Qualitative Hazard Analysis

2009_2nd semester

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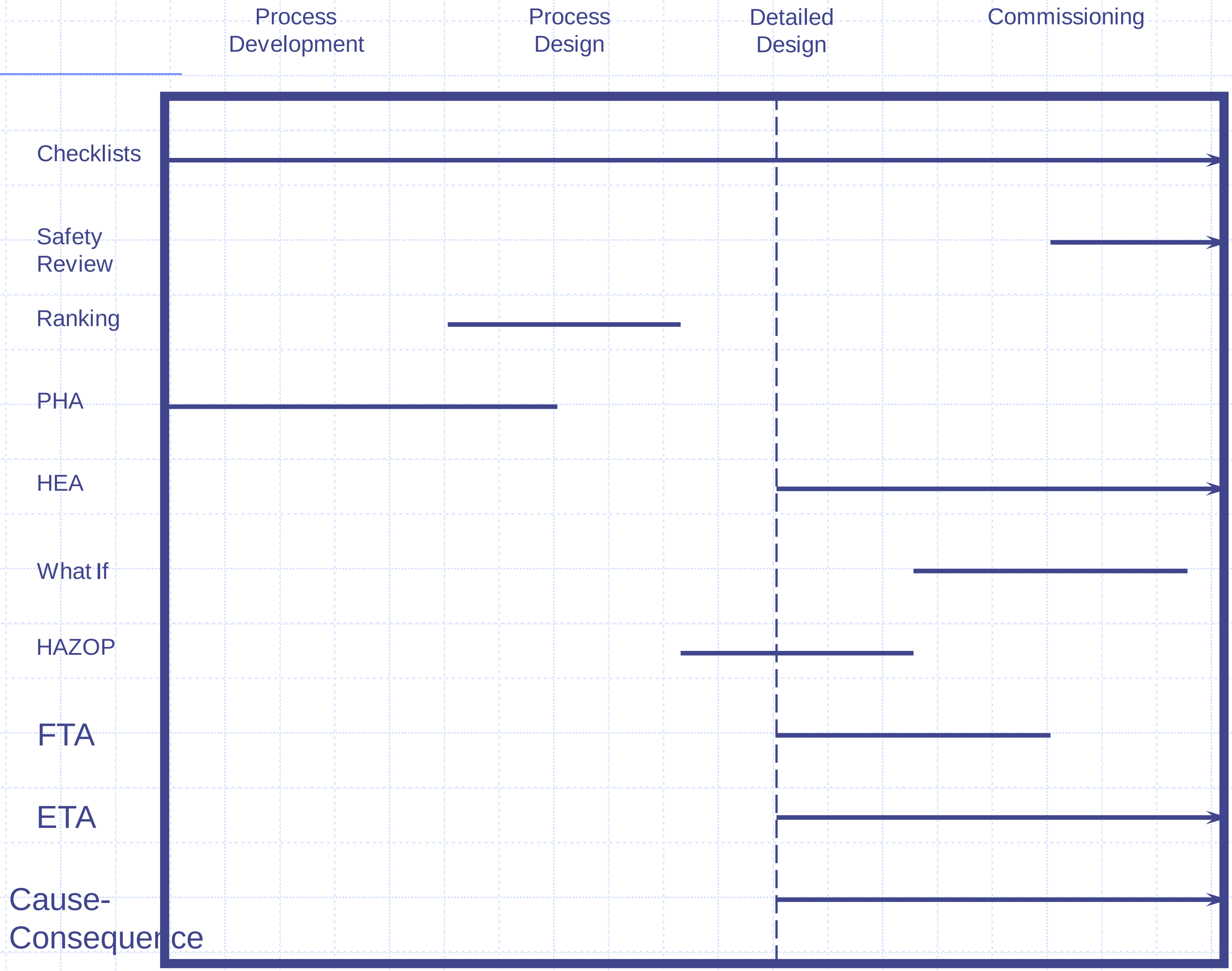
Introduction

- Successful hazard evaluation study can be defined as one in which
  - The need for risk information has been met
  - The results are of high quality and are easy for decision makers to use
  - The study has been performed with the minimum resources needed to get job done

Hazard Evaluation

- Factors influencing the selection of hazard evaluation technique
  - Motivation for the study
  - Type of result needed
  - Type of information available to perform the study
  - Characteristics of the analysis problem
  - Perceived risk associated with the subject process or activity
  - Resource available and analyst/management preference


Process Development
Process Design
Detailed Design
Commissioning
Checklists
Safety Review
Ranking
PHA
HEA
What If
HAZOP
FTA
ETA
Cause-Consequence

	Site selection/ early design state	Design stage of new plants	Operational stage of new and existing plants	Modifications to existing plants
Process system checklist	B	B	A	B
Safety Audit/review	C	C	A	C
Dow and Mond Hazard Indices	C	B	A	C
Preliminary Hazard Analysis	A	C	C	A
Hazard Operability Studies	C	A	B	A
'What if' Analysis	A	C	B	A
Failure Mode and Effect Analysis	C	A	A	B
Fault tree Analysis	C	A	A	B
Event tree Analysis	C	A	A	B
Cause-Consequence Analysis	C	B	A	B
Human Reliability Analysis	C	A	A	B

A : Best suited
B : Could be used
C : last suited (not advised)

Qualitative Hazard Evaluation Technique

- Safety Review
- Checklist Analysis
- Relative Ranking
- Preliminary Hazard Analysis
- What-If Analysis
- What-If Checklist Analysis
- HAZard and OPerability Analysis
- Failure Mode and Effects Analysis
- Fault Tree Analysis
- Event Tree Analysis
- Cause-Consequence Analysis
- Human Reliability Analysis

Safety Review

- Purpose
  - Keeps operating personnel alert to the process hazards
  - Review operating procedures for necessary revisions
  - Seek to identify equipment or process changes that could have introduces new hazard
  - Evaluate the design basis of control and safety system
- Types of result
  - Qualitative descriptions of potential safety problem and suggested corrective actions
- Resource requirements
  - P&ID, flowcharts, plant procedures for start-up, shutdown, maintenance and emergencies, hazardous incident reports, process material characteristics

Overview

- Detailed inspection to identify hazardous process design characteristics, plant conditions, operating practice or maintenance activities
- Conduct periodic inspection of an operating plant helps ensure that implemented risk management program meet original expectations and standards
- Address all plant equipment. Instrumentation, associated utilities, environmental protection facility, maintenance areas and service

Preparing for the review

- Define which systems, procedures, operations and personnel will be evaluated
- Following task should be completed
  - Assemble a detailed description of the plant
  - Review the known hazards and process history with the review team members
  - Review all of the applicable codes, standards and company requirement
  - Schedule interviews with specific individual responsible for safe process operation
  - Request available records concerning personnel injuries, accident/incident reports, equipment inspection, pressure relief valve testing, safety/health audits etc.

Performing the review

- Obtain and review copies of plant drawing as well as operating, maintenance and emergency procedures
- Some question that might be addresses are
  - Is there a system for keeping important process documentation and drawing up-to-date?
  - Is the equipment in good condition?
  - Are the pressure relief or other safety property installed, well maintained and properly identified?
  - Do plant records show the history of inspecting/testing of the equipment and the safety devices?
  - Are safe practice followed and permits used?

Checklist Analysis

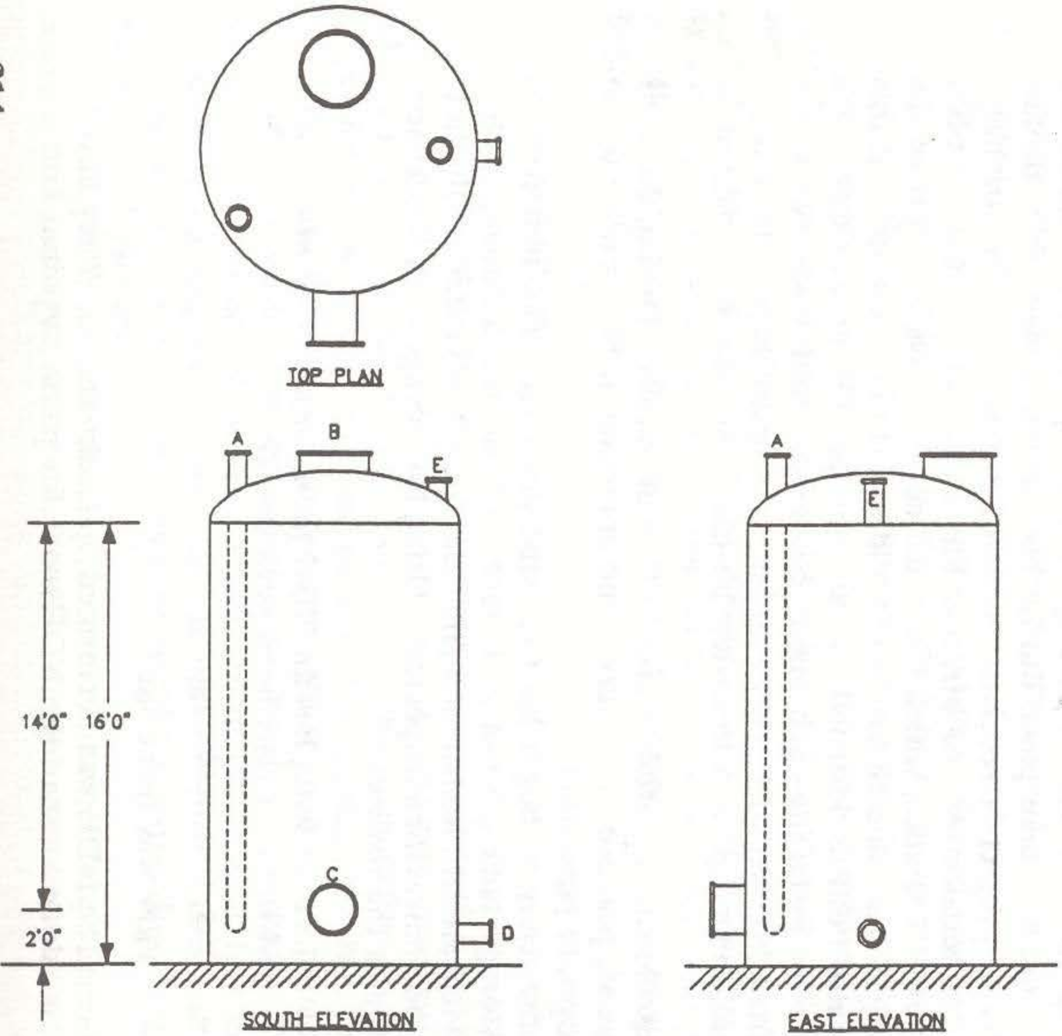
- Purpose
  - Ensure that organizations are complying with standard practices
- Type of results
  - List of questions based on deficiencies or difference
  - Completed checklist contains “yes”, “no”, “not applicable” or “need more information” answer to the question
- Resource requirement
  - Engineering design procedure, operating practices manual
  - Experiences manager or engineer with knowledge of process

Overview

- Experience –based approach
- Use s list of specific items to identify known types of hazards, design deficiencies and potential accident situation
- Can be used to evaluate materials, equipment or process
- Ensure that a piece of equipment conforms with accepted standards and it may also identify areas that required further evaluation

Analysis procedure

- Selecting or developing an appropriate checklist
  - Appropriate checklist from available
  - Analyst must use his own experience and the information available from authoritative reference to generate an appropriate checklist
- Performing the review
  - Include tours and visual inspections of the subject process areas by the HE team members
  - Reviewer respond to the checklist issues based on observations from site visits, system documentation, interviews with operating personnel and personnel perception
- Documenting the results
  - Summarize the deficiencies noted during the tours or meeting and any specific recommendation



NOZZLE SCHEDULE			
MARK	SIZE	TYPE	DESCRIPTION
A	2"	150#	FILL
B	20"	150#	MANWAY
C	16"	150#	MANWAY
D	2"	150#	DISCHARGE
E	2"	150#	VENT

DESIGN DATA
DIMEN: 8' DIA. X 16' STR. SIDE CAPACITY: 13,500 GAL DES. PRESSURE SHELL: 50 PSIG OPERATING PRESSURE SHELL: ATMOS DESIGN TEMPERATURE SHELL: 250°F OPERATING TEMPERATURE SHELL: 120°F TEST PRESSURE SHELL: 100 PSIG SHELL THICKNESS 5/16" MATERIAL OF CONSTR. CARBON STEEL REMARKS: FIBERGLASS LINED

				REV	DATE	DESCRIPTION
DRAWING NO. H-107	HCl STORAGE TANK	ABC VCM PLANT ANYWHERE, USA	DRAWN BY DFM DATE 9/8/88			
SCALE: NONE			CHECKED BY WGB DATE 10/20/88			

Figure 16.1 Schematic of the HCl storage tank.

