Use of PSA to support Accident Management at NPPs

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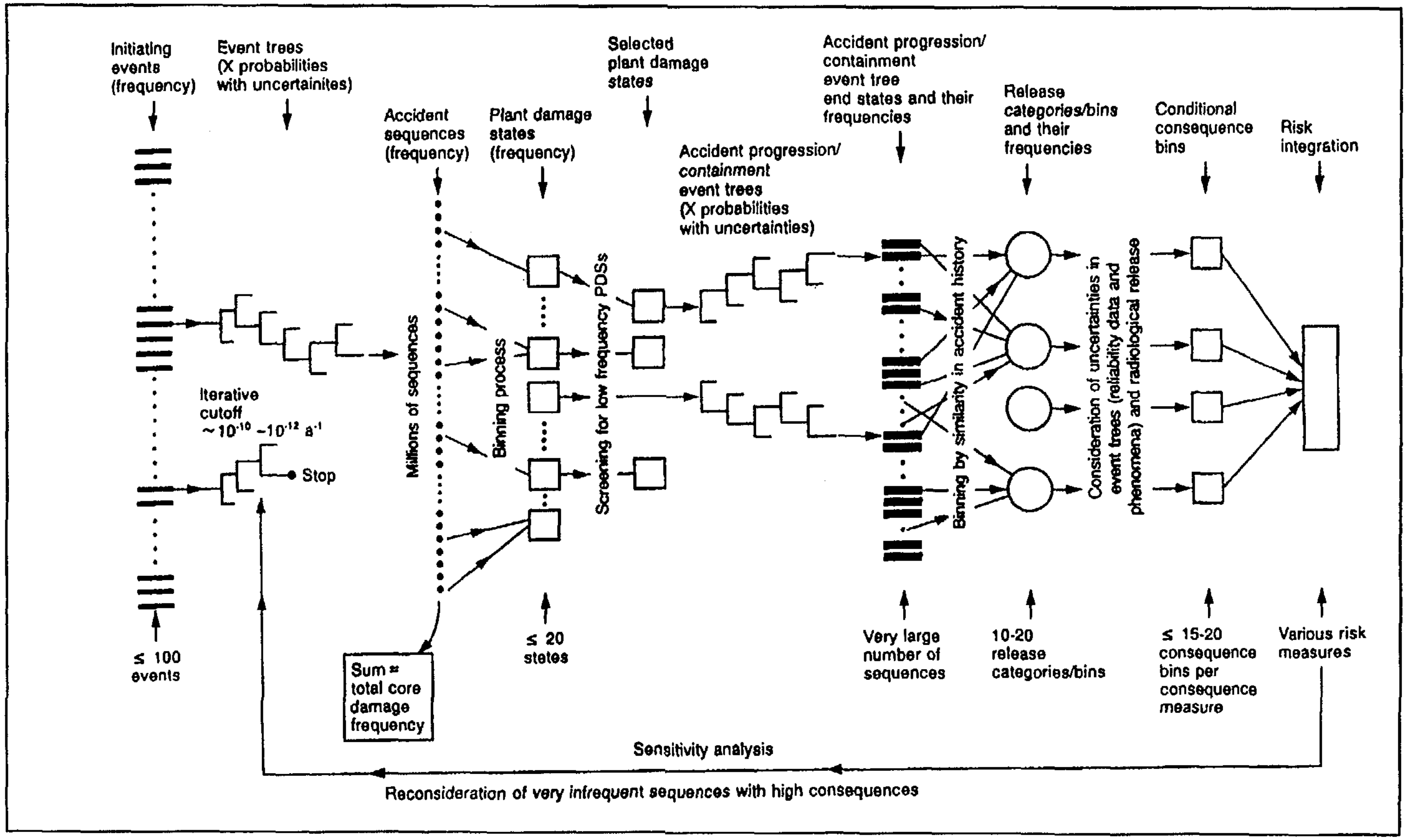
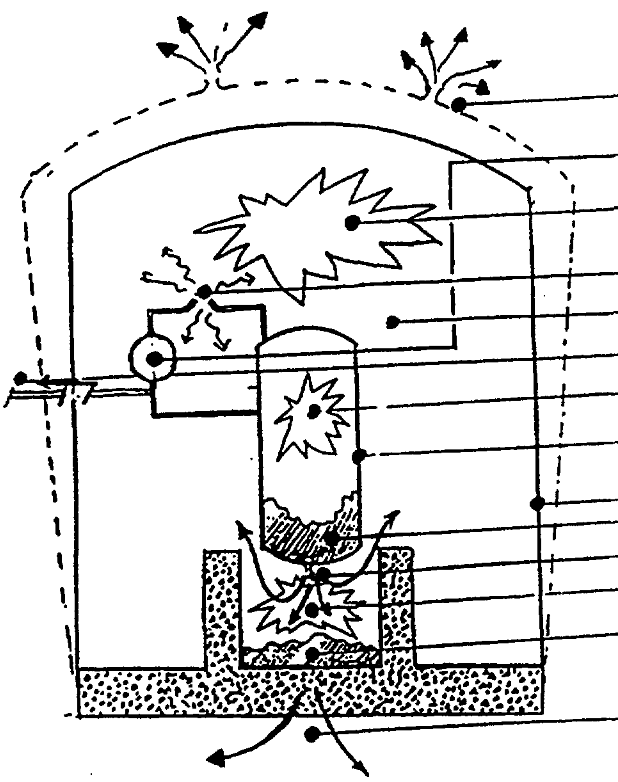


