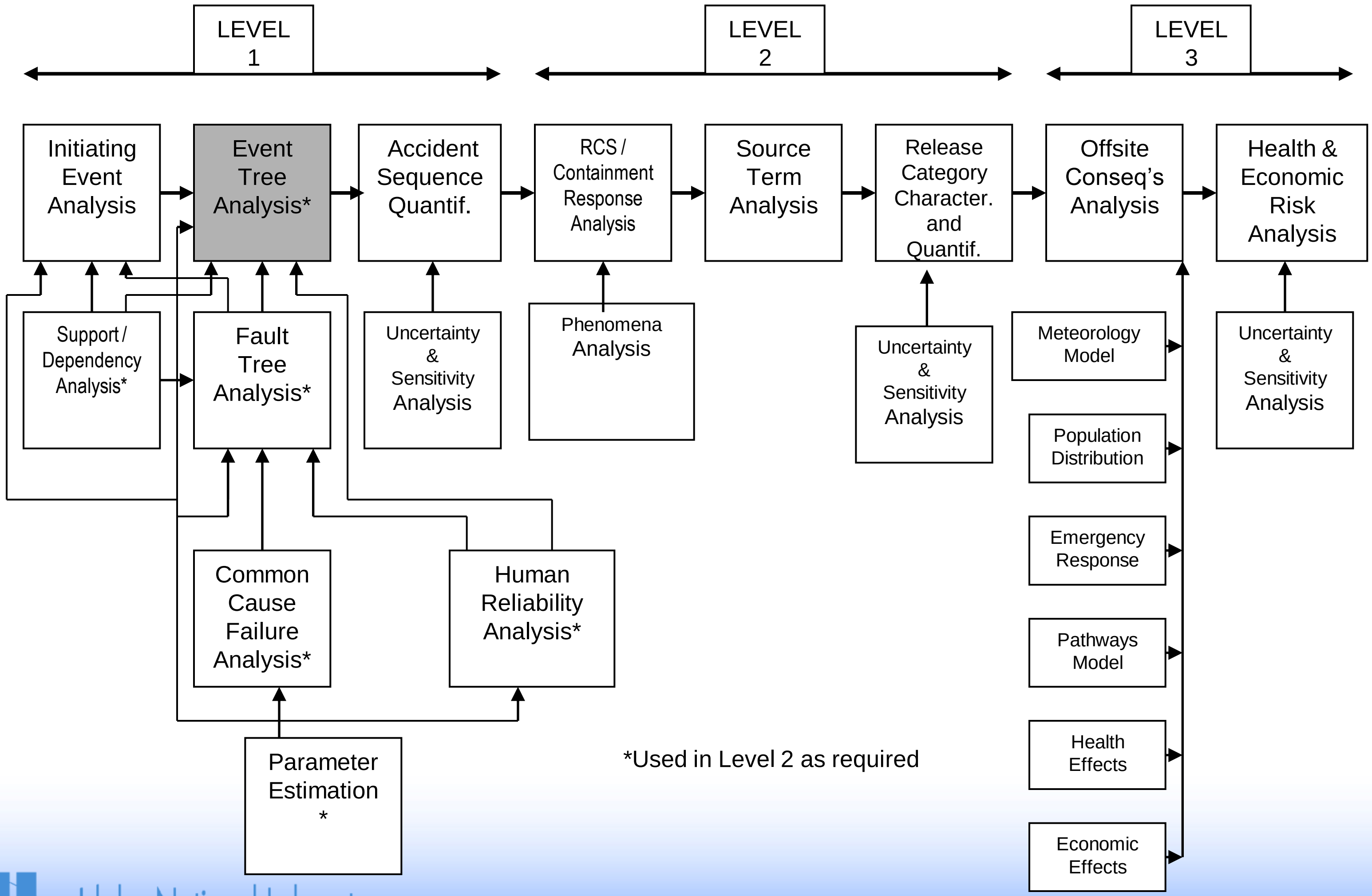
MODULE E

ACCIDENT SEQUENCE ANALYSIS USING EVENT TREES

Accident Sequence Analysis Using Event Trees

- **Purpose: Students will learn purposes and techniques of event tree analysis. Students will learn how event tree analysis is related to the identification and quantification of accident sequences.**
- **Objectives:**
  - **Describe the purposes of event tree analysis**
  - **Describe techniques and notations employed in event tree construction**
  - **Describe the relationship between event tree construction and deterministically-identified success criteria**
  - **Compare PRA accident sequences (as depicted by the event trees) and the traditional SAR design basis accidents**
- **References: NUREG/CR-2300**