Table 16.1 Checklist Analysis Results for the HCl Storage Tank Inspection

Item To Check	O.K. (Sign and Date)
1. Nondestructive examination (NDE) performed	
a. NDE examiners are ASME-certified	I.M.B. 1/5/89
b. Approved ASME NDE method used	I.M.B. 1/5/89
c. NDE results in engineering file	I.M.B. 1/5/89
2. Postweld heat treatment and hardness testing performed	
a. Postweld heat treatment in accordance with ASME code	I.M.B. 1/5/89
b. Brinell hardness testing performed	I.M.B. 1/5/89
c. Test results in engineering files	I.M.B. 1/5/89
3. Vessel foundation elevation and slope checked	Action Required
4. Vessel material and construction materials in compliance with specifications and job requirements	I.M.B. 1/5/89
5. All welds inspected and tested	I.M.B. 1/5/89
6. All tack welds in vertical joints properly removed	I.M.B. 1/5/89
7. Vessel wall plate in good condition (or properly repaired if damaged) and contains all pertinent information	I.M.B. 1/5/89
8. Vessel hydrotested	I.M.B. 1/5/89
9. Dimensional check of vessel performed	I.M.B. 1/5/89
10. Elevation and orientation of nozzles checked. Vessel is on centerlines, is level, and is properly grouted. Foundation bolts tightened	I.M.B. 1/5/89
11. Ladders and platforms installed as per drawings	I.M.B. 1/5/89
12. Trays level and correct orientation. Downcomer clearance, weir height, drain holes, gaskets, bolts, etc., installed per specification	Not Applicable
13. Internal pipes installed with correct bolts and gaskets	I.M.B. 1/5/89
14. Internal lining intact	Action Required
15. Internal tray manways closed	Not Applicable
16. Packing installed	Not Applicable

Relative Ranking

- Purpose
  - Determine the process areas or operation that are the most significant with respect to the hazard of concern in a given study
- Types of result
  - An ordered list of process equipment, operation or activities
- Resource requirements
  - Basic physical and chemical data on the substance used in the process or activity

Overview

- Rank process areas or plant operations by comparing the hazards attributes of chemicals
- Distinguish between several process areas based on the magnitude of hazards, likelihood of accidents and/or severity of potential accidents
- Can address fire, explosion and/or toxicity hazards and associated safety, health, environmental and economic effects for a process or activity

- Relative ranking techniques may be used during any phase of a plant or process lifetime to:
  - Identify the individual process areas that contribute most to the anticipated overall hazard and accident attributes of a facility
  - Identify the key material properties, process conditions and/or process characteristics that contribute most to the anticipated hazards and accident of a single area or an entire facility
  - Compare to anticipate hazard and accident attributes of process areas or facilities to other whose attributes are better understood

- Considering factor for implementing the relative ranking index
  - Material properties
  - Process conditions
  - Process characteristics and support systems
    - Purging, ventilation, cooling, heating etc
  - System design and construction
    - Fire proofing, equipment layout, corrosion resistance etc
  - Operational activities
    - Operator training, written procedures etc.
  - PSM activities
    - Inspection and testing intervals, maintenance activities etc.
  - Exposure possibilities
    - Operation time and frequency, number of operator activities etc.

Summary of relative ranking indexes-1

- Dow Fire and Explosion Index(F&EI)
  - Rankings of process units can be used
    - To direct specific safety improvement efforts relating to important parameters used in the F&EI calculation
    - To identify areas for more detailed hazard evaluation or risk analysis study
- Mond Index
  - Extension of the Dow F&EI
  - Includes factors that address the toxicity hazards associated with materials in process units
- Substance Hazard Index(SHI)
  - Way of ranking material hazards defined as “equilibrium vapor concentration(EVC) of a material at 20C divided by an acute toxicity concentration”

Summary of relative ranking indexes-2

- Chemical Exposure Index(CEI)
  - Addresses five types of factors that can influence the effects of release of the material
    - Acute toxicity
    - Volatile portion of material which could be released
    - Distance to areas of concern
    - Molecular weight of the substance
    - Various process parameters such as temperature, pressure, reactivity and so forth

Analysis Procedure

- Preparing for the review
  - Information for preparing the analysis
    - Site plan
    - Lists of materials, chemical properties and quantities
    - General process diagram and equipment layout drawing
    - Design and operating data
    - Technical guides for the selected ranking technique
  - Performing the review
    - Follow the instruction in the technical guide for that technique to perform the evaluation
    - The calculates risk index should be summarized to facilitate comparisons among the area
  - Document the results

Table 6.3 Data for the Relative Ranking Example

Facility	Hazardous Substance	Mass of Chemical in Largest Single Container ($\times 10^3$ kg)	SHI	Population Within 1-Mile Radius of Facility ($\times 10^3$)	LFL (ppm)
Plant A	Chlorine	90	73,000	2	na[a]
	Ammonia	1,000	2,400	2	na
Plant B	Arsine	.01	1,000,000	0.5	na
	Sulfur dioxide	10	10,000	0.5	na
	Ammonia	90	2,400	0.3	na
Plant C	Hydrogen fluoride	30	50,000	3	na
	Chlorine	10	73,000	3	na
Plant D	Propylene oxide	120	3,300	7	28,000
	Sulfur dioxide	10	10,000	7	na

[a] na = not applicable for this example.

Table 6.4 Results from the Relative Ranking Example

Facility/Substance	SHI ($\times 10^3$)	MSHI ($\times 10^3$)	Rank
Plant A/chlorine	73	1390	1
Plant C/hydrogen fluoride	50	822	2
Plant C/chlorine	73	693	3
Plant D/sulfur dioxide	10	221	4
Plant A/ammonia	2.4	152	5
Plant B/arsine	1,000	50	6
Plant D/propylene oxide	3.3	18	7
Plant B/sulfur dioxide	10	16	8
Plant B/ammonia	2.4	11	9

EXHIBIT A

FIRE AND EXPLOSION INDEX

DOW

		LOCATION ANYWHERE USA		DATE 2/10/94
PLANT VCM PLANT – SITE #1	PROCESS UNIT 150 PSIG PVC	EVALUATED BY DD	REVIEWED BY AD	

MATERIALS AND PROCESS

MATERIALS IN PROCESS UNIT: VCM WATER DISPERSANTS INITIATOR

STATE OF OPERATION: START-UP SHUT-DOWN ✓ NORMAL OPERATION

BASIC MATERIAL(S) FOR MATERIAL FACTOR: VCM

	PENALTY	PENALTY USED	
MATERIAL FACTOR (SEE TABLE I OR APPENDICES A OR B) Note requirements when unit temperature over 140 F)			21
1. GENERAL PROCESS HAZARDS			
BASE FACTOR	1.00	1.00	
A EXOTHERMIC CHEMICAL REACTIONS (FACTOR .30 to 1.25)		0.5	
B ENDOTHERMIC PROCESSES (FACTOR .20 to .40)		—	
C MATERIAL HANDLING & TRANSFER (FACTOR .25 to 1.05)		0.5	
D ENCLOSED OR INDOOR PROCESS UNITS (FACTOR .25 to .90)		—	
E ACCESS	.35	0.2	
F DRAINAGE AND SPILL CONTROL (FACTOR .25 to .50) ______ Gals.		0.25	
GENERAL PROCESS HAZARDS FACTOR (F_1)		2.45	
2. SPECIAL PROCESS HAZARDS			
BASE FACTOR	1.00	1.00	
A TOXIC MATERIAL(S) (FACTOR 0.20 to 0.80) Nh = 2		0.4	
B SUB-ATMOSPHERIC PRESSURE (< 500 mm Hg)	.50	—	
C. OPERATION IN OR NEAR FLAMMABLE RANGE ☐ INERTED ☐ NOT INERTED			
1. TANK FARMS STORAGE FLAMMABLE LIQUIDS	.50		
2. PROCESS UPSET OR PURGE FAILURE	.30	0.3	
3 ALWAYS IN FLAMMABLE RANGE	.80		
D. DUST EXPLOSION (FACTOR .25 to 2.00) (SEE TABLE II)		—	
E. PRESSURE (SEE FIGURE 2) OPERATING PRESSURE 75 psig RELIEF SETTING 100 psig		0.32	
F. LOW TEMPERATURE (FACTOR .20 to .30)		—	
G. QUANTITY OF FLAMMABLE/UNSTABLE MATERIAL: QUANTITY 13000 lbs., H_c = 8000 BTU/lb			
1 LIQUIDS, GASES AND REACTIVE MATERIALS IN PROCESS (SEE FIG. 3)		0.16	
2 LIQUIDS OR GASES IN STORAGE (SEE FIG. 4)			
3 COMBUSTIBLE SOLIDS IN STORAGE, DUST IN PROCESS (SEE FIG. 5)			
H. CORROSION AND EROSION (FACTOR .10 to .75)		0.1	
I. LEAKAGE – JOINTS AND PACKING (FACTOR .10 to 1.50)		0.3	
J. USE OF FIRED HEATERS (SEE FIG. 6)		0.1	
K. HOT OIL HEAT EXCHANGE SYSTEM (FACTOR .15 to 1.15) (SEE TABLE III)		—	
L. ROTATING EQUIPMENT	.50	0.5	
SPECIAL PROCESS HAZARDS FACTOR (F_2)		3.18	
UNIT HAZARD FACTOR ($F_1 \times F_2 = F_3$)		7.79	
FIRE AND EXPLOSION INDEX ($F_3 \times MF = F\&EI$)			164

Figure 18.3 Fire and explosion index calculations for low-pressure PVC reactor site #1.

EXHIBIT B

LOSS CONTROL CREDIT FACTORS

1. Process Control (C_1)

.98 ✓	a) Emergency Power	.98		f) Inert Gas	.94 to .96	
	b) Cooling	.97 to .99		g) Operating Instructions/ Procedures	.91 to .99	
	c) Explosion Control	.84 to .98	✓	h) Reactive Chemical Review	.91 to .98	.91
.98 ✓	d) Emergency Shutdown	.96 to .99				
	e) Computer Control	.93 to .99				

C_1 Total 0.87 *

2. Material Isolation (C_2)

.96 ✓	a) Remote Control Valves	.96 to .98	✓	c) Drainage	.91 to .97	.95
	b) Dump/Blowdown	.96 to .98		d) Interlock	.98	

C_2 Total 0.91 *

3. Fire Protection (C_3)

	a) Leak Detection	.94 to .98		f) Sprinkler Systems	.74 to .97	
	b) Structural Steel	.95 to .98		g) Water Curtains	.97 to .98	
	c) Buried Tanks	.84 to .91		h) Foam	.92 to .97	
.97 ✓	d) Water Supply	.94 to .97	✓	i) Hand Extinguishers/Monitors	.95 to .98	.97
	e) Special Systems	.91		j) Cable Protection	.94 to .98	

C_3 Value 0.94 *

Credit Factor = $C_1 \times C_2 \times C_3$ = 0.74 Enter on Line D Below

UNIT ANALYSIS SUMMARY

A-1.	F & EI	164
A-2.	Radius of Exposure	137 ft.
A-3.	Value of Area of Exposure	$MM
B.	Damage Factor	
C.	Base MMPD (A-3 X B)	$MM
D.	Credit Factor	
E.	Actual MMPD (C X D)	$MM
F.	Days Outage (MPDO)	days.
G.	Business Interruption Loss (BI)	$MM

* Product of all factors used.

BACK OF FORM C-22380 R-4-87 (471-036)

Figure 18.4 Radius of exposure calculations for low-pressure PVC reactor site #1.

