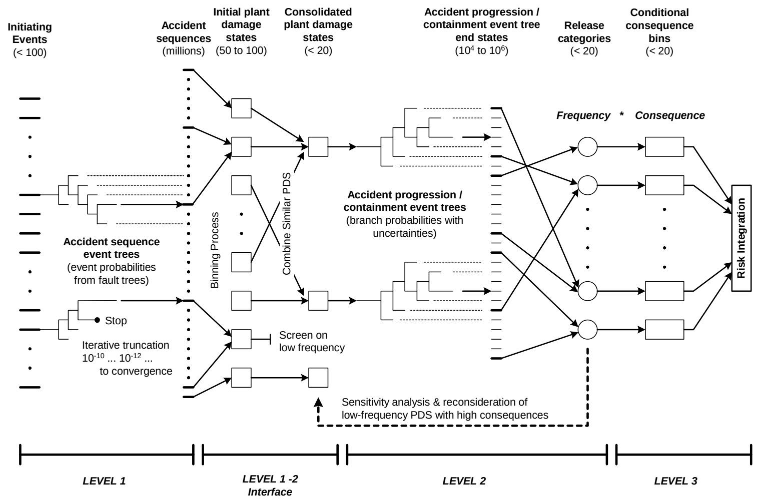
Additional Work is Often Required to Link Level 1 Results to Level 2



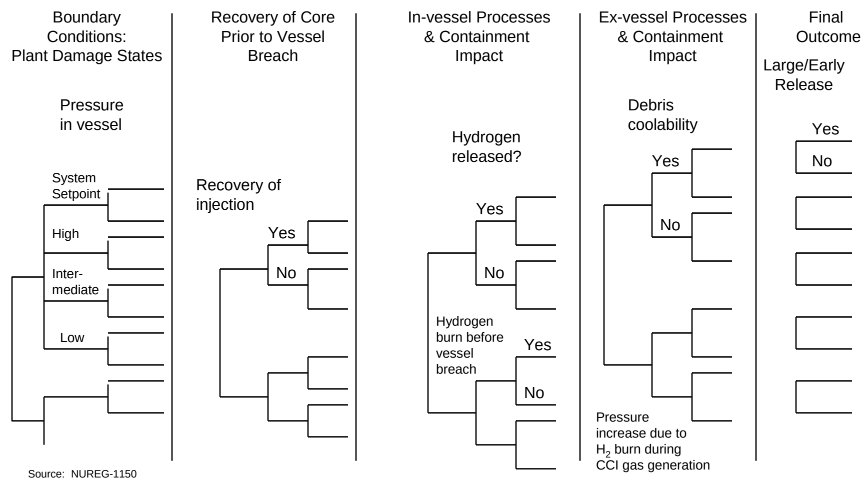
Major Tasks:

- 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

Typical Steps in Level 2 Probabilistic Model



Schematic of Accident Progression Event Tree



Source: NUREG-1150

Accident Progression Analysis

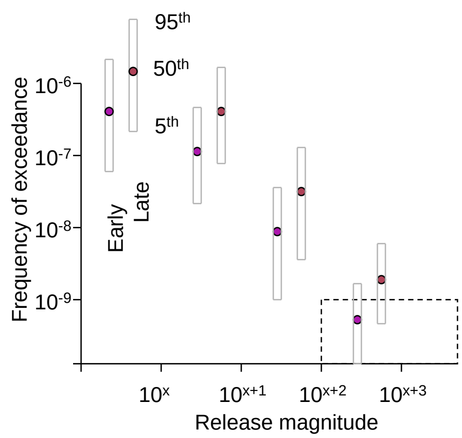
- There are 4 major steps in Accident Progression Analysis
  - 1. Develop the Accident Progression Event Trees (APETs)
  - 2. Perform structural analysis of containment
  - 3. Quantify APET issues
  - 4. Group APET sequences into accident progression bins

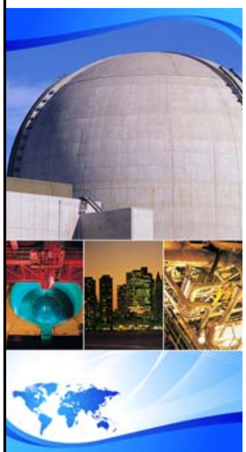
Containment Response

- 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





EPRI/NRC-RES FIRE PRA METHODOLOGY

Module 2: Circuit Analysis Basics

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

Joint RES/EPRI Fire PRA Course
June & October 2009

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 Breaker & 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

Typical Circuit Devices & Symbols

Refer to Symbol
Library Handout

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 & Ductbank Layout Drawings
- Specialty Drawings (Electrical Penetration, Logic, Load Lists, Coordination Diagrams, Short Circuit Calcs)
- Piping & Instrument Diagrams

Types of Drawings and How to Read Them

- Review Drawings…
- Get your color markers ready

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

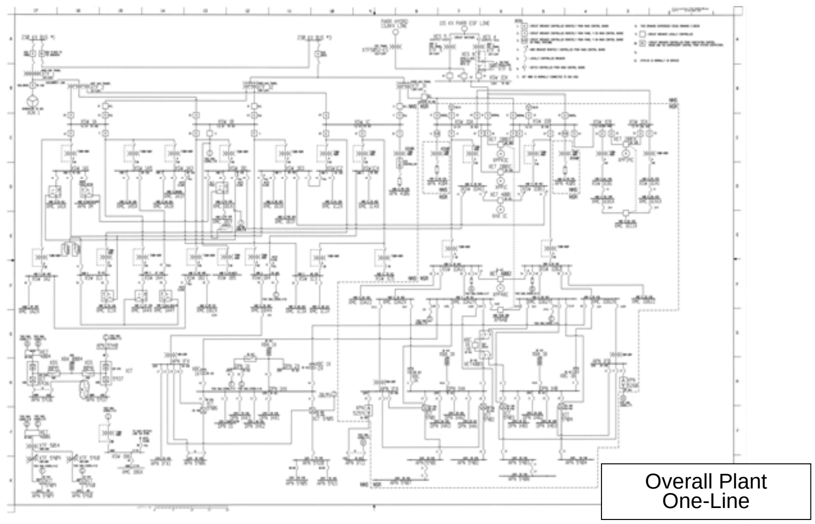
CIRCUIT ANALYSIS BASICS
Plant Electrical Distribution System Design

- 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

- 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



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
  - Ductbanks
  - 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, drawout 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 relay (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
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 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
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
- 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
- Frequently Asked Questions (FAQ) Process

CIRCUIT ANALYSIS BASICS

Fire PRA Circuit Analysis – Module 2 Training Topics

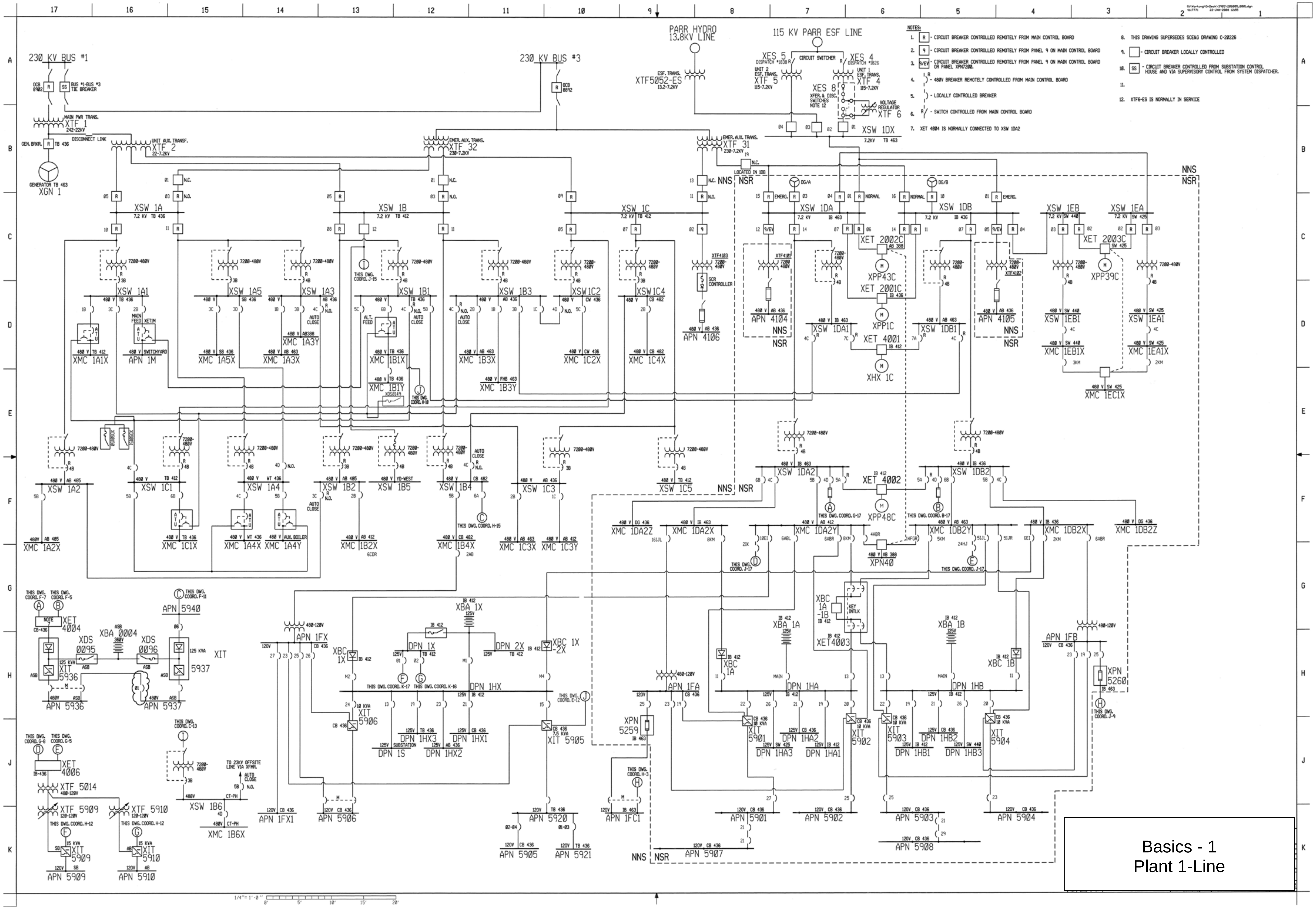
- Task 3: Fire PRA Cable Selection
  - What cables are associated with the FPRA components?
- Task 9: Detailed Circuit Analysis
  - Which cables can affect the credited functionality?
  - What failure modes are possible given fire damage to the cable?
- Task 10: Circuit Failure Mode Likelihood Analysis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

CIRCUIT ANALYSIS BASICS

Questions ?

Electrical Basics
Sample Drawing Index

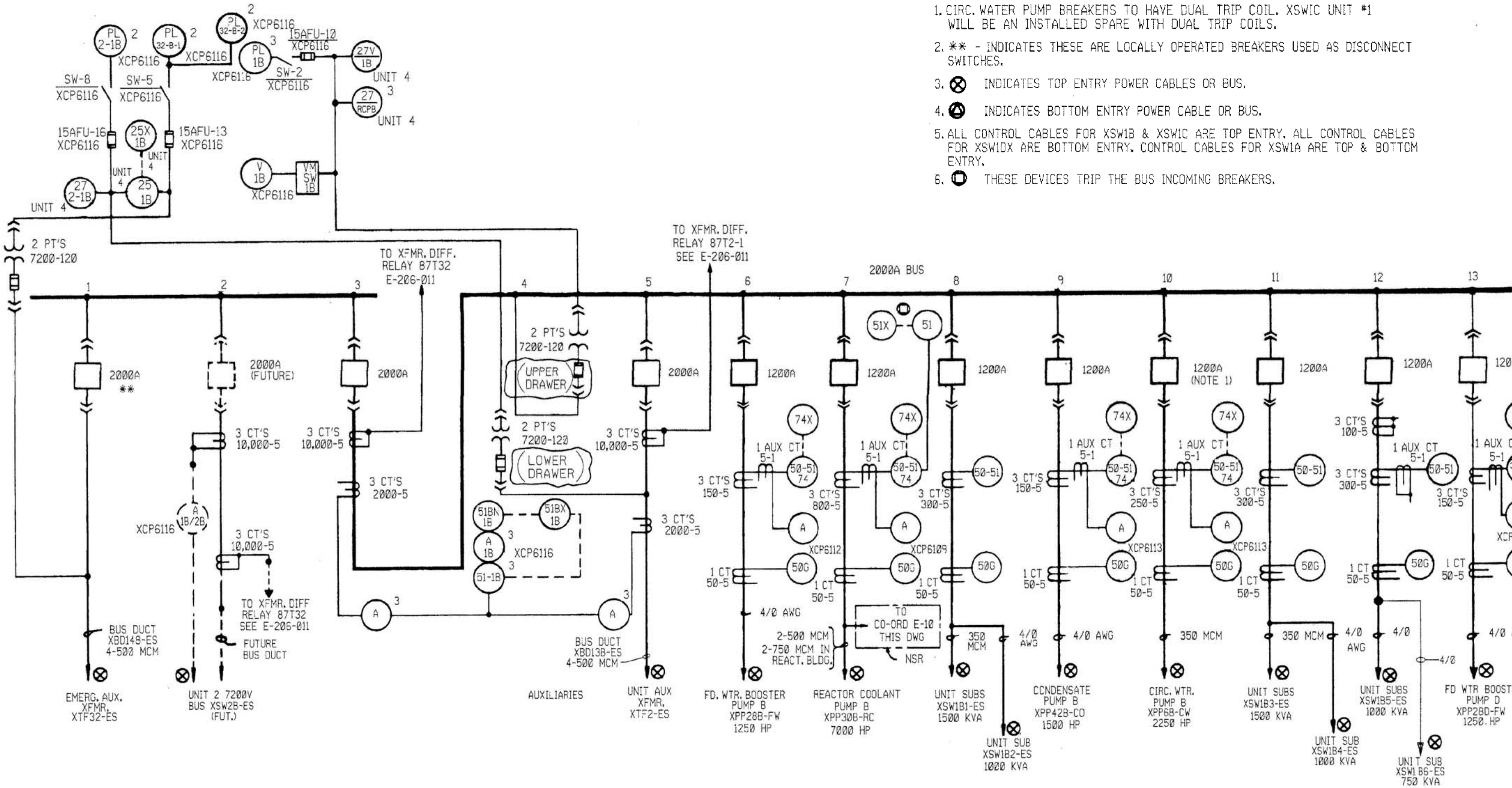
Basics 1	Overall Plant 1-Line
Basics 2	7.2 kV Bus 1-Line
Basics 3	4.16 kV Bus 1-Line
Basics 4	600 V 1-Line
Basics 5	480 V MCC 1-Line
Basics 6	7.2 kV 3-Line Diagram
Basics 7	4.16 kV 3-Line Diagram
Basics 8	AOV Elementary & Block Diagram
Basics 9	4.16 kV Pump Schematic
Basics 10	480 V Pump Schematic
Basics 11	MOV Schematic (with Block included)
Basics 12	12-/208 VAC Panel Diagram
Basics 13	Valve Limit Switch Legend
Basics 14	AOV Schematic (with Block included)
Basics 15	Wiring (or Connection) Diagram
Basics 16	Wiring (or Connection) Diagram
Basics 17	Tray & Conduit Layout Drawing
Basics 18	Embedded Conduit Drawing
Basics 19	Instrument Loop Diagram



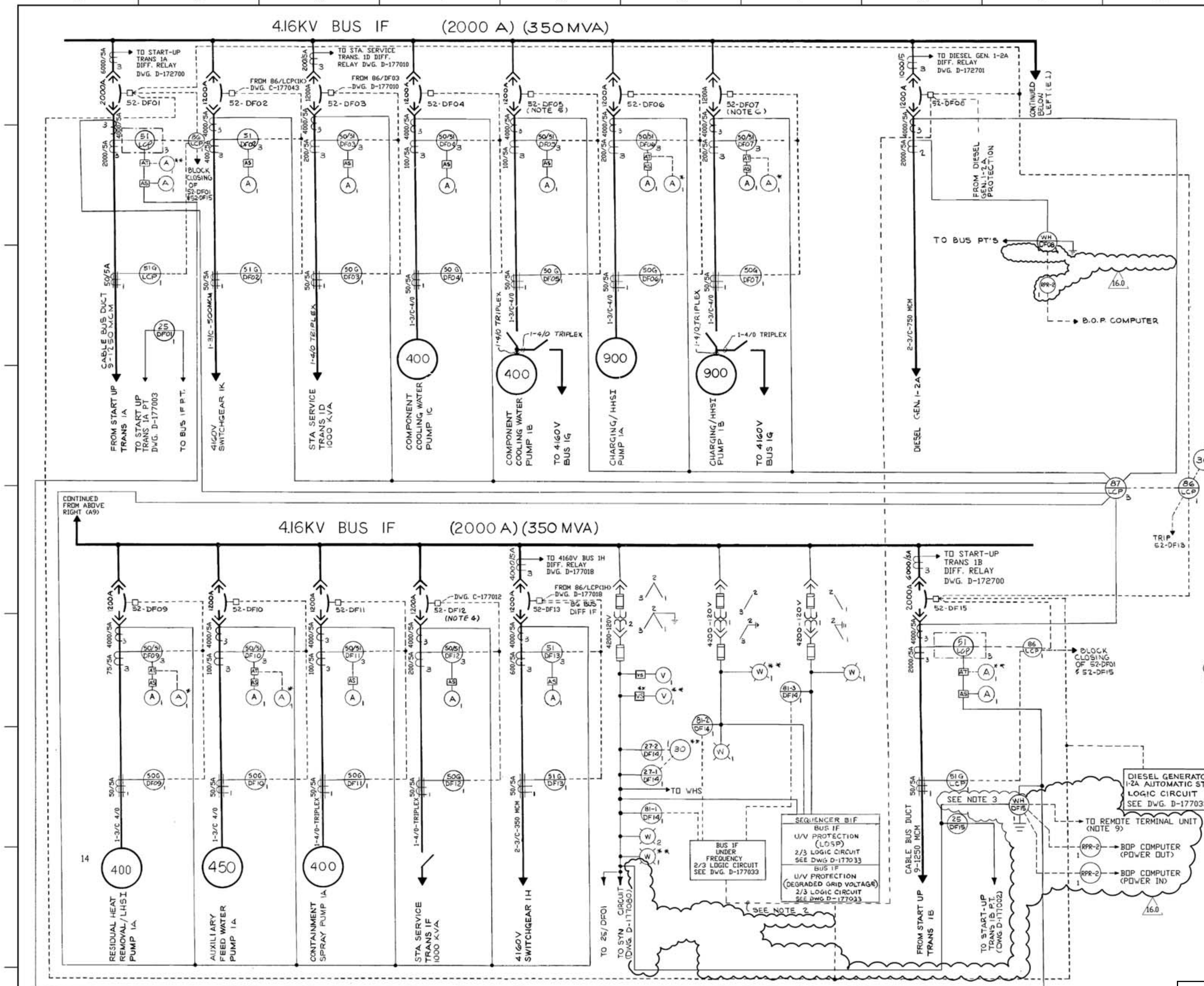
Basics - 1
Plant 1-Line

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 & XSW1C ARE TOP ENTRY. ALL CONTROL CABLES FOR XSW1DX ARE BOTTOM ENTRY. CONTROL CABLES FOR XSW1A ARE TOP & BOTTOM ENTRY.
6. (□) THESE DEVICES TRIP THE BUS INCOMING BREAKERS.