Initiating events (frequency)
Event trees (X probabilities with uncertainites)
Accident sequences (frequency)
Plant damage states (frequency)
Selected plant damage states
Accident progression/ containment event trees (X probabilities with uncertainties)
Accident progression/ containment event tree end states and their frequencies
Release categories/bins and their frequencies
Conditional consequence bins
Risk integration
Iterative cutoff ~10^-10 -10^-12 a^-1
Stop
Millions of sequences
Binning process
Screening for low frequency PDSs
Binning by similarity in accident history
Consideration of uncertainties in event trees (reliability data and phenomena) and radiological release
≤ 100 events
Sum ≈ total core damage frequency
≤ 20 states
Very large number of sequences
10-20 release categories/bins
≤ 15-20 consequence bins per consequence measure
Various risk measures
Sensitivity analysis
Reconsideration of very infrequent sequences with high consequences



ACCIDENT PROGRESSION PHENOMENA IN THE CONTAINMENT

SEVERE ACCIDENT SEQUENCES

Examples of core damage sequences from level 1

- Steam generator tube rupture, secondary open
- Transient initiator + failure of secondary cooling + failure of F&B due to failure of PORVs to open
- Large LOCA + partial failure of safety injection

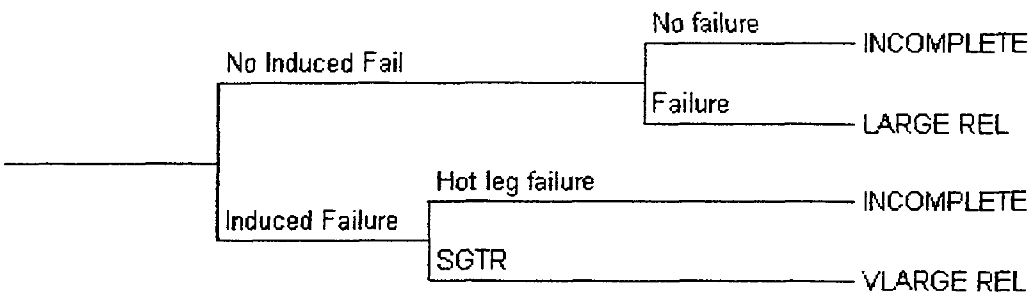
Evaluation in level 2 is direct for:

- Steam generator tube rupture, secondary open → Bypass PDS → VERY LARGE RELEASE

Evaluation in level 2 gives various possible sequences:

Transient initiator + failure of secondary cooling + failure to open PORVs for "feed and bleed" → High pressure PDS →

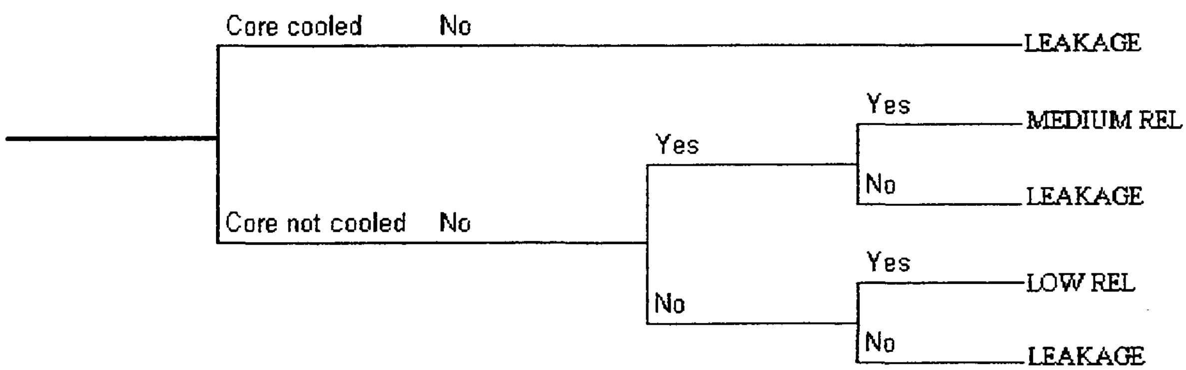
High Pressure PDS	Induced primary failure	Type of induced failure	Early containment failure	Consequence



Evaluation in level 2 gives various possible sequences:

Large LOCA + partial failure of safety injection →
Low pressure, "partial" core damage PDS →

Low pressure, partial core damage PDS	Core cooled in-vessel	Early containment failure	Core-concrete interaction	Late containment failure