Preliminary Hazard Analysis-1

- Overview
  - Customarily performed during the process plant's conceptual design or siting phase or during early development to determine ant hazards that exist
  - Two principle advantage
    - It can identify potential hazards at a time when they can be corrected at minimal cost and disruption
    - It can help the development team identify and/or develop operating guidelines that can be used throughout the life of the process

Preliminary Hazard Analysis-2

- Analysis procedure
  - Preparing for the review
    - Gather available information about the subject plant
  - Performing the review
    - Identifies major hazards and accident situations that could result in an undesired consequence
    - Considering factors for performing the PHA
      - Hazardous plant equipment and materials
      - Safety-related interfaces between plant equipment items and materials
      - Environmental factors that may influence the plant equipment and materials
      - Operating, testing, maintenance and emergency procedures
      - Facility support
      - Safety-related equipment

Preliminary Hazard Analysis-3

- Hazard category
  - PHA team assigns each potential accident situation to one of the following hazard categories based on the significance of the causes and effects of the accident
    - Hazard Category Ⅰ - Negligible
    - Hazard Category Ⅱ - Marginal
    - Hazard Category Ⅲ - Critical
    - Hazard Category Ⅳ - Catastrophic

Table 6.5 Typical Format for a PHA Worksheet

Area:______________________________ Meeting Date:____________________

Drawing Number:__________________ Team Members:___________________

Hazard	Cause	Major Effects	Hazard Category	Corrective/Preventive Measures Suggested

Table 6.6 Sample Page from the PHA Table for the H_2S System Example

Area: H_2S Process **Meeting Date:** 03/17/93
Drawings: none **Analyst:** R. U. Safe

Hazard	Cause	Major Effects	Hazard Category[a]	Corrective/ Preventive Measures
Toxic release	1) H_2S storage cylinder rupture	Potential for fatalities from large release	IV	(a) Provide warning system (b) Minimize on-site storage (c) Develop procedure for cylinder inspection
	2) H_2S not completely reacted in process	Potential for fatalities from large release	III	(a) Design system to collect and destroy excess H_2S (b) Design control system to detect excess H_2S and shut down process (c) Develop procedures to ensure availability of excess destruction system prior to plant start-up

[a]Hazard Category: I-negligible, II-marginal, III-critical, IV-catastrophic.

- Develop a training program to be presented to all employees before start-up (and subsequently to all new employees) on H_2S effects and emergency procedures.

A sample page from the PHA table for the H_2S system example is shown in Table 6.6.

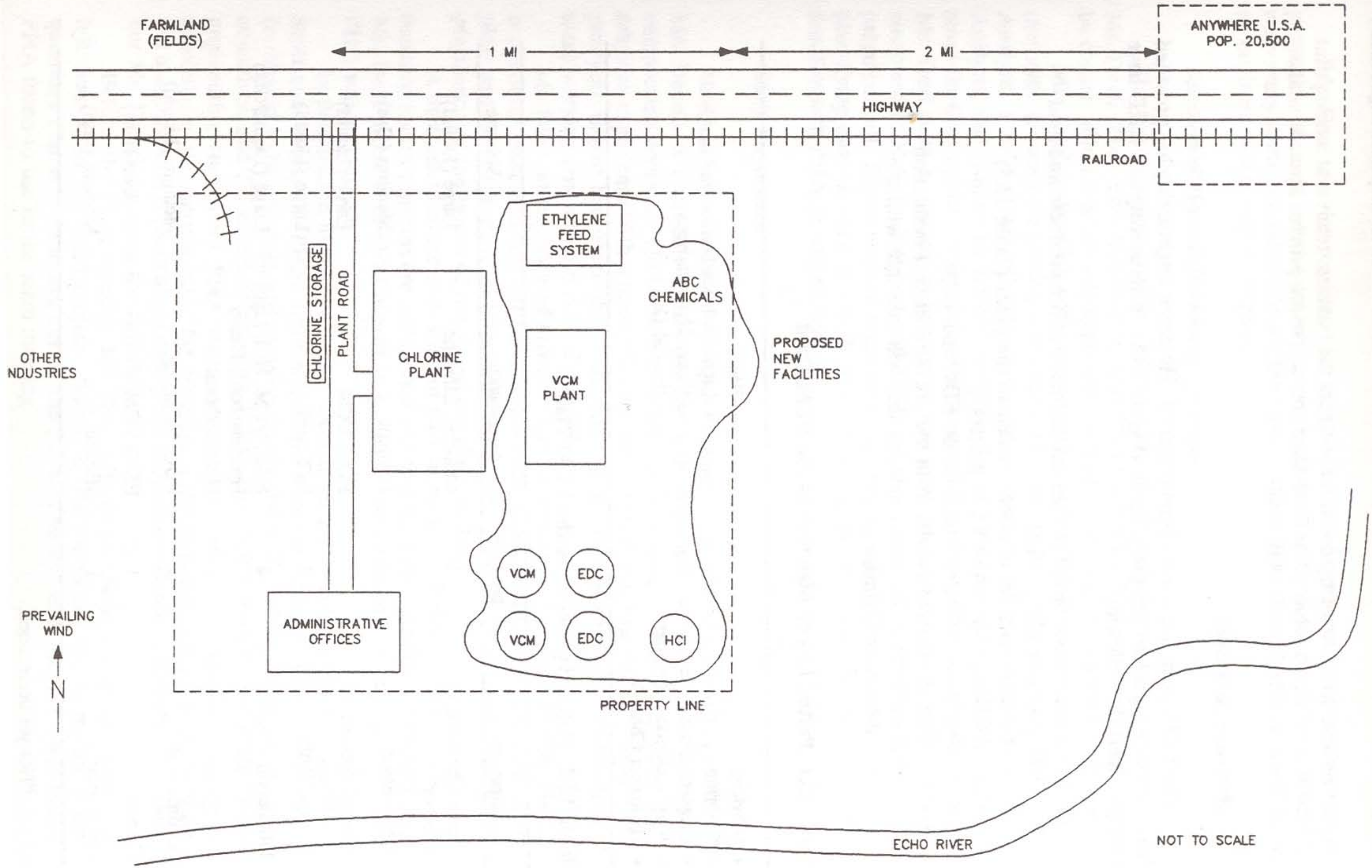


Figure 13.1 VCM plant layout.

Table 13.4 Sample PHA Results for the VCM Plant Conceptual Design

Area: VCM Plant — Conceptual Design
Drawing: Figure 13.1
Meeting Date: 2/7/86
Team: Ms. Deal (Leader — ABC Process Hazards), Mr. Dennis (ABC Process Hazards), and Mr. Scott (ABC Anywhere Plant)

Hazard	Cause	Major Effects	Hazard Category[a]	Corrective Action/ Preventive Measure
Toxic Release	1. Chlorine line gasket/packing leak	1. Small chlorine release on-site	I	1. None
	2. Chlorine line rupture (i.e., vehicle accident, blocked-in line)	2. Large chlorine release, major on-site impact. Potential off-site impacts	IV	2a. Verify chlorine line is evacuated whenever the VCM plant is down for extended time 2b. Provide valves and interlocks to positively isolate the line in the event of a rupture 2c. Train VCM plant personnel to respond to chlorine releases 2d. Equip VCM plant personnel with PPE for chlorine 2e. Do not bury chlorine pipeline

Toxic Release (cont'd)	3. Direct chlorination reactor exotherm	3. Large chlorine/EDC/ ethylene release. Depending on reactor size/operating conditions, potential off-site impacts	IV	3a. Consider moving VCM plant west of Plant Road 3b. Perform dispersion studies to assess off-site impact of chlorine/EDC release due to exotherm 3c. Verify reactor pressure relief system can handle this release
	4. Direct chlorination reactor rupture	4. Large chlorine/EDC/ ethylene release. Depending on reactor size/operating conditions, potential off-site impacts	IV	4. Minimize inventory of chlorine/EDC in reactor
	5. Direct chlorination reactor relief valve lift	5. Potential large EDC/chlorine/ethylene release	III	5. Verify the reactor pressure relief system incinerator and scrubber are sized to handle this release
	6. EDC storage sphere rupture	6. Large release of EDC, potential off-site impact. Potential river contamination	IV	6. Consider moving EDC sphere away from river
	7. Flood damages EDC sphere	7. Large release of EDC, potential off-site impact. Potential river contamination	IV	7a. Consider moving EDC sphere away from river 7b. Verify EDC (and other tanks) support structure designed to withstand flood conditions

[a]Hazard Category: I-negligible, II-marginal, III-critical, IV-catastrophic.

What-If Analysis-1

- Purpose
  - Identify hazards, hazardous situations or specific accident events that could produce an undesirable consequence
- Types of results
  - A list of questions and answers about the process
  - A tabular listing of hazardous situations, their consequence, safeguards and possible options for risk reduction
- Resource requirements
  - Experiences manager or engineer with knowledge of process

What-If Analysis-2

- Overview
  - Creative, brainstorming examination of a process or operation
  - Review the subject process or activity in meetings that revolve around potential safety issues identified by the analysts
  - Can be used to examine virtually any aspect of facility design and operation(e.g. building, power system, raw materials, product, storage, operating procedure, plant security, management practice and so forth)
  - Address potential accident situation implied by the questions and issues posed by the team
    - "What if the raw material is the wrong concentration?"
    - "If the concentration of acid were doubled, the reaction could not be controlled and a rapid exothermic would result

Table 6.7 Typical Format for a What-If Analysis Worksheet

Area: ______________________ Meeting Date: ______________

Drawing Number: ____________ Team Members: ______________

What-If	Consequence/ Hazard	Safeguards[a]	Recommendation

[a]This column is a recent improvement in documentation format; some analysts use it while others do not.

Analysis procedure

- Preparing for the review
  - Information needed for a What-If analysis includes process description, drawing and operating procedures
  - Prepare some preliminary What-If questions to “seed” the analysis meeting
- Performing the review
  - Two way that the meeting can be conducted
    - One way preferred by some is to first list on a chart pad or marking board all of the safety issues and question, then begin considering them
    - Another way is to consider each question and issue one at a time, with the team determining the significance of each situation

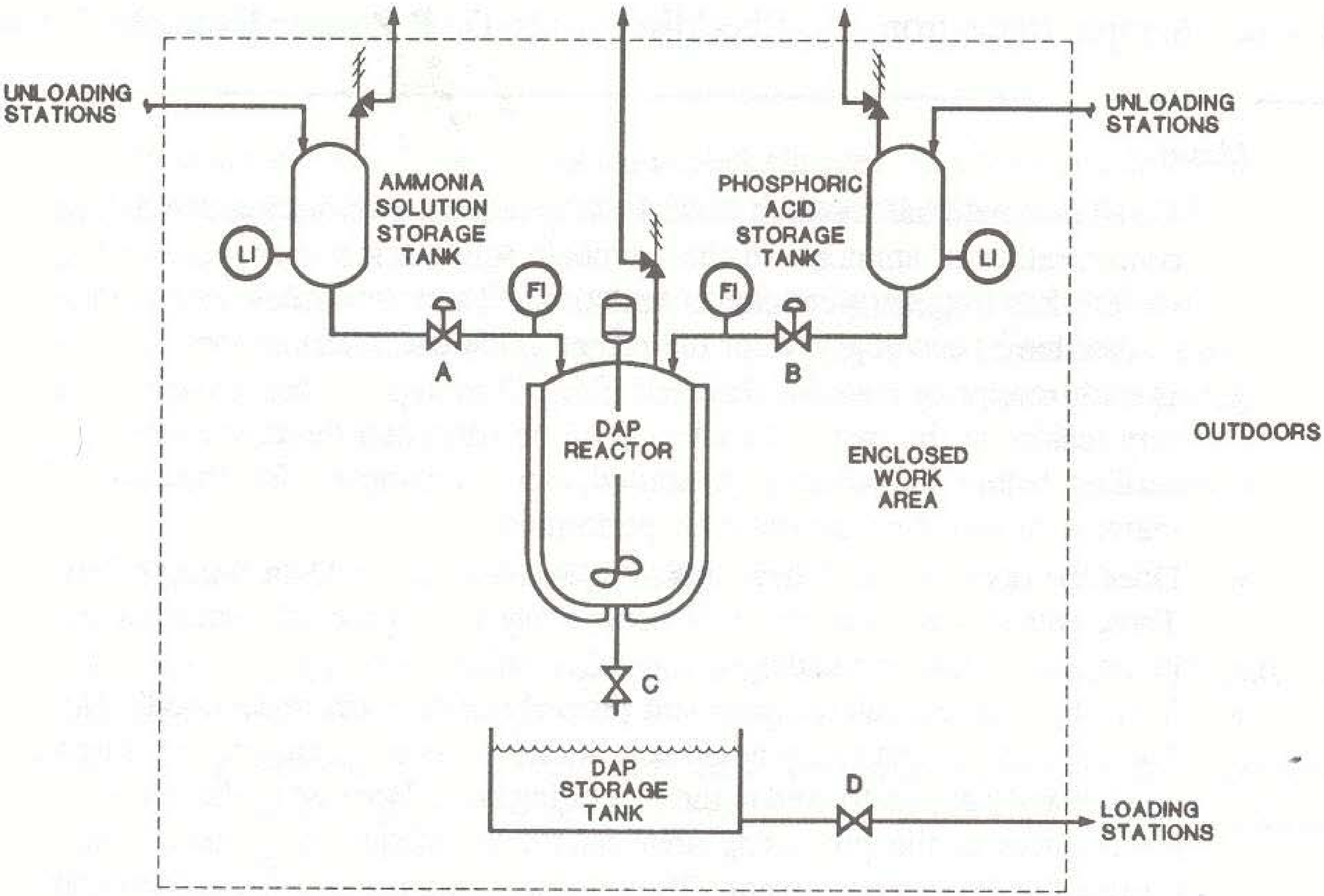


Figure 6.1 DAP process schematic for the checklist analysis example.