7.2 KV SWGR. BUS 1B XSW1B-ES



DEVICE	DESCRIPTION	MFR/TYPE	REMARKS
51 / LCP	START UP TRANS 1A OVER CURRENT RELAY	GE/IAC53B	
25 / SEE REMARKS	BUS IF SYNCHRONISM CHECK RELAY	GE/IJS52A	APPLICABLE TO CELLS DF01 & DF15
51 / DF02	4160V SWITCHGEAR 1K OVER CURRENT RELAY	GE/IAC53B	
50G / SEE REMARKS	GROUND SENSOR RELAY	GE/PJC11AV	APPLICABLE TO CELLS DF03 TO DF07, DF09 TO DF12
50/51 / DF03	STATION SERVICE TRANS 1D OVER CURRENT RELAY	GE/IAC53B	
50/51 / DF04	COMP. COOLING WATER PUMP 1C OVER CURRENT RELAY	GE/IAC66B	
50/51 / DF05	COMP. COOLING WATER PUMP 1B OVER CURRENT RELAY	GE/IAC66B	
50/51 / DF06	CHARGING/HHSI PUMP, 1A OVER CURRENT RELAY	GE/IAC66B	
50/51 / DF07	CHARGING/HHSI PUMP 1B OVER CURRENT RELAY	GE/IAC66B	
50/51 / DF09	RHR PUMP 1A OVER CURRENT RELAY	GE/IAC66B	
50/51 / DF10	AUX FEED WATER PUMP 1A OVER CURRENT RELAY	GE/IAC66B	
50/51 / DF11	CTMT SPRAY PUMP 1A OVER CURRENT RELAY	GE/IAC66B	
50/51 / DF12	STATION SERVICE TRANS 1F OVER CURRENT RELAY	GE/IAC53B	
51 / DF13	4160V SWITCHGEAR 1H OVER CURRENT RELAY	GE/IAC53B	
86 / LCP	BUS DIFFERENTIAL LOCKOUT RELAY	GE/HEA	
87 / LCP	BUS IF DIFF. PROTECTIVE RELAY	GE/PVD11C	
RPR-2	REPEATING PULSE RELAY	SOLID STATE INSTRUMENT	LOC. IN MN CONT. RM. METER AND RELAY PANEL.
27-1,2 / DF14	BUS IF UNDER VOLTAGE RELAY	GE/IAV54E	
51G / SEE REMARK	INVERSE TIME GROUND RELAY	GE/IAC54A	APPLICABLE TO CELLS DF02 & DF13
81-(1,2&3) / DF14	BUS IF UNDER FREQUENCY RELAY	GE/SFF201B1A	DIESEL GENERATOR 1-2A 2/3 LOGIC CIRCUIT
51 / LCP	START UP TRANS 1B OVER CURRENT RELAY	GE/IAC53B	
86 / LCP	START UP TRANS 1B LOCKOUT RELAY	GE/HEA	
86 / LCP	START UP TRANS 1A LOCKOUT RELAY	GE/HEA	
51G / LCP	VERY INVERSE TIME GROUND RELAY	GE/IAC54A	APPLICABLE TO CELLS DF01 & DF15
WH	WATT HOUR METER	JEMSTAR JS05R6010-B6-DNP	

16.0

NOTES:

1. * -DENOTES MAIN CONTROL BOARD IN MAIN CONTROL ROOM.
2. BUS 1F UNDER FREQUENCY TRIP BREAKER 52-DF08 ONLY WHEN DIESEL 1-2A IS OPERATING IN PARALLEL WITH SYSTEM.
3. WH. METER IS BI-DIRECTIONAL. 16.0
4. FOR KEY INTERLOCKING OF BKR. 52-DF12(SEE DWG C-177118).
5. FOR KEY INTERLOCKING OF BKR. 52-DF05(SEE DWG C-177119).
6. FOR KEY INTERLOCKING OF BKR. 52-DF07(SEE DWG C-177120).
7. LCP-DENOTES LOCAL CONTROL PANEL.
8. **-DENOTES EMERG. POWER BOARD IN MAIN CONTROL ROOM. 16.0
9. REMOTE TERMINAL UNIT IN MAIN CONTROL ROOM.

REFERENCE DRAWINGS:

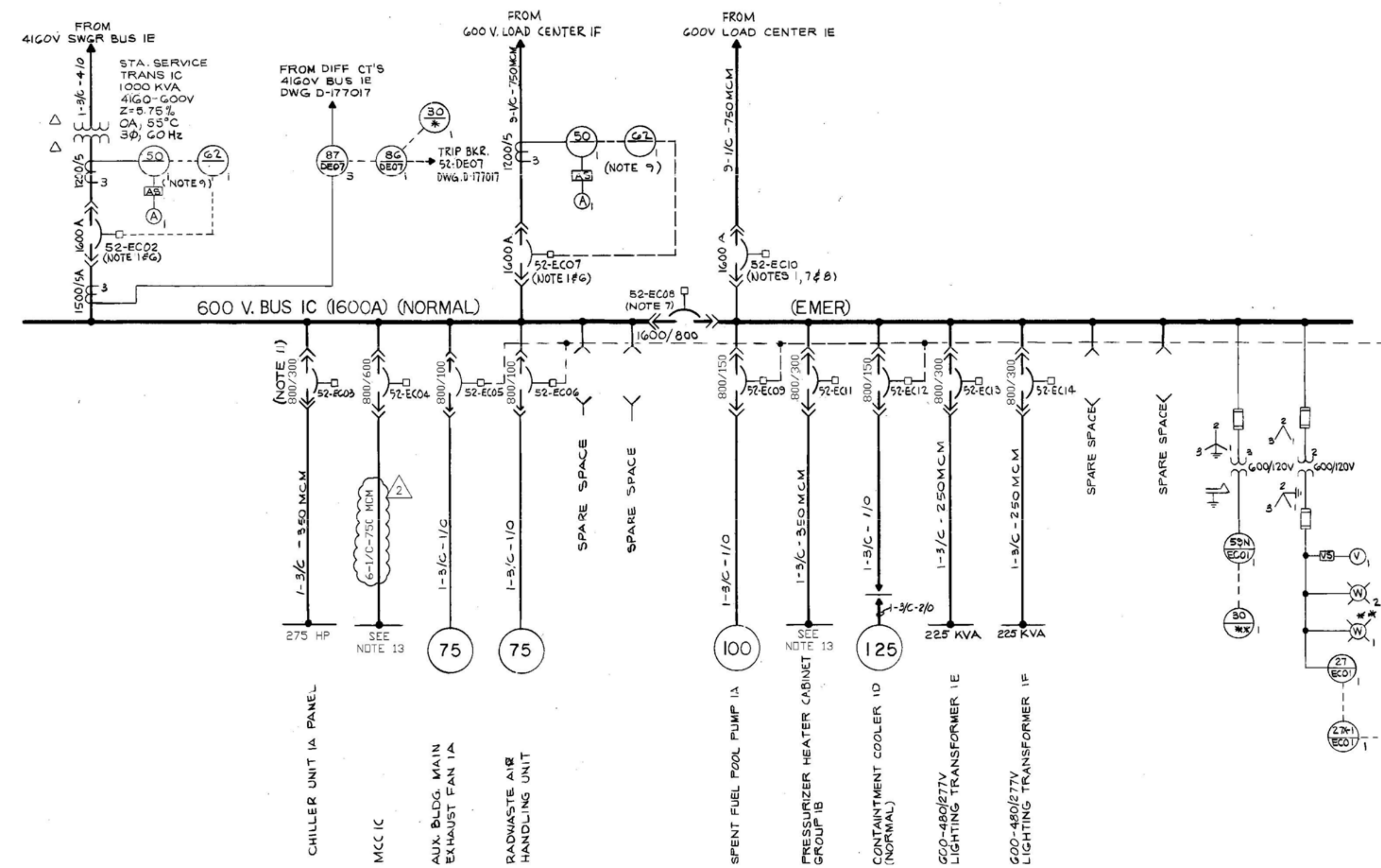
D-177001 SINGLE LINE ELEC. AUX. SYSTEM (EMERGENCY 4160V & 600V).
A-177538 ELEC. GENERAL DETAILS & NOTES.

CAD D1770051.DWG
ACADOVY JDL-03

JLD RLP DEW
VER. NO. 16.0 DATE 6-21-06
REVISED PER ABN 104044900E020, VER. 1.0

Basics - 3
4.16 kV One-Line

DRAWING CATEGORY CRITICAL



DEVICE	DESCRIPTION	MFR/ TYPE	REMARKS
50 / NOTE 9	STA. SERVICE TRANS. 1C OVER CURRENT RELAY, 3Ø	GE/PJC 32G	
62 / NOTE 9	TIME DELAY RELAY	AGASTAT/ 7012 PA	
50 / NOTE 9	OVER CURRENT RELAY 3Ø, FOR INCOMING FEEDER FROM LOAD CENTER 1F.	GE / PJC 32G	
62 / NOTE 9	TIME DELAY RELAY	AGASTAT/ 7012 PA	
87 / DE07	STA. SERVICE TRANS. 1C DIFFERENTIAL RELAY	GE/12STD15C5A	
86 / DE07	STA. SERVICE TRANS. 1C LOCKING-OUT RELAY	GE/HEA	
59N / EC17	BUS 1C OVER VOLTAGE RELAY (GRD. DETECTION)	WEST./CV-8	
27 / EC17	BUS 1C UNDER VOLTAGE RELAY	WEST./CV-2	
27X-1 / EC17	BUS 1C UNDER VOLTAGE AUXILIARY RELAY	WEST./MG-6	

NOTES

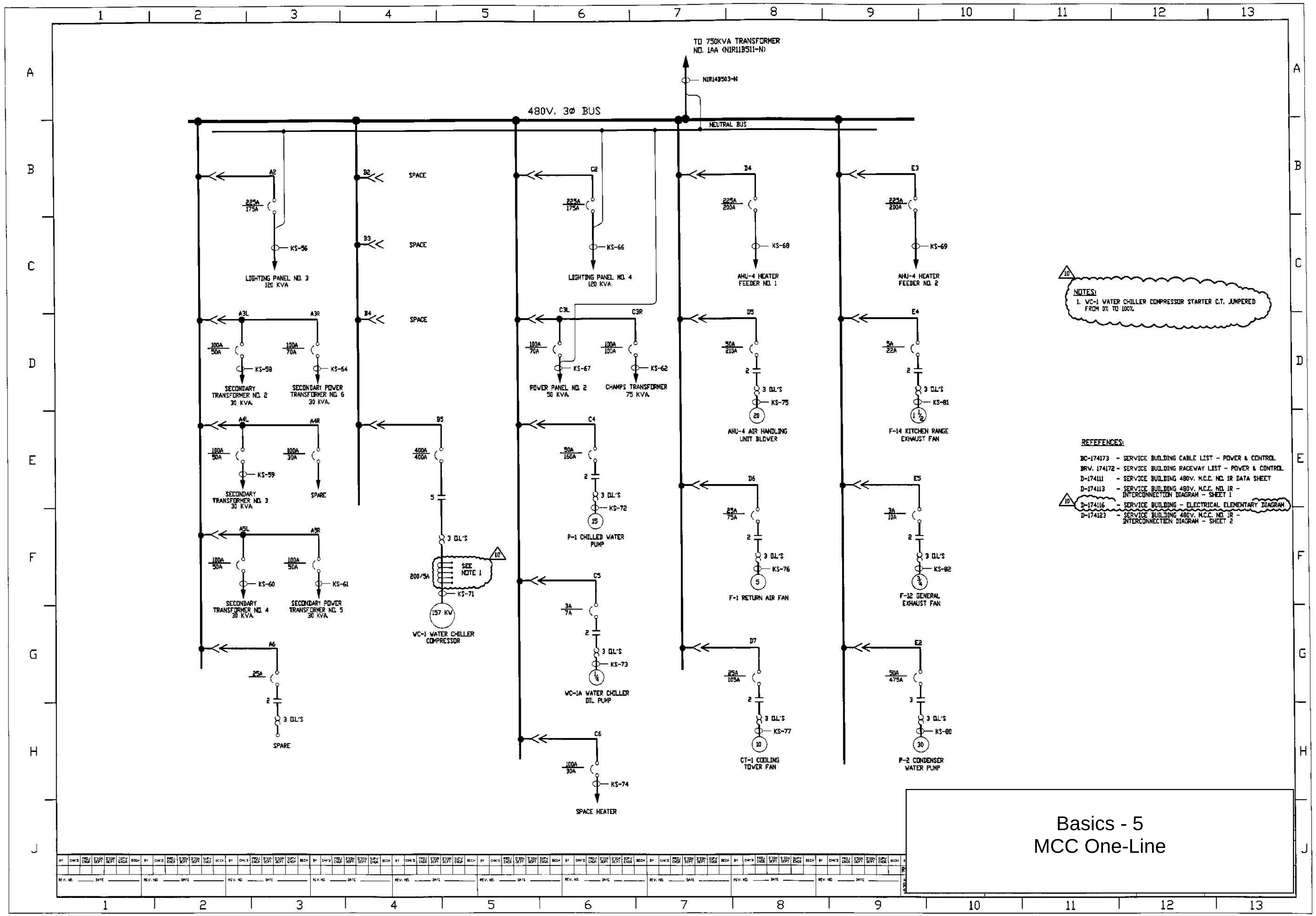
1. ALL BKRS. EXCEPT 52-EC02, 52-EC10 & 52-EC07 HAVE SOLID STATE TRIP UNITS WITH THE FOLLOWING DESIGNATIONS: (BREAKER FRAME/SENSOR RATING - AMPERES).
2. * - DENOTES MAIN CONTROL BOARD IN MAIN CONTROL RM.
3. INTERRUPTING RATING OF ACB'S IS 22,000 AMPS RMS SYMMETRICAL (MIN.).
4. BUS SHORT CIRCUIT RATING 22,000 AMPS. SYMMETRICAL.
5. STA. SERVICE TRANSFORMER "ASKAREL" TYPE.
6. BREAKERS 52-EC02 AND 52-EC07 ARE KEY INTERLOCKED SO THAT ONLY ONE CAN BE CLOSED AT ANY TIME (DWG. D-177124).
7. BREAKERS 52-EC08 AND 52-EC10 ARE ELECTRICALLY INTERLOCKED SO THAT ONLY ONE CAN BE CLOSED AT ANY TIME.
8. BREAKER 52-EC10 AND 52-EE07 ARE ELECTRICALLY OPERATED FROM A SINGLE CONTROL SWITCH IN THE MAIN CONTROL ROOM.
9. LOCATED IN TERMINAL BLOCK COMPARTMENT ABOVE ASSOCIATED BREAKER
10. ** - DENOTES EMERGENCY POWER BOARD IN MAIN CONTROL ROOM.
11. NEW SENSOR, REVISED TO AGREE WITH FIELD CHANGES TO BE MADE.
12. THIS DRAWING SUPERSEDES DRAWING NO. C-177009 SH. 1, REVISION 13.
13. FOR CONNECTED AND RUNNING LOADS, CONTACT SCS ENG. - FARLEY PROJECT.