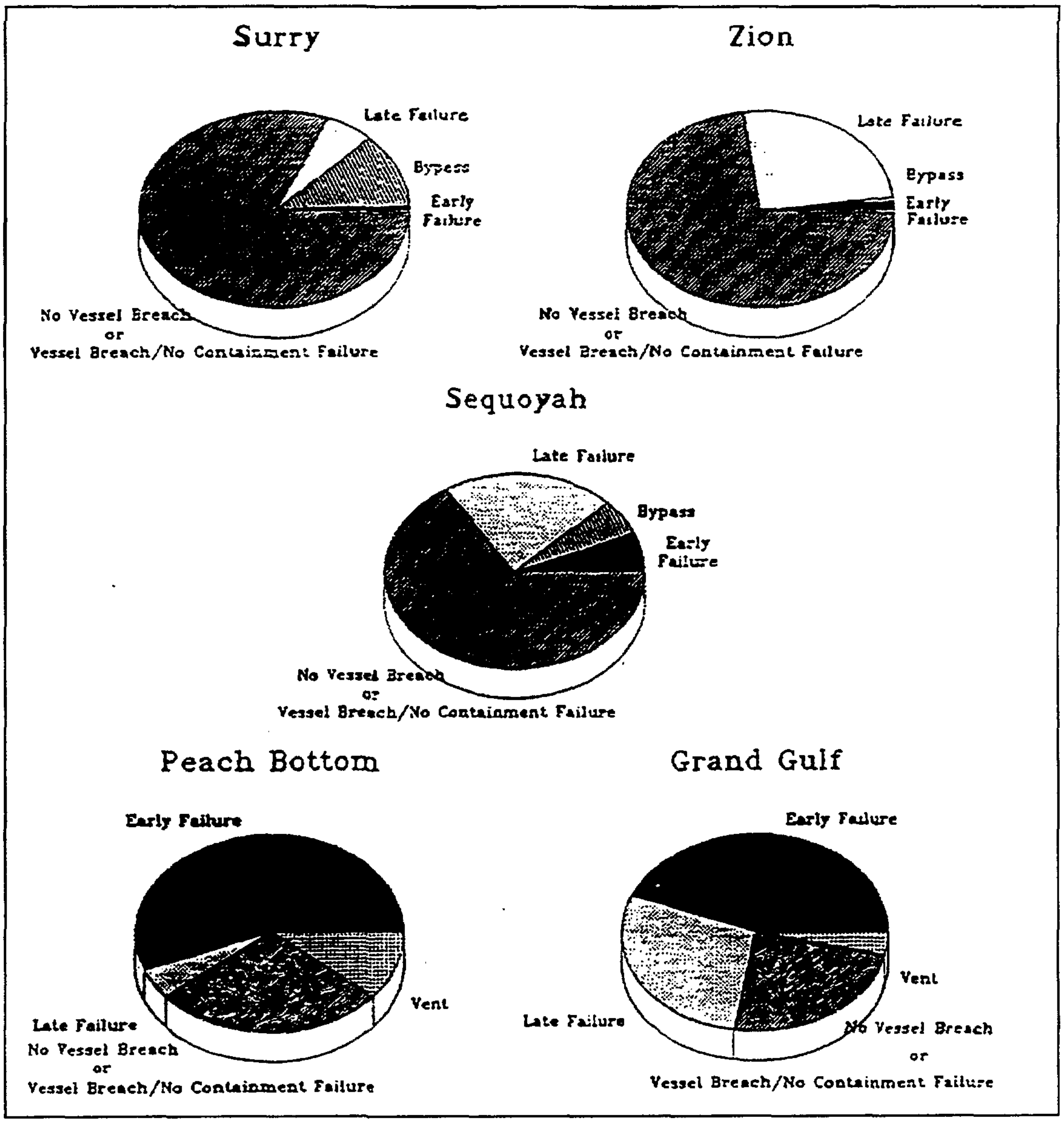


RESULTS: MEAN FREQUENCIES FOR INTERNAL EVENTS (from NUREG-1150)

Plant	Type	Core Damage Frequency	Frequency of Early Failure or Bypass of Containment
Surry	PWR	4×10^{-5}	3.7×10^{-6}
Peach Bottom	BWR Mk I	4.5×10^{-6}	2.5×10^{-6}
Sequoyah	PWR	5.7×10^{-5}	6×10^{-6}
Grand Gulf	BWR Mk III	4×10^{-6}	1.73×10^{-6}
Zion	PWR	3.4×10^{-4}	5×10^{-6}

RESULTS FROM NUREG-1150

Relative probability of containment failure modes (internal events)



RESULTS

SUMMARY OF RADIOLOGICAL SOURCE TERM ESTIMATES

Release			Release group (fraction)							
Bin	Frequency	Phase	Xe	I	Cs	Te	Ba	Sr	Ru	La
1	R(1)	Early	0.95	0.08	0.08	0.5	0.002	8.0×10^{5}	—	—
		Late	0.05	0.005	0.005	0.04	0.01	0.02	—	0.001
		Total	1.00	0.085	0.085	0.09	0.012	0.02	—	0.001
2	R(2)	Early	..	..	..	..	..	..	..	..
		Late	..	..	..	..	..	..	..	..
		Total	..	..	..	..	..	..	..	..
..	..	Early	..	..	..	..	..	..	..	..
		Late	..	..	..	..	..	..	..	..
		Total	..	..	..	..	..	..	..	..
N	R(N)	Early	..	..	..	..	..	..	..	..
		Late	..	..	..	..	..	..	..	..
		Total	..	..	..	..	..	..	..	..

RESULTS AND INSIGHTS

WWERs

No complete source term analyses yet available for WWER type reactors (present knowledge base regarding accident progression from vessel type LWRs is applicable to WWERs)

WWER 440/230

- Core damage frequency range between 3.10^{-3} and 3.10^{-4} depending on degree of backfitting (limited and expensive backfitting)

- Due to the large water inventory in the coolant systems, accident evolution is very slow providing good conditions for accident management

- Steam generator leaks (tube ruptures and header breaks) can be isolated with the main gage valves in the primary cooling loops. For other PWRs there is usually an important and significant source term contribution from this kind of sequences

- Confinement has very little capability regarding mitigation of severe accidents (unless very expensive upgrading is carried out)

RESULTS AND INSIGHTS

WWER 440/213

- Core damage frequency range can be reduced to 1.10^{-4} depending on degree of backfitting

- Due to the large water inventory in the coolant systems, accident evolution is very slow providing good conditions for accident management

- Steam generator leaks (tube ruptures and header breaks) can be isolated with the main gate valves in the primary cooling loops. For other PWRs there is usually an important and significant source term contribution from this kind of sequences

- Large free containment volume

RESULTS AND INSIGHTS

WWER 1000

- Core damage frequency range between 10^{-4} and 10^{-5} after some improvements, good conditions for accident management