Table 6.9 Sample Page from the What-If Analysis Table for the DAP Process Example

Process: DAP Reactor
Topic Investigated: Toxic Releases

Analysts: Mr. Safety, Ms. Opera, Mr. Design
Date: 05/13/95

What-If	Consequence/Hazard	Safeguards	Recommendation
the wrong feed material is delivered instead of phosphoric acid?	Potentially hazardous phosphoric acid or ammonia reactions with contaminants, or production of off-specification product	Reliable vendor Plant material handling procedures	Ensure adequate material handling and receiving procedures and labeling exist
the phosphoric acid concentration is too low?	Unreacted ammonia carryover to the DAP storage tank and release to the work area	Reliable vendor Ammonia detector and alarm	Verify phosphoric acid concentration before filling storage tank
the phosphoric acid is contaminated?	Potentially hazardous phosphoric acid or ammonia reactions with contaminants, or production of off-specification product	Reliable vendor Plant material handling procedures	Ensure adequate material handling and receiving procedures and labeling exist
valve B is closed or plugged?	Unreacted ammonia carryover to the DAP storage tank and release to the work area	Periodic maintenance Ammonia detector and alarm Flow indicator in phosphoric acid line	Alarm/shutoff of ammonia (valve A) on low flow through valve B
too high a proportion of ammonia is supplied to the reactor?	Unreacted ammonia carryover to the DAP storage tank and release to the work area	Flow indicator in ammonia solution line Ammonia detector and alarm	Alarm/shutoff of ammonia (valve A) on high flow through valve A

HAZOP (Hazard and Operability Analysis)

- Purpose
  - Review a process or operation in a systematic fashion to determine whether process deviations can be lead to undesirable consequence
- Types of results
  - Identification of hazards and operating problem and recommendation
- Resource requirements
  - P&ID, equivalent drawing other detailed process information

Overview

- Identification and Evaluation of Safety Hazards and Operability Problems
- Guide-Word" Approach
  - Apply Guide Word to Process Parameters to Create Deviations
- Identification of Hazards, Operating Problems and Recommendations
  - Causes, Effects, and Safeguards

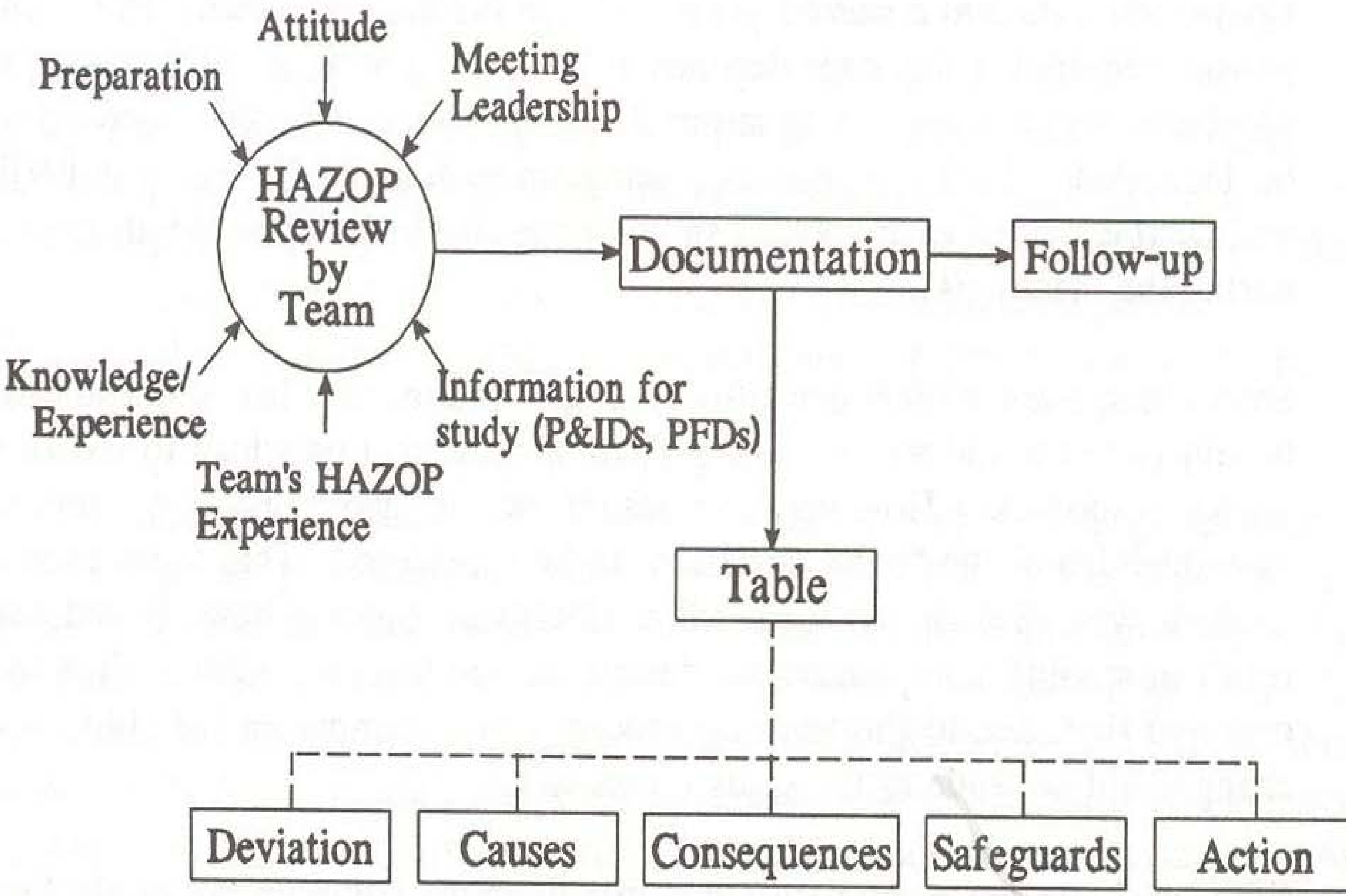


Figure 6.4 Overview of the HAZOP analysis technique.

- "Guide-Word" Approach
  - Apply Guide Words to Process Parameters to Create Deviations
  - Guide Words + Parameter = Deviation
    - No + Flow = No Flow
    - More + Pressure = High Pressure
    - As Well As + One Phase = Two Phase
    - Other Than + Operation = Maintenance

Table 6.14 Original HAZOP Analysis Guide Words and Meanings

Guide Words	Meaning
No	Negation of the Design Intent
Less	Quantitative Decrease
More	Quantitative Increase
Part Of	Qualitative Decrease
As Well As	Qualitative Increase
Reverse	Logical Opposite of the Intent
Other Than	Complete Substitution

Table 6.15 Common HAZOP Analysis Process Parameters

Flow	Time	Frequency	Mixing
Pressure	Composition	Viscosity	Addition
Temperature	pH	Voltage	Separation
Level	Speed	Information	Reaction

Analysis procedure-1

- Preparing for the review
  - Define the purpose, objective and scope of the study
  - Select the team
    - Ensure the availability of an adequately sized and skilled HAZOP team
    - Consist of a leader, a scribe and two other individuals who have an understanding of the design and operation of the subject process
  - Obtain the necessary data
    - Consist of various drawings in the form of P&IDs, flowsheets and plant layout schematics
  - Arrange the necessary meetings

Analysis procedure-2

- Performing the review
  - Applies all of the relevant guide words to each process section or step, and they record following result
    - The deviation with its causes, consequences, safeguards and action
    - The need for more complete information to evaluate the deviation
  - To ensure effective meeting, the team leaders must keep several factors in mind
    - Do not compete with the members
    - Take care to listen to all of the members
    - During meeting, do not permit anyone to be put on the defensive
  - To minimize inappropriate problem solving, the leader can
    - Complete the study of one process deviation and associated suggested actions before proceeding to the next deviation
    - Ensure all hazards associated with a process section before considering suggested actions for improving safety

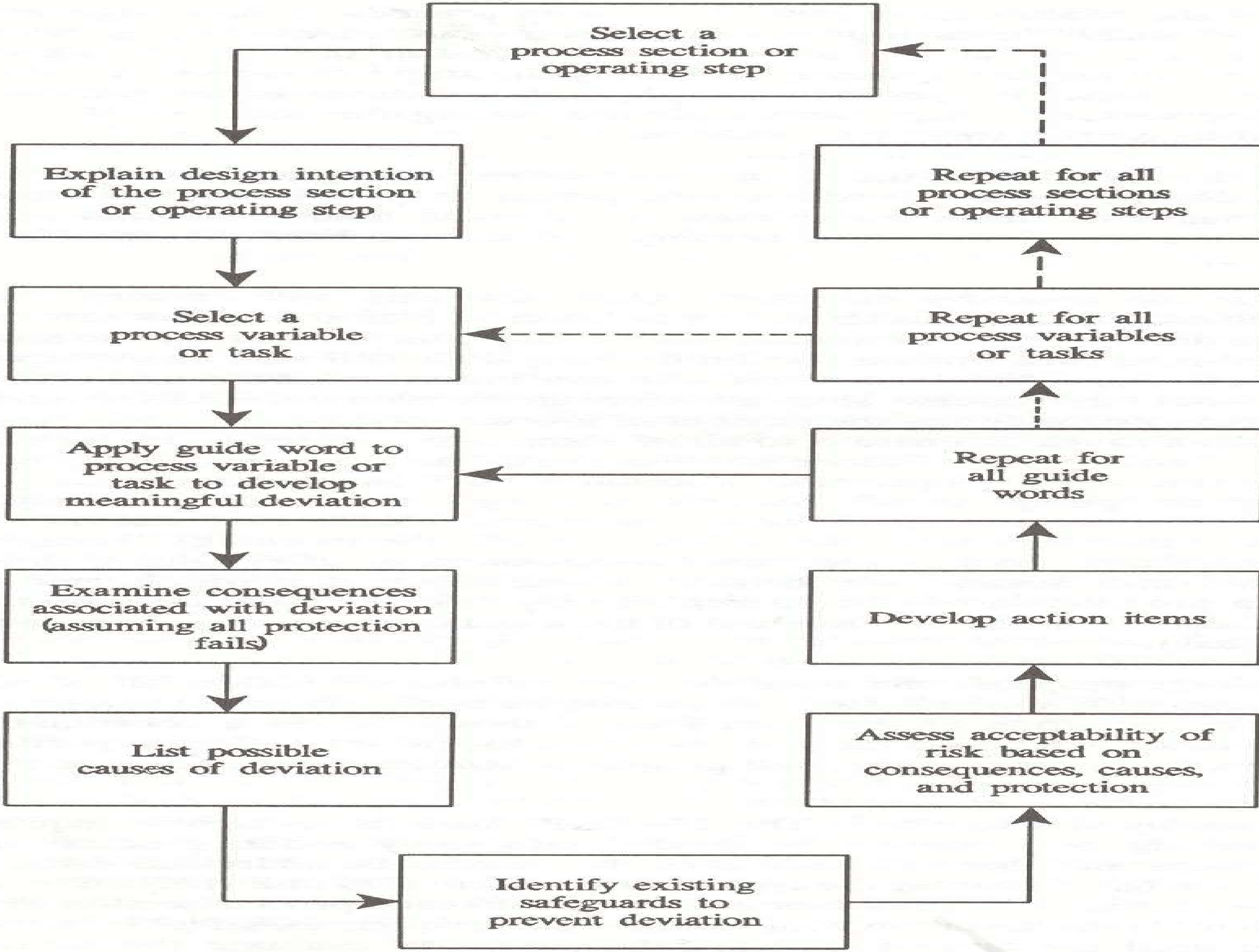


Figure 6.5 HAZOP analysis method flow diagram.