REFERENCE DWGS

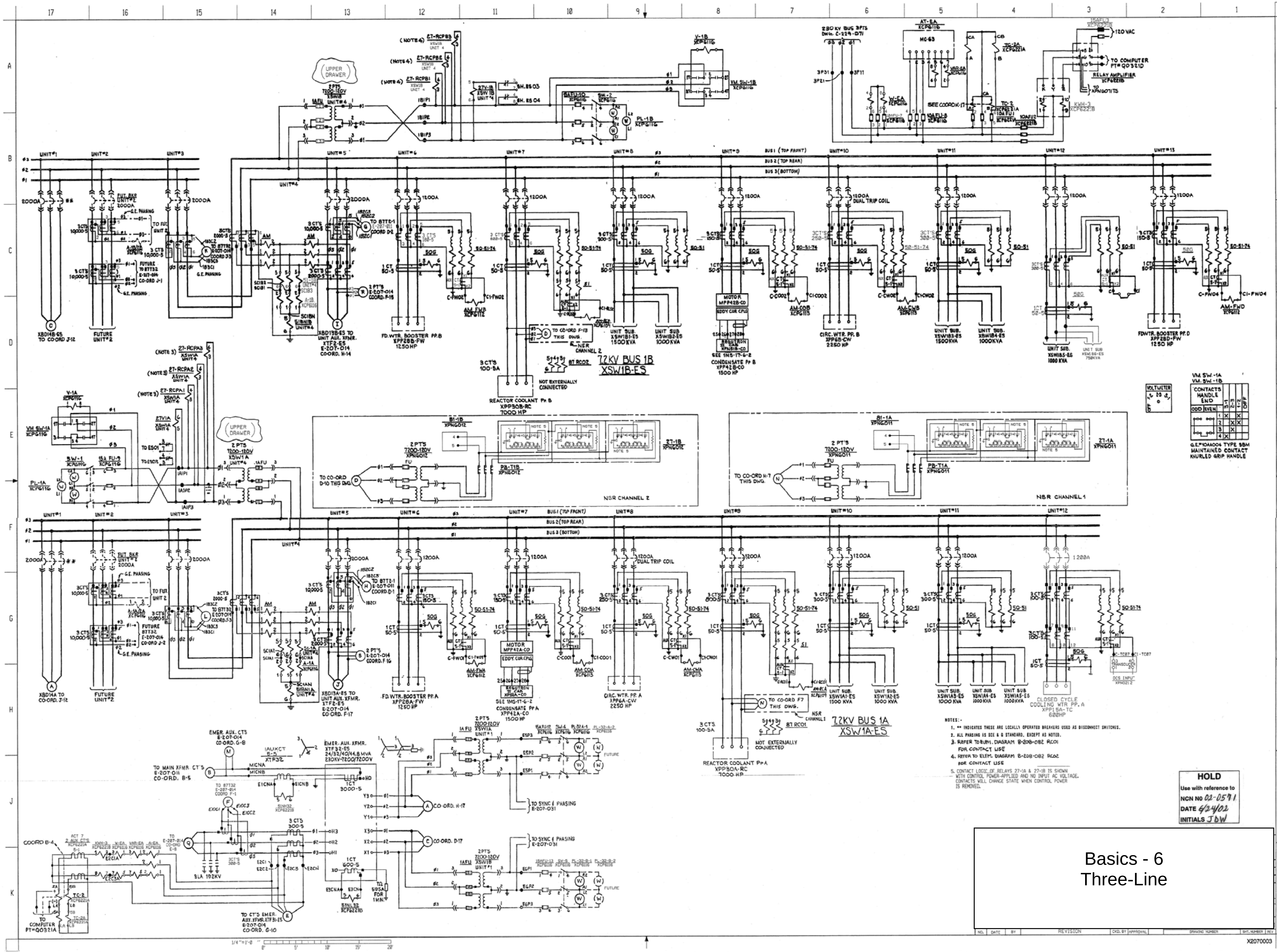
D-177001-SINGLE LINE ELEC AUX SYSTEM (4160V & 600V)

A-177538-ELEC GENERAL DETAILS & NOTES

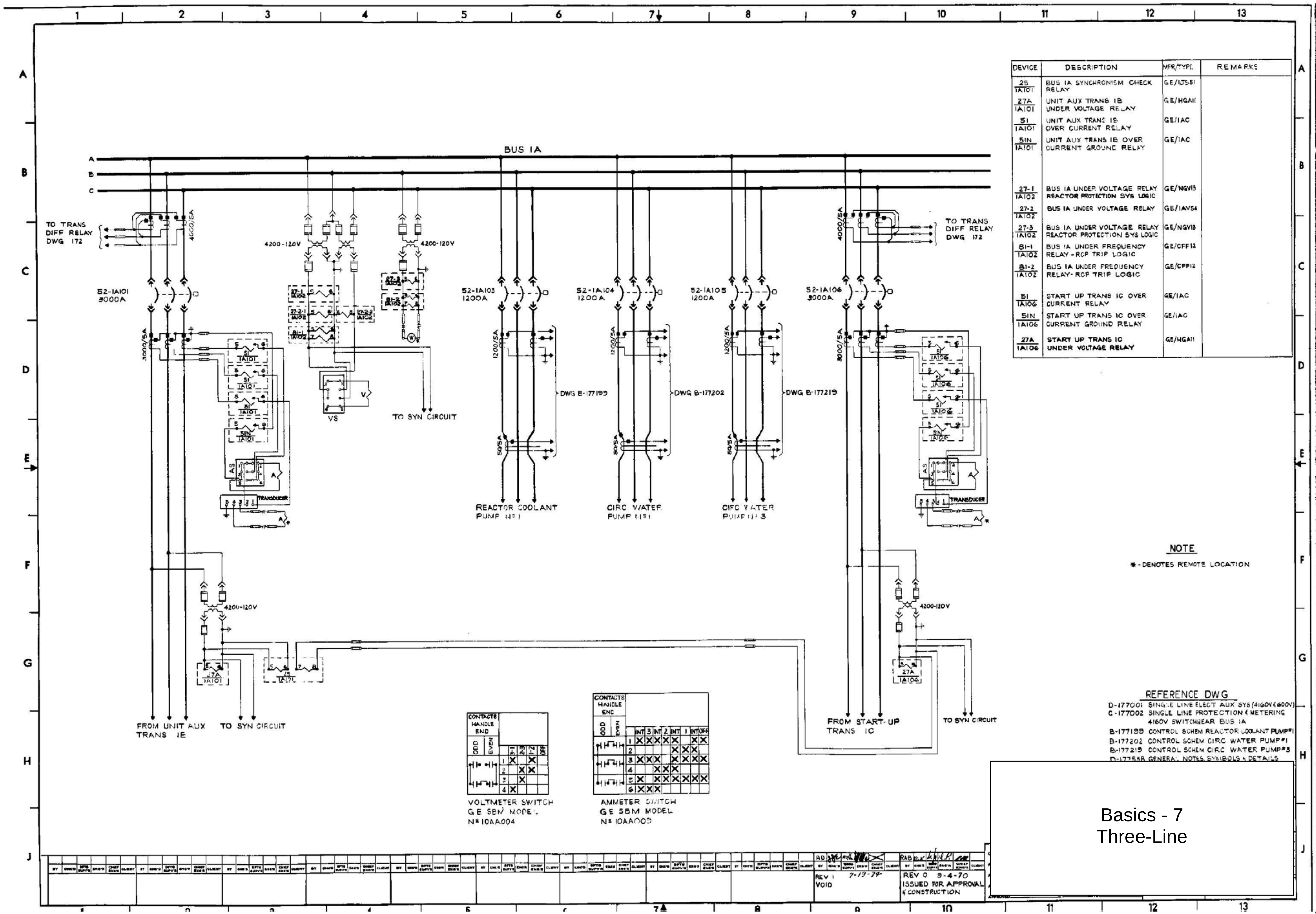
Basics - 4
600 V One-Line



Basics - 5
MCC One-Line



7.2KV BUS 1B
XSW1B-ES
7.2KV BUS 1A
XSW1A-ES
NSR CHANNEL 2
NSR CHANNEL 1
UPPER DRAWER
REACTOR COOLANT P# B
XPP30B-RC
7000 HP
REACTOR COOLANT P# A
XPP30A-RC
7000 HP
NOT EXTERNALLY CONNECTED
TO COMPUTER
120 VAC
HOLD
Use with reference to
NCN NO 02-0571
DATE 6/24/02
INITIALS JDW
Basics - 6
Three-Line
X2070003



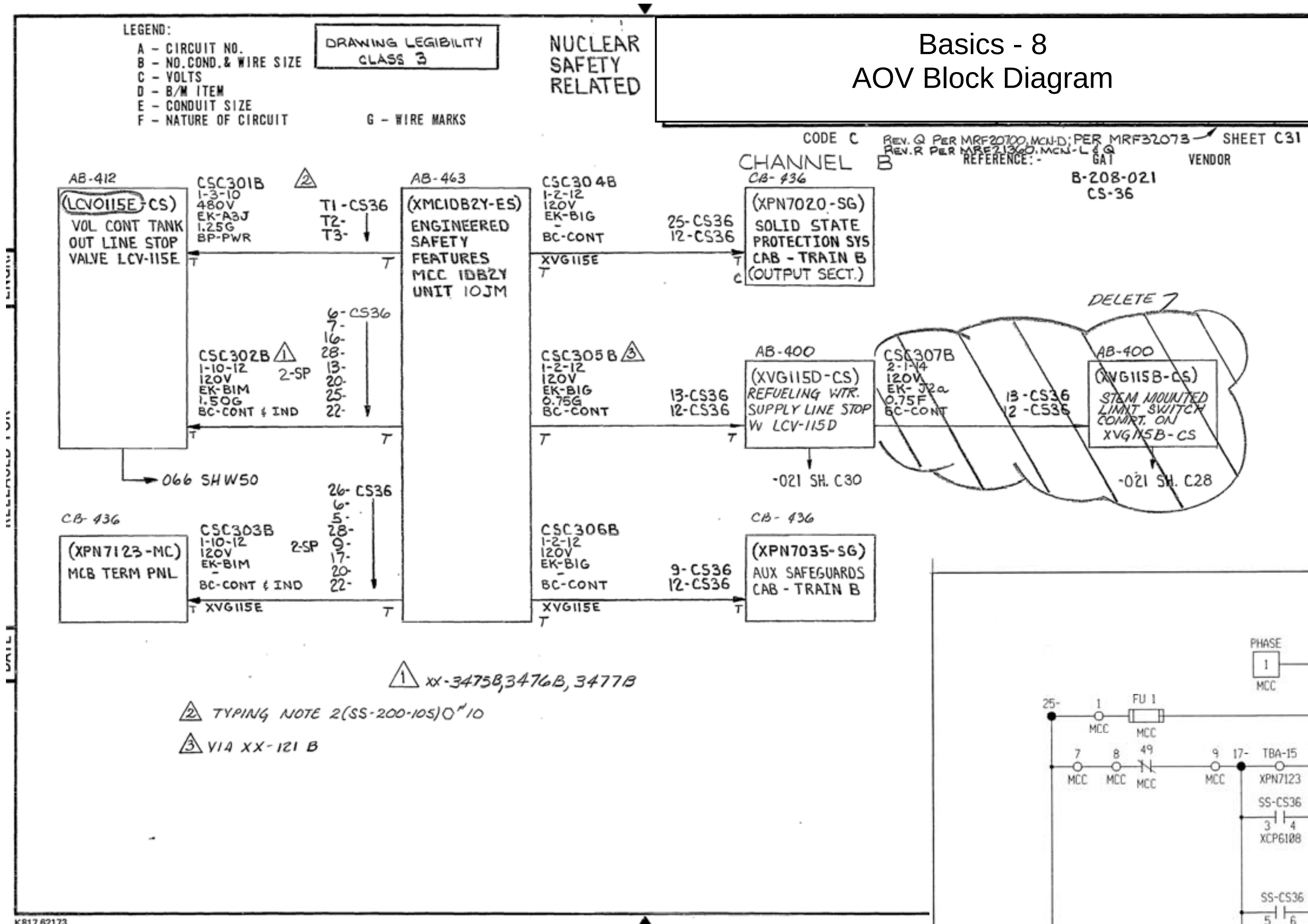
DEVICE	DESCRIPTION	MFR/TYPE	REMARKS
25 / 1A101	BUS 1A SYNCHRONISM CHECK RELAY	GE/IJS51	
27A / 1A101	UNIT AUX TRANS 1B UNDER VOLTAGE RELAY	GE/HGA11	
51 / 1A101	UNIT AUX TRANS 1B OVER CURRENT RELAY	GE/IAC	
51N / 1A101	UNIT AUX TRANS 1B OVER CURRENT GROUND RELAY	GE/IAC	
27-1 / 1A102	BUS 1A UNDER VOLTAGE 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	

REFERENCE DWG

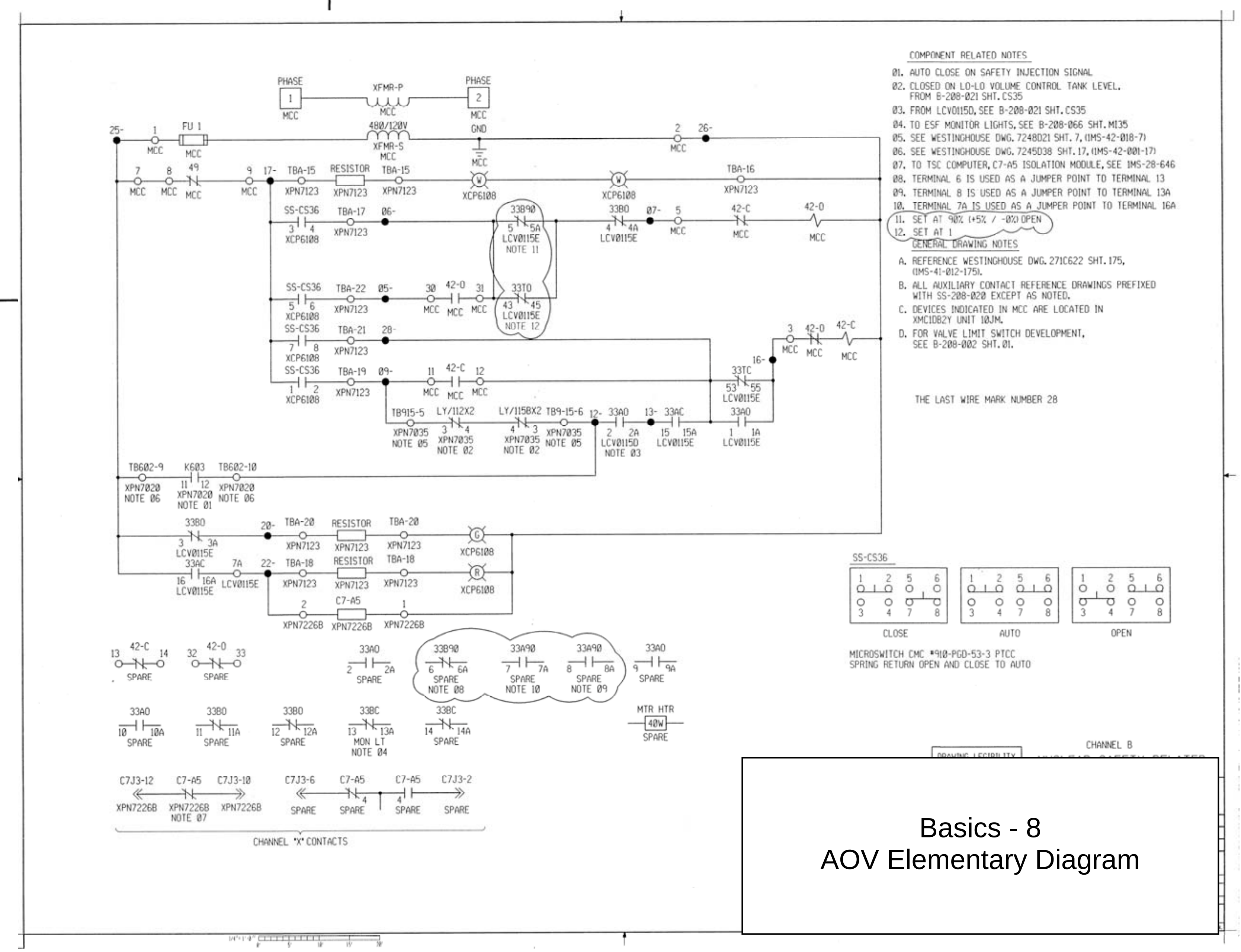
D-177001 SINGLE LINE ELECT AUX SYS (4160V & 600V)
C-177002 SINGLE LINE PROTECTION & METERING 4160V SWITCHGEAR BUS 1A
B-177199 CONTROL SCHEM REACTOR COOLANT PUMP #1
B-177202 CONTROL SCHEM CIRC WATER PUMP #1
B-177219 CONTROL SCHEM CIRC WATER PUMP #3
D-177538 GENERAL NOTES, SYMBOLS & DETAILS