- Steam generator leaks (tube ruptures and header breaks) have an important and significant source term contribution

- According to the screening Level 2 analyses dominant source term characteristics for WWER 1000 are either containment by-pass scenarios (steam generator leaks) or relatively rapid basemat penetration. Accident management could improve the situation and render this source term characteristics more favorable

- Otherwise, robust containment

RESULTS AND INSIGHTS

CANDUs

Considerable uncertainties regarding accident progression for CANDUs (damage propagation in the core region)

RBMKs

No systematic severe accident analyses available for RBMKs

ACCIDENT MANAGEMENT

A BASIS FOR ACCIDENT MANAGEMENT

- In the past it was assumed that containment failure was inevitable if the core melted

- The present understanding is that

  1. Once the core has started to melt, the progression of the melt is avoidable and core cooling can be restored

  2. Core melt does not necessarily cause vessel or containment failure

- With the increased understanding of phenomenological behavior in accidents, improved methods have been developed to better predict the course of accidents

ACCIDENT MANAGEMENT: WHAT FOR?

- To prevent core damage: restoration of core cooling and control of reactivity
- To maintain the integrity or delay the failure of the RCS
- To maintain the integrity or delay the failure of the confinement/containment
- To mitigate the release of radioactive material

ACCIDENT MANAGEMENT IN NPPs

BACKGROUND

IAEA-Technical Report Series No. 368 (1994):

"Accident Management Programmes in Nuclear Power Plants, a Guidebook"

Accident Management			
(1) To prevent core damage	**(2) To terminate the progression of core damage if it begins, and retain the core within the reactor vessel**	**(3) To maintain containment integrity as long as possible**	**(4) To minimize the effects of releases of radioactive material to the environment**
	Severe Accident Management		

DEFENCE IN DEPTH PRINCIPLE

DESIGN:

Successive barriers to prevent release of radioactive material:

- Fuel matrix (fuel pellets)
- Cladding
- Primary coolant boundary
- Containment

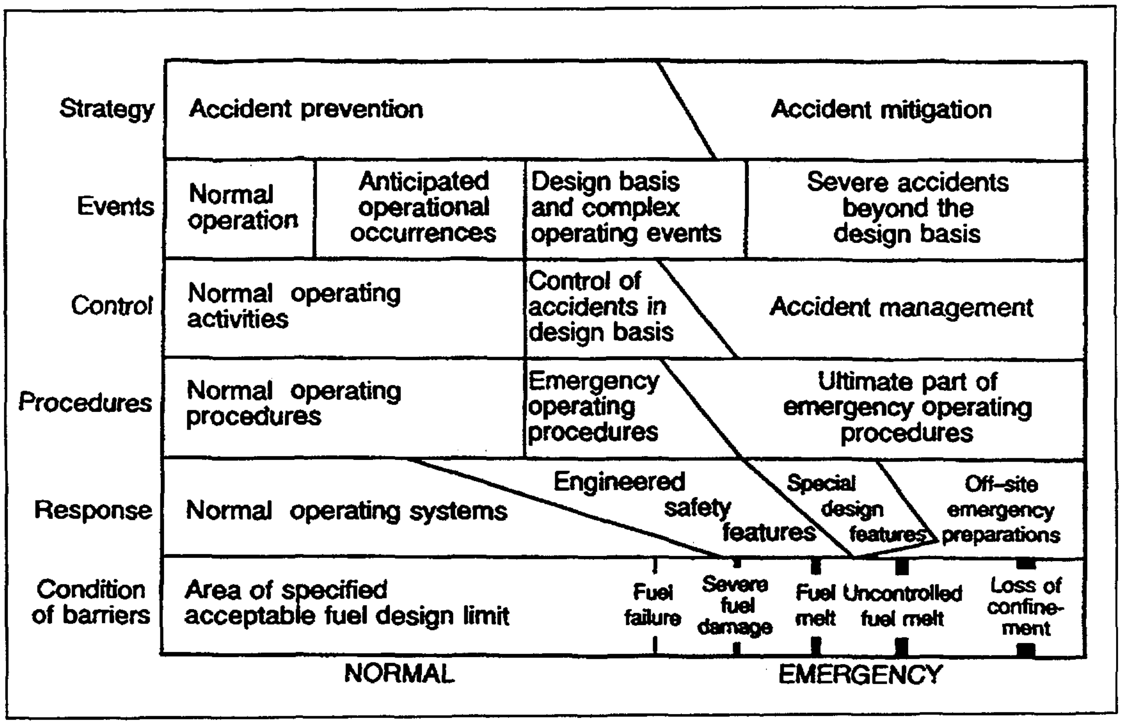
Protection of these barriers by:

- Margins in design
- Quality and status surveillance
- Operating limits and procedures
- Safety systems

Accident management can be regarded as a further line of protection by:

- Preventing that the plant leaves the design range after a disturbance
- Preventing failure of the barriers
- Delaying failure of the barriers
- Providing additional mitigation to minimize or terminate releases to environment

DEFENCE IN DEPTH PRINCIPLE



INSAG-3 "Basic Safety Principles for Nuclear Power Plants" (Items 282 to 288 provide an explanation for this figure)

KEY POINTS INFLUENCING THE DEVELOPMENT OF ACCIDENT MANAGEMENT STRATEGIES

1) Assessment of vulnerabilities and capacities:

Evaluation of the status of core cooling, reactivity, RCS and containment integrity under different plant conditions

2) Development of accident management strategies:

Focused towards maintaining the safety functions

3) Structured process to match strategies and vulnerabilities:

Safety objectives → safety functions → challenges to safety functions → mechanisms that cause the challenges → definition of strategies

4) Definition of procedures and guidance:

Taking also into account the available instrumentation, time for human actuation (diagnosis, actuation, evaluation of consequences), potential for confusing signals, etc.

5) Validation of SAM procedures

ASSESSMENT OF PLANT VULNERABILITIES AND CAPABILITIES

(1) Identify vulnerabilities of safety systems and functions

(2) Identify possible mechanisms and phenomena which can challenge the barriers to the release of radioactive material

- Assessment of vulnerabilities should be based on analysis of the plant's response to accidents beyond the design basis
- It should be done in a realistic manner, using best estimate methods, not with conservative approaches used for design basis analyses
- It should include all modes of operation, such as full power, reduced power and shutdown for refuelling

Assessment of plant vulnerabilities and capabilities: *INPUTS*

PLANT OPERATIONAL INFORMATION

- Event and incident reports
- Technical specifications
- Procedures
- Surveillance, test and inspection reports

ANALYSES

- Full scope Level 1, 2 PSA
- FSAR
- Plant manufacturer reports and analyses
- Regulatory documents
- Analyses for simulators and operator training programmes
- Evaluation of instrumentation behavior and limitations for accident diagnosis and control
- Review of existing procedures including an assessment of their limitations
- Evaluation of available capabilities and means for emergency situations

RESEARCH AND GENERIC ISSUES

- Severe accident research
- Generic PSAs, generic studies and analyses done for similar or reference plants, event information

Assessment of plant vulnerabilities and capabilities: *PROCESS STEPS*

(1) Identify severe accident sequences on the basis of PSA results. High consequence, low probability events should be included in the consideration of accident management vulnerabilities

(2) Categorize the important accident sequences into functional groups based on the PSA

(3) Identify key phenomenological behavior and timing

(4) Identify key equipment responses for important sequences

(5) Identify key personnel responses for important sequences

Assessment of plant vulnerabilities and capabilities: *PRODUCTS*

(1) Selection of typical accident sequences with emphasis on:

Consequences: Sequences with the highest probability or largest radiological consequences

Timing: Sequences that require the least amount of time to develop

Environment: Sequences that produce the most harsh environment for equipment and personnel

(2) Identification of failure modes of equipment and systems for dominant accident sequences

(3) Identification of operator actions to prevent, mitigate and recover from accidents

(4) Identification of instruments needed and instrument limitations (and failures from accident conditions)

(5) Summary of key phenomenological behavior and timing (in-vessel, ex-vessel, containment)