Principal Steps in PRA



*Used in Level 2 as required

Event Trees

- Typically used to model the response to an initiating event
- Features:
  - One event tree for each initiating event (or initiating event group)
  - Related to plant functions/systems/operations
  - Identifies relationships in event occurrence
  - Identifies relative timing of event occurrence
  - Provides event sequence progression
  - Provides end-to-end traceability of accident sequences
- Primary use
  - Identification of accident sequences which result in some outcome of interest (usually core damage and/or containment failure)
  - Forms the basis for accident sequence quantification

(3.8): FCS SMALL LOCA EVENT TREE

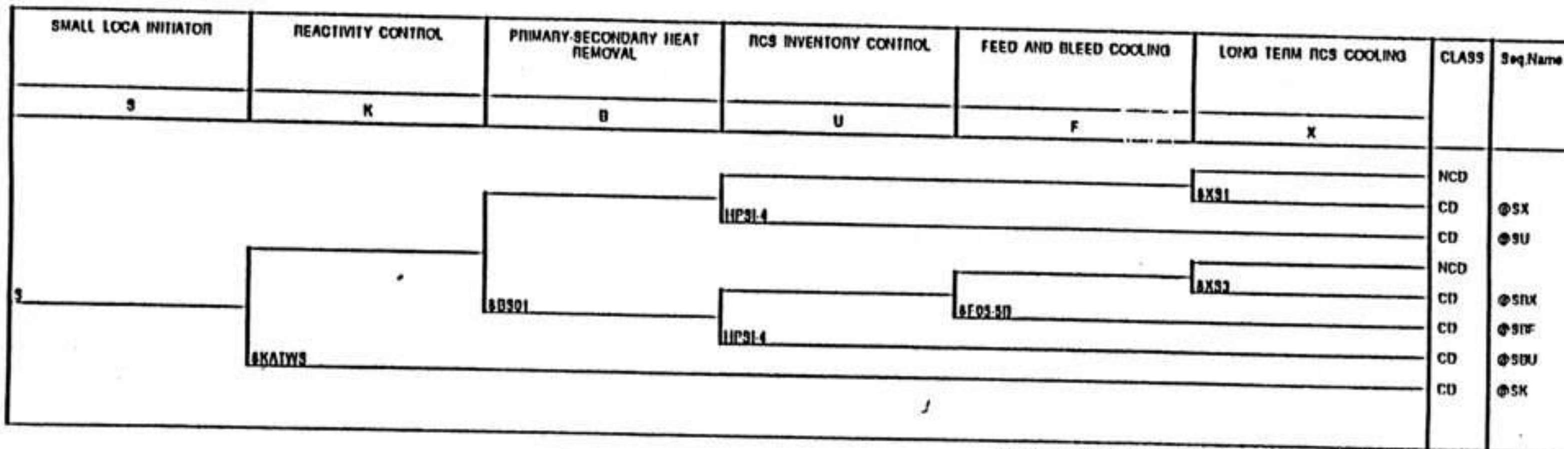


FIG. (3.8): FCS SMALL LOCA EVENT TREE A:\ETREE\FIG38.TRE 8-27-93

Small LOCA Event Tree

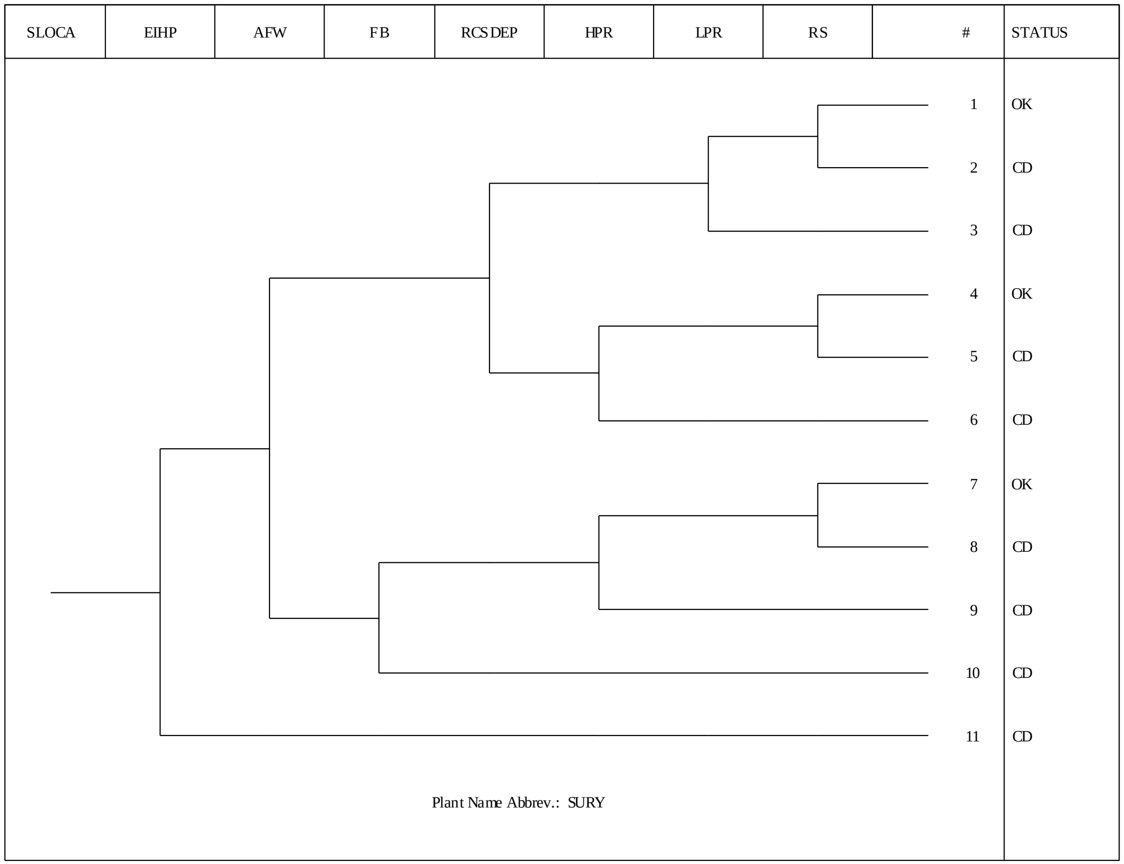


Table 3.# SDP Worksheet Example — Small LOCA (SLOCA)

Safety Functions Needed:	Full Creditable Mitigation Capability for Each Safety Function:
Early Inventory, High Pressure Injection (EIHP) [4]	1/2 charging pump trains or use of 1 spare charging pump [6] (1 multi-train system)
Secondary Heat Removal (AFW)	1/2 MDAFW trains (1 multi-train system) [1] or 1/1 TDAFW train (1 ASD train) with 1/5 safety relief valves or 1/1 SG PORV for the associated 1/3 SGs
RCS Cooldown/Depressurization (RCSDEP)	Operator depressurizes and cools down RCS using 1/3 ADVs and 1/2 Pzr Sprays (operator action = 3) [5]
Primary Heat Removal, Feed/Bleed (FB)	1/2 PORVs open for Feed/Bleed (operator action = 2) [2]
Low Pressure Recirculation (LPR)	1/2 LHSI pumps auto initiated by RMT (1 multi-train system) [3]
High Pressure Recirculation (HPR)	1/2 charging pump trains with 1/2 LHSI pumps auto initiated by RMT (1 multi-train system) [3]
Recirculation Spray (RS)	1/2 inside RS (1A or 1B) trains or 1/2 outside RS (2A or 2B) trains (2 multi-train systems)

Circle Affected Functions		IEL	Remaining Mitigation Capability Rating for Each Affected Sequence	Recovery Credit	Results
1 SLOCA - RS (2,5,8) **3 + 6**	**9**				
2 SLOCA - LPR (3) **3 + 3**	**6**				
3 SLOCA - RCSDEP [5] - HPR (6) **3 + 3 + 3**	**9**				
4 SLOCA - AFW - HPR (9) **3 + 4 + 3**	**10**				