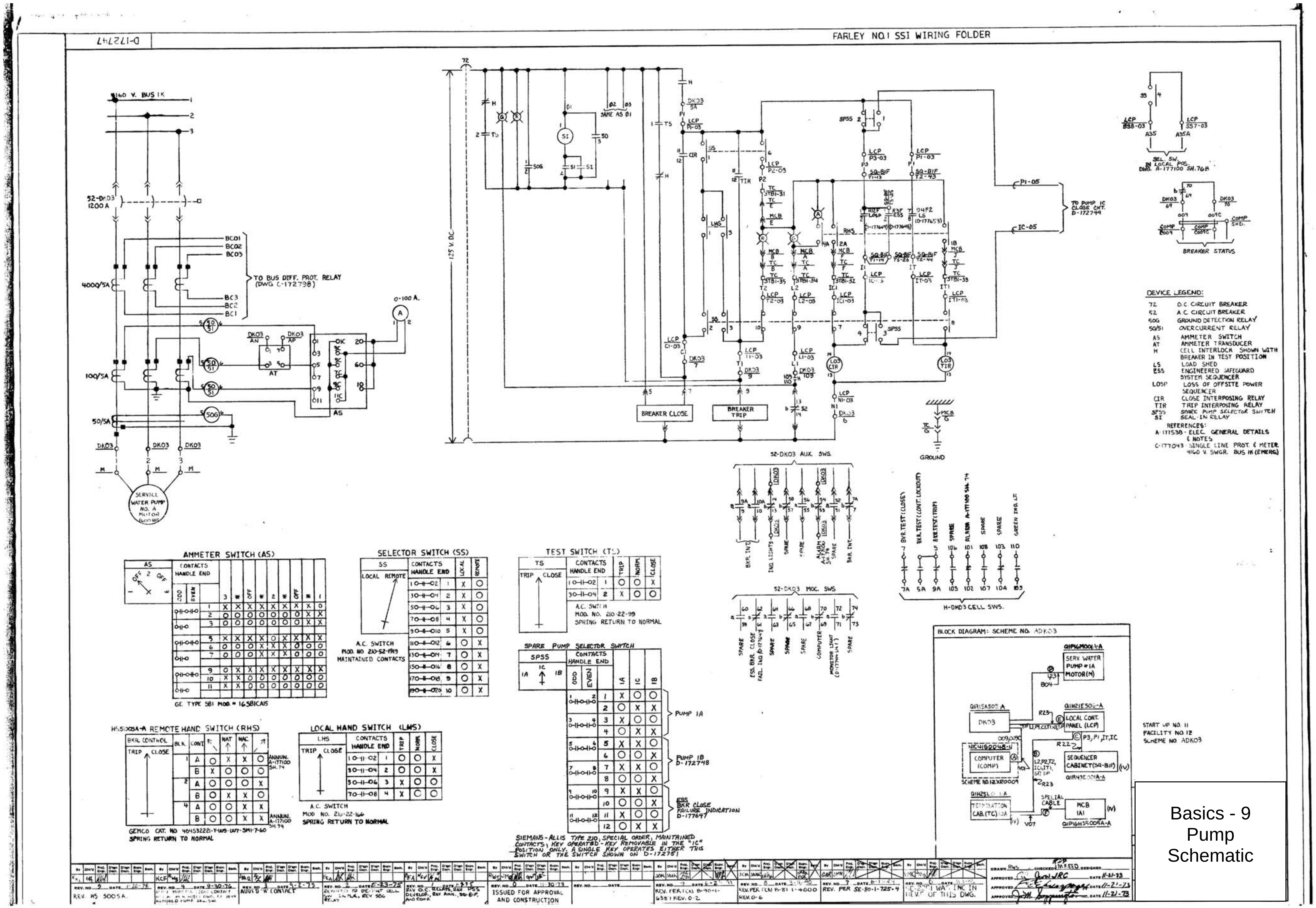
Basics - 7
Three-Line

Basics - 8
AOV Block Diagram



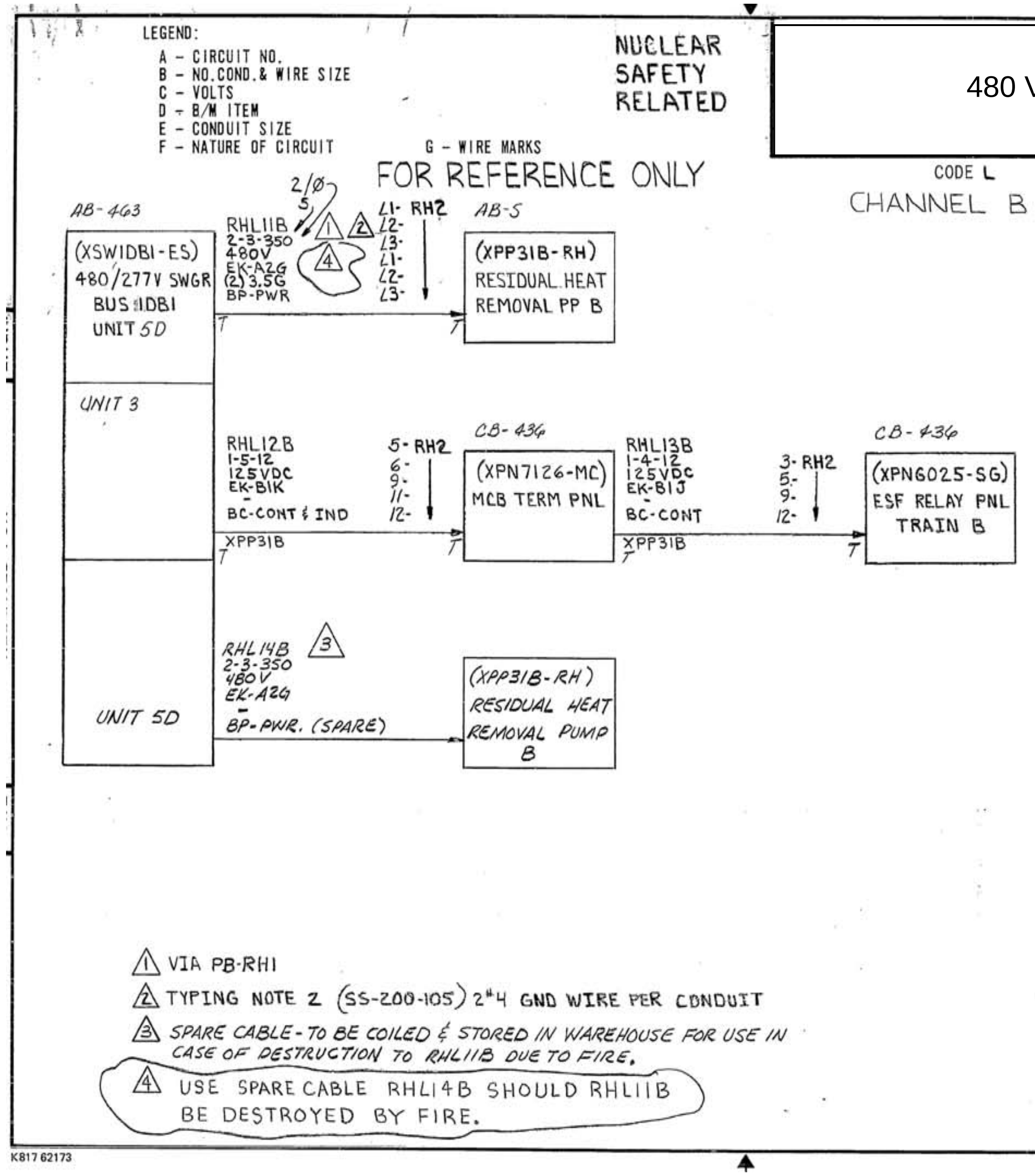
Basics - 8
AOV Elementary Diagram

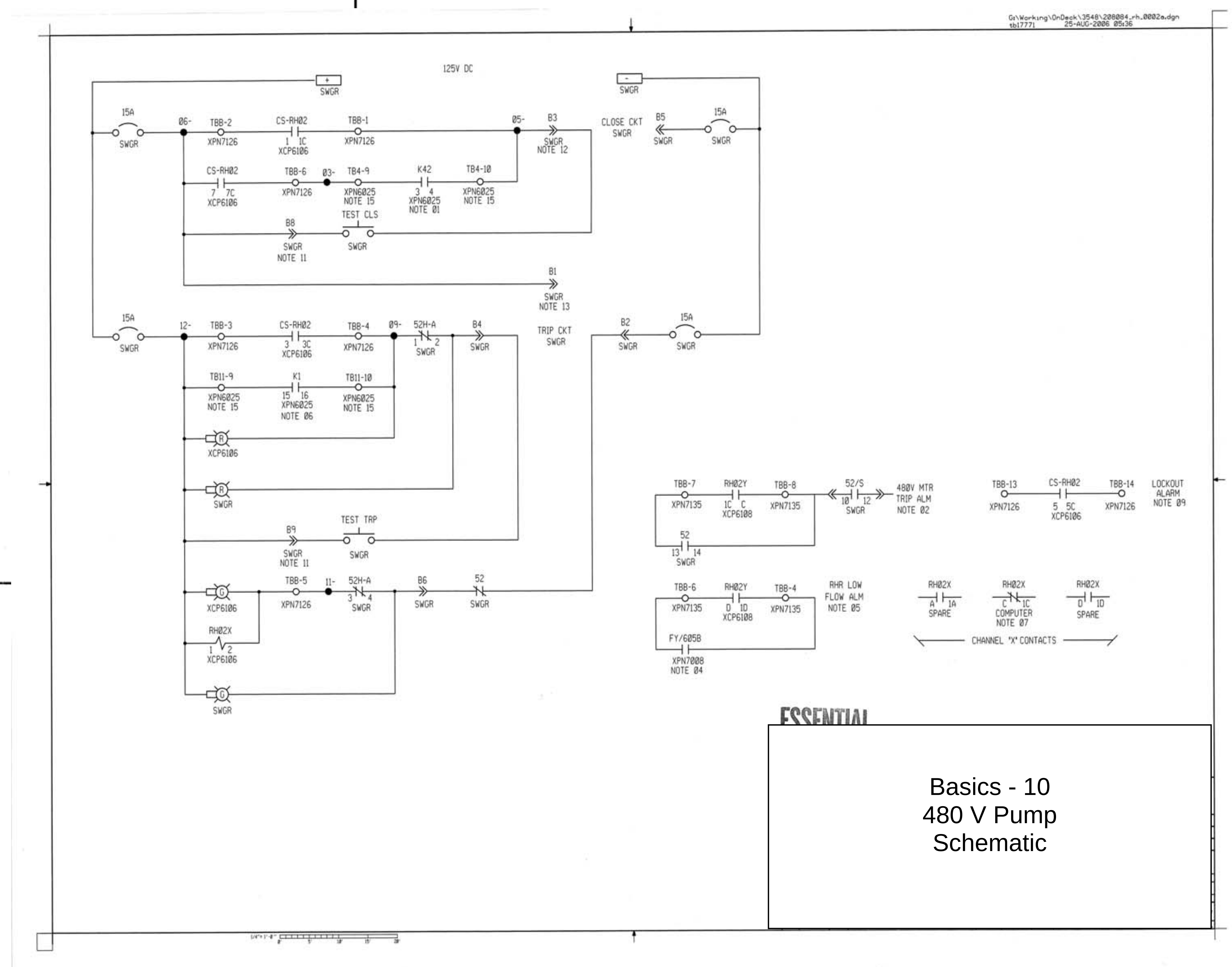




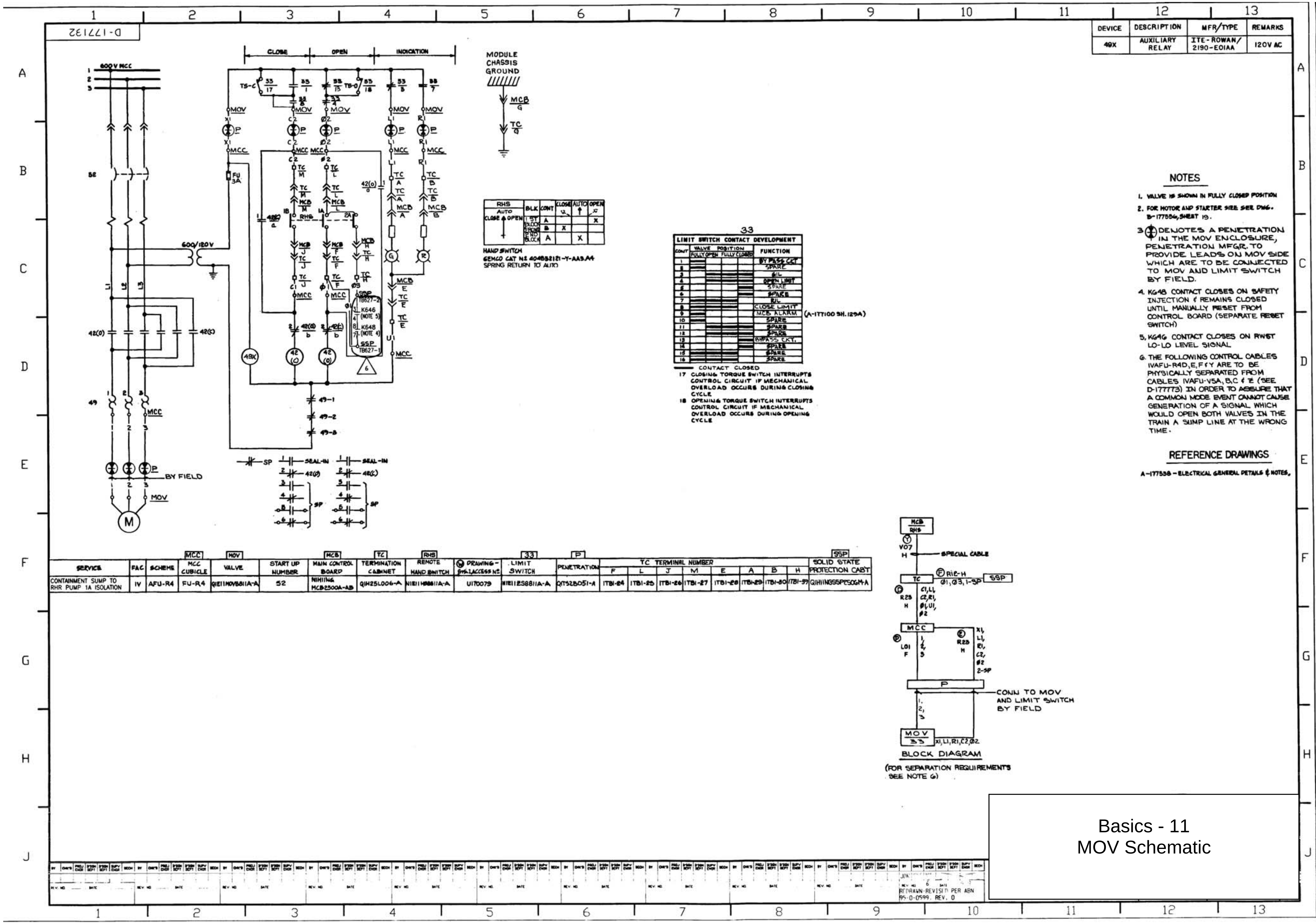
Basics - 9
Pump
Schematic

Basics - 10
480 V Pump Block Diagram

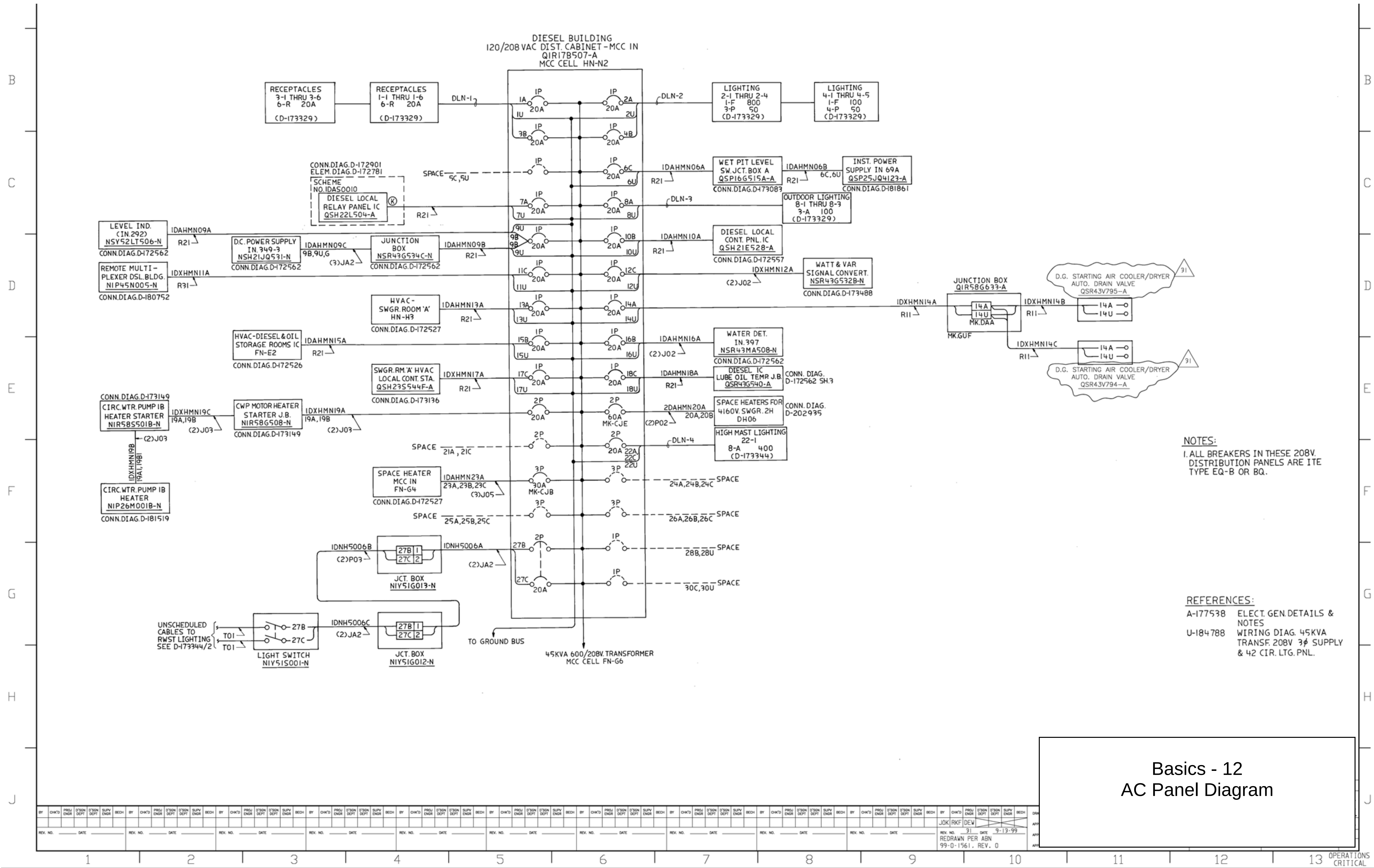




Basics - 10
480 V Pump Schematic



Basics - 11
MOV Schematic



Basics - 12

AC Panel Diagram

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

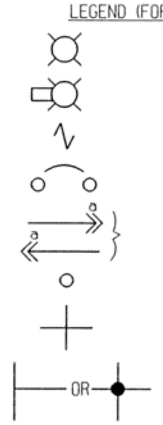
SWITCH	CONTACT	OPEN	INTERMEDIATE	CLOSED
OT/LS	24-25			
CT/LS	26-27			
OAS1	15-16			
CAS1	6-7			
OAS2	17-18			
CAS2	8-9			

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)

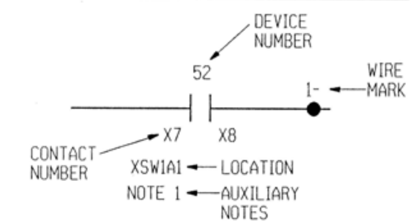


INDICATING LIGHT
INDICATING LIGHT WITH RESISTOR
COIL/SOLENOID VALVE
BREAKER
BREAK IN CIRCUIT SHOWING CONTINUATION ON ANOTHER LINE
EQUIPMENT TERMINAL [TERMINAL NUMBER ABOVE / LOCATION BELOW
INDICATES NO CONNECTION
OR — INDICATES CONNECTION

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 DEVICE CLOSED	33bc			
	33bc			
	33ac			
	33ac			
SWITCH ACTUATED DEVICE OPEN	33ao			
	33ao			
	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.

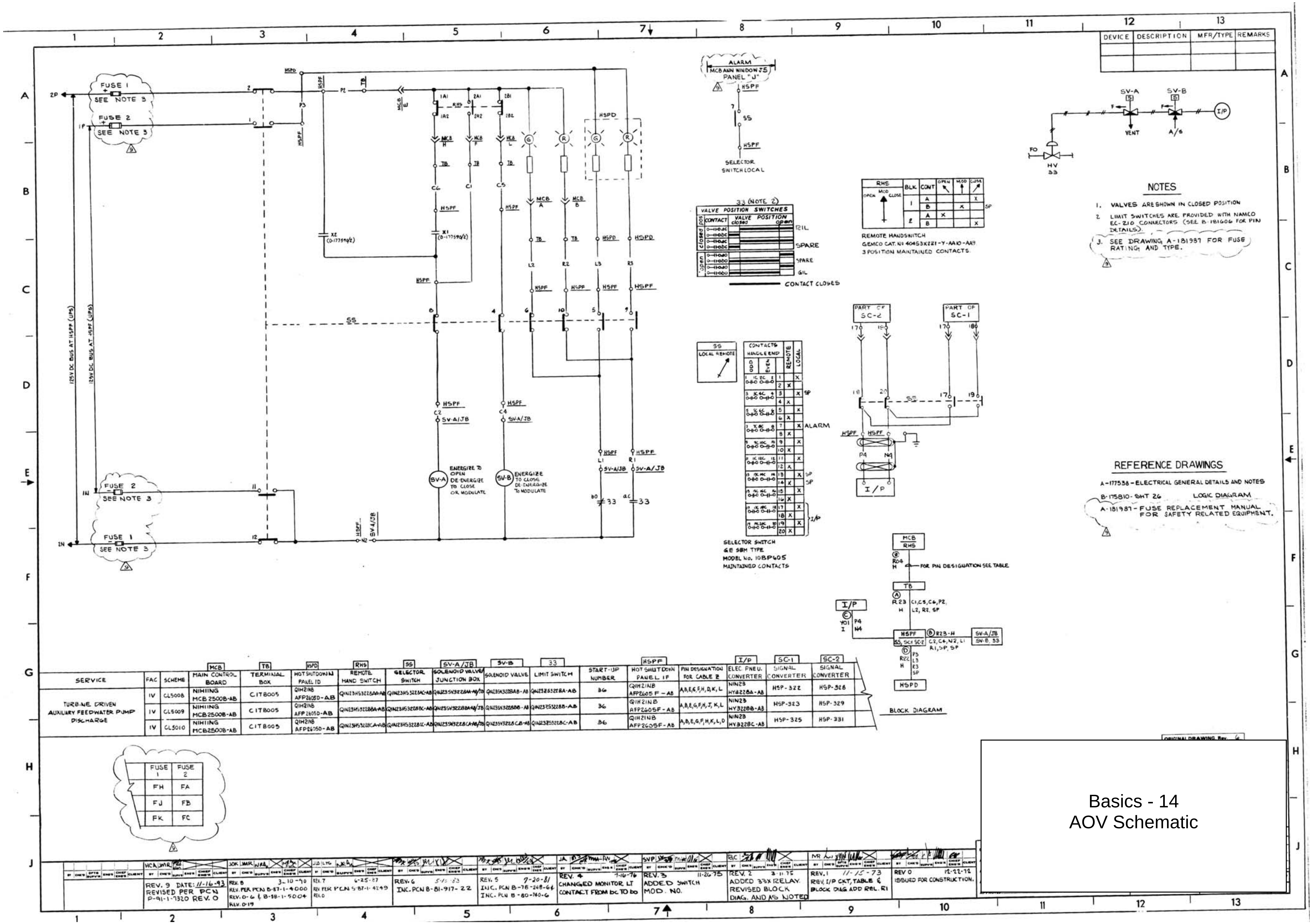
1. INTERMEDIATE POSITIONS ARE EXPRESSED IN PERCENTAGE OF FULL OPEN. EX. 33A05 CONTACT ACTUATES WHEN THE VALVE IS 5% OPEN.
2. THE TOLERANCE FOR ROTOR 2 CONTACTS SET AT 25% OPEN IS ± 2.5%.
3. LIMITORQUE VALVES STROKED OPEN TO A POSITION OF ≥90% ARE CONSIDERED 'FULLY OPEN' WITH THE EXCEPTION OF XVG2802A & 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 CLASS 1

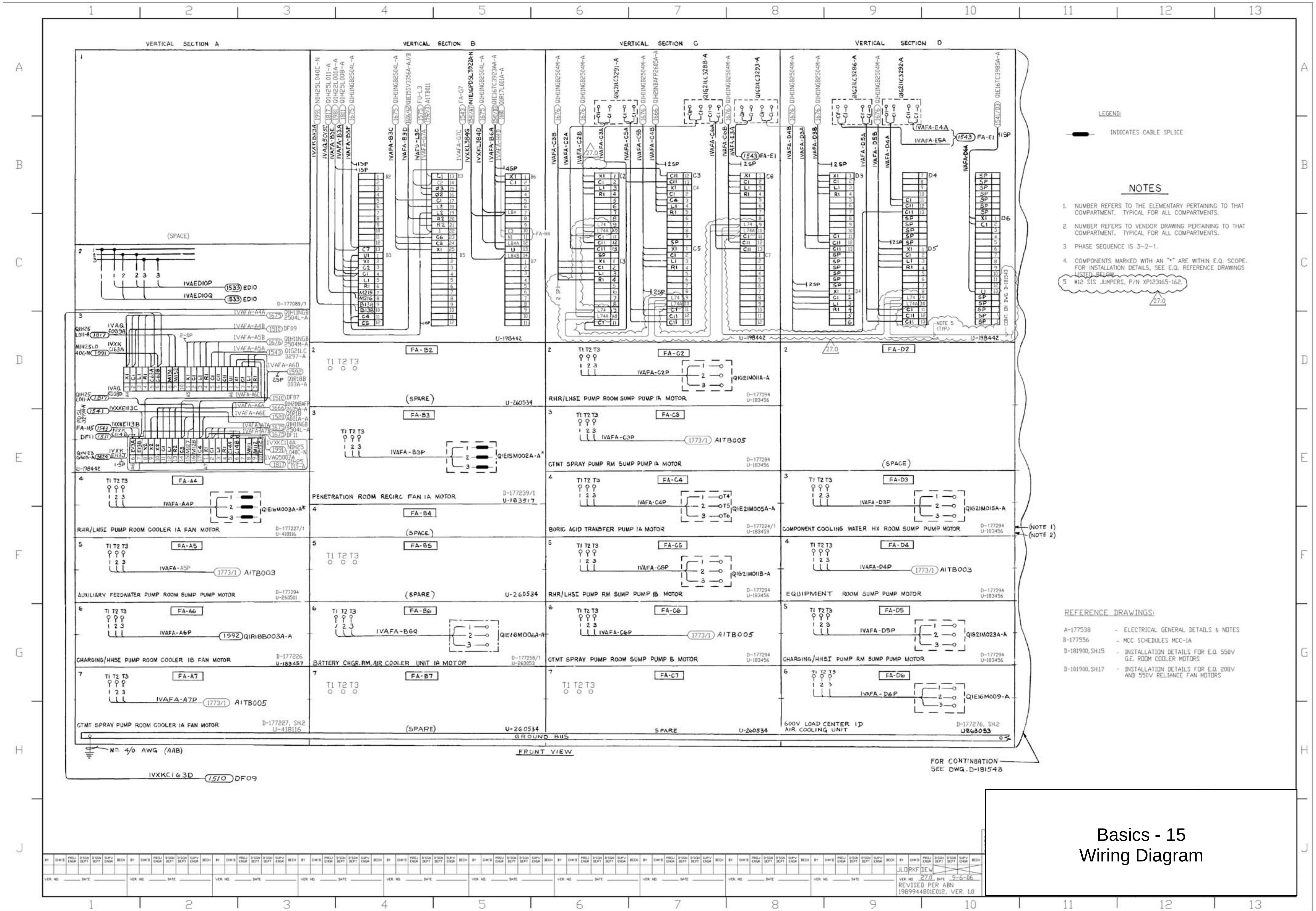
Basics - 13
Valve Limit Switch Legend

208002_xx_0001

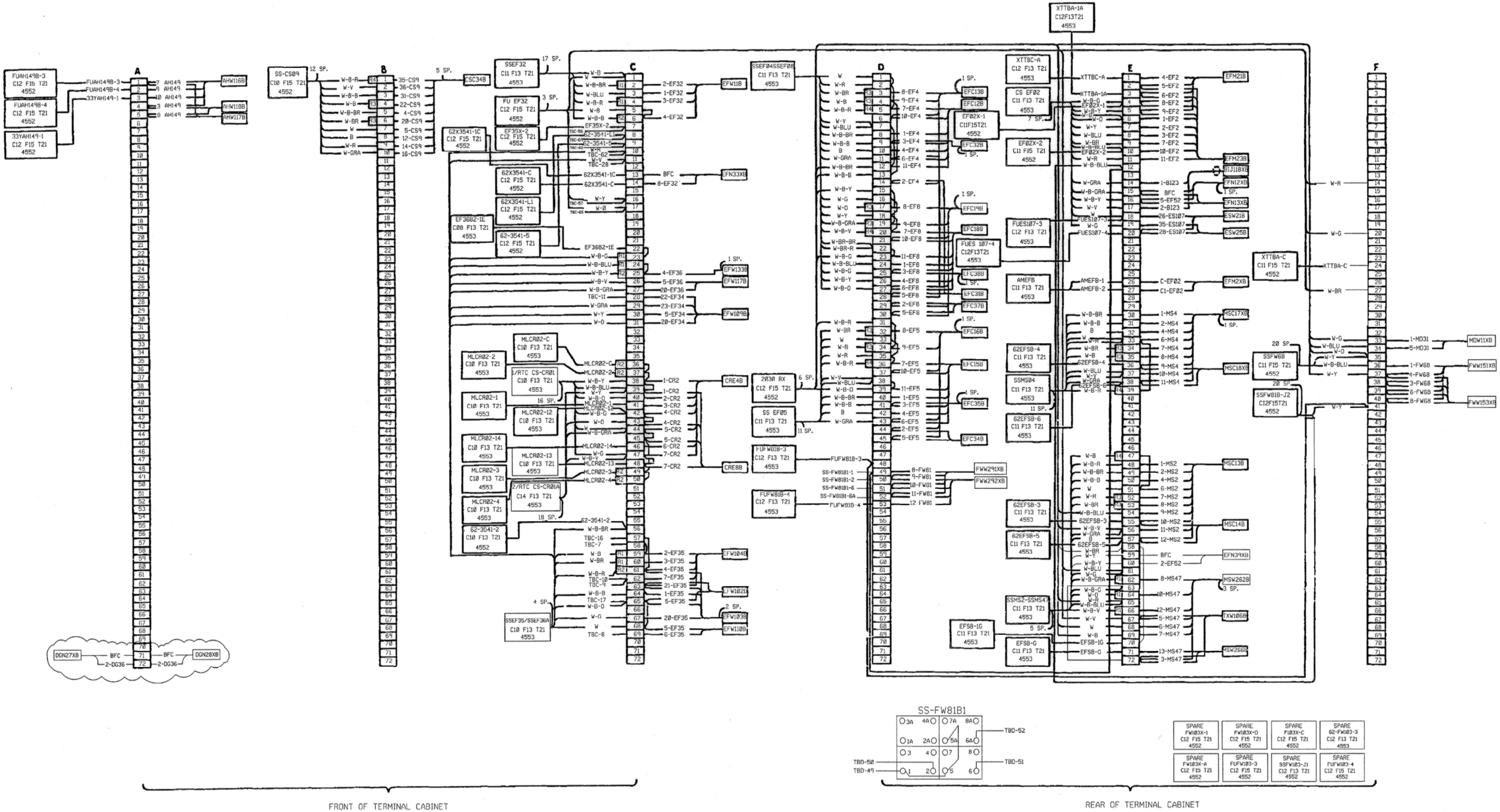


SERVICE	FAC	SCHEME	MCB MAIN CONTROL BOARD	TB TERMINAL BOX	HSPD HOT SHUTDOWN PANEL ID	RHS REMOTE HAND SWITCH	SS SELECTOR SWITCH	SV-A/JB SOLENOID VALVE/JUNCTION BOX	SV-B SOLENOID VALVE	33 LIMIT SWITCH	START-UP NUMBER	HSPF HOT SHUT DOWN PANEL 1F	PIN DESIGNATION FOR CABLE 2	I/P ELEC PNEU. CONVERTER	SC-1 SIGNAL CONVERTER	SC-2 SIGNAL CONVERTER
TURBINE DRIVEN AUXILIARY FEEDWATER PUMP DISCHARGE	IV	CL5008	NIH1ING MCB 2500B-AB	C1TB005	Q1H2INB AFP2605D-AB	Q1N23HS3228AA-AB	Q1N23HS3228AC-AB	Q1N23SV3228AA-AB/JB	Q1N23SV3228AB-AB	Q1N23ZS3228A-AB	36	Q1H21NB AFP2605F-AB	A,B,E,G,F,H,D,K,L	N1N23 HY3228A-AB	HSP-322	HSP-328
	IV	CL5009	NIH1ING MCB2500B-AB	C1TB005	Q1H2INB AFP2605D-AB	Q1N23HS3228BA-AB	Q1N23HS3228BC-AB	Q1N23SV3228BA-AB/JB	Q1N23SV3228BB-AB	Q1N23ZS3228B-AB	36	Q1H21NB AFP2605F-AB	A,B,E,G,F,H,J,K,L	N1N23 HY3228B-AB	HSP-323	HSP-329
	IV	CL5010	NIH1ING MCB2500B-AB	C1TB005	Q1H2INB AFP2605D-AB	Q1N23HS3228CA-AB	Q1N23HS3228CC-AB	Q1N23SV3228CA-AB/JB	Q1N23SV3228CB-AB	Q1N23ZS3228C-AB	36	Q1H21NB AFP2605F-AB	A,B,E,G,F,H,K,L,D	N1N23 HY3228C-AB	HSP-325	HSP-331