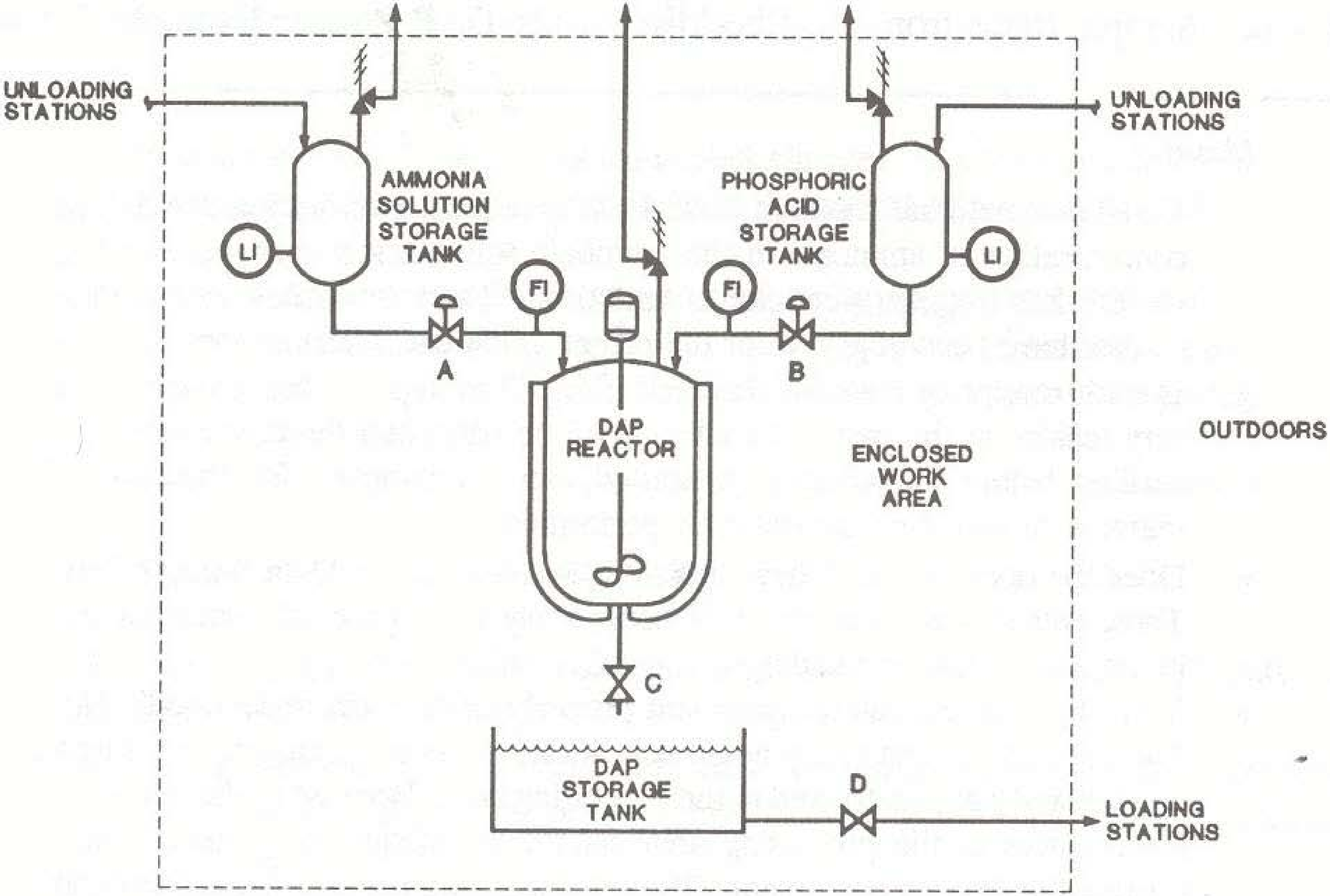


Figure 6.1 DAP process schematic for the checklist analysis example.

Table 6.18 (cont'd)

Team: HAZOP Team #3
Meeting Date: 6/27/81

Drawing Number: 70-0BP-57100
Revision Number: 3

Item No.	Deviation	Causes	Consequences	Safeguards	Actions
2.9	Leak	Corrosion Erosion External impacts Gasket and packing failures Maintenance errors	Small continuous leak of ammonia to the enclosed work area	Periodic maintenance of line Periodic inspection tours by operator in the DAP process area	Ensure adequate ventilation exists for enclosed work area

Team: HAZOP Team #3
Meeting Date: 6/27/81

Drawing Number: 70-0BP-57100
Revision Number: 3

Item No.	Deviation	Causes	Consequences	Safeguards	Actions
3.0 Vessel - Phosphoric acid solution storage tank. Safely contain acid feed at ambient temperature and pressure (dwg: Figure 6.6)					
3.7	Low concentration of phosphoric acid	Low phosphoric acid concentration supplied by the vendor Error in charging phosphoric acid to the supply tank	Unreacted ammonia in the reactor carried over to the DAP storage tank and released to the enclosed work area	Acid unloading and transfer procedure Ammonia detector and alarm	Ensure existence of adequate material handling and receiving procedures and labeling Consider verifying the phosphoric acid concentration in the storage tank before operation Ensure adequate ventilation exists for enclosed work area and/or consider using an enclosed DAP storage tank

Table 6.18 Sample Pages from the HAZOP Analysis Table for the DAP Process Example

Team: HAZOP Team #3 **Drawing Number:** 70-0BP-57100
Meeting Date: 6/27/81 **Revision Number:** 3

Item No.	Deviation	Causes	Consequences	Safeguards	Actions
1.0 Vessel - Ammonia solution storage tank. Safely contain ammonia feed at ambient temperature and pressure (dwg: Figure 6.6)					
1.1	High level	Unloading ammonia from the unloading station without adequate space in the ammonia storage tank	Potential release of ammonia to the atmosphere	Level indicator on the storage tank	Review ammonia unloading procedures to ensure adequate space in the storage tank before unloading
				Ammonia storage tank relief valve to the atmosphere	
		Ammonia storage tank level indicator fails low			Consider sending the relief valve discharge to a scrubber
					Consider adding an independent high level alarm for the ammonia storage tank

Team: HAZOP Team #3
Meeting Date: 6/27/81

Drawing Number: 70-0BP-57100
Revision Number: 3

Item No.	Deviation	Causes	Consequences	Safeguards	Actions
	2.0 Line - Ammonia feed line to the DAP reactor. Deliver ammonia to reactor at y gpm and z psig (dwg: Figure 6.6)				
2.1	High flow	Ammonia feed line control valve A fails open Flow indicator fails low Operator sets ammonia flow rate too high	Unreacted ammonia carryover to the DAP storage tank and release to the work area	Periodic maintenance of valve A Ammonia detector and alarm	Consider adding an alarm/shutdown of the system for high ammonia flow to the reactor Ensure periodic maintenance and inspection for valve A is adequate Ensure adequate ventilation exists for enclosed work area and/or consider using an enclosed DAP storage tank

FMEA(Failure Mode and Effect Analysis)

- Purpose
  - Identify single equipment and system failure mode and each failure mode’s potential effect on the system or plant
- Types of results
  - Generates a qualitative, systematic reference list of equipment, failure modes and effects
- Resource requirements
  - A system or plant equipment list or P&ID, knowledge of equipment function and failure modes, knowledge of system or plant function and response to equipment failures

Overview

- Evaluates the ways equipment can fail(or be improperly operated) and the effects these failure can have on a process
- Describe potential consequences and relate them only to equipment failure
- Identification of Single Equipment and System Failure Modes and Potential Effects
- Qualitative and Systematic Reference List of Equipment, Failure Modes, and Effects

Table 6.19 Typical Format for an FMEA Worksheet

DATE:________________ PAGE: ________ of ________
PLANT:________________ SYSTEM:________________
REFERENCE:________________ ANALYST(S):________________

Item	Identification	Description	Failure Modes	Effects	Safeguards	Actions

Analysis procedure

- Defining the study problem
  - Identifies the specific items to be included in the FMEA and the conditions under which they are analyzed
  - Defining the problem involved
    - Establishing an appropriate level of resolution for the study
      - Determines the extent of detail included in the FMEA
    - Defining the boundary conditions for the analysis
      - Identifying the physical system boundaries including the interfaces with other processes and utility system
      - Establishing the system analytical boundaries including the failure modes, operating consequences, cause or existing safeguard and the initial operating condition or position of equipment
      - Collecting up-to-date reference information that identifies the equipment and its functional relationship to the plant/system

- Performing the review
  - Performed in a deliberate, systematic manner to reduce the possibility of omission and to enhance the completeness of the FMEA
  - Following items should be standard entries in an FMEA table
    - Equipment identification
      - Equipment number or identifier from system drawing such as P&ID are usually available
    - Equipment description
      - Include the equipment type, operating configuration and other service characteristics that may influence the failure modes and effects
    - Should list all of the failure modes for each component that are consistent with the equipment description
    - Considering all conceivable malfunctions that alter the equipment's normal operating state

- Effects
  - Describe both the immediate effects of a failure at the failure location and the anticipated effects of the failure on other equipment for each identified failure mode
- Safeguard
  - Describe any safety features or procedures associated with the system that can reduce the likelihood of a specific failure occurring or that can mitigate the consequence of the failure for each identified failure mode
- Action
  - Should list any suggested corrective actions for reducing the likelihood of effects associated with the failure mode

Table 6.20 Examples of Equipment Failure Modes Used in an FMEA

Equipment Description	Example Failure Modes
Pump, normally operating	• Fails on (fails to stop when required) • Transfers off (stops when required to run) • Seal leak/rupture • Pump casing leak/rupture
Heat exchanger, high pressure on tube side	• Leak/rupture, tube side to shell side • Leak/rupture, shell side to external environment • Tube side, plugged • Shell side, plugged • Fouling