5 SLOCA - AFW - FB (10) **3 + 4 + 2**	**9**				
6 SLOCA - EIHP (11) **3 + 3**	**6**				

Identify any operator recovery actions that are credited to directly restore the degraded equipment or initiating event:

If operator actions are required to credit placing mitigation equipment in service or for recovery actions, such credit should be given only if the following criteria are met: 1) sufficient time is available to implement these actions, 2) environmental conditions allow access where needed, 3) procedures exist, 4) training is conducted on the existing procedures under conditions similar to the scenario assumed, and 5) any equipment needed to complete these actions is available and ready for use.

Notes:

1. Use of 1/3 opposite unit's AFW trains via crosstie is possible. The crosstie function can be considered as a possible recovery action for a deficiency in the unit's AFW system. In both cases, the discharge pathways to the SGs are the same which may limit the credit that may be applicable.
2. The human error probability (HEP) assessed in the PRA for establishing bleed and feed cooling is 2.66E-3. A credit of 2 is assigned based on a survey of the operation action at similar plants.
3. When the RWST level reaches its low setpoint, the RMT system automatically initiates the switchover of the low pressure injection pumps to the recirculation mode. The sump suction valves open and the RWST suction valves close. The changeover to high head recirculation will also take place automatically on low RWST level. The recirculation mode transfer (RMT) system automatically initiates the switchover of the suction of the high pressure injection pump from the RWST to the low pressure injection pump discharges on low RWST level.
4. Based on the licensee's comments, in case of EIHP failure secondary cooldown using the 1/3 SG ADVs and 50% AFW flow for LPI and LPR is not credited.
5. The HEP assessed in the PRA for operator depressurizing and cooling down the RCS is 5.33E-3. A credit of 3 is assigned and verified through benchmarking.
6. The spare charging pump can be aligned as a recovery action when the charging pump aligned to the bus is failed. A credit of 1 can be assigned for use of the spare charging pump.

Principal Steps in Event Tree Development

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

Determining Boundaries

- Mission time
- Dependencies among safety functions or systems
- Sequence end states - undesired outcome
  - Core damage
  - Core vulnerable
  - Containment vulnerable
- Extent of operator actions explicitly modeled in event tree

Success Criteria

- Start with functional event tree showing the fundamental safety functions for the reactor core and containment
  - Reactor subcriticality
  - Core heat removal
  - Core inventory makeup
  - Primary coolant system integrity
  - Containment pressure suppression
  - Containment heat removal
  - Containment integrity

Success Criteria (cont.)

- Identify which of the fundamental safety functions will be challenged or required to mitigate the accident initiator
- Identify systems which can perform each of the required fundamental safety functions
- Identify the minimum required 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

Example of Success Criteria Variability

- **Examples from CEOG SIT AOT analyses for Large LOCAs**
  - Fort Calhoun: Need 3 of 3 SITs to unbroken legs
  - Millstone 2: Need 2 of 3 SITs to unbroken legs
  - St. Lucie: Need 3 of 4 SITs to unbroken legs
  - Palo Verde 1, 2, 3: Need 2 of 3 SITs to unbroken legs

Event Tree Development

- An event tree consists of an initiating event (one per tree), followed by a number of headings (or top events), and then the event tree structure or success/failure branching for the respective top events
- The top events represent the systems, components, and/or operations identified by success criteria
- To the extent possible, the top events are ordered in the time-related sequence in which they would occur
  - Selection of top events and their ordering reflects the EOPs
- Each node (or branch point) below a top event represents the success or failure of the respective top event.
  - Logic typically binary
    - Downward branch failure of top event
    - Upward branch success of top event
  - Logic can have more than binary branch, with each branch representing a specific status of the respective top event

Event Tree Development (Continued)

- Branches can be pruned logically (branch points for specific nodes removed) to remove unnecessary combinations of system success requirements
    - This minimizes the total number of sequences that will be generated and eliminates illogical sequences
  - – 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)

Plant Damage States

- **Also called "Accident Classes" or "Endstates."**
- **Can use "indicators" to relate a core damage accident sequence to the existing status of plant safety function such as:**
  - **the status of the reactor coolant system at the onset of core damage,**
  - **the status of various systems' operability,**
  - **the status of water inventories,**
  - **the status of the containment, and**
  - **the timing of the onset of core damage.**
- **Plant damage states are used to group accident sequences with similar outcomes for core damage analysis and to simplify subsequent use in Level 2/3 analysis.**

Example Category Definitions for PDS Indicators

1. Status of RCS at onset of Core Damage
   - T no break (transient)
   - A large LOCA (6” to 29”)
   - S1 medium LOCA (2” to 6”)
   - S2 small LOCA (1/2” to 2”)
   - S3 very small LOCA (less than 1/2”)
   - G steam generator tube rupture with SG integrity
   - H steam generator tube rupture without SG integrity
   - V interfacing LOCA
2. Status of ECCS
   - I operated in injection only
   - B operated in injection, now operating in recirculation
   - R not operating, but recoverable
   - N not operating and not recoverable
   - L LPI available in injection and recirculation of RCS pressure reduced
3. Status of Containment Heat Removal Capability
   - Y operating or operable if/when needed
   - R not operating, but recoverable
   - N never operated, not recoverable

Event Tree Interpretation Exercise

- **In an instructor-led discussion with the class, investigate the following about the North Anna IPE:**
  - Sources of initiating event information (Table 3.1.1-1 on p. 3-145)
  - Initiating event classes (Table 3.1.1-2 on p. 3-146)
  - Distinction between T2 and T2A (Tables 3.1.1-7, 3.1.1-8, and actual events in Table 3.1.1-10. See pp. 3-151 through 3-158 and 3-160 through 3-165)
  - Support system initiators (Table 3.1.1-12, pp. 3-170 through 3-174)
  - Required functions and systems (success criteria) for T2A (Table3.1.1-15 on p. 3-178)
  - On T2A event tree (p. 3-343) and using the event tree heading information on pp. 3-188 to 3-193, note the following:
    - Top events (compared with success criteria) and their ordering
    - System logical dependencies (pruning)
    - Endstates (OK and core damage with different "containment states" for Level 2 PRA)
    - Which sequences depict a SAR DBA scenario (only sequence P01)
    - Discuss what is happening in selected sequences