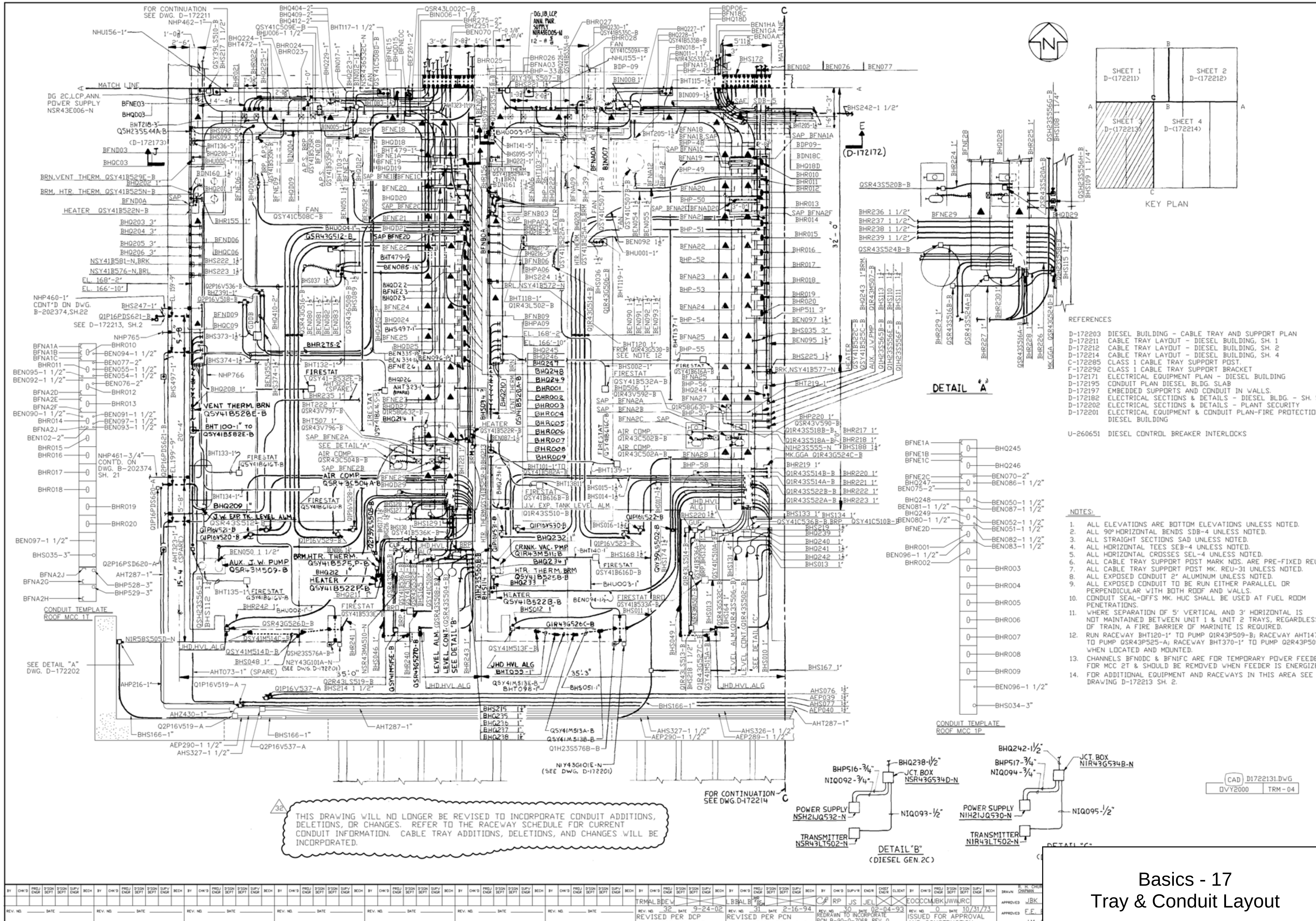
Basics - 14
AOV Schematic



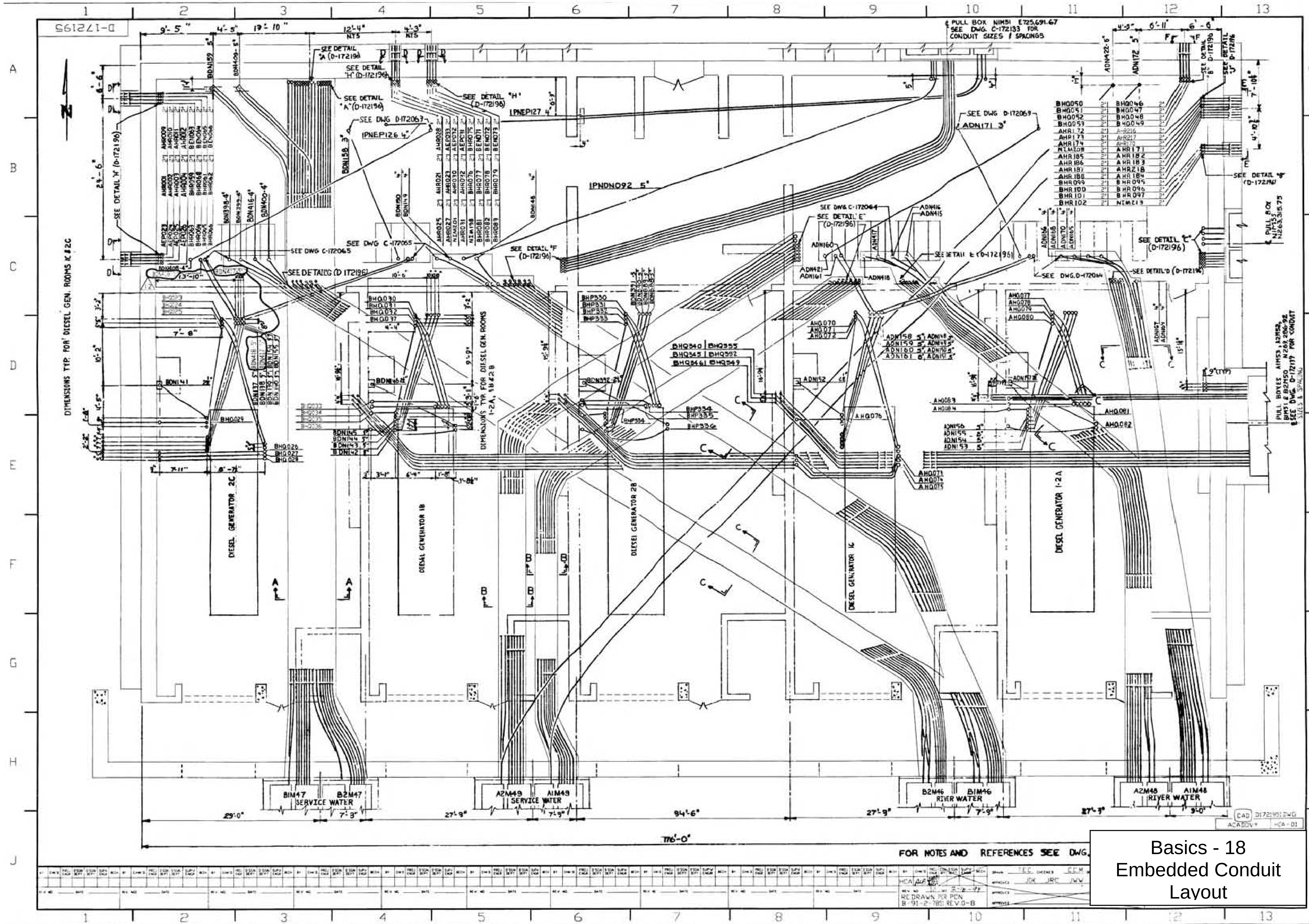
Basics - 15
Wiring Diagram



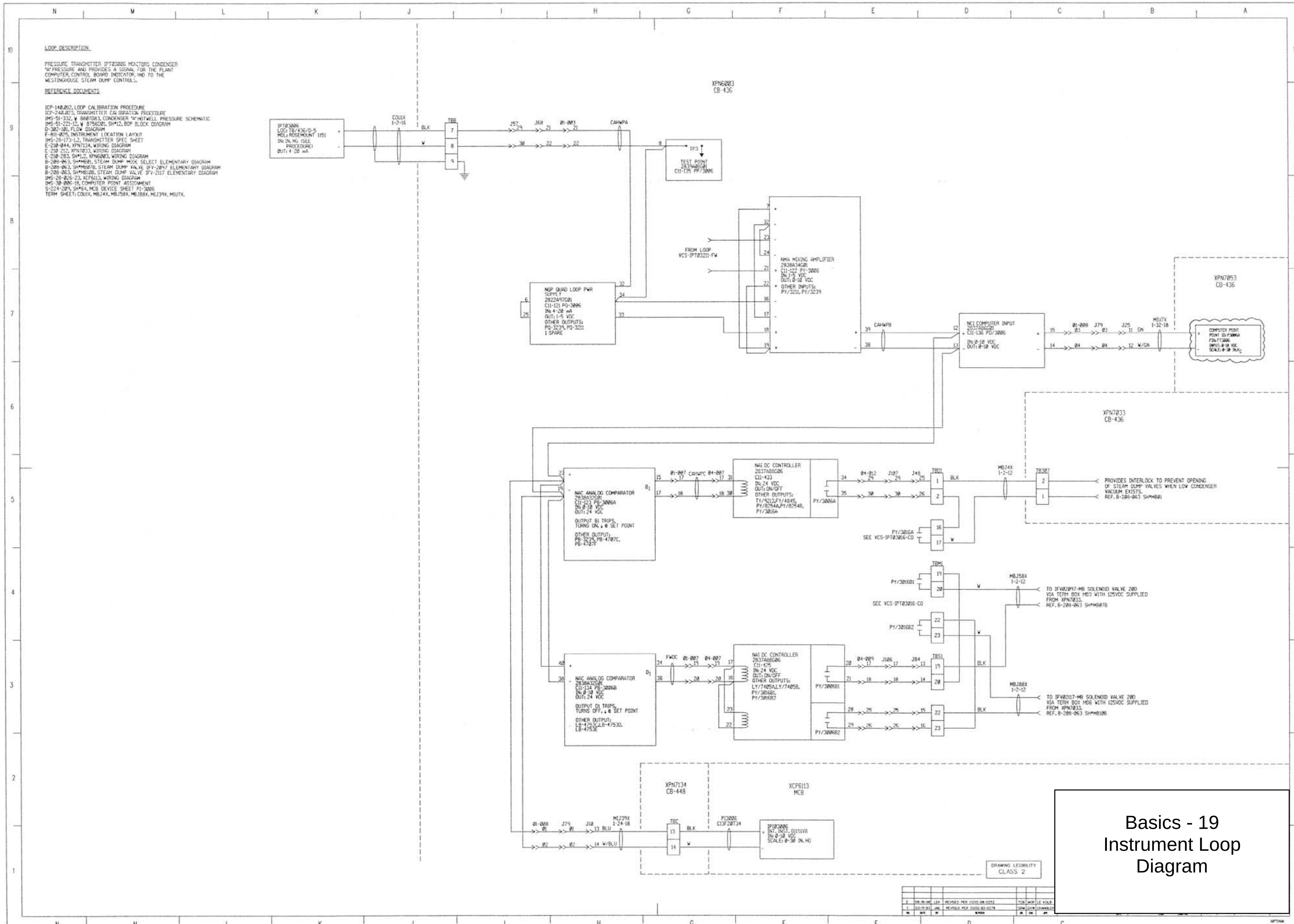
Basics - 16
Wiring Diagram



Basics - 17
Tray & Conduit Layout



Basics - 18
Embedded Conduit Layout



Basics - 19
Instrument Loop Diagram

ANSI/IEEE Standard Device Numbers

---

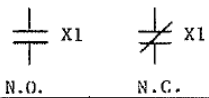
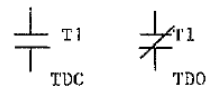
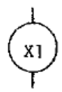
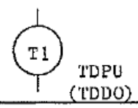
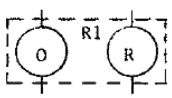
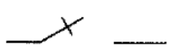
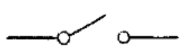
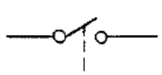
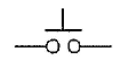
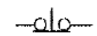
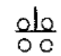
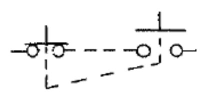
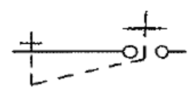
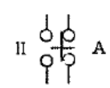
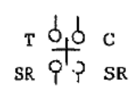
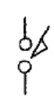
1 - Master Element
2 - Time Delay Starting or Closing Relay
3 - Checking or Interlocking Relay
4 - Master Contactor
5 - Stopping Device
6 - Starting Circuit Breaker
7 – Rate of Change Relay
8 - Control Power Disconnecting Device
9 - Reversing Device
10 - Unit Sequence Switch
11 – Multifunction Device
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

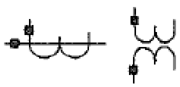
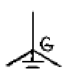
B – Bus
F – Field
G – Ground or generator
N – Neutral
T – Transformer

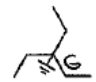
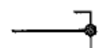
TYPICAL ELECTRICAL DRAWING SYMBOLS AND CONVENTIONS

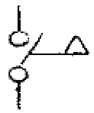
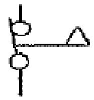
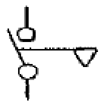
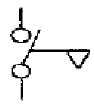
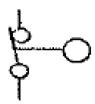
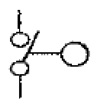
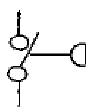
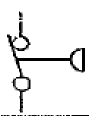
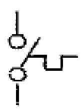
ELECTRICAL SYMBOLS

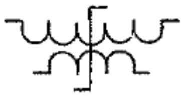
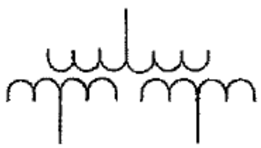
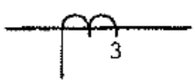
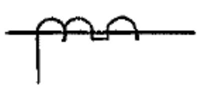
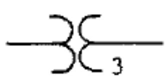
CONTACTS, SWITCHES, CONTACTORS AND RELAYS

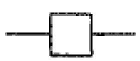
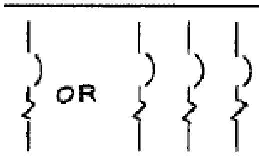
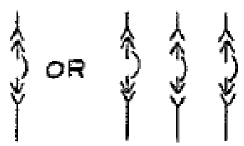
SYMBOL	DESCRIPTION
	Relay contact - Shown with relay in de-energized or in reset position. (Show relay coil designation near contact.)
	Timing Relay Contact - TDC indicates contact closes at end of timing period. TDO contact opens at end of timing period.
	Coil - Relay, contactors, circuit breaker, solenoid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

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

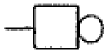
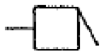
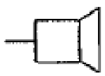
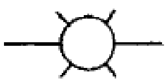
	3-phase, 3 wire zigzag, grounded neutral
	Connection to earth ground (may be plant grounding system)
	Connection to chassis or frame
○	Terminal - may be added to any of the following symbols at connection points.
	Short circuit (not a fault)
□	Terminal - Designates termination point of field run cables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

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

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

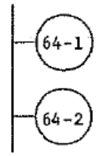
	Fuse - General
	High Voltage Primary Fuse Cutout
	Lightning Arrester - General Gap Type
	Lightning Arrester - Valve or film type
	Circuit Breaker - General
	Power Circuit Breaker - (Show location of operating mechanism)
	Circuit Breaker, 3-pole with magnetic - overload device in each pole. (Show rating)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

INDICATORS & ALARMS

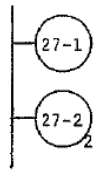
	Bell, electric
	Buzzer
	Horn - General
	Annunciator - General
	Indicating Light - General
	Use the following to specify color: A - Amber B - Blue C - Clear G - Green NE - Neon O - Orange OP - Opalescent P - Purple R - Red W - White Y - Yellow

RELAYS

The following methods are used on drawings to identify relays:

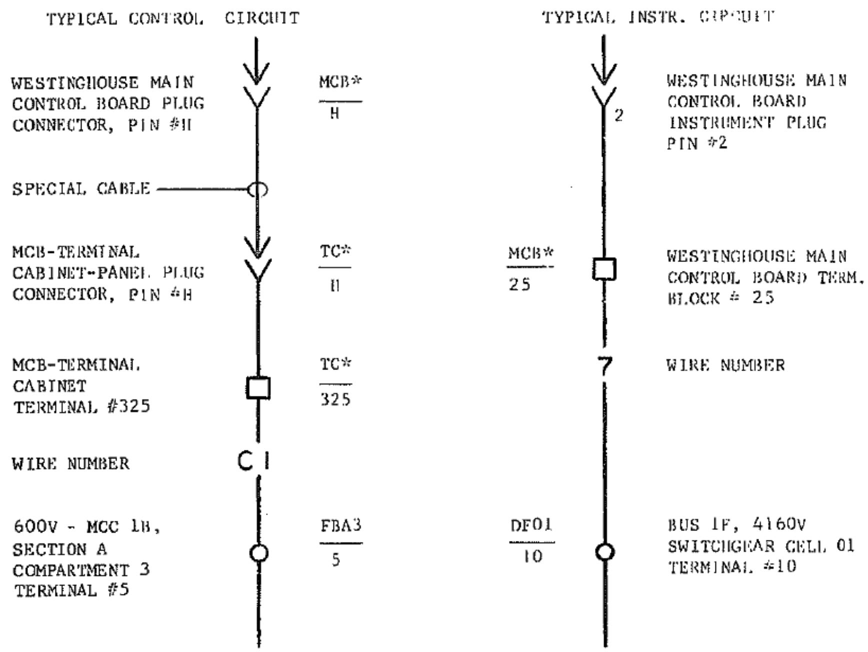
1) 

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

2) 

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

ELEMENTARY DIAGRAM CONNECTIONS



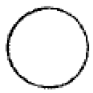
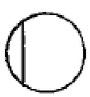
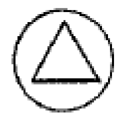
*Abbreviation for equipment - The corresponding equipment number will appear in a table on the elementary diagram (e.g. MCB = Q1H12C005)

WIRE NUMBERING

WIRE NUMBERING SYSTEM

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

Wire Number	Purpose	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)	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)		