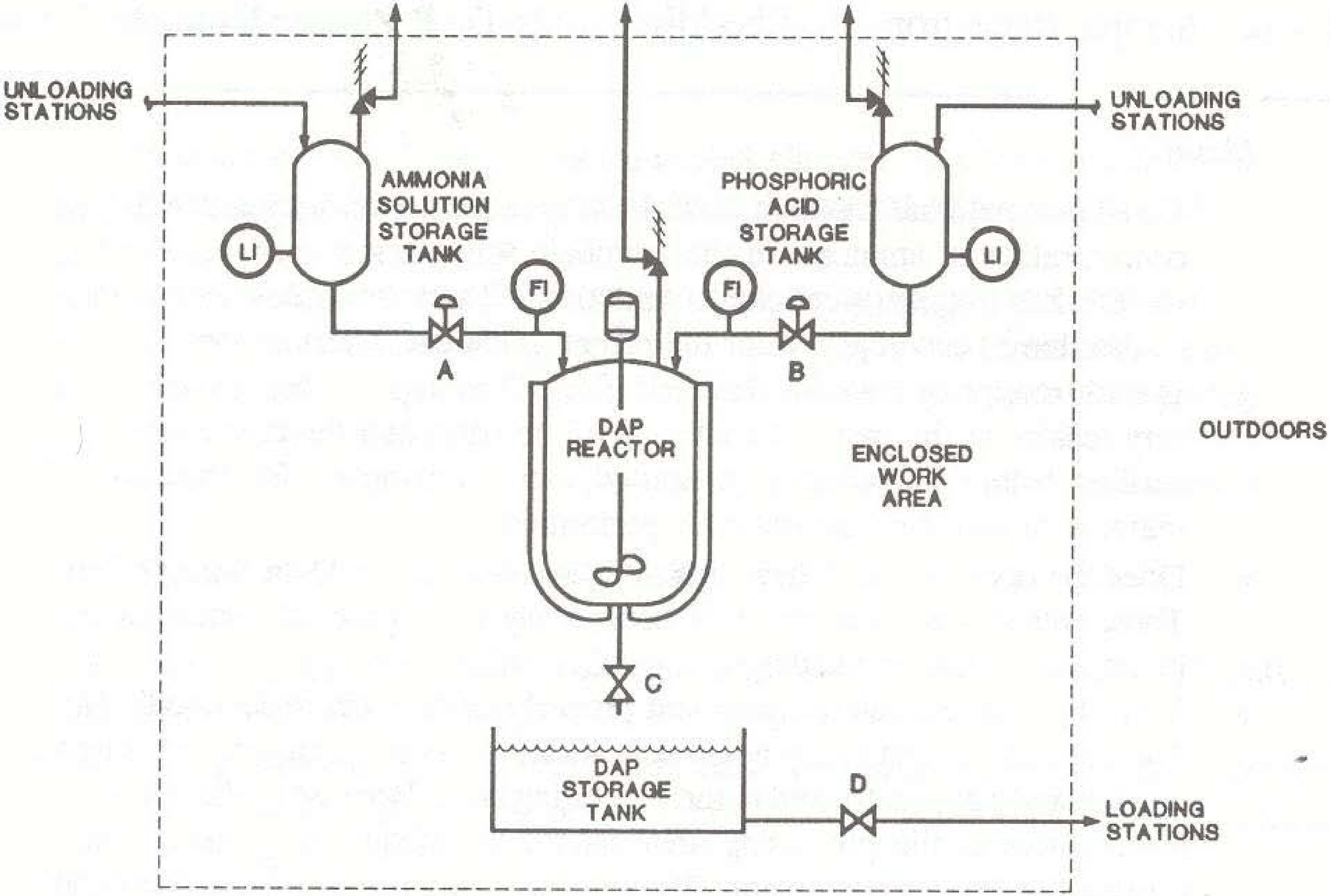


Figure 6.1 DAP process schematic for the checklist analysis example.

Table 6.21 Sample Pages from the FMEA Table for the DAP Process Example

DATE: 1/21/91		**PAGE:** 5 of 20	
PLANT: DAP Plant		**REFERENCE:** Figure 6.7	
SYSTEM: Reaction System		**ANALYST(s):** Mr. Ray Johnson	

Item	Identification	Description	Failure Modes	Effects	Safeguards	Actions
4.1	Valve B on the phosphoric acid solution line	Motor-operated, normally open, phosphoric acid service	Fails open	Excess flow of phosphoric acid to the reactor High pressure and high temperature in the reactor if the ammonia feed rate is also high May cause a high level in the reactor or the DAP storage tank Off-specification production (i.e., high acid concentration)	Flow indicator in the phosphoric acid line Reactor relief valve vented to the atmosphere Operator observation of the DAP storage tank	Consider alarm/shutdown of the system for high phosphoric acid flow Consider alarm/shutdown of the system for high pressure and high temperature in the reactor Consider alarm/shutdown of the system for high level in the DAP storage tank

Table 6.21 (cont'd)

	DATE: 1/21/91 PLANT: DAP Plant SYSTEM: Reaction System			PAGE: 6 of 20 REFERENCE: Figure 6.7 ANALYST(s): Mr. Ray Johnson		
Item	**Identification**	**Description**	**Failure Modes**	**Effects**	**Safeguards**	**Actions**
4.2	Valve B on the phosphoric acid solution line	Motor-operated, normally open, phosphoric acid service	Fails closed	No flow of phosphoric acid to the reactor Ammonia carry-over to the DAP storage tank and release to the enclosed work area	Flow indicator in the phosphoric acid line Ammonia detector and alarm	Consider alarm/shutdown of the system for low phosphoric acid flow Consider using a closed tank for DAP storage and/or ensure adequate ventilation of the enclosed work area
4.3	Valve B on the phosphoric acid solution line	Motor-operated, normally open, phosphoric acid service	Leak (external)	Small release of phosphoric acid to the enclosed work area	Periodic maintenance Valve designed for acid service	Verify periodic maintenance and inspection is adequate for this valve
4.4	Valve B on the phosphoric acid solution line	Motor-operated, normally open, phosphoric acid service	Rupture	Large release of phosphoric acid to the enclosed work area	Periodic maintenance Valve designed for acid service	Verify periodic maintenance and inspection is adequate for this valve

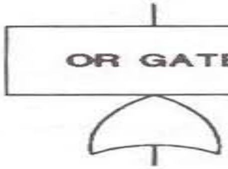
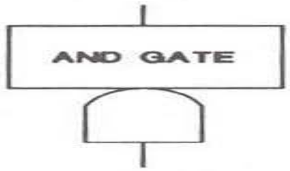
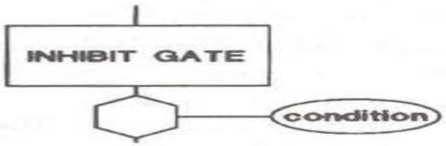
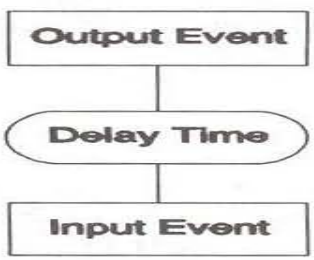
Fault Tree Analysis

- Purpose
  - Identify of equipment failure and human errors that can result in an accident
- Type of Results
  - System failure logic model that use Boolean logic gate (AND, OR) to describe how equipment failure and human errors can combine to cause a main system failure
- Resource requirements
  - Detailed understanding of how the plant or system function, detailed process drawing and procedure, knowledge of component failure modes and their effects

Overview

- Deductive technique that uses Boolean logic symbols(I.e. AND gate, OR gate) to break down the cause of a top event basic equipment failure and human errors
- Top event are specific hazardous situation that are typically identified through the use of a more broad-brush HE technique(e.g. What-If, HAZOP)
- Use a minimal cut set(MCS) that is a smallest combination of component failure which, if they all occur or exist simultaneously, will cause the top event to occur

Table 6.22 Logic and Event Symbols Used in Fault Trees

	**OR Gate**	The output event occurs if any of the input events occur
	**AND Gate**	The output event occurs only when all the input events exist simultaneously
	**INHIBIT Gate**	The output event occurs when the input event occurs and the inhibit condition is satisfied
	**DELAY Gate**	The output event occurs when the input event has occurred and the specified delay time has expired
	**INTERMEDIATE Event**	A fault event that results from the interactions of other fault events that are developed through logic gates such as those defined above
	**BASIC Event**	A component failure that requires no further development. A basic event is the lowest level of resolution in a fault tree

Analysis procedure-1

- Defining the problem
  - To define the problem you must select
    - The top event
    - Boundary conditions for the analysis
      - Level of resolution
      - Physical system boundaries
      - Initial condition
      - Other assumption
    - Top event
      - One of the most important aspects of the first step
      - The accident(or undesired event) that is the subject of the Fault Tree analysis
    - Physical system boundaries
      - Equipment and equipment's interface with other processes

Analysis procedure-2

- Constructing the Fault Tree
  - Begins at the top event and proceeds, level by level until all fault events have been traced to their basic contributing cause
  - Uses deductive cause and effect reasoning to determine the immediate, necessary and sufficient causes that result in the top event
- Analyzing the Fault Tree method
  - Solution method has four steps
    - Uniquely identify all gates and basic event
    - Resolve all gates into sets of basic event
    - Remove duplicate events within sets
    - Delete all supersets

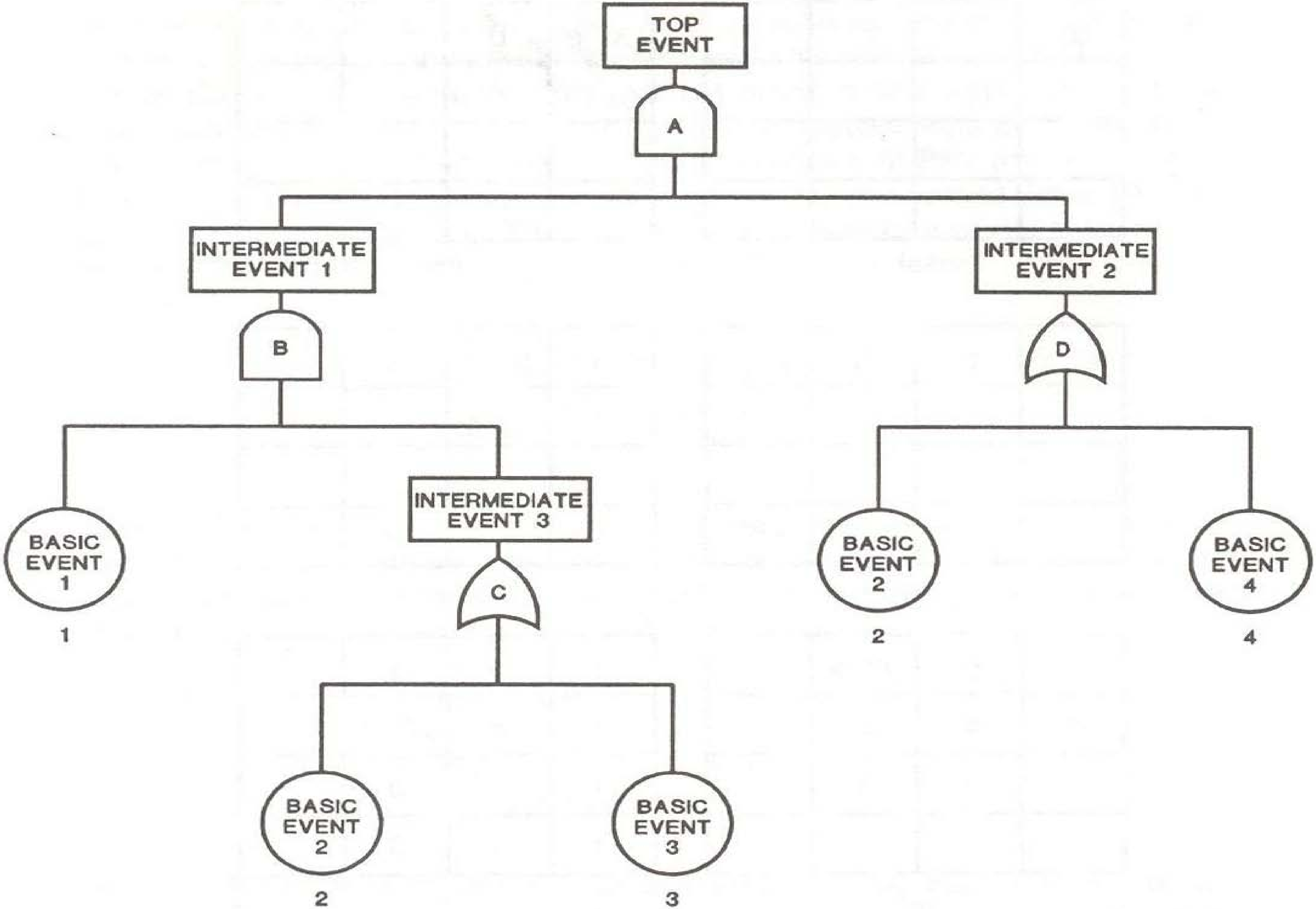


Figure 6.9 Sample fault tree.

Example

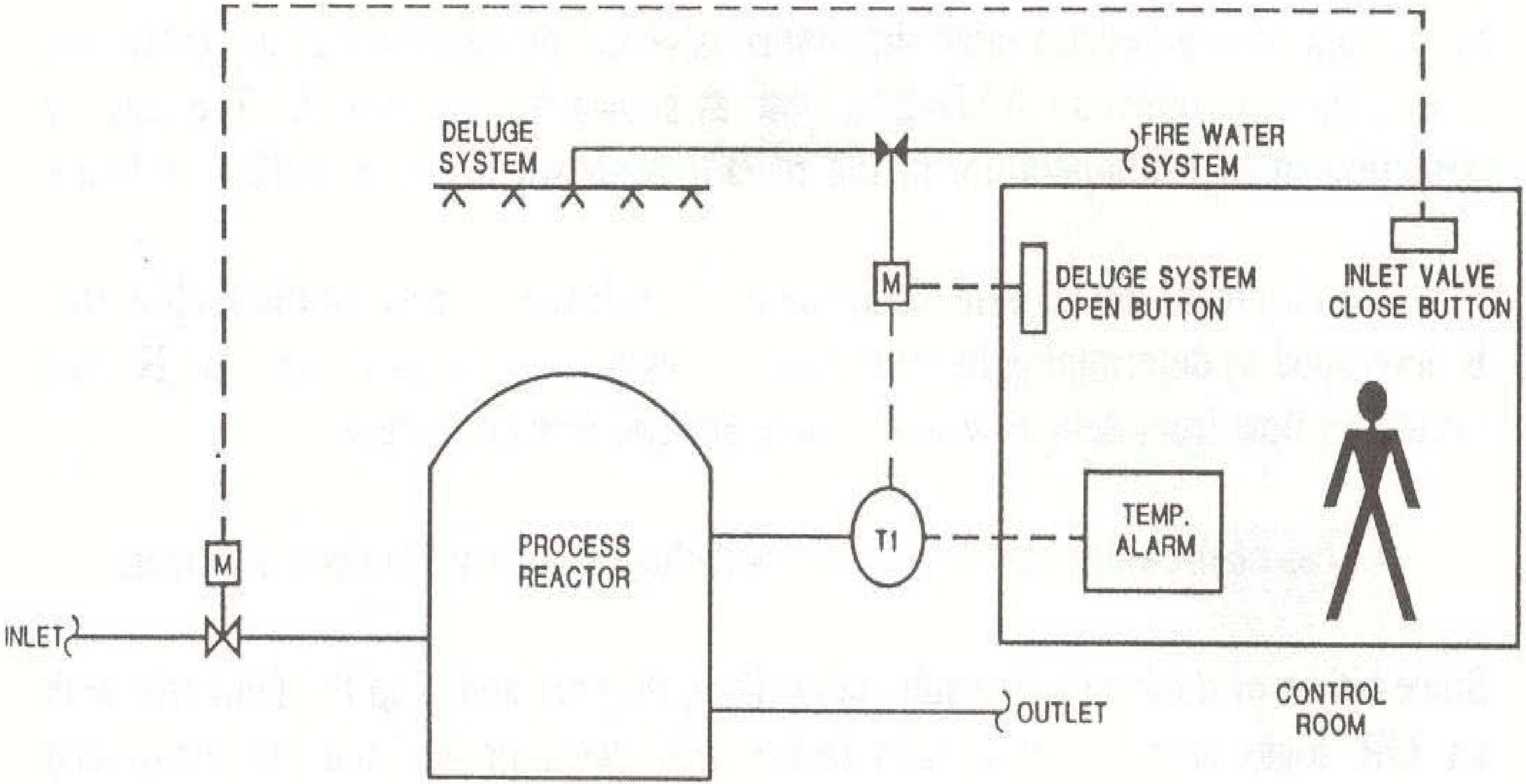


Figure 6.11 Emergency cooling system schematic for the fault tree analysis example.

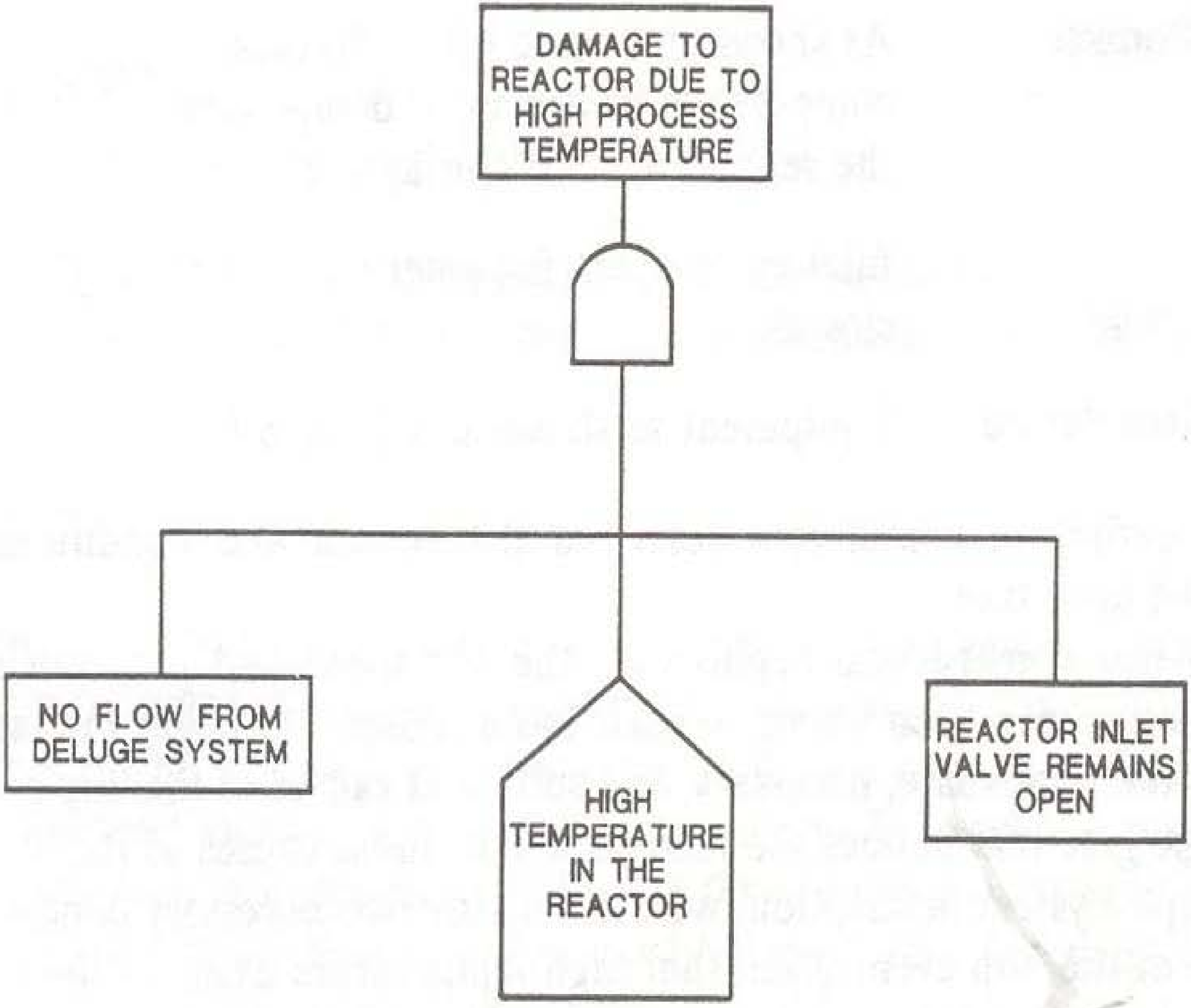


Figure 6.12 Development of the top event for the emergency cooling system example.

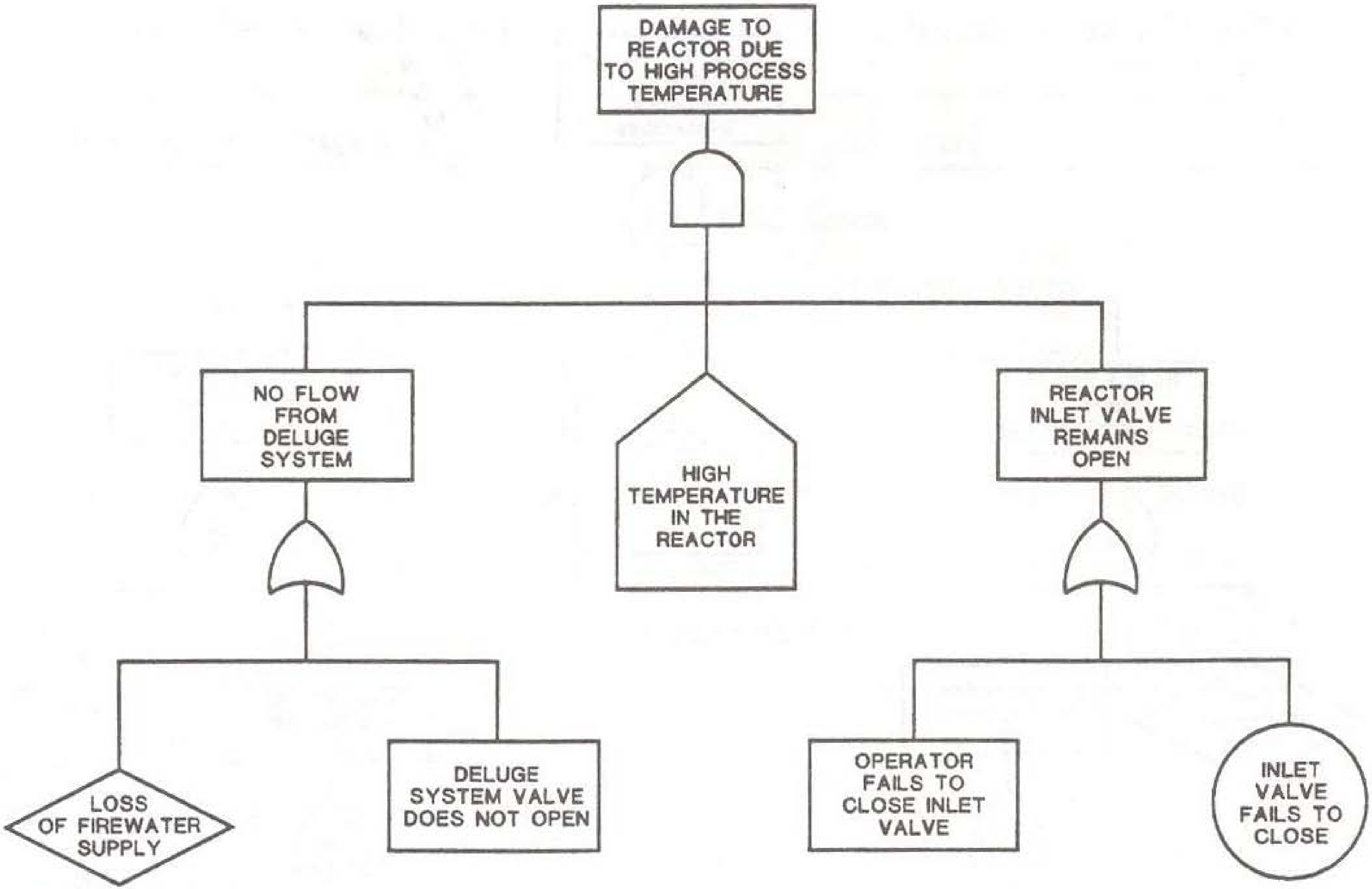


Figure 6.13 Development of the tirst two in...mediate events for the emergency cooling example.