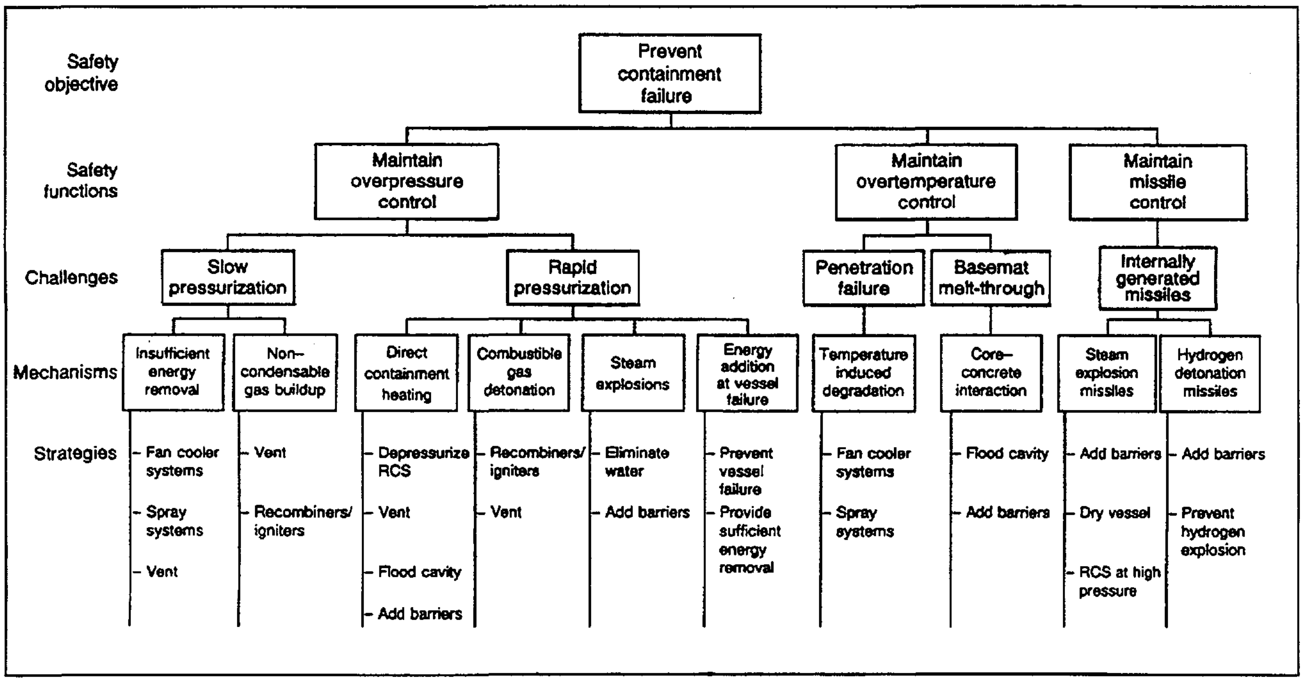
(6) Identification of hardware needed

(7) Summary of plant and personnel capabilities and vulnerabilities

DEVELOPMENT OF STRATEGIES

- Based on the knowledge of the plant vulnerabilities
- Focused towards compliance with the safety objectives through the preservation of the safety functions
- There should be a systematic evaluation of the possible strategies which could be adopted at each level of severity of the accident (i.e. core damage, core melt-down, RCS boundary melt through, etc)
- Suitable strategies should be capable of being carried out under the physical plant conditions associated with the particular challenge to the safety function that has to be preserved

STRUCTURED PROCESS TO MATCH STRATEGIES AND VULNERABILITIES



Example tree for the systematic development of strategies to comply with the safety objective: Prevention of containment failure

USE OF PSA TO SUPPORT ACCIDENT MANAGEMENT AT NPPs

Summary

- Identification of significant severe accident sequences. Selection criteria should be based on the frequency and consequences of the sequences
- Categorization of the important accident sequences into groups that have similar characteristics with respect to accident progression
- Identification of weak points and critical features (containment and containment functions)
- Evaluation of consequences of failed systems, operator errors, inoperative equipment, potential use of non-safety-related equipment to restore safety functions, etc.
- Development of accident chronologies
- Identification of success paths
- Prioritization actions to reduce risk

USE OF PSA TO SUPPORT ACCIDENT MANAGEMENT AT NPPs

Cautions and Limitations

- CAUTION when using PSA insights from other plants
- PSAs used in support of Accident Management should be realistic rather than conservative