	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

ABBREVIATIONS

A	Ammeter
AH	Ampere-hour
C	Coulombmeter
CMA	Contact-making (or breaking) ammeter
CMC	Contact-making (or breaking) clock
CMV	Contact-making (or breaking) voltmeter
CRO	Oscilloscope or cathoderay oscillograph
DB	DB (decibel) meter· Audio level/meter
DBM	DBM (decibels referred to 1 milliwatt (meter)
DM	Demand meter
DTR	Demand-totalizing relay
F	Frequency meter
G	Galvanometer
GD	Ground detector
I	Indicating
INT	Integrating
UA	Microammeter
MA	Milliammeter
NM	Noise meter
OHM	Ohmmeter
OP	Oil pressure
OSCG	Oscillograph, string
PF	Power factor
PH	Phasemeter
PI	Position indicator
RD	Recording demand meter
REC	Recording
RF	Reactive factor
SY	Synchroscope
t^{o}	Temperature meter
THC	Thermal converter
TLM	Telemeter
TT	Total time; Elapsed time
V	Voltmeter
VA	Volt-ammeter
VAR	Varmeter
VARH	Varhour meter
VI	Volume indicator; Meter, audio level
VU	Standard volume indicator Meter, audio level
W	Wattmeter
WH	Watthour meter

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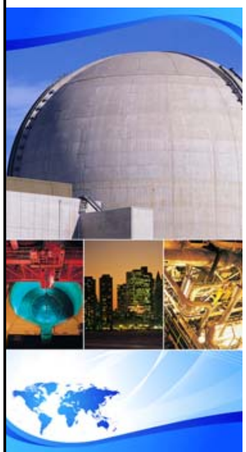


EPRI/NRC-RES FIRE PRA METHODOLOGY

Definitions

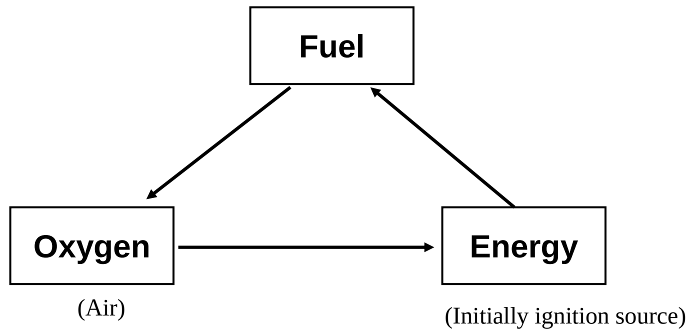
A Collaboration of U.S. NRC Office of Nuclear Regulatory Research (RES) & Electric Power Research Institute (EPRI)

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



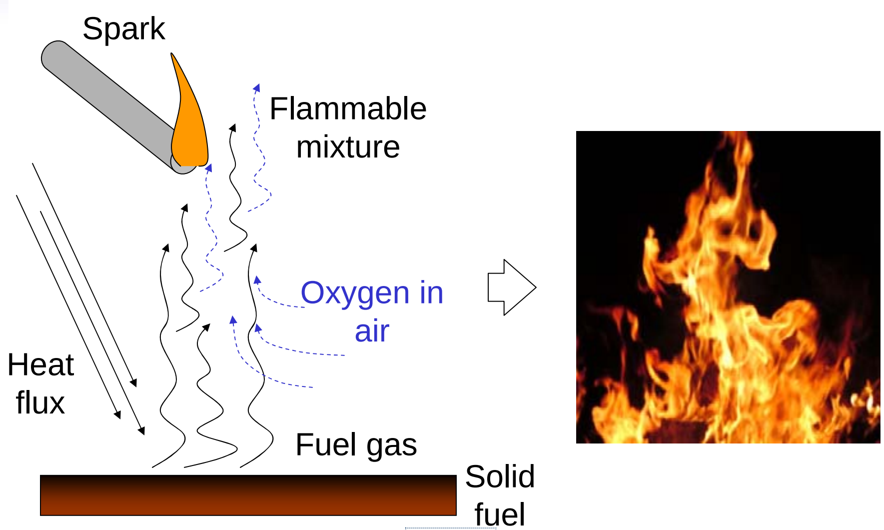
Materials that May Burn

- 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

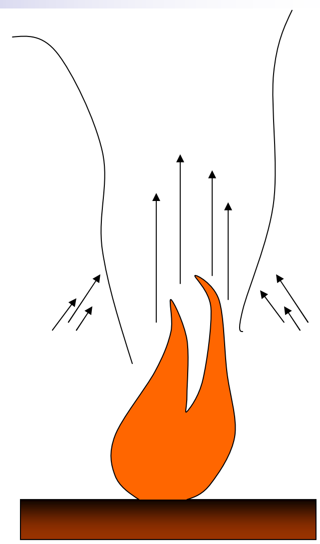
- Flame characteristics
  - Flame color depends on the material burning
  - Most flames are visible to the naked eye
  - Flame temperature can range from 1,500ºF to 3,500ºF – For example . . .
    - Laminar flames ~ 3,500 ºF, e.g., a candle flame
    - Turbulent flames ~ 1,500 ºF, e.g., a fire place

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

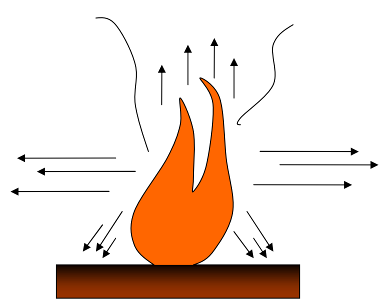
Fire Plume

- 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



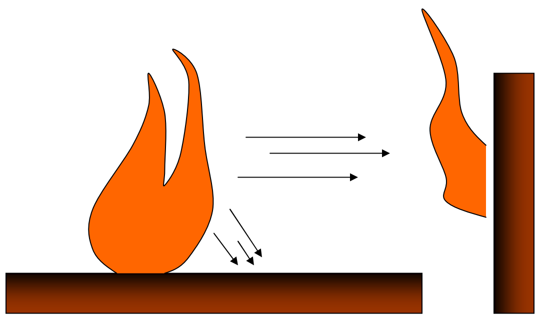
Radiative Heat of a Fire

- 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 . . .

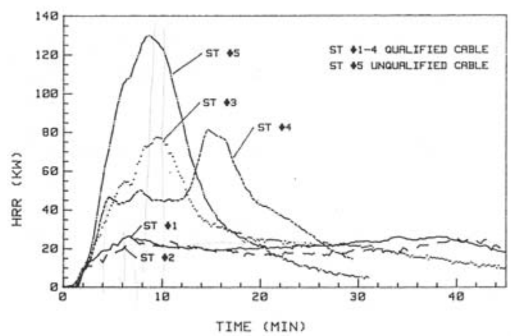


Figure 8. Heat Release Rate Plots for Scoping Tests #1 through 5

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.

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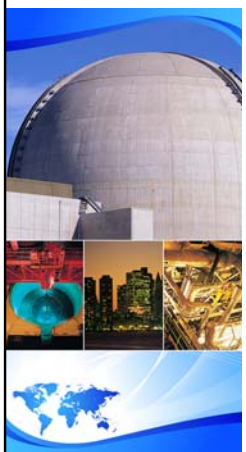

EPRI/NRC-RES FIRE PRA METHODOLOGY

Fires in the Open and Fully Ventilated Fires

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

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

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Introduction to Fire Analysis

Slide 2

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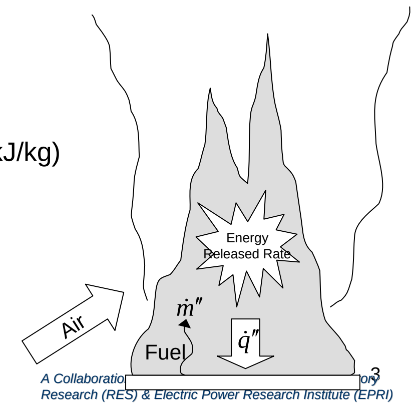
2

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)

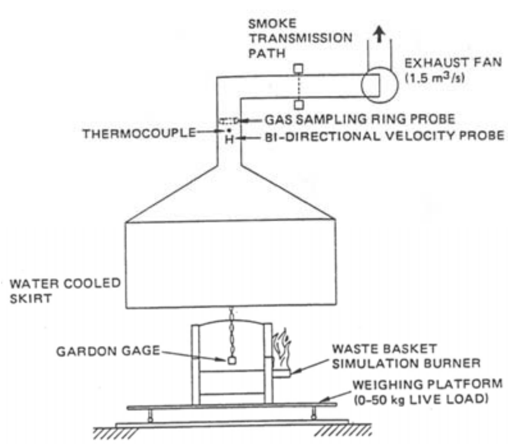


Heat Release Rate

- Can be estimated experimentally using oxygen consumption calorimeters

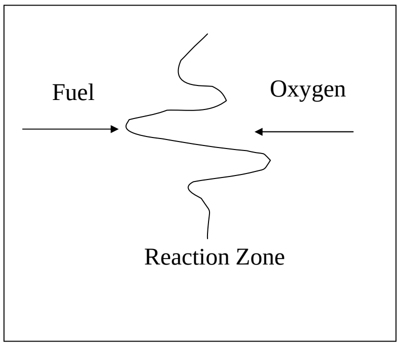
$$\dot{Q} = \dot{m}_{O_2} \cdot \Delta H_c (kJ / kg_{O_2})$$

  - 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.

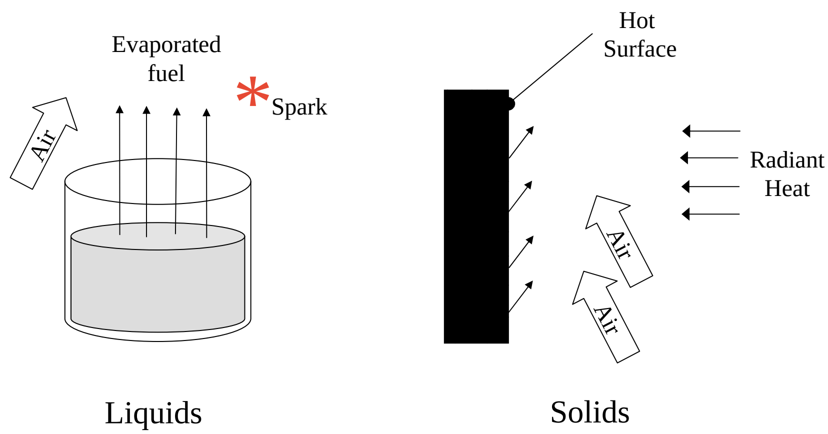
Ignition of Liquids

- 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

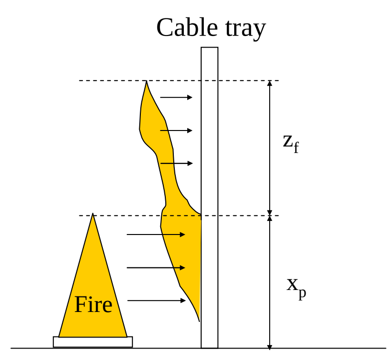
- Solids do not vaporize like liquids when heated. They form gaseous decomposition compounds leaving behind possible char in a process called pyrolysis.
- At some point, the gases ignite by piloted ignition or auto-ignition.
- Typically, piloted ignition temperatures for solids range from 250°C (~480°F) 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



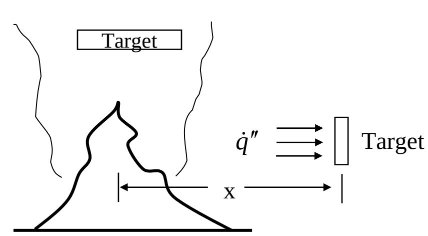
Typical Flame Spread Rates

- 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

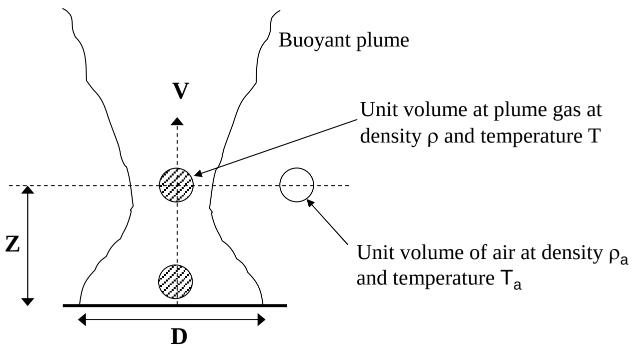
- Regions nearby the fire where damage is expected. For fires in the open:
  - Flame Radiation



  - Convection inside the fire plume

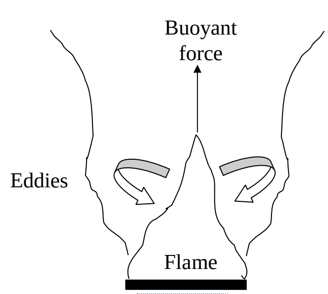
Buoyant Flow

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



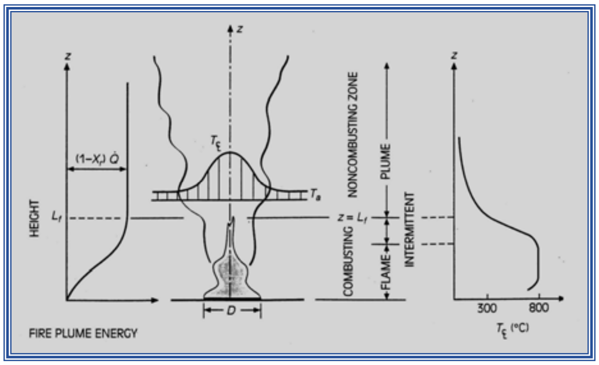
Turbulent Entrainment

- 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.

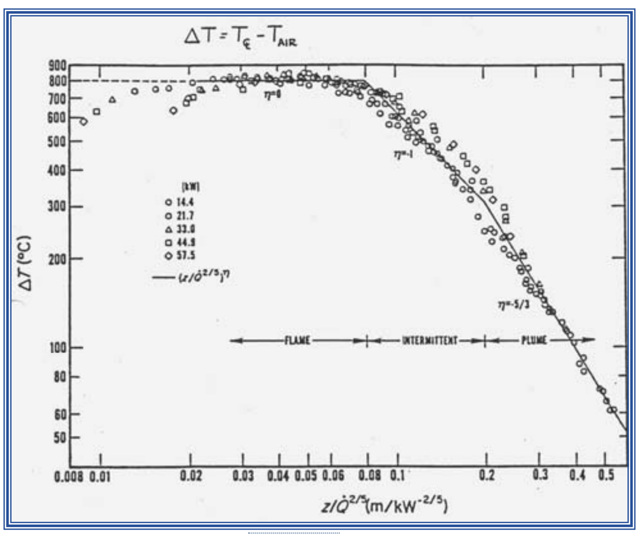


Turbulent Fire Plume

- 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**

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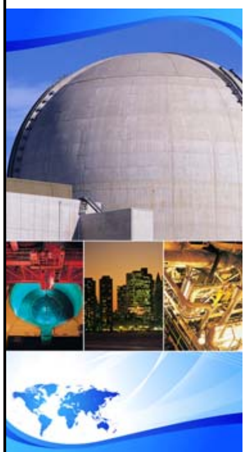


EPRI/NRC-RES FIRE PRA METHODOLOGY

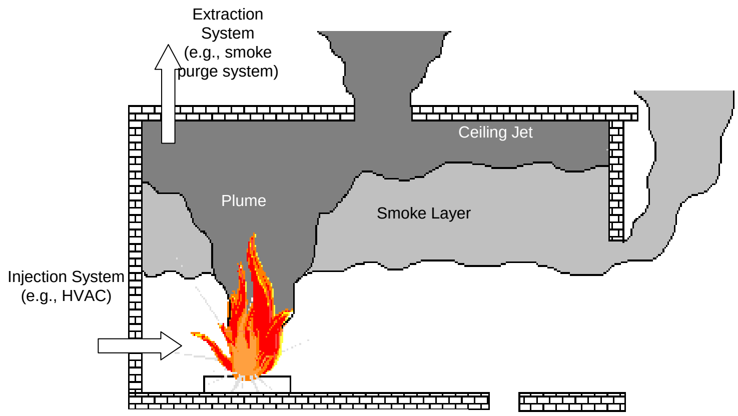
Compartment Fires

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



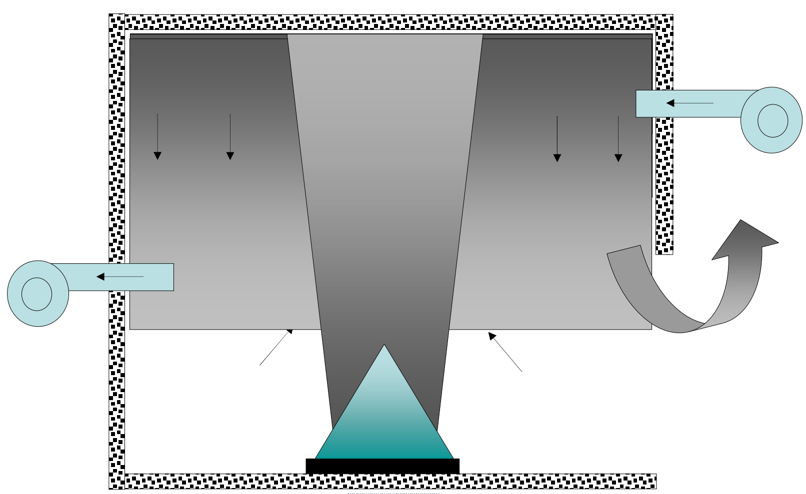
Phases in a Compartment Fire

- 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

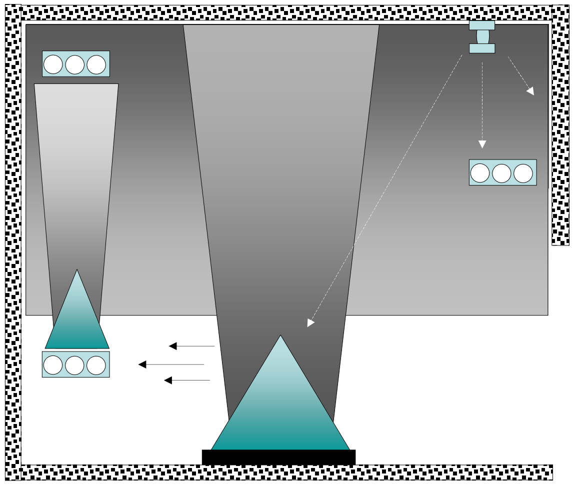
Phases in a Compartment Fire

- 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



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Introduction to Fire Analysis

