Structure of SAMGs

Joint IAEA-ICTP Essential Knowladge Workshop on
Nuclear Power Plant Design Safety – Updated IAEA Safety Standards 9-20 October 2017

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Overview

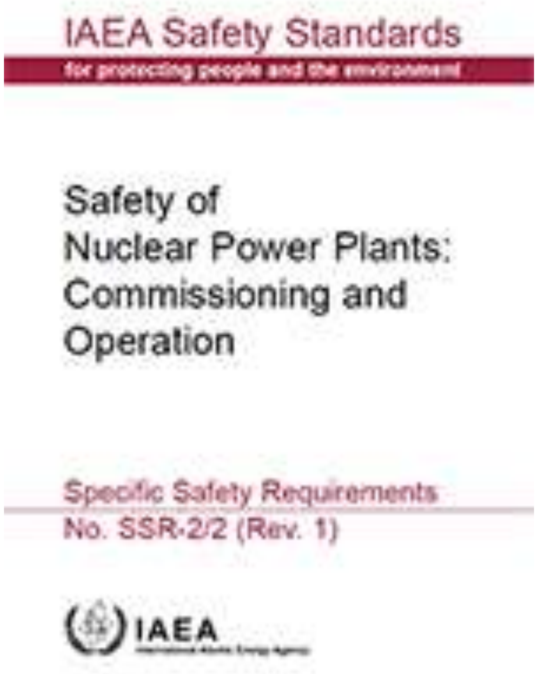
- Introduction
- Examples
  - Generic SAMG Implementation
  - Plant specific SAMG
  - IPE Background
  - Background Documents – Strategies/Setpoints
  - Procedures
  - Conclusions
- Potential Issues from Regulator
- References

AMP in IAEA Standards

APōS

IAEA SSR-2/2, rev.1, Req.#19 Accident Management Programme (para 5.8-5.9)

- The operating organization shall establish, and shall periodically review and as necessary revise, an accident management programme.



- **IAEA SSR-2/1, rev.1, para#2.10: „.. the establishment of accident
- management procedures..”

Fission Products Barrier

- For AM development, it is important to understand the challenges to Fission Product (FP) barriers
- Mitigating strategies may compete for resources, therefore, it is important to establish priorities

An understanding of severe accident phenomena is critical to AM

Core Damage States

OX

- Degraded fuel conditions
- Cladding oxidation significant
- Fuel degradation sufficient to lead to appreciable fuel debris relocation
- Potential for critical fuel configurations

OX = **Ox**idized Fuel

BD

- Degraded fuel conditions with RCS/RPV challenged
- Significant fuel relocation
- Coolability of the fuel geometry degraded

BD = **B**adly **D**amaged core

EX

- Degraded fuel conditions with RCS/RPV lower head breached
- Core debris relocation into containment occurred
- Direct attack of the concrete containment can occur

EX = core **Ex**-vessel

Ref: EPRI Technical Basis Report, 2012, courtesy J. Gabor, ERIN Engineering

Spent Fuel Pool Damage States

SFP-OX

- Degraded conditions
- Cladding oxidation significant
- Fuel degradation sufficient to lead to appreciable fuel debris relocation
- Potential for critical fuel configurations

SFP-BD

- Degraded conditions with challenge to SFP structure
- Significant material relocation
- Coolability of the fuel assembly geometry degraded

Ref: EPRI Technical Basis Report, 2012,
courtesy J. Gabor, ERIN Engineering

Containment Damage States

CC

- Containment intact and cooled

CC = **c**losed and **c**ooled

CH

- Containment challenged
- Appreciable buildup of energy
- Presence of flammable gases in containment

CH = **ch**allenged

B

- Containment bypass
- Direct pathway from RCS/RPV out of containment (e.g. SGTR, ISLOCA)

B = **B**ypassed

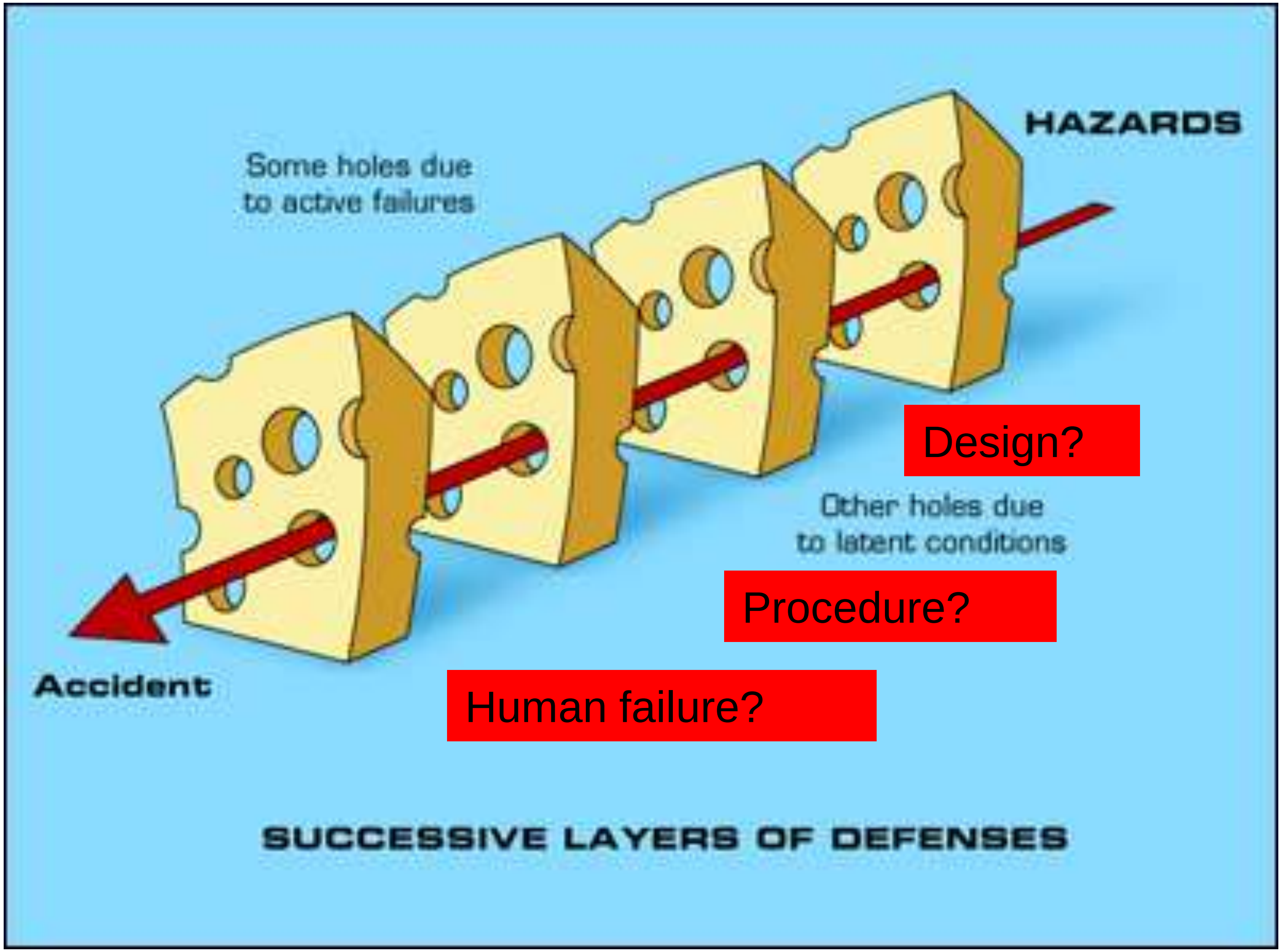
I

- Containment impaired
- Containment isolation failure or some other breach
- Direct pathway out of containment exists

I = **I**mpaired

Ref: EPRI Technical Basis Report, 2012, courtesy J. Gabor, ERIN Engineering

Vulnerabilities?



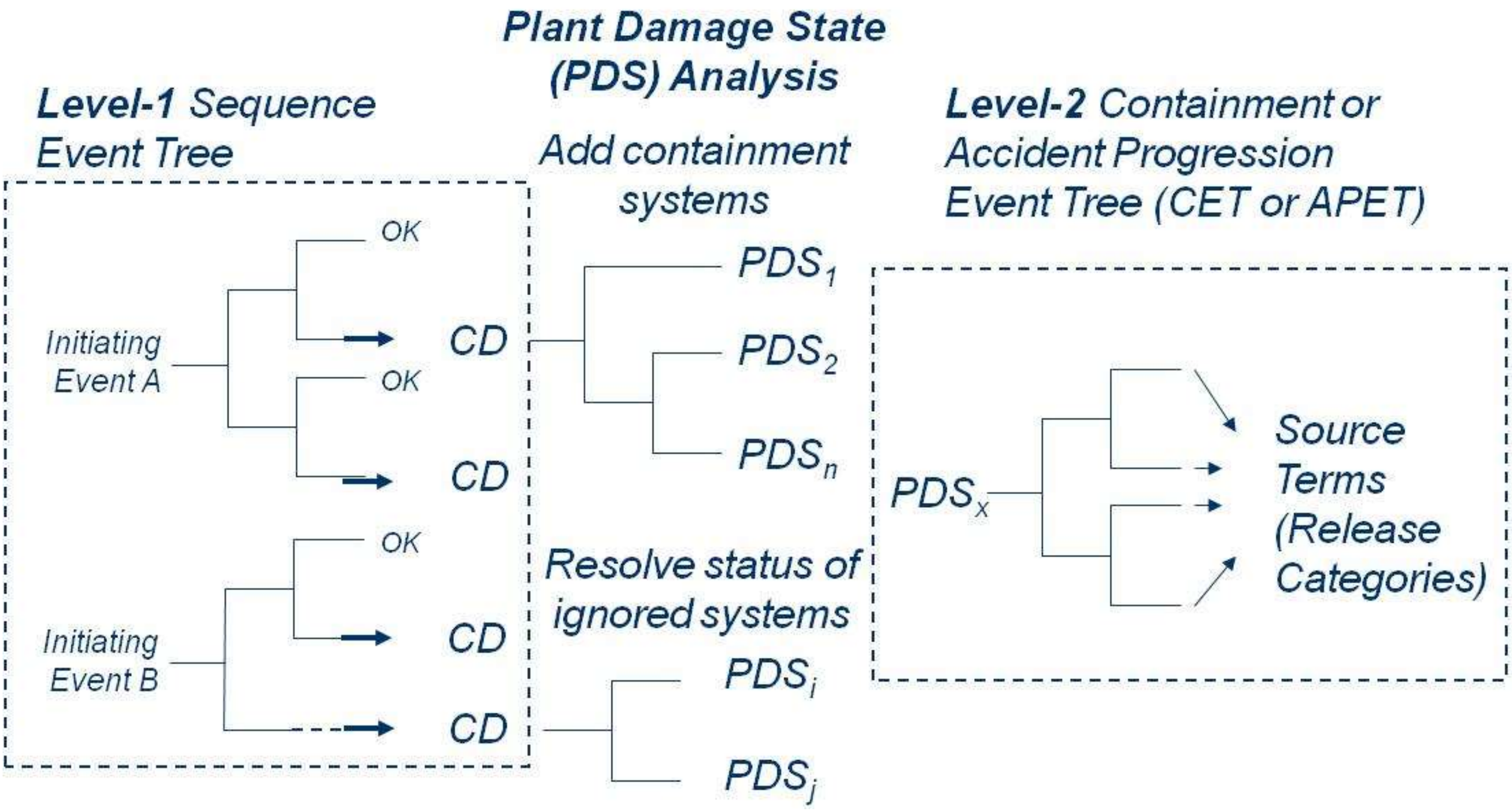
PSA Background

- 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

PSA Level 1 and 2

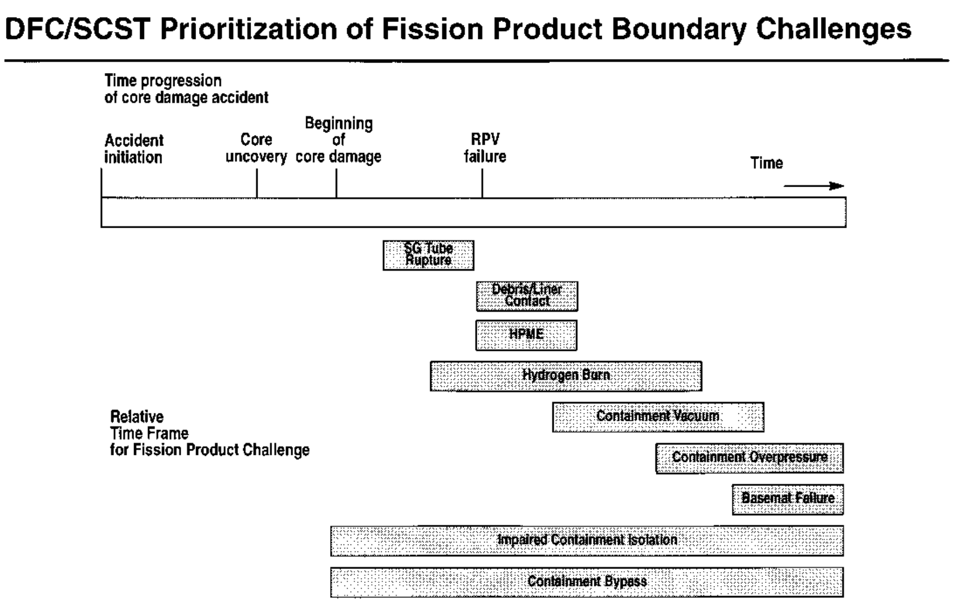
- Plant specific analysis (IPE – Individual Plant Examination) - plant response on Severe accident
  - PSA Level 1:
    - Event Trees and Fault Tree,
    - Core Damage State Evaluation
  - PSA Level 2
    - Containment Event Trees (PDS evaluation)
    - Deterministic analysis capability to simulate severe accidents (MAAP, MELCOR,..

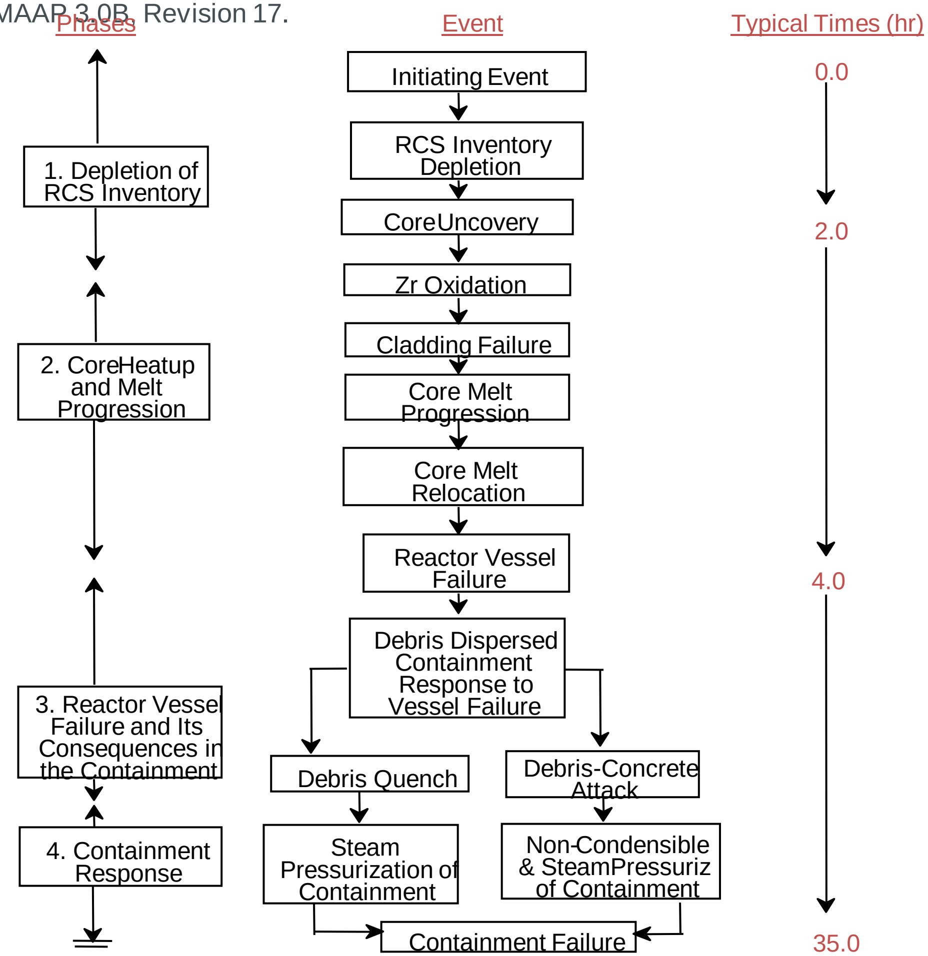
Link Level 1 Results to Level 2



Timing and severity of challenges to the barriers against releases of radioactive material - generic

- The initiating events were selected based on the dominant core melt sequences of a number of IPEs. The time sequence information was obtained from the IPE source term analyses which were performed with MAAP 3.0B, Revision 17.





Relationship between IPE and SAMG

Plant-specific Severe Accident Management insights were developed based on the following:

IPE – Individual Plant Examination

Dominant core damage sequences from Level 1 study have been grouped and assessed following the criteria set out in NUMARC 91-04, Severe Accident Issue Closure Guideline

↓

For beyond 24 hour sequence (loss of SW, loss of CCW, station blackout), insights were developed based on the accident scenarios

↓

The Level 2 results have been grouped into release categories and insights have been derived based on these categories. Also, the phenomenological evaluations have been reviewed to gather additional insights.

Level 1 PSA

Sequences that lead to core damage after 24 hours

Level 2 PSA

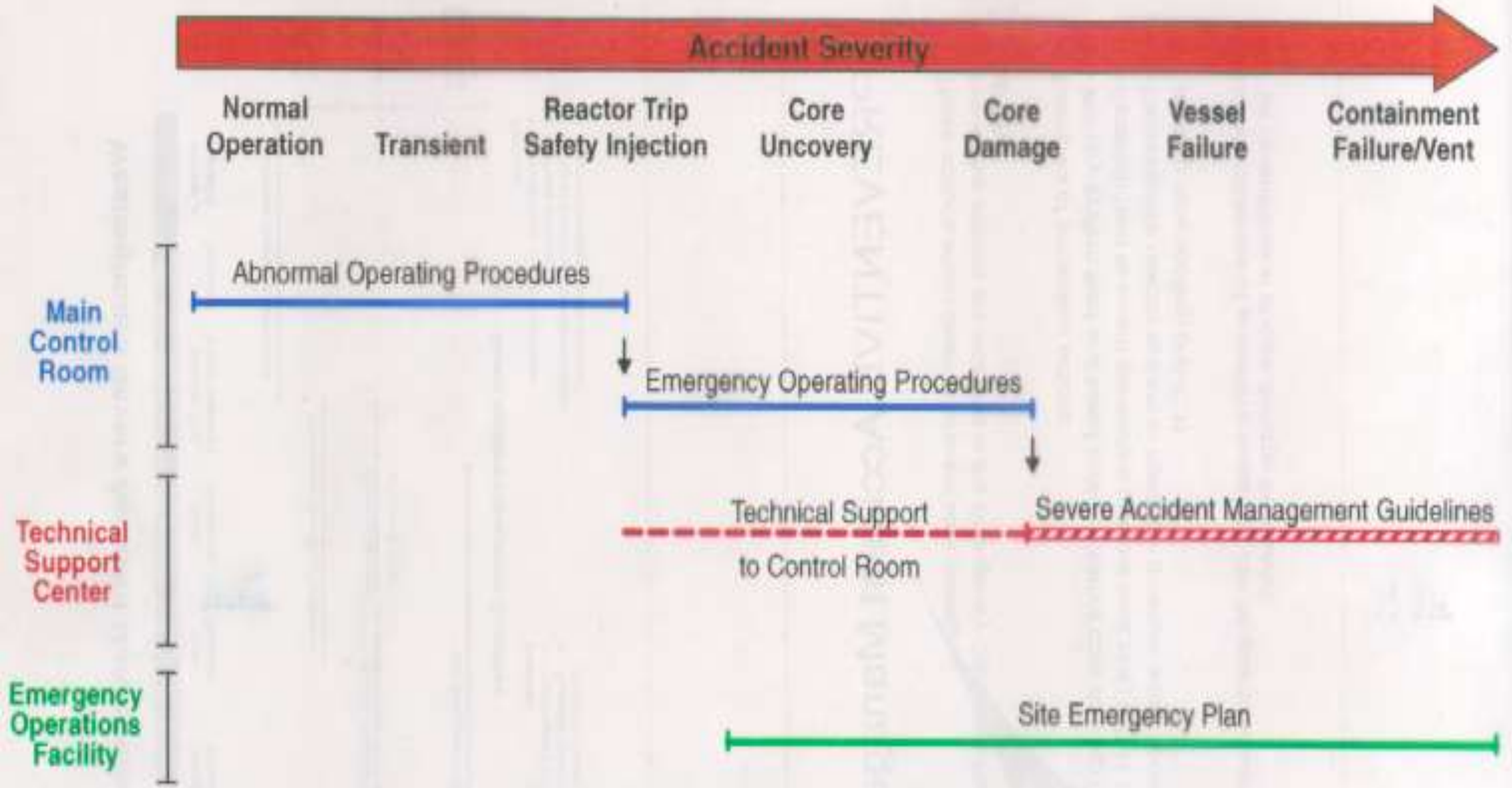
NEK IPE / IPEEE Insights

- Internal events
  - CDF comparable to US plants
  - Risk profile - no outliers
  - Insights - generic for PWR plants (switchover to recirculation, heat sink - AWF / feed & bleed, SGTR - RCS cooldown & depressurization)
- Internal flood
  - Flood zones with dominant risk contribution identified
  - Contribution to Total CDF small

The overall capability of the plant to respond to and recover from an accident situation

Accident Management measures or strategies may be **PREVENTIVE or MITIGATIVE (or BOTH)**

Westinghouse Severe Accident Management



Severe Accident Management Guidelines

Purpose

- Protect fission product boundaries
- Mitigate releases
- Mitigate severe accident phenomena
- Restore controlled stable condition

Features

- Implemented by TSC
- Separate from EOPs
- Symptom based

MITIGATIVE Accident Management

Mitigative actions
- ***mitigate core damage and protect fission product boundaries***
- are included in the *Severe Accident Management Guidelines (SAMG)*

Examples of Mitigative Actions :
- Vent containment (protect containment boundary integrity) (SCG-2)
- Establish feed to steam generators (protect SG tube integrity, scrub releases) (SAG-1)
- Depressurize reactor system (prevent high pressure vessel failure) (SAG-2)

The effectiveness of mitigative measures can be quantified using Level 2 PSA (quantification of fission product release frequency and magnitude)

Accident Management Overview

<table>
<tr><th></th><th colspan="3">ACCIDENT MANAGEMENT</th></tr>
<tr><td>EVENT</td><td>Design basis accident</td><td colspan="2">Beyond design basis accident</td></tr>
<tr><td>OBJECTIVE</td><td colspan="2">Prevent damage to core</td><td>Mitigate effects of core damage</td></tr>
<tr><td>AM TYPE</td><td colspan="2">PREVENTIVE</td><td>MITIGATIVE</td></tr>
<tr><td rowspan="2">Procedure/ guideline</td><td colspan="2">Emergency Operating Procedures</td><td rowspan="2">Severe Accident Management Guidelines</td></tr>
<tr><td>Optimal Recovery</td><td>Critical Safety Function Restoration</td></tr>
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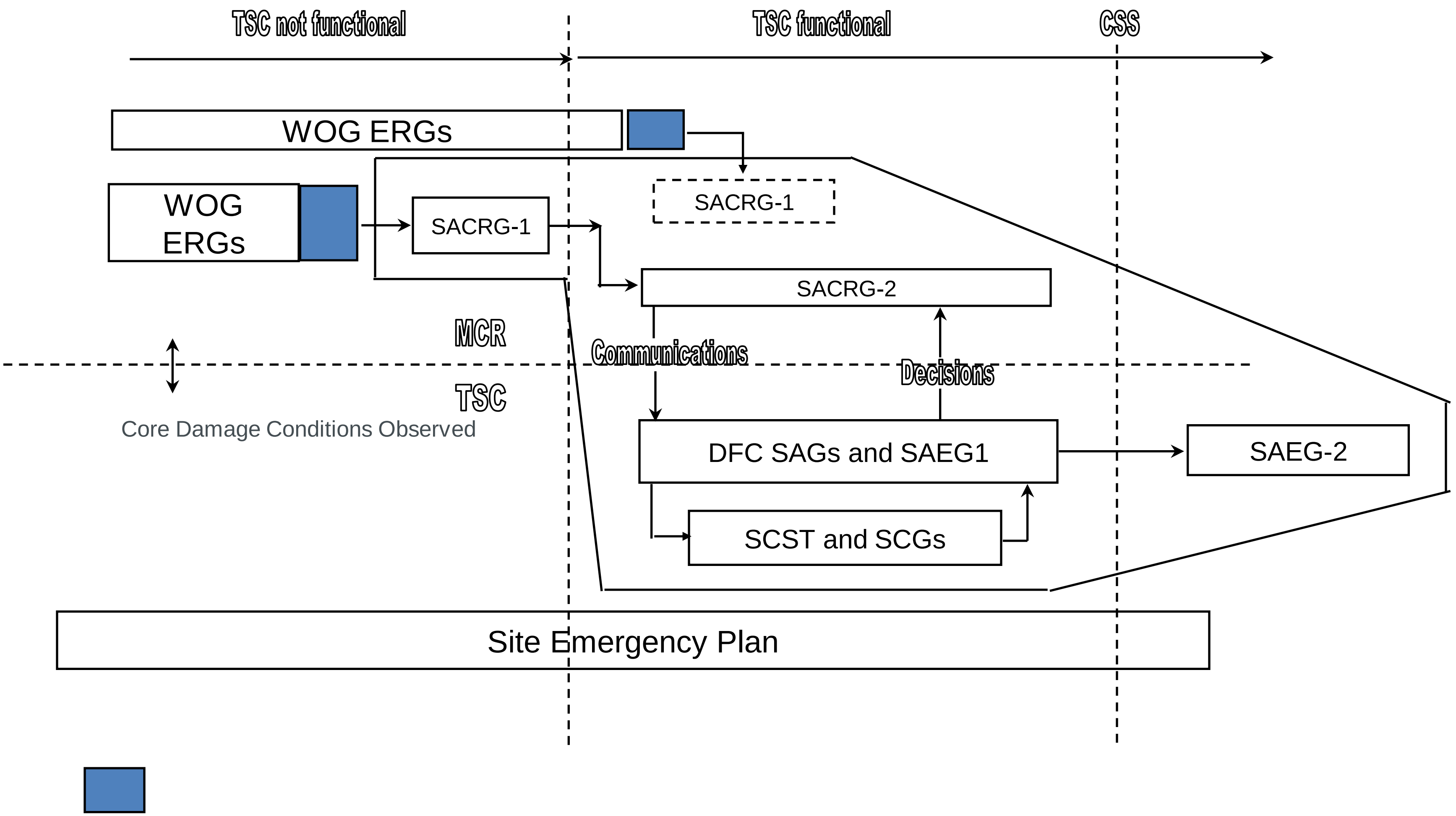
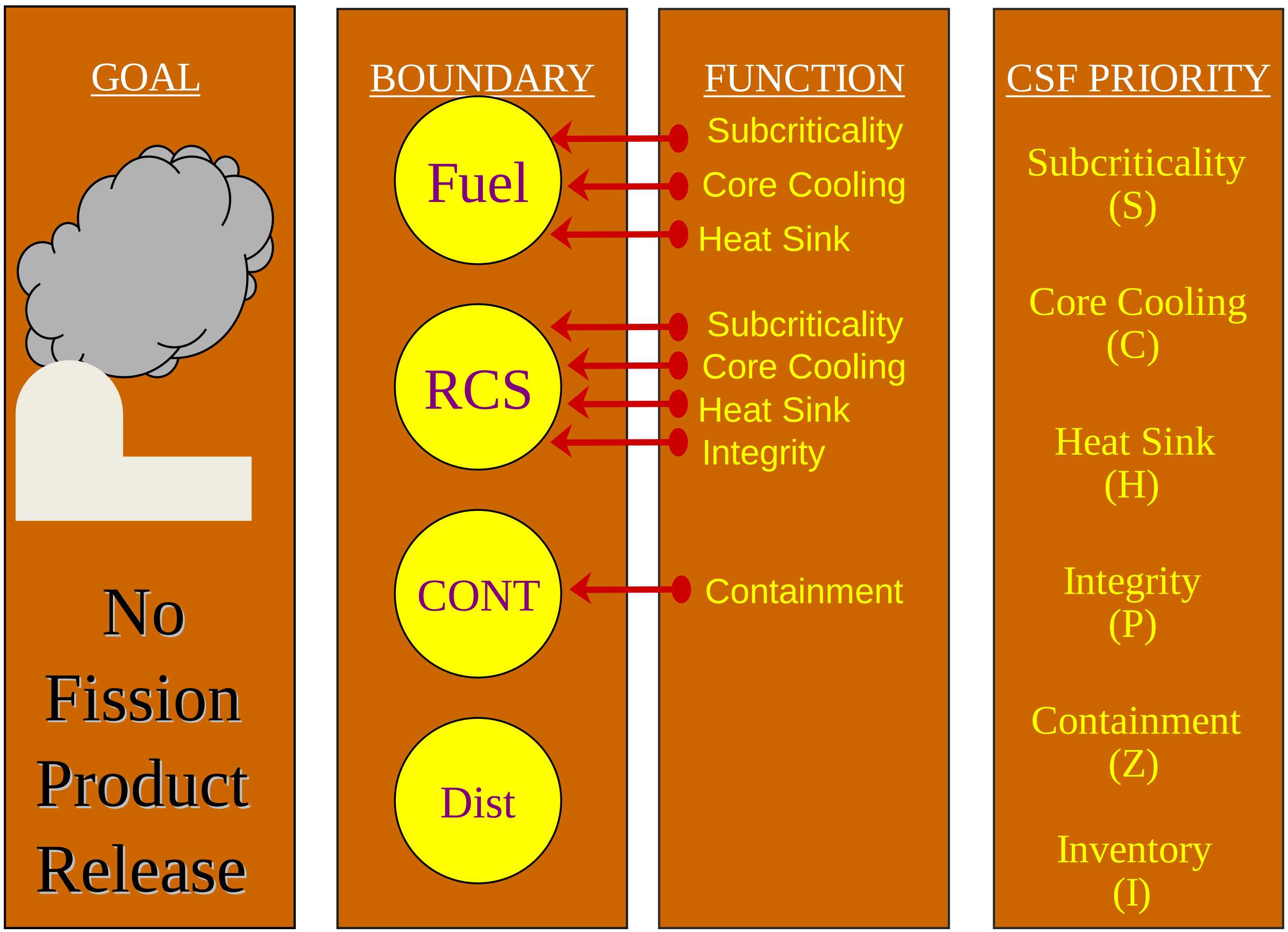
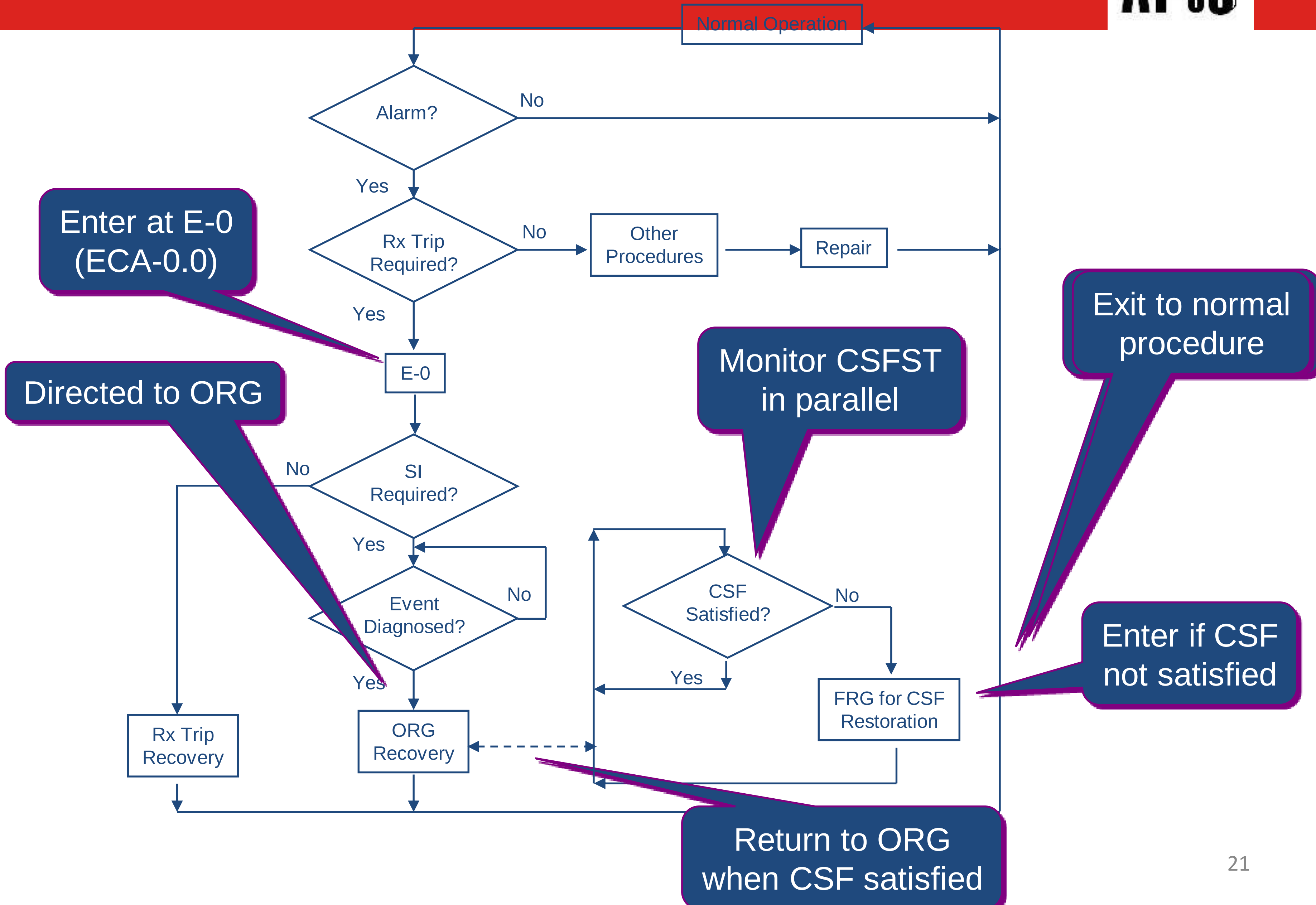
WOG SAMG Structure Interface with ERGs



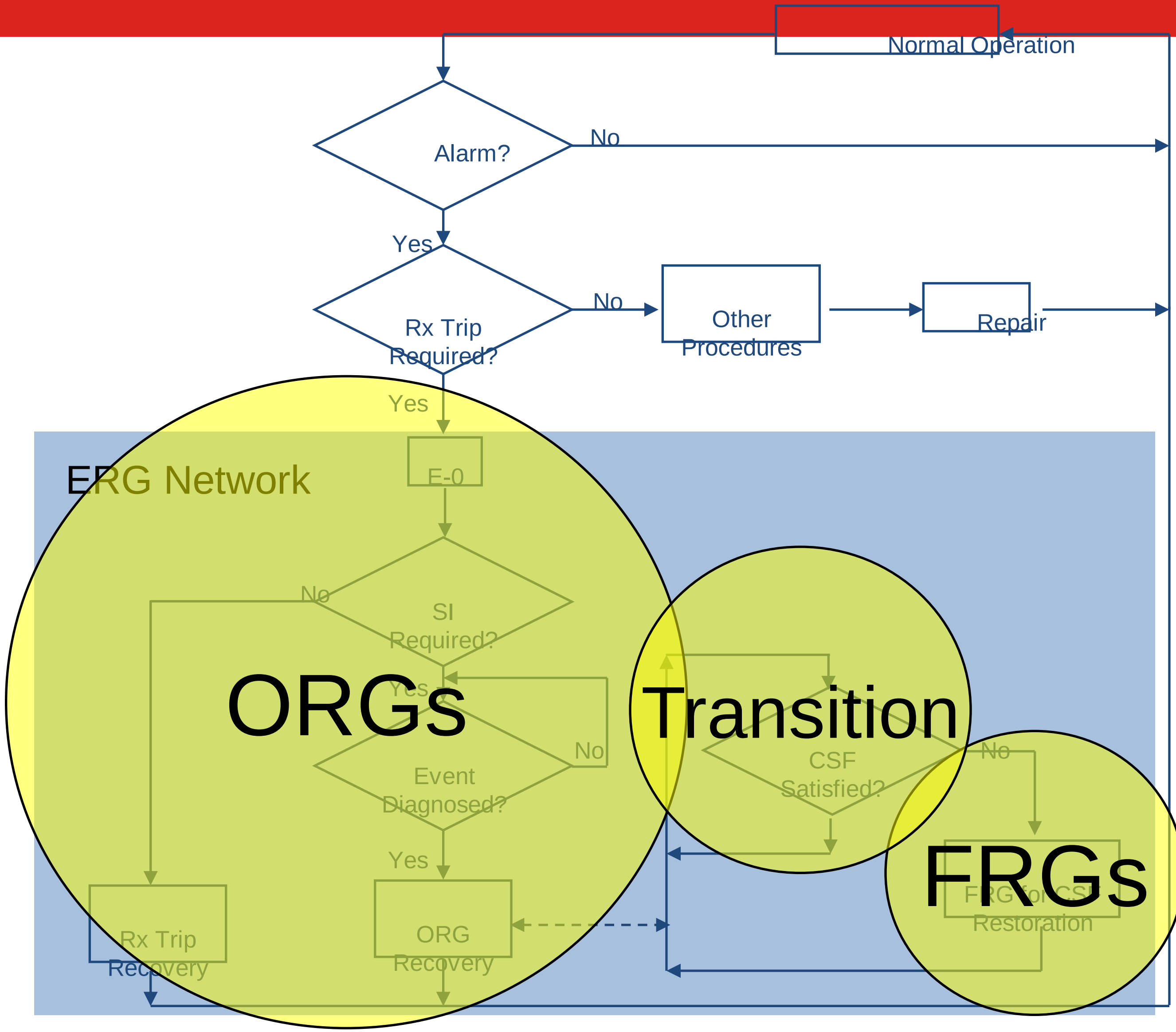
Critical Safety Functions Tree



Emergