NARSIS Workshop

Training on Probabilistic Safety Assessment for Nuclear Facilities

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Principles Of Severe Accident Risk Analysis

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Overview

- PRA/PSA Background
- Accident Progression Logic Model
- Principles of PSA Level 1- Level 2 interface
- Priciples of PSA Level 2
- NARSIS Project

PRA/PSA Background

- 1985: US NRC issued "Policy Statement on Severe Accidents Regarding Future Designs and Existing Plants" - formulated an approach for systematic safety examination of existing plants
- To implement this approach, GL 88-20 issued, requesting that all licensees perform an IPE in order *"to identify plant-specific vulnerabilities to severe accidents"*
- Internal events + internal floods
- Submittal guidance: NUREG-1335

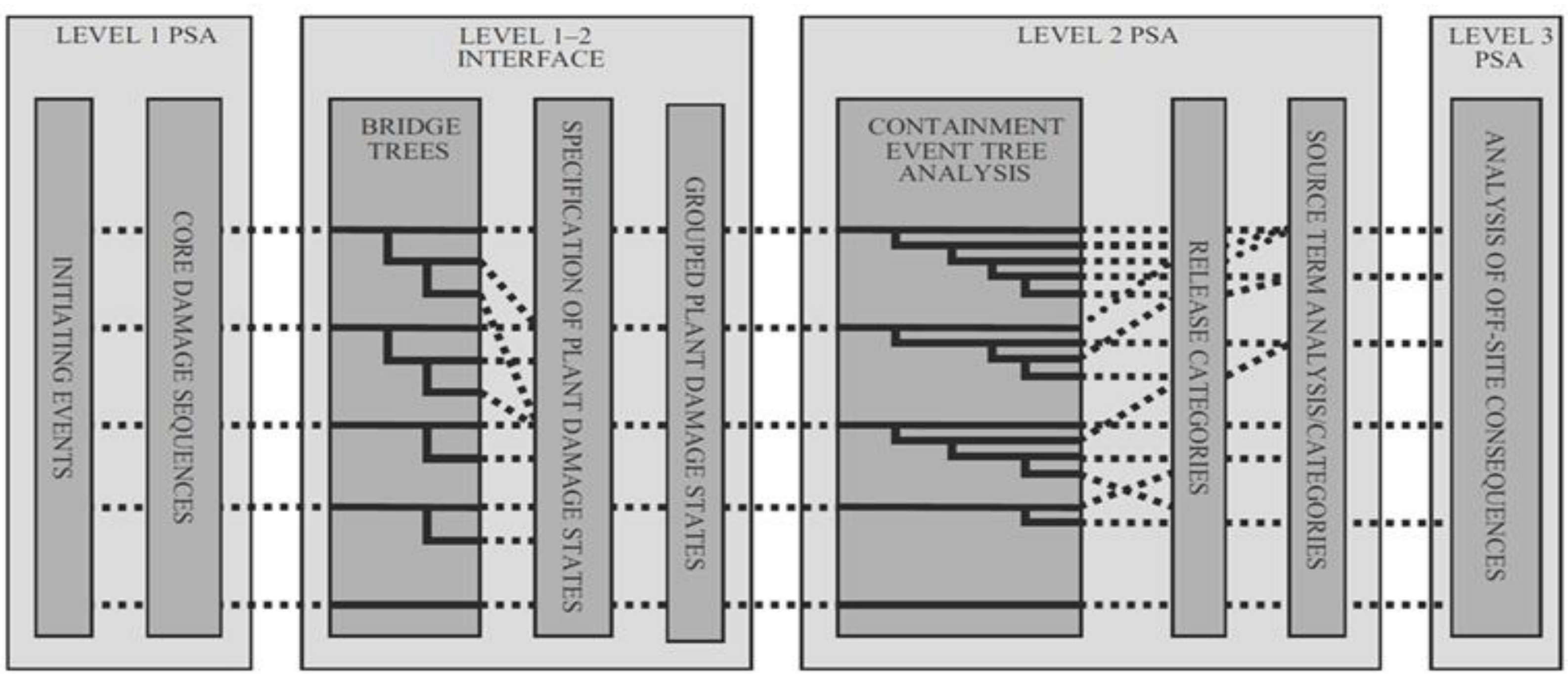
PRA/PSA Background (continued)

- 1991: US NRC issued Supplement 4 to GL 88-20 "IPEEE for Severe Accident Vulnerabilities"
- Each licensee to perform an IPE of external events to identify vulnerabilities, if any, to severe accidents
- The external events (**hazard)** considered in IPEEE include:
  - seismic events
  - internal fires
  - high winds, floods and other (HFO) external events
- Procedural and submittal guidance: NUREG-1407

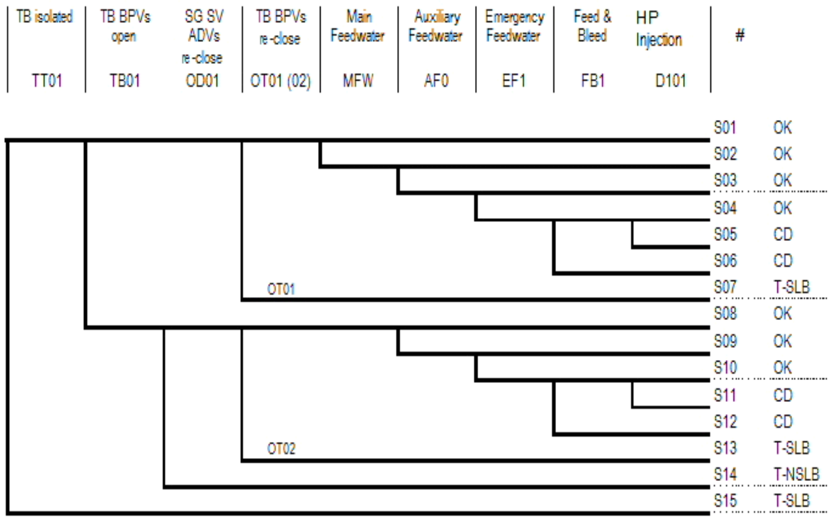
Similar to post Fukushima WENRA requirements for "stress tests"

Accident Progression Logic Model

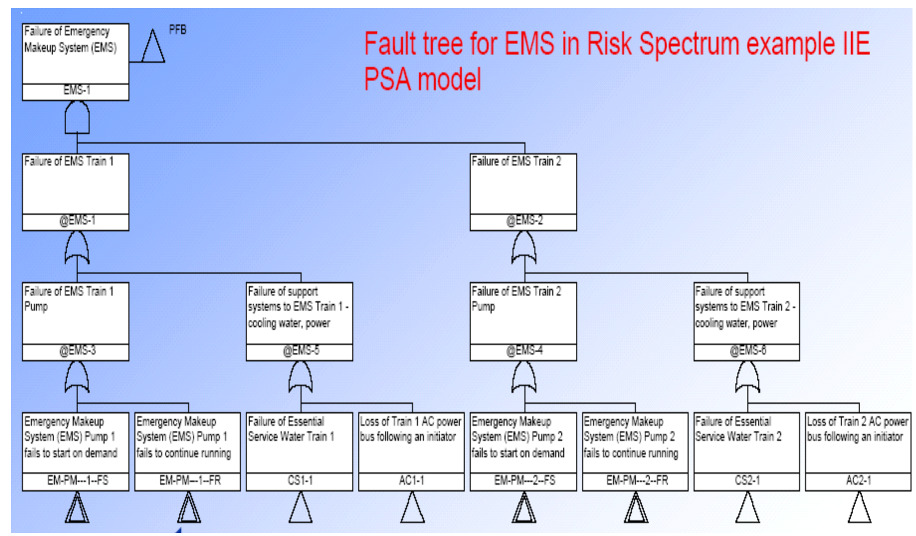
- Development of methodology which can be used to put all possible accident sequences into some kind of systematic order so that they can be analytically (e.g. logically) processed; and
- Based on such methodology, define a set of induced damage states resulting from those sequences, for further analysis (e.g. for risk quantification).



Probabilistic Safety Analysis Approach



Example Event Tree



Example Fault Tree

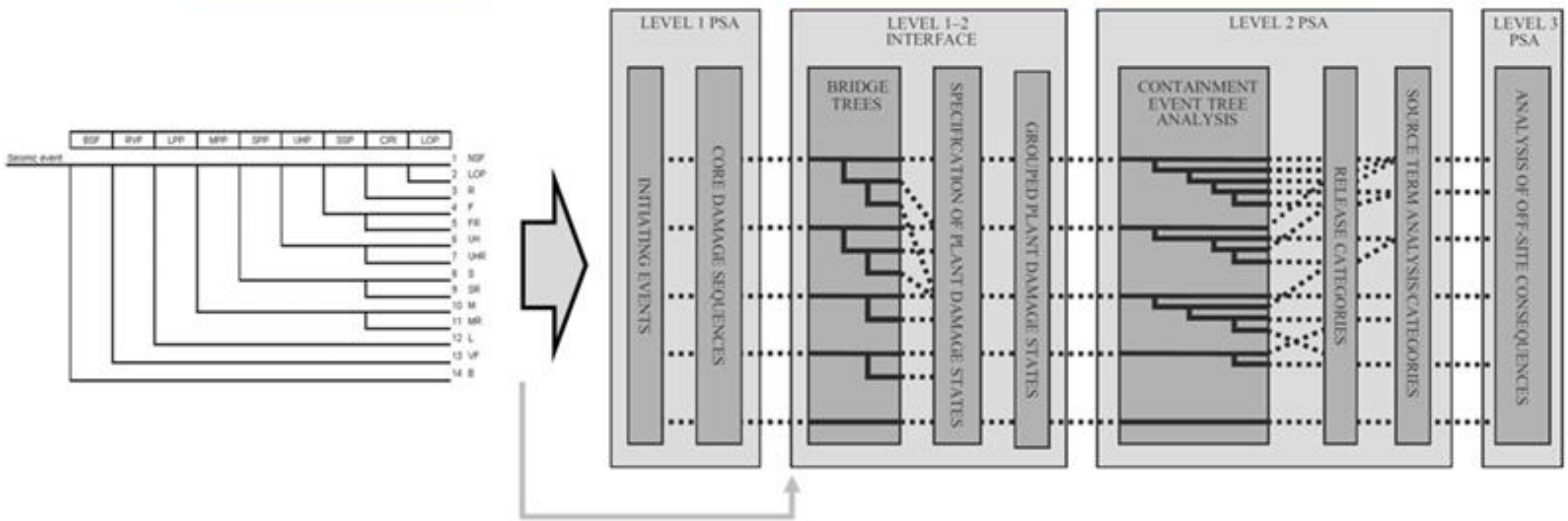
Logic Modelling Framework for Hazard-Induced Severe Accident Sequences

Seismic damage sequences

Core damage sequences

Containment systems response sequences

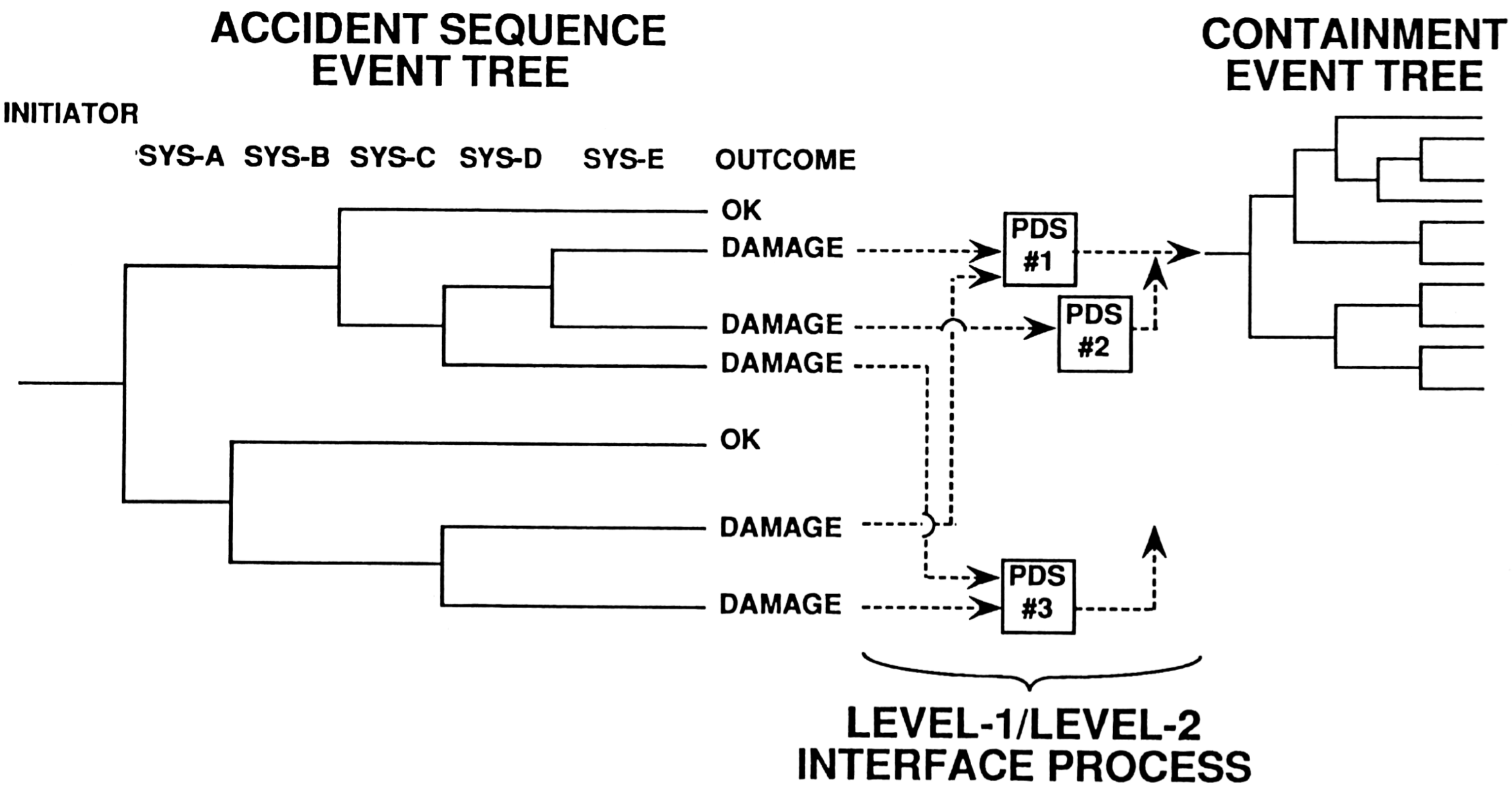
Accident progression sequences (phenomena)



Specific seismic sequences (e.g. building structural failures)

Level 1 – Level 2 Interface

- PDS binning process

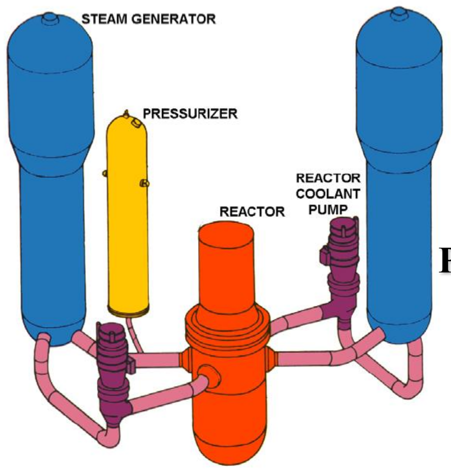


Principles for Characterization of Plant Damage States (PDS)

Term Plant Damage State (PDS) represents a group of accident sequences **resulting with similar response of plant systems / ESFs, similar damage to the reactor core and similar challenge to the containment**. The PDSs (induced by a hazard / initiator or by progression of triggered accident sequence) are typically characterized by a set of attributes. Those attributes usually include:

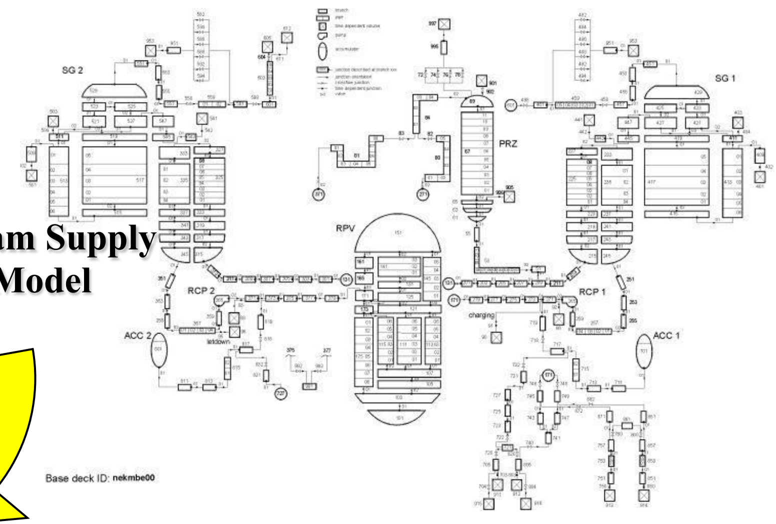
- Initiating event type ;
- Time of core damage;
- Pressure at reactor vessel failure;
- Status of ECCS;
- Status of containment heat removal (CHR);
- Status of containment integrity.