Slide 7

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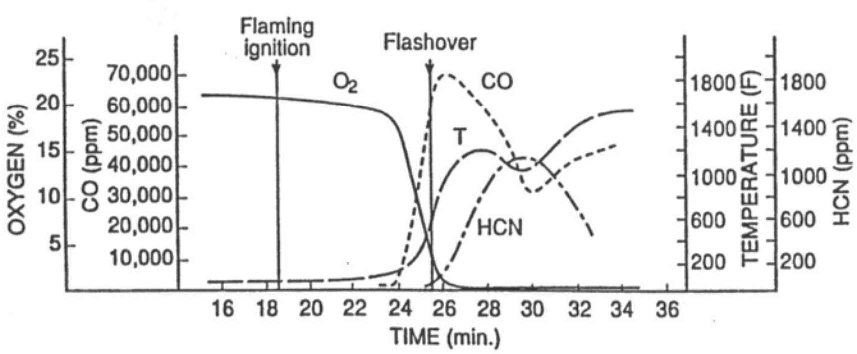
Sense of Scale

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

Data at 5.5 ft. height

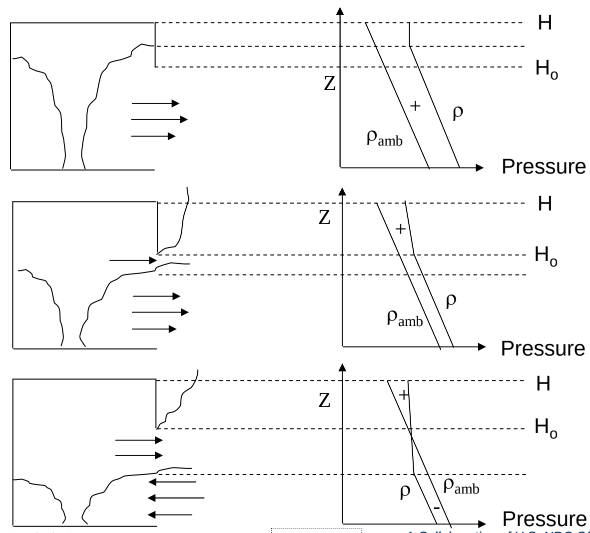


Introduction to Fire Analysis

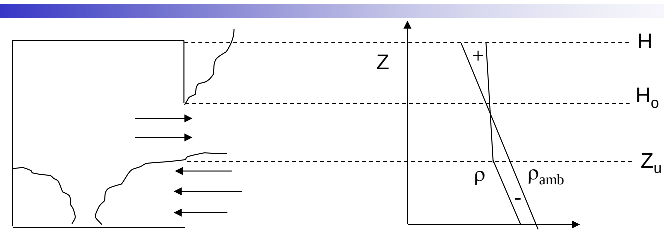
Slide 8

Research (RES) & Electric Power Research Institute (EPRI)

Pressure Profiles & Vent Flows



Pressure Profiles & Vent Flows



$$P_i(h) = P_i(0) - \rho_o g Zu - \rho_u g(h - Zu)$$

Inside Profile

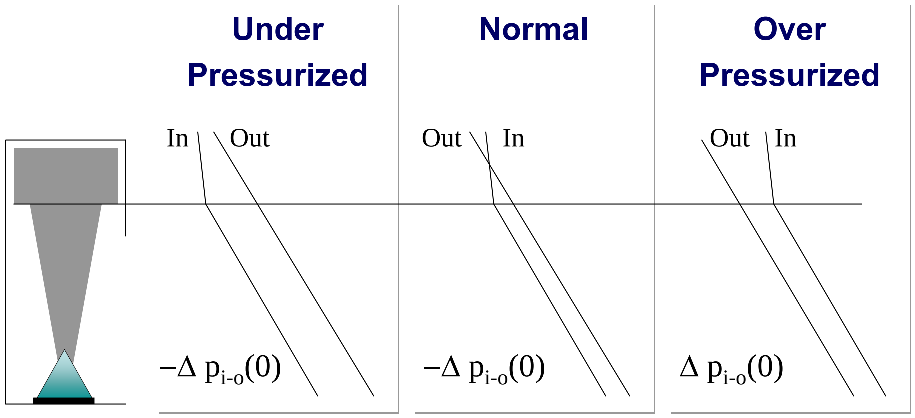
$$P_o(h) = P_o(0) - \rho_o g h$$

Outside Profile

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

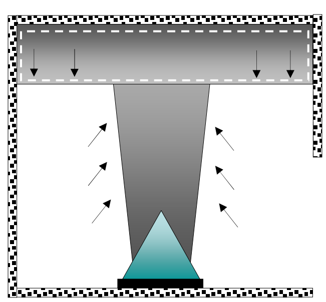
ΔP Profile

Pressure Profiles & Vent Flows



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



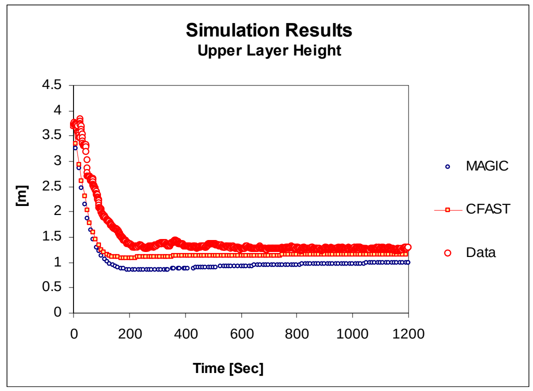
Smoke Layer

Room size:

– 22 x 7 x 3.7 m

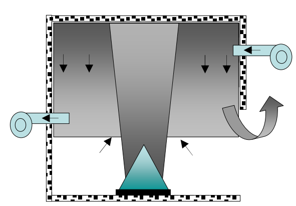
Fire: ~1 MW

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

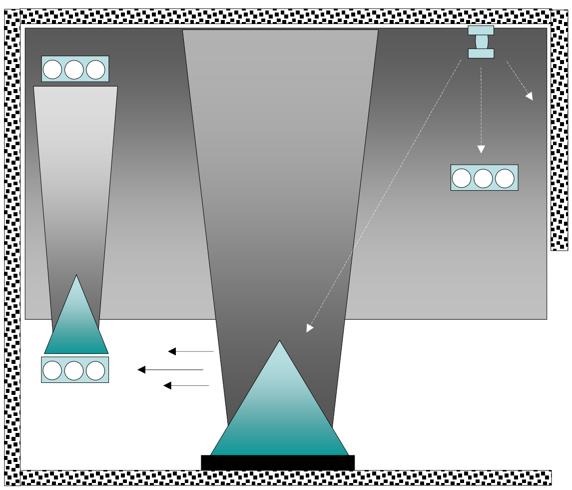


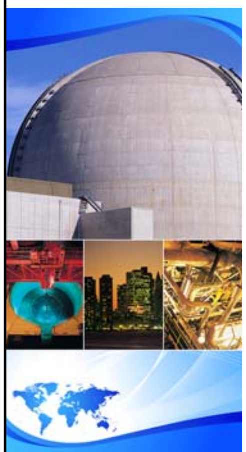
Heat Transfer

- 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





EPRI/NRC-RES FIRE PRA METHODOLOGY

Detection and Suppression

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

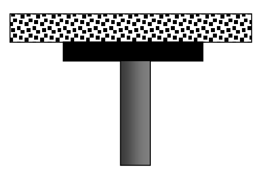
- Continuous fire watch
- Hotwork fire watch
- Continuously manned rooms, e.g., the control room

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

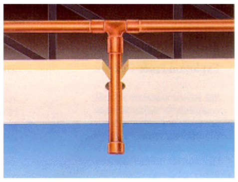
- Heat detectors
  - Detection devices
  - Sprinkler heads
  - Linear heat detectors



- 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

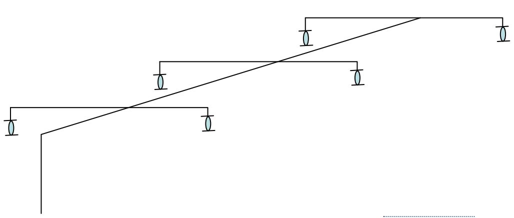
- Prompt suppression
- Automatic sprinklers
- Dry-Pipe/Pre-action sprinklers
- Deluge systems
- CO2: Automatic or Manual
- Halon: Automatic or Manual
- Fire brigade

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.

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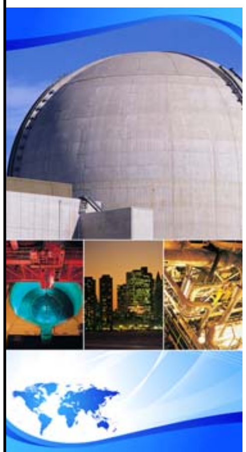


EPRI/NRC-RES FIRE PRA METHODOLOGY

Analysis Tools

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

Analysis Tools: Outline

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

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

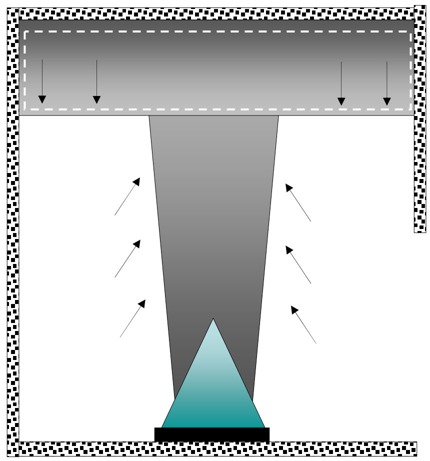
- Heat release rate, flame height and flame radiation
- Fire plume velocity, temperature heat flux, and entrainment
- Ceiling jet velocity, temperature, and heat flux
- Overall room temperature
- Target temperature, and time to target damage

Example of Hand Calcs: FDT's

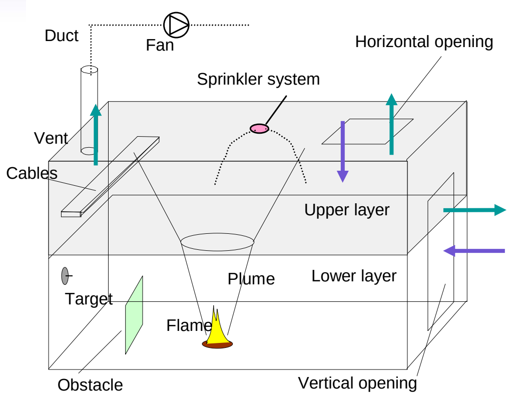
- **FDTs** are a series of Microsoft Excel® spreadsheets issued with **NUREG-1805, "Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program**."
- The primary goal of FDTs was to be a training tool to teach NRC Fire Protection Inspectors.
- 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



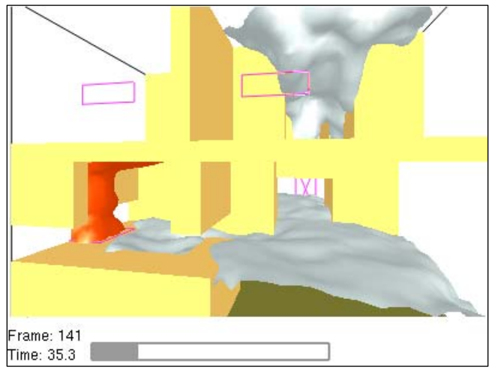
Example of a Zone Model: MAGIC



- **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.**

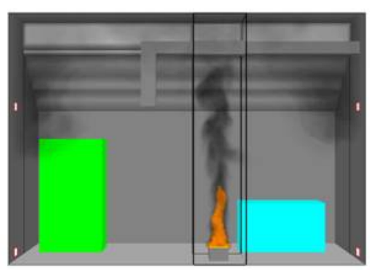
Field Models

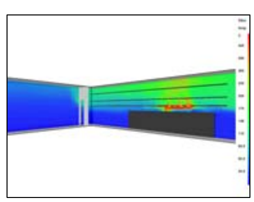
- Solve a simplified form of the Navier Stokes equations for low velocity flows
- Calculation time in the order of hours, days or weeks
- May help in modeling complex geometries

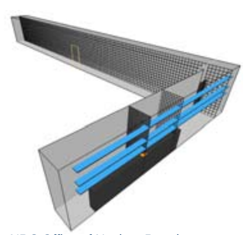


Example of Field Model: FDS

- 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*

Fire PRA Workshop, 2009, Palo Alto, CA
Introduction to Fire Analysis

Slide 15

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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

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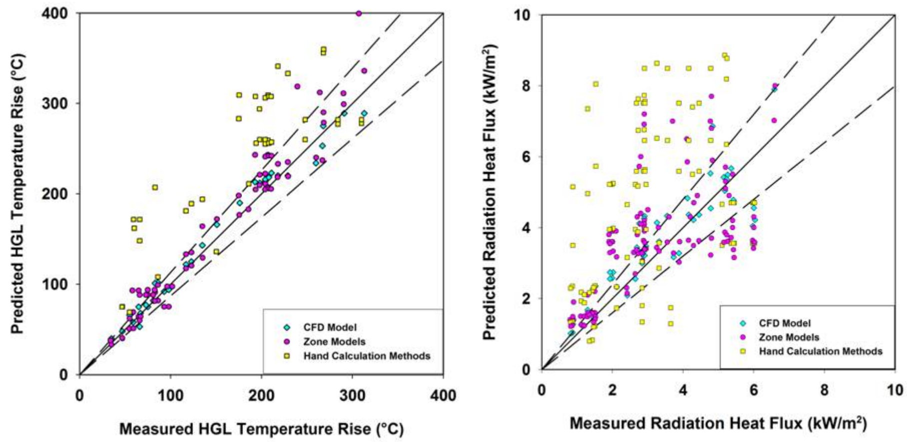
Verification and Validation



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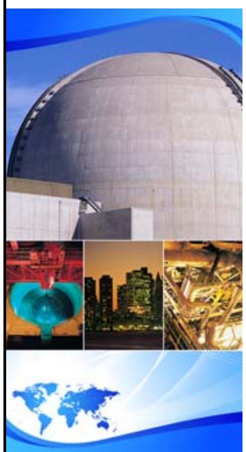


EPRI/NRC-RES FIRE PRA METHODOLOGY

Day 1: Presentation # 6 – Fire Scenarios

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

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

Fire Scenario

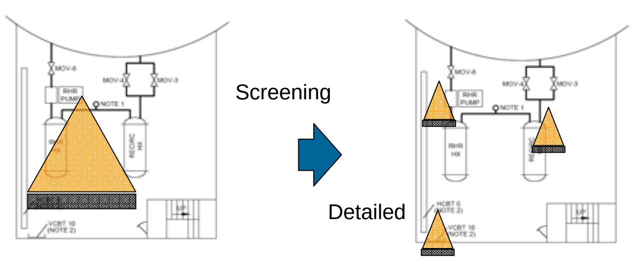
- A set of elements representing a fire event:
  - The ignition source, e.g., electrical cabinets, pumps
  - Intervening combustibles, e.g., cables
  - Targets, e.g., power, instrumentation or control cables
  - Fire protection features, e.g., automatic sprinklers
  - The compartment where the fire is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

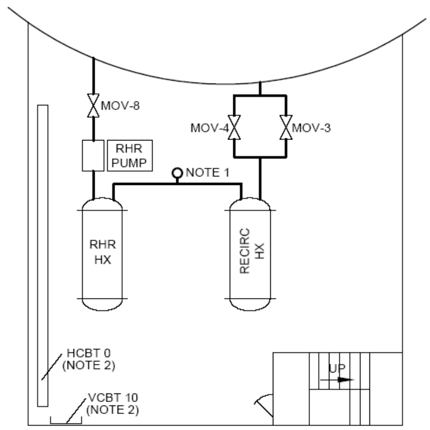
- In the initial stages of screening, fire scenarios are defined in terms of compartments and loss of all items within each compartment.
  - Assumes all items fail in the worst failure mode
  - Detection and suppression occur after the worst damage takes place
  - Fire does not propagate to adjacent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

Fire Scenario
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

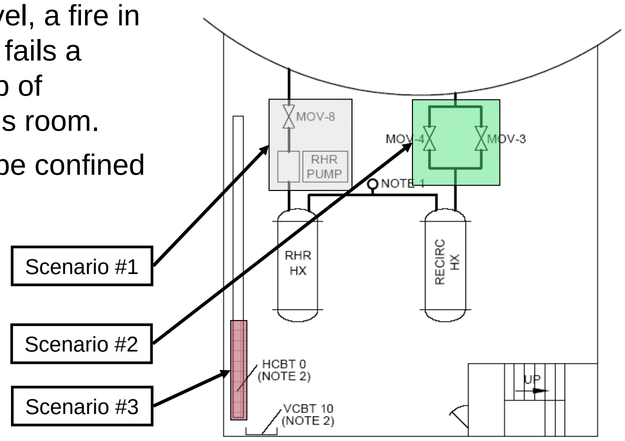
Fire Scenario
Example – Screening Level

- 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



Fire Scenario
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

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

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

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

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

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