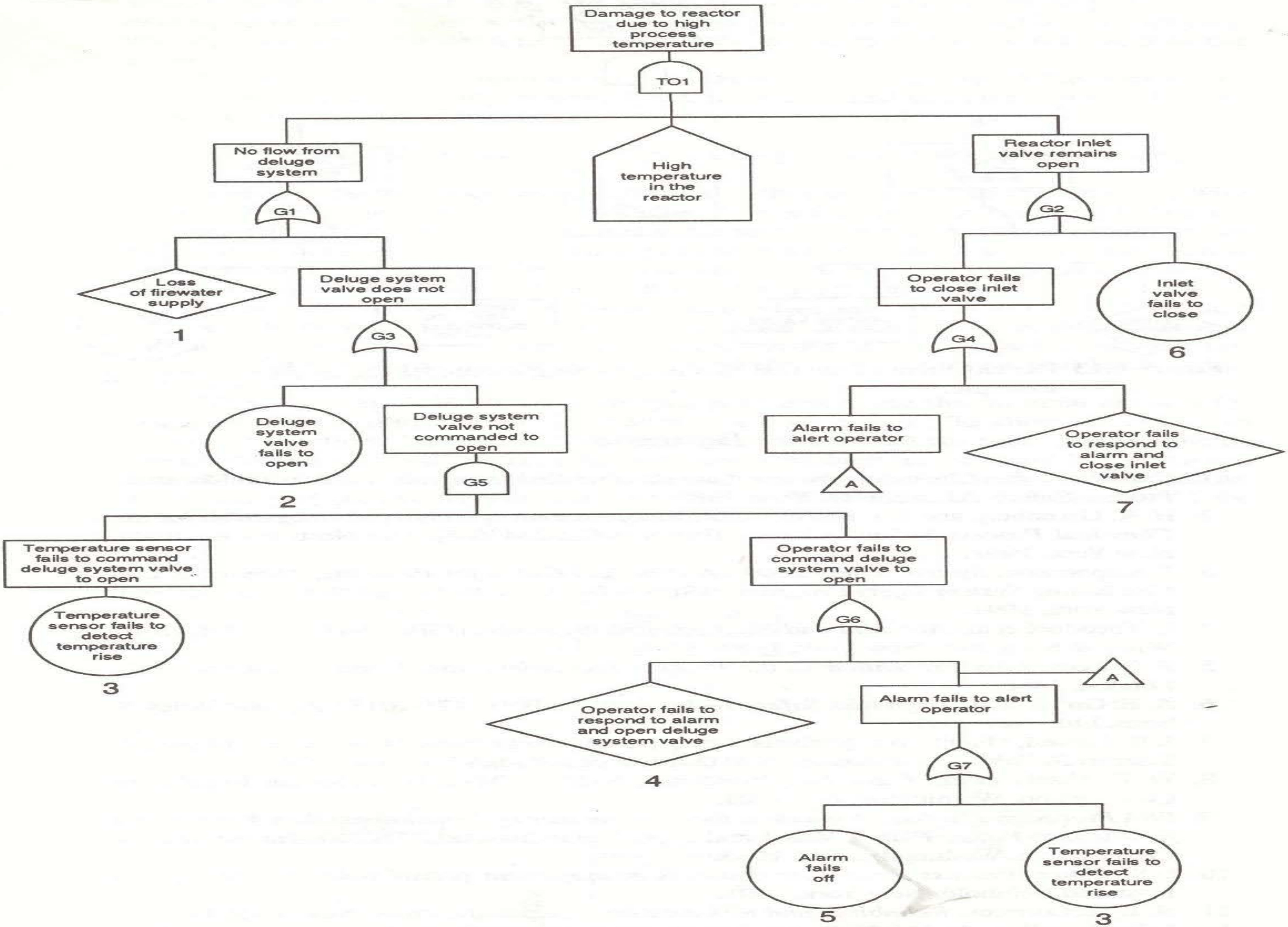


Figure 6.14 Completed fault tree for the emergency cooling system example.

Table 6.24 Minimal Cut Sets for the Emergency Cooling System Example Fault Tree

MCS No.	Basic Event	Type of Events
1	3	Active equipment failure
2	1, 7	Active equipment failure, human error
3	2, 7	Active equipment failure, human error
4	1, 5	Active equipment failure, active equipment failure
5	1, 6	Active equipment failure, active equipment failure
6	2, 5	Active equipment failure, active equipment failure
7	2, 6	Active equipment failure, active equipment failure

Event Tree Analysis

- Purpose
  - Identify the various accident that can occur in a complex process
- Types of results
  - Event tree models and the safety system successes or failure that lead to each defined outcome
- Resource requirements
  - Knowledge of potential initiating events and knowledge of safety system function or emergency procedures that potential mitigate the effect of each initiating event

Overview

- Evaluate the potential for an accident that is the result of a general type of equipment failure or process upset
- Inductive reasoning process where the analyst begins with an initiating event and develops the possible sequences of events that lead to potential accident
- Emphasize the initial cause of potential accident and works from the initiating event to the event's final effects

- Analysis procedure
  - Identifying the initial event of interest
  - Identifying the safety functions designed to mitigate the initiating event
  - Constructing the event tree
  - Describing the resulting accident sequence outcomes
  - Determining the accident sequence minimal cut set
  - Documenting the result

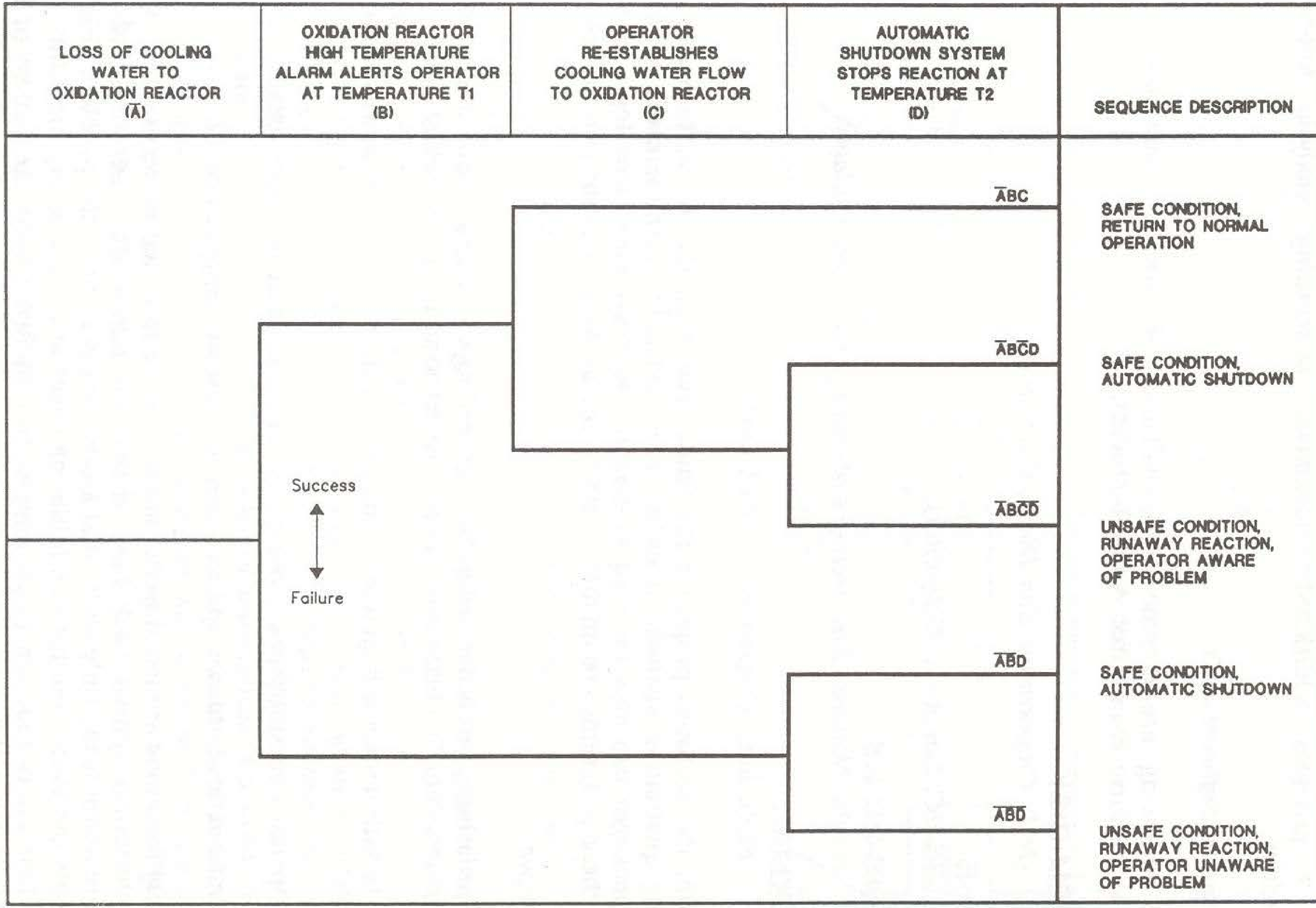


Figure 6.20 Event tree for the example initiating event "loss of cooling water to the oxidation reactor."

Cause-Consequence Analysis

- Purpose
  - Identify the basic cause and consequence of potential accident
- Types of results
  - Generating diagrams portraying accident sequence and qualitative description of potential accident outcomes
- Resource requirements
  - Knowledge of component failure or process
  - Knowledge of safety systems or emergency procedures
  - Knowledge of the potential impacts of all these failure

Overview

- Combines the inductive reasoning features of Event Tree Analysis with the deductive reasoning feature of Fault Tree Analysis
- The result is a technique that relates specific accident consequences to their many possible causes
- Advantage of this technique
  - Uses a graphical method that can proceed in both direction; forward, toward the consequence of the event and backward, toward the basic causes of an event

Analysis procedure

- Selecting an event or type of accident situation to be evaluated
  - Top event(as in a Fault Tree Analysis)
  - Initiating event(as in an Event Tree Analysis)
- Identifying the safety functions
- Developing the accident paths resulting from the events
- Developing the initiating event and the safety function failure event to determine their basic cause
- Evaluating the accident sequence minimal cut sets
- Documenting the result

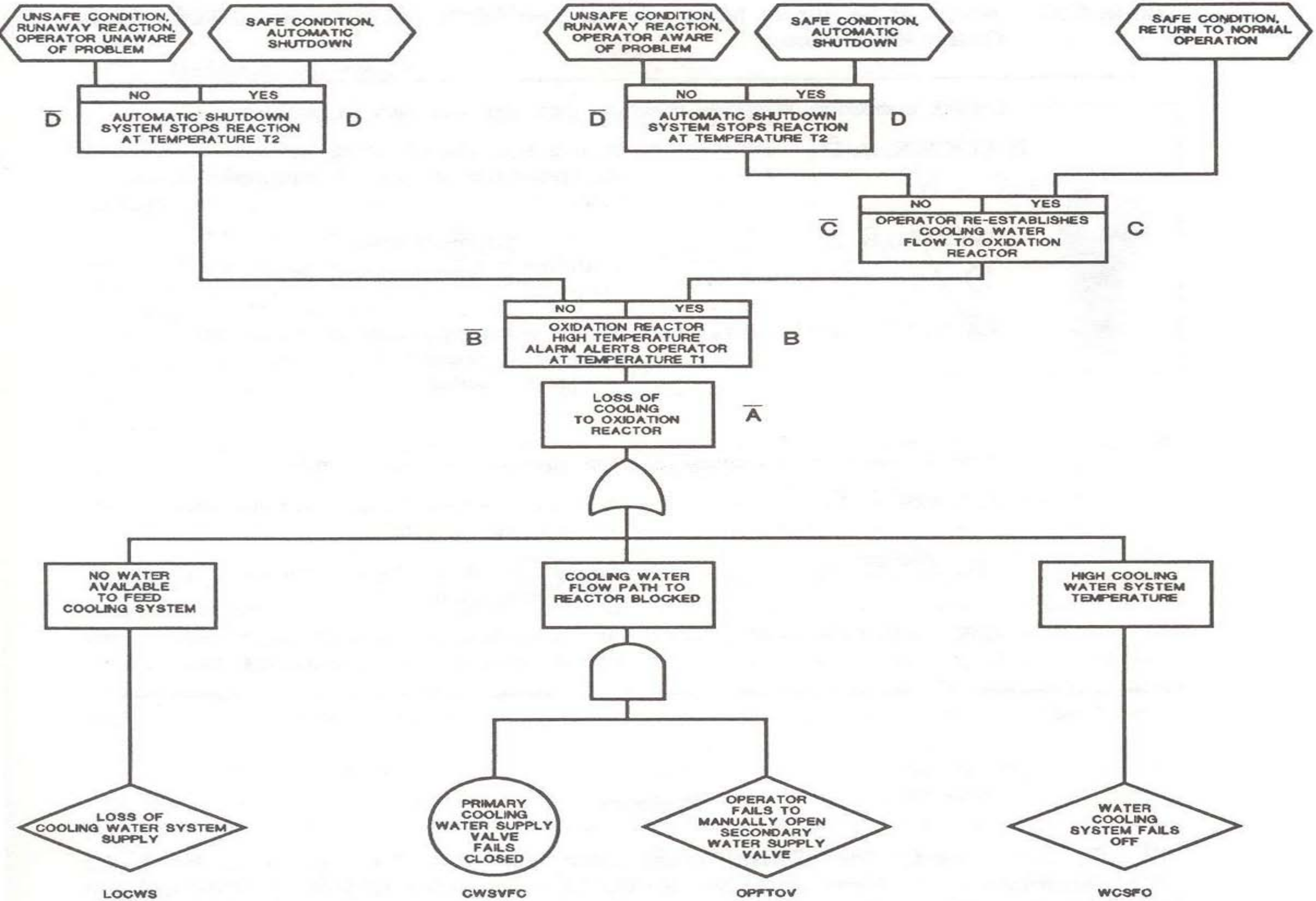


Figure 6.23 Cause–consequence diagram for the example initiating event “loss of cooling water to the oxidation reactor.