Deterministic Safety Analysis Approach

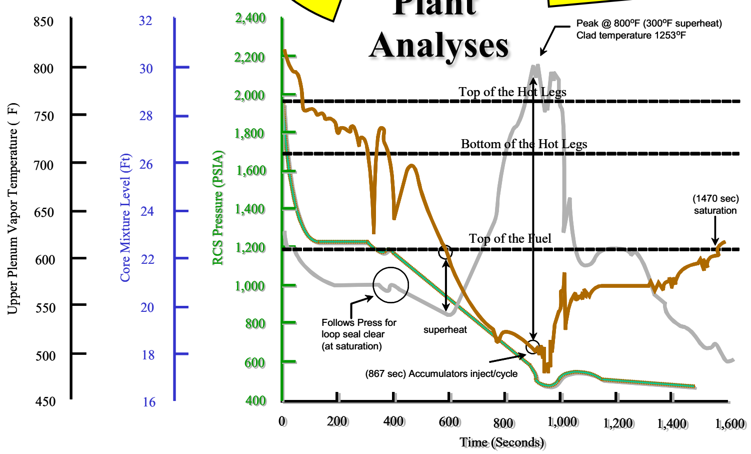


Plant Layout

Nuclear Steam Supply System Model

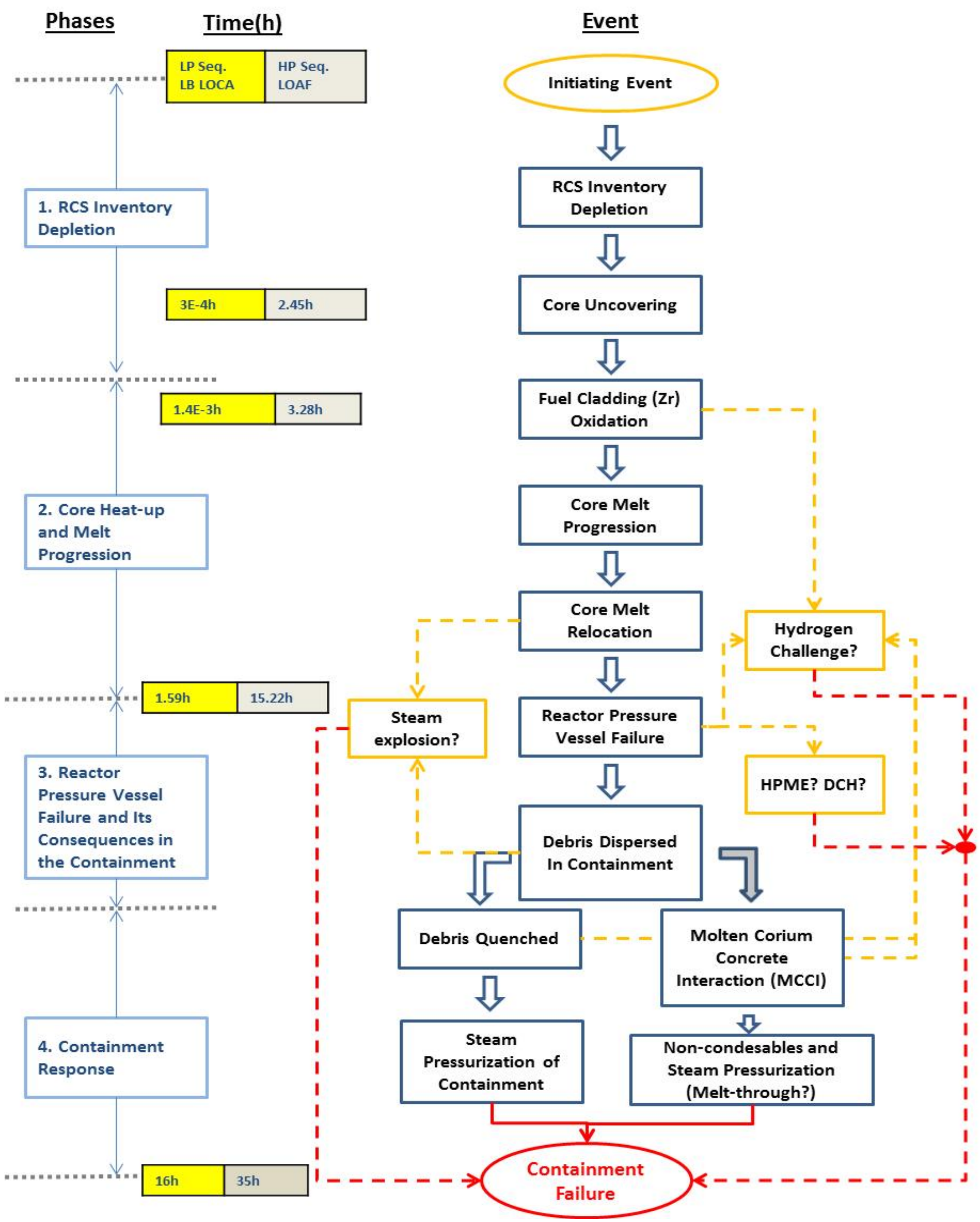


Plant Analyses



Severe Accident Progression

- Initiating event type;
  - LOCA
  - Non LOCA
- Time of core damage;
- Pressure at reactor vessel failure
  - HP sequence
  - LP sequence
- Status of Core Cooling;
  - No AF
  - No HPSI
  - No LPSI
- Status of containment heat removal (CHR);
- Status of containment integrity;
  - HPME, DCJ
  - MCCI



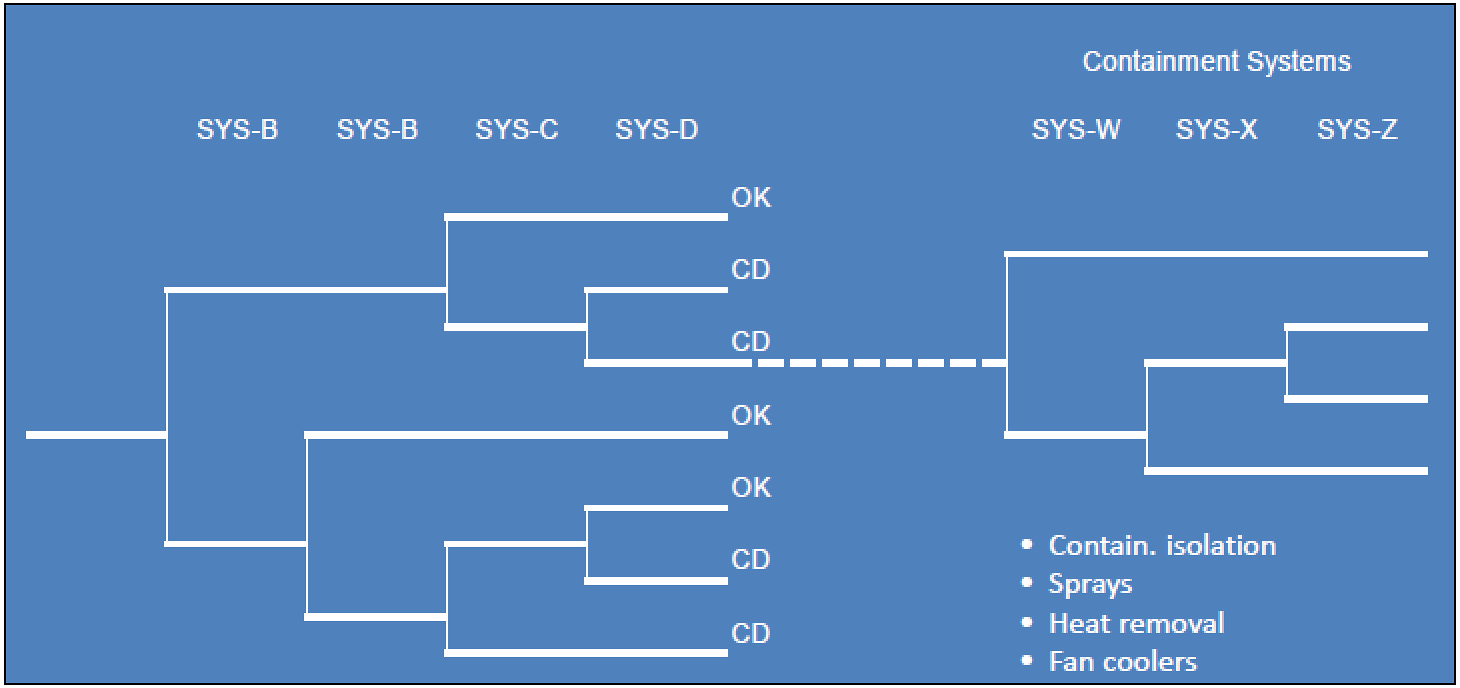
Level 1 – Level 2 Interface

- **Dependencies**
- Containment safeguards tree(s) must be directly coupled to Level 1 sequence events trees to properly handle dependencies
  - Shared components
  - Common support systems
  - Prior human actions

Level 1 – Level 2 Interface

Containment Safeguards Tree

- Extend Level 1 sequence event trees to include containment systems

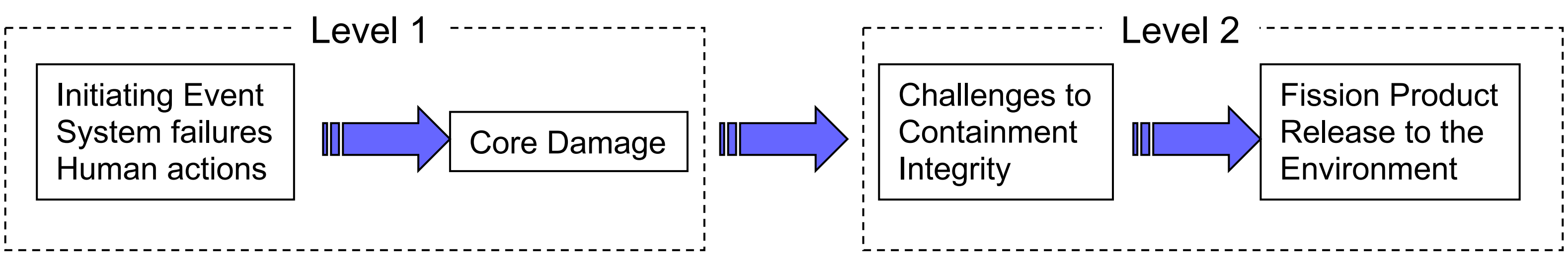


Containment Event Tree

- The purpose of CET:
  - To provide a logical and systematic approach to map the large number of accident sequences that may occur. Each path represents a possible accident sequence resulting in some final containment state and possible release category.
  - To provide a means of quantifying the likehood of each of the identified accident sequences. Thus, benefit in risk reduction can be realized due to consideration of the state of the containment, which has not previously been accounted for in the plant system analysis.
  - To provide a convenient method of identifying the release timing and magnitude of fission products. Each sequence results in some release category.

Containment Event Tree

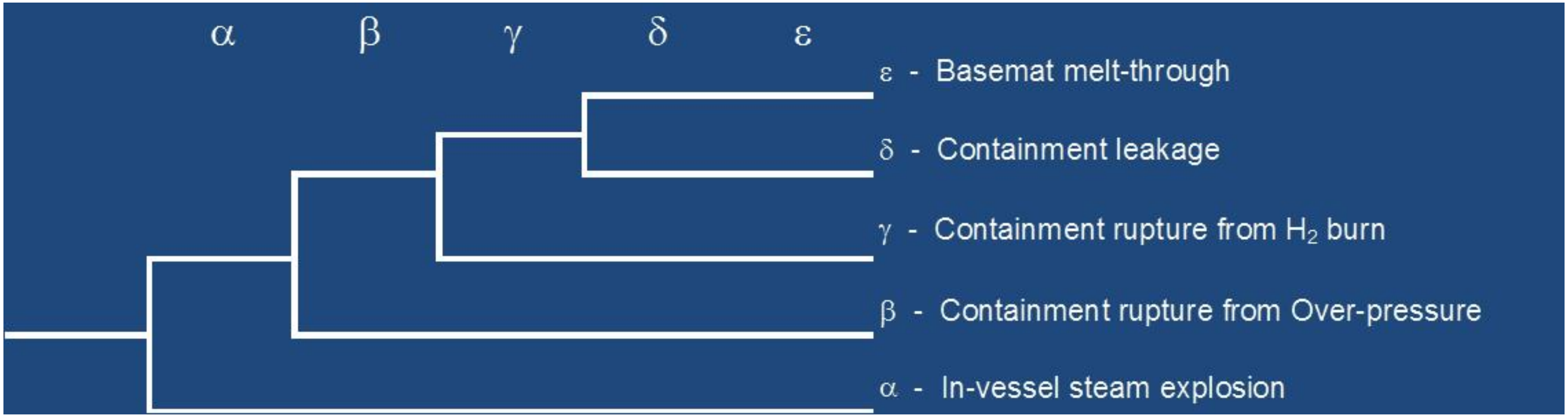
- CET is a logical framework for estimating the range of consequences associated with a given accident sequence.



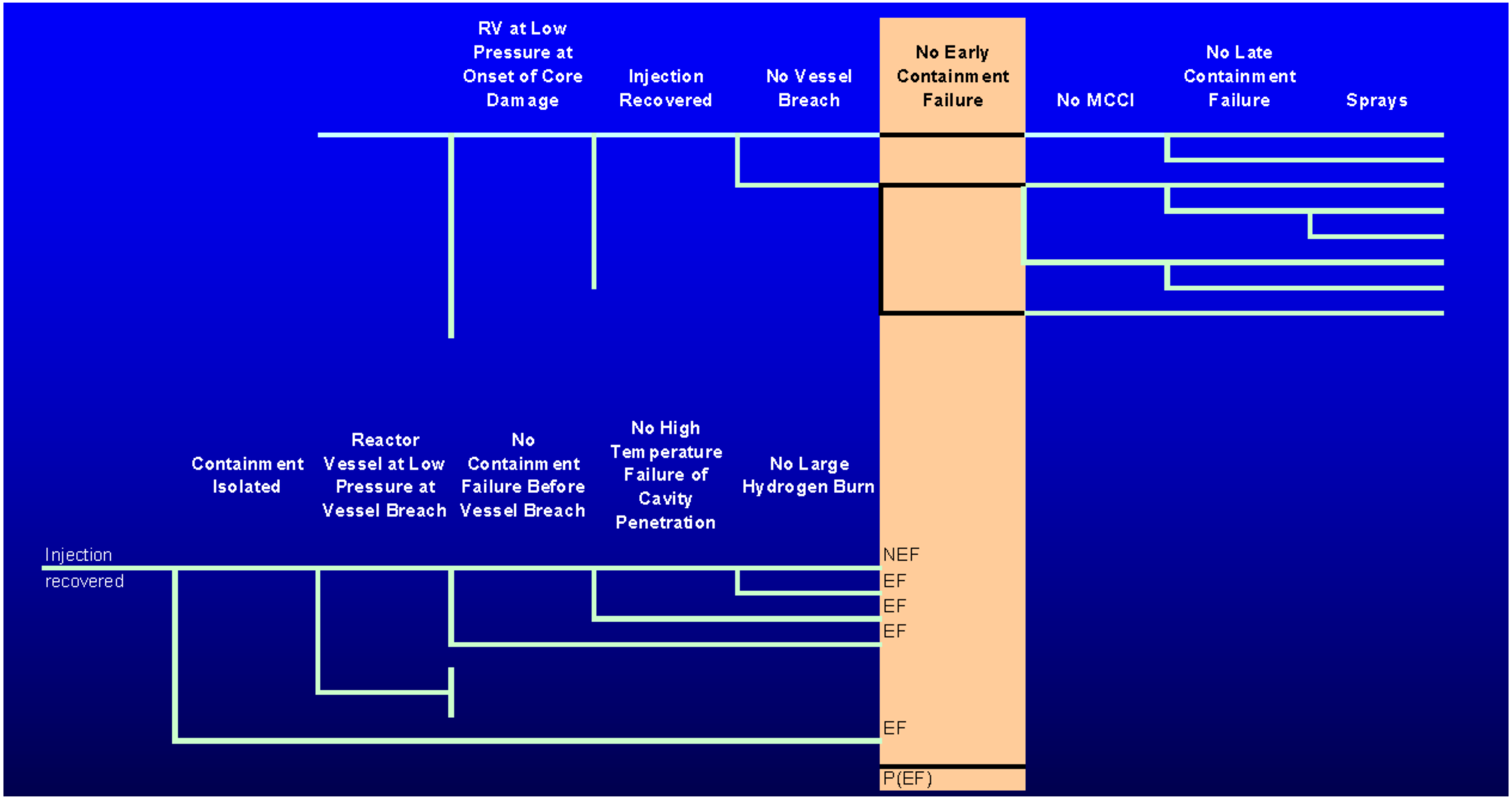
- CET is a time-line of accident progression
  - It represents the sequence of events that could lead to failure of the containment pressure boundary and fission product release to the environment

Containment Event Tree

- Genesis of CET
- "Containment Failure Modes" formed the Top Events in CETs in the first reactor Level 2 PSA (WASH-1400):



Containment Event Tree Example



Release Categories (CET End-states Binning)

Statement of the problem

- A probabilistic treatment of severe accident progression leads to numerous possible pathways that an accident might proceed in time
  - For a given PDS, the CET expands into many branches, each representing a distinct accident progression
- It is simply impractical to 'calculate' a source term for each pathway through the CET.
  - **How can you characterize the source term for each pathway through the CET with a limited number of detailed calculations?**

Release Categories

Solution: CET End-state binning

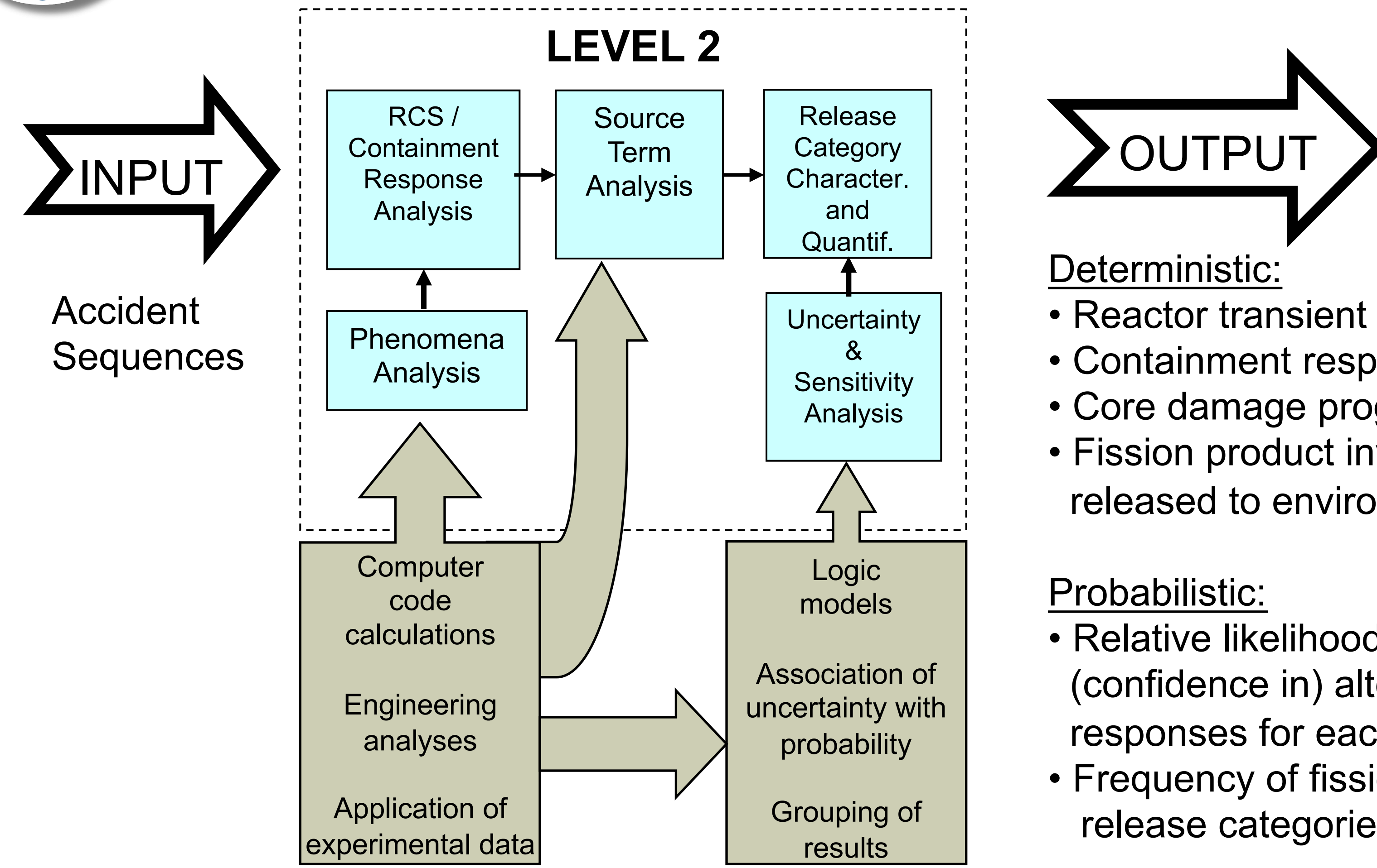
- Rather than 'calculate' a source term for each end-state of the CET, define 'rules' to group end-states with similar source terms.
  - Each group is referred to as a source term 'bin' or '**release category**'
  - Rules (binning criteria) are based on knowledge gained from multiple source term calculations

Containment Event Tree

Summary

- A CET is a Probabilistic Logic Framework for estimating the range of e consequences associated with a given accident sequence.
  - Several formats have been successfully used in past studies
  - No single format is “best”……each can be made to work.
  - Each format has advantages and disadvantages that must be weighted before starting
- Quantification of a CET requires knowledge of a wide range of information
  - Chronology and interdependencies of severe accident events
  - Plant-specific computer code calculations
  - Key findings of experimental studies of complex phenomena
- CET development is a GROUP effort

Level 2 PSA: Summary of 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

Accident Management Program

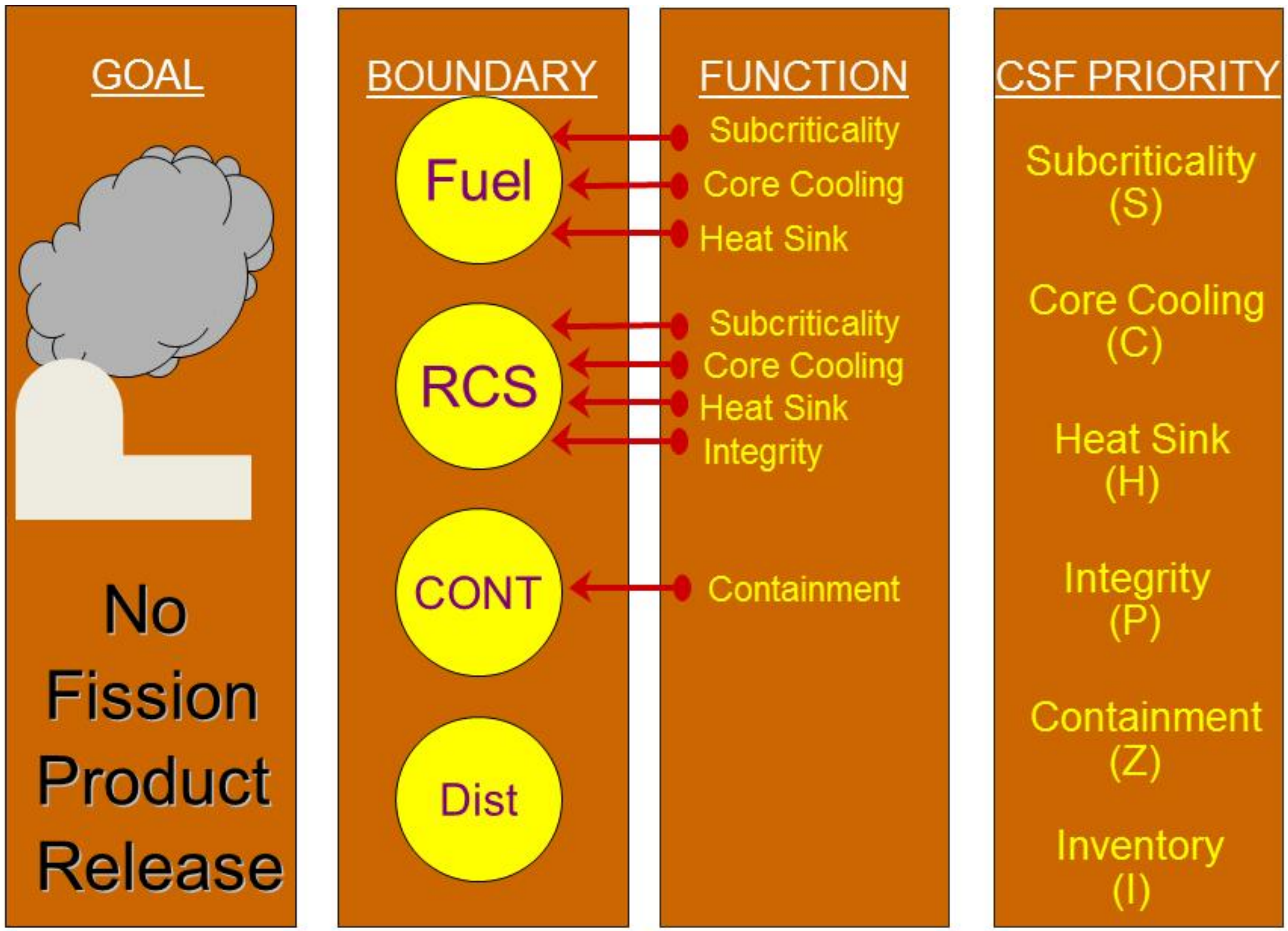
	< Design Envelope >			<DEC envelope>		
					< Severe Accident >	
Plant Conditions	**DBC**			**DEC**		Practically eliminated events
	NO	AOO	DBA	A Without severe core degradation	B With severe core degradation	
Decision Making	**< MCR staff >**				**< TSC staff >**	
Procedure Domain	**< SOP/ARP/AOP Domain >**		**< EOP Domain >**		**< SAMG Domain >**	

SAMGs are guidelines not procedures

Prevent Core Damage

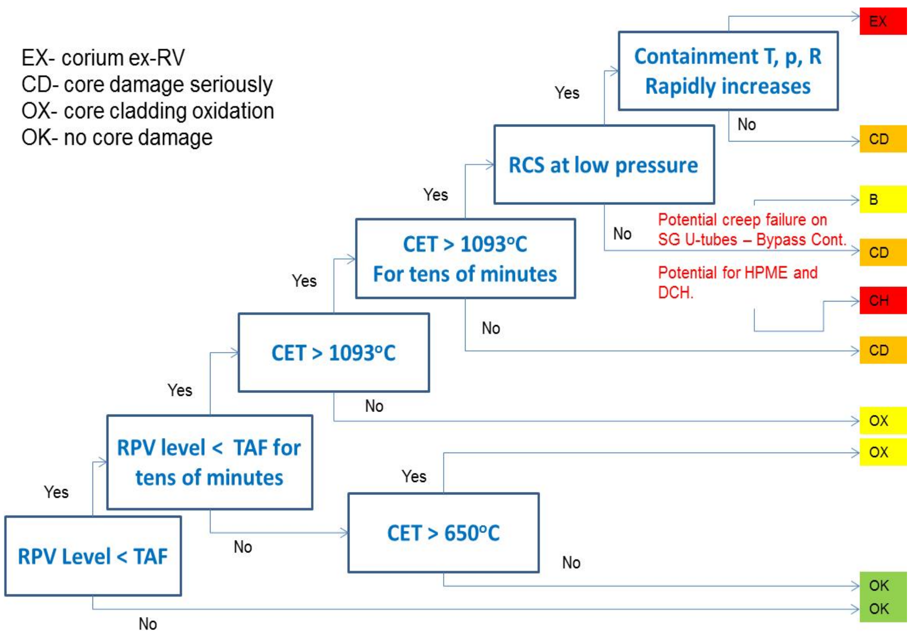
Mitigate effects of core damage and protect containment

Accident Management Program



Accident Management Program

EX- corium ex-RV
CD- core damage seriously
OX- core cladding oxidation
OK- no core damage



Core Damage Status Tree

CORE DAMAGE STATES

State	Condition	Accident Progression without operator action
OX (cladding oxidation)	CET > 650degC for 10 minutes RPVL < TAF	CD CH (hydrogen burn)
CD (Core Damage)	CET > 1093degC for tens of minutes RPVL < TAF	RPV melt-through (CH depend on RCS pressure) CH (hydrogen burn)
OK	CET < 354degC, quenched, cooled	

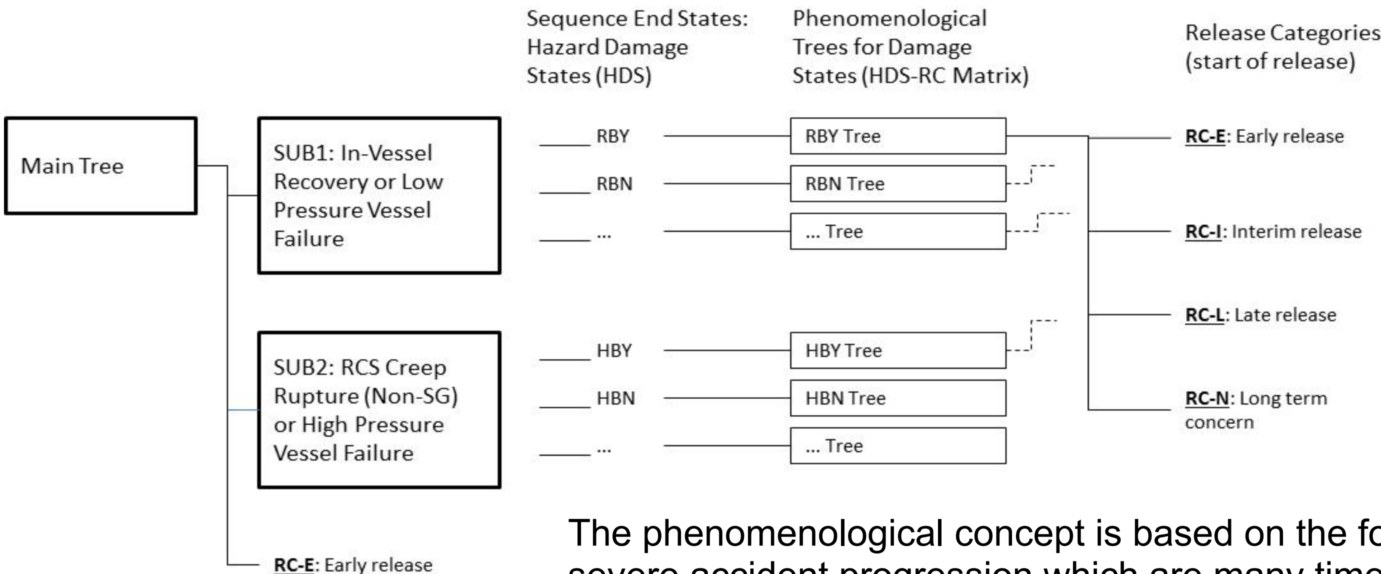
RCS STATES

State	Condition	Accident Progression without operator action
Intact: Pressurized	CET > 650degC for 10minutes OR 1093degC Prcs > 15.7MPa	RCS sudden depressurization: • SG U-tubes creep Failure (containment bypassed B) • HL creep failure (CH for containment) • RPV failure with HPME (CH – DCH, pressure, temperature, hydrogen)
Intact/Failed: Depressurized	CET > 650degC for 10minutes OR 1093degC Prcs < 0.3MPa RPVL < BAF	RPV melt-through (CH – hydrogen burn, MCCI)
OK	CET < 354degC, quenched, cooled	

CONTAINMENT STATES

State	Condition	Accident Progression without operator action
Intact	Pcont > 0.2MPa, not-cooled Design Basis Leakage	CH Environmental impact
Bypassed	Pcont <0.2MPa Design Basis Leakage or more	Environment Impact
CH (Containment Challenge)	0.6 MPa > Pcont >0.3MPa Tcont > 127degC Hydrogen >4% and Pcont < 0.15MPa	Containment Failure • Overpressure • Overtemperature • DCH (steam explosion potential) • MCCI (potential containment basement melt-through) Environment Impact
OK	Pcont < 0.3MPa, cooled Hydrogen < 4% Design Basis Leakage	

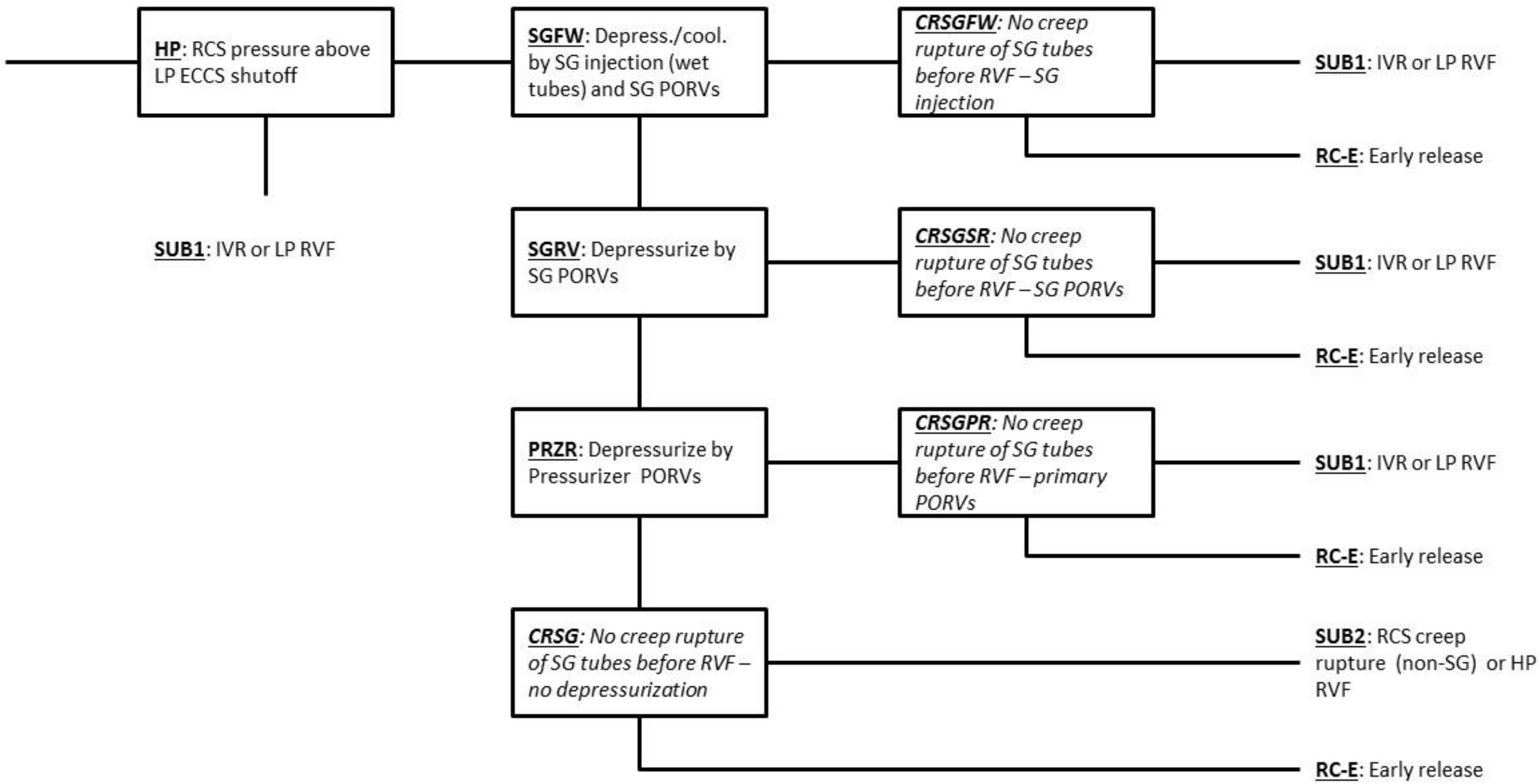
NARSIS: Simplified APET



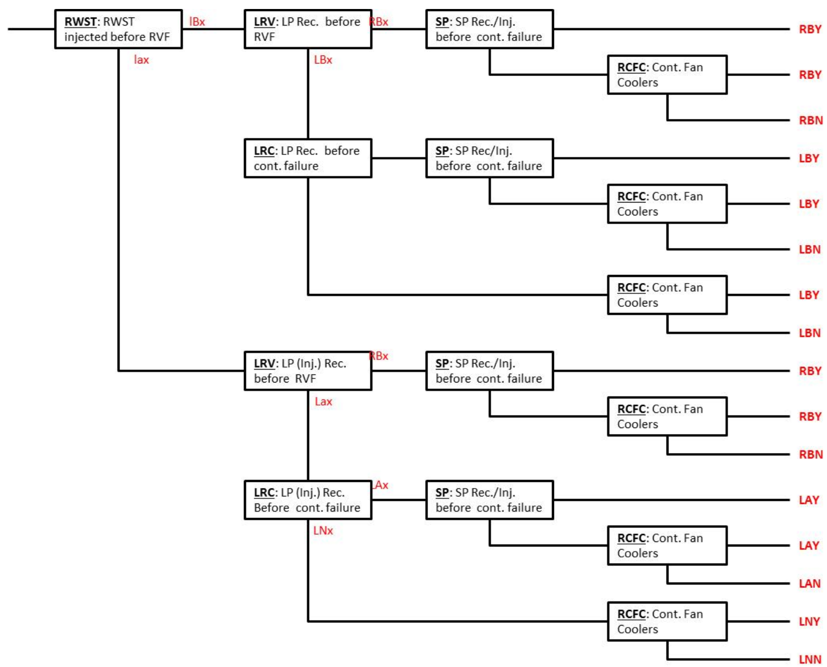
The phenomenological concept is based on the four time windows during severe accident progression which are many times considered in Level 2 PSAs:

- Time window covering the time up to the reactor vessel failure (TW1);
- Time window following the reactor vessel failure and covering the dynamic phenomena associated with ex-vessel phase (TW2);
- Time window following the end of the dynamic phenomena and covering a specified period of time, such as one day or similar (TW3);
- Longer term time window (TW4).

NARSIS: Simplified APET for - Main Tree



NARSIS: Simplified APET



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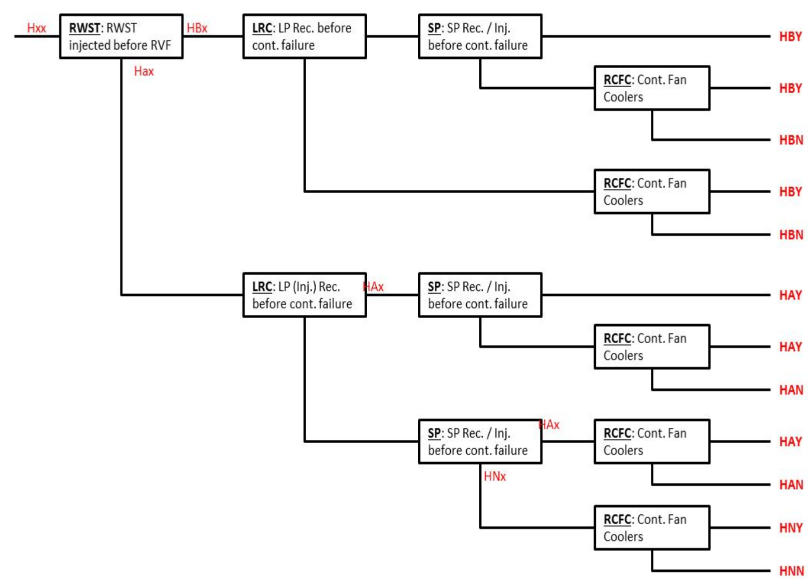
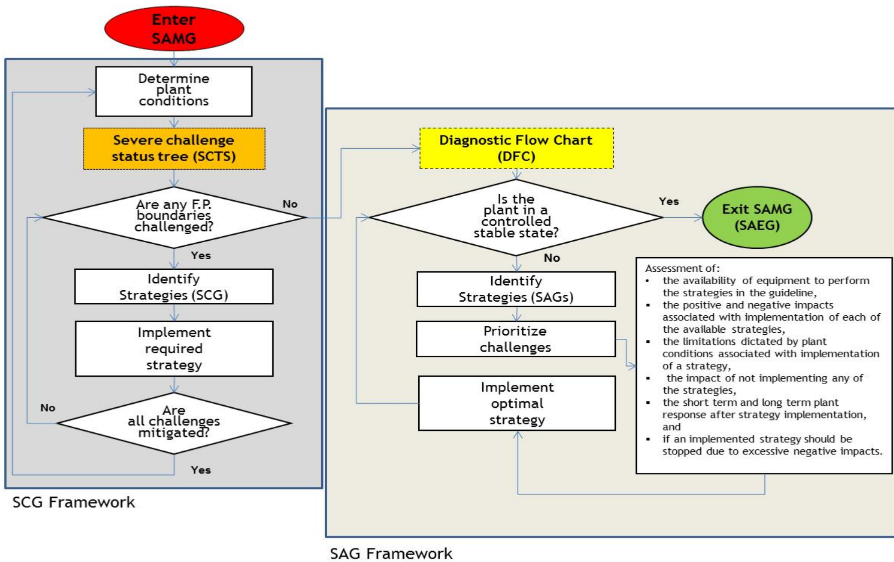
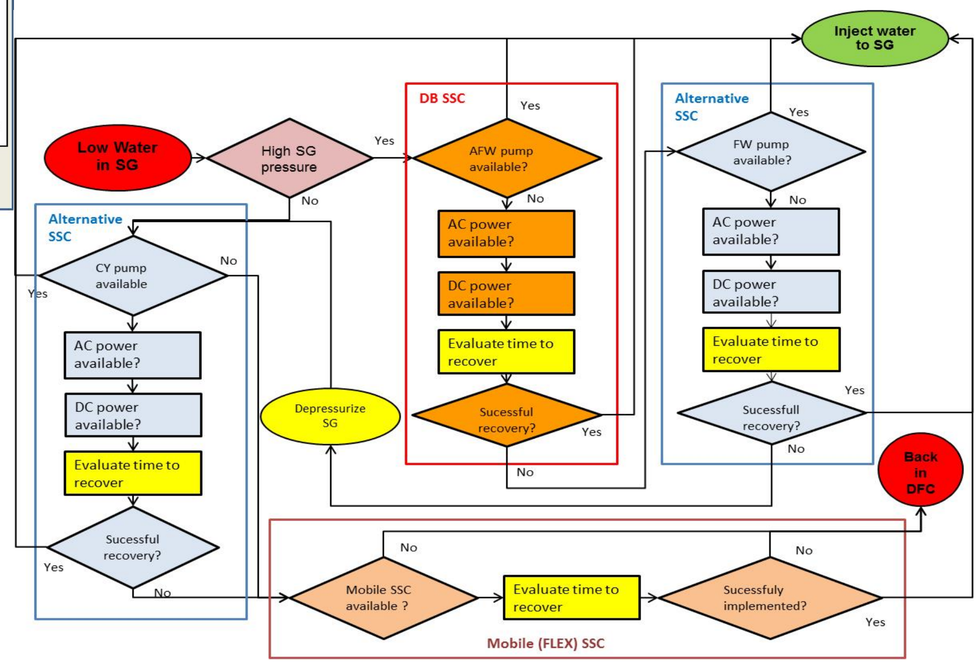


NARSIS: Modeling SAMGs



SAMG Decision Making Project

Determination the availability of equipment to perform the strategies in the guideline SAG-1 (Inject to SGs)



NARSIS: Modeling SAMGs

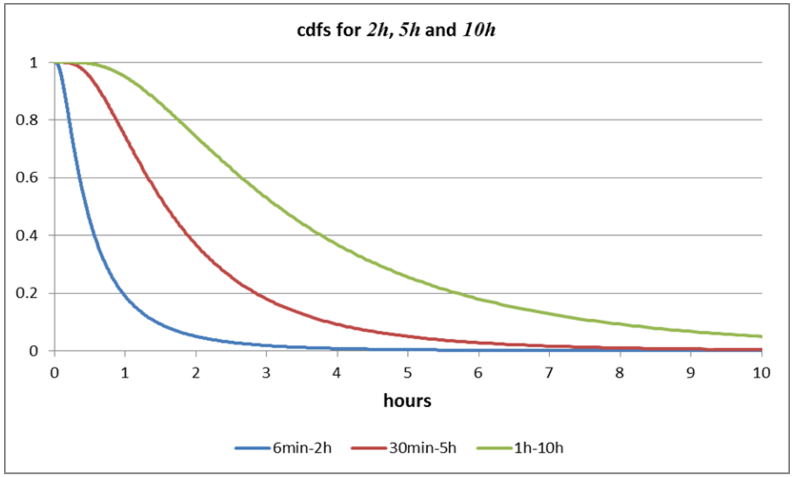
Alternatives:

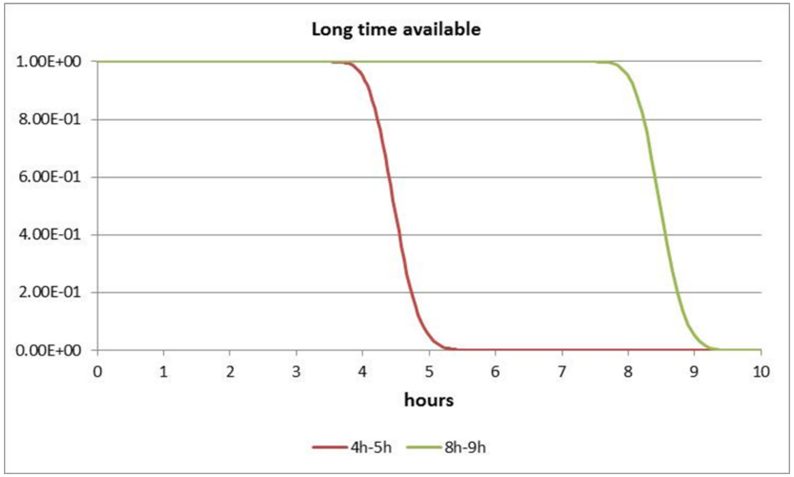
A. Equipment to implement the function is considered adequate and is available now.

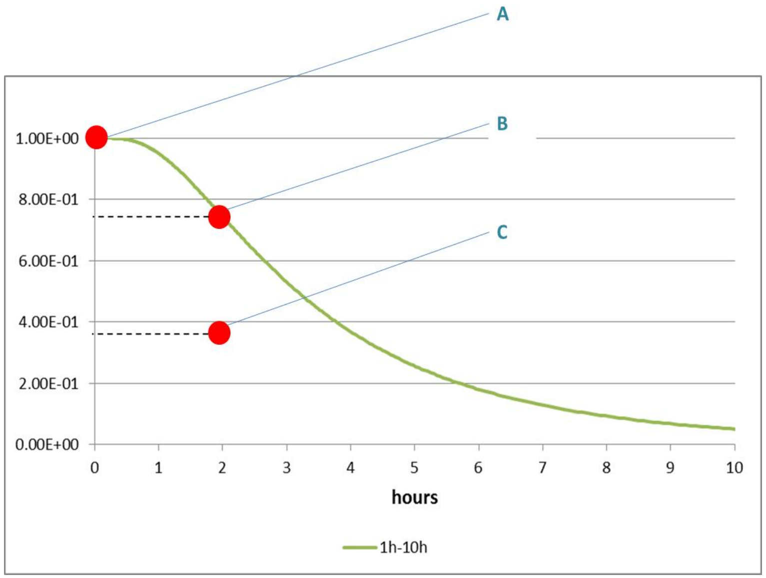
B. Equipment to implement the function is considered adequate, but is not available now. Assessor is confident that it will be available in less than 2 hours.

C. Equipment is to be available in less than 2 hours, but it may or may not be really adequate (e.g. 50% confidence).

NARSIS: Modeling SAMGs

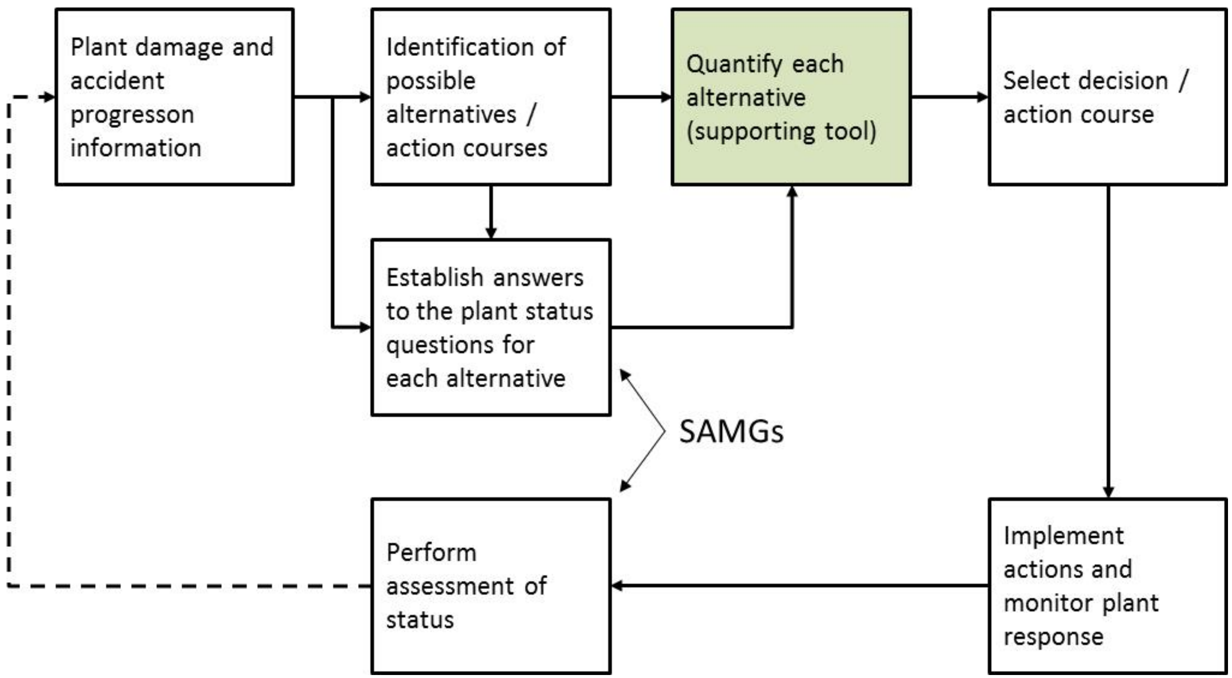






Examples of Adjusted Probabilities for Establishing or Recovering a Function

NARSIS: Concept of SAMG Supporting Tool



NARSIS: Illustration of Comparison of Two Alternatives

Alternative #1: By mobile pump inject to SG and cooldown / depressurize RCS from secondary side (SGs).

HP: 1
- PRZR : 1
- SGFW: 0.8
- SGRV : 1

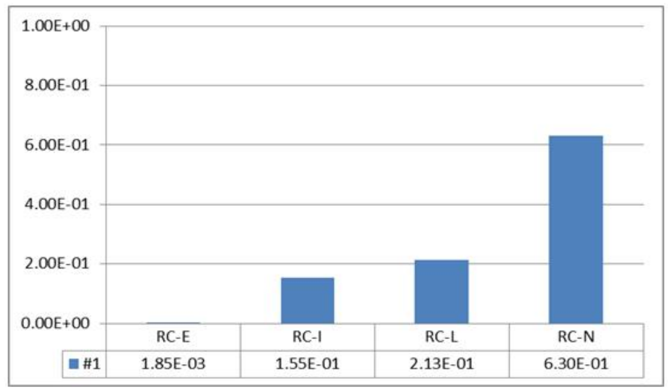
RWST : 0

LRV : 0

LRC : 1

SP : 1

RCFC : 1



Alternative #2: By mobile pump inject RWST into containment (no HP pump to enable injection into RCS) and depressurize RCS by Pressurizer PORVs.

HP: 1
- PRZR : 1
- SGFW: 0
- SGRV : 1

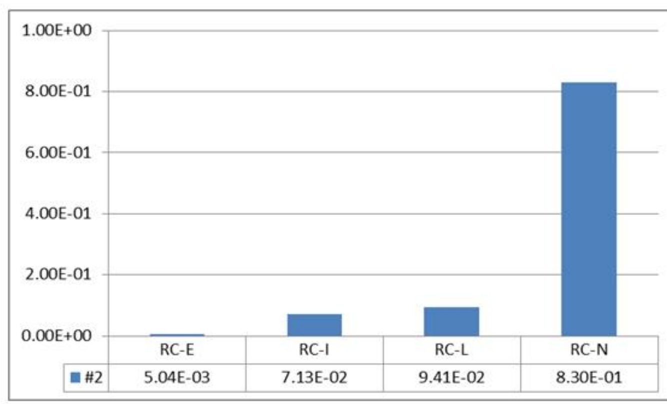
RWST : 0.5

LRV : 0.5

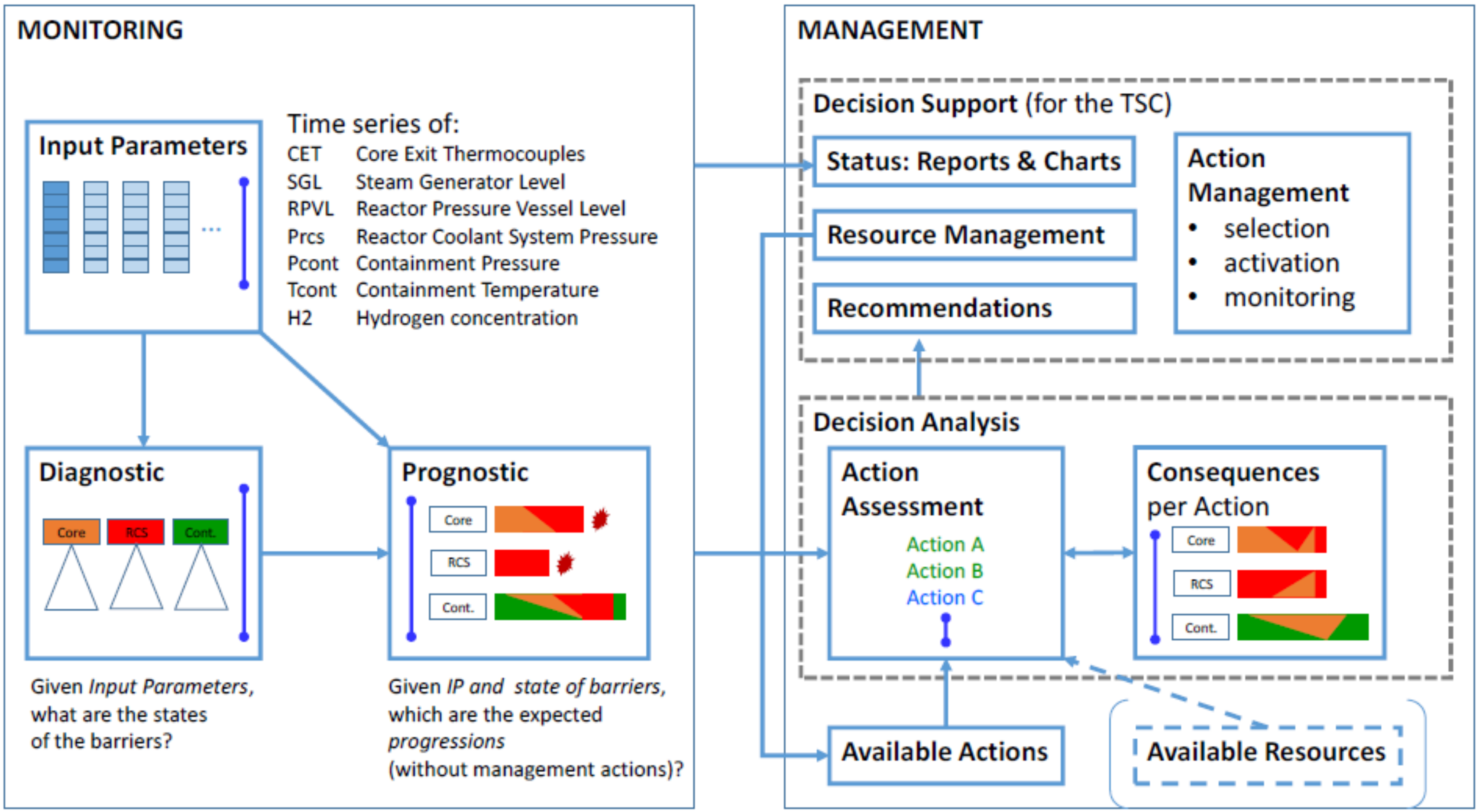
LRC : 1

SP : 1

RCFC : 1



NARSIS: Development of SAMG Supporting Tool (SEVERA)



The End

- Thank You for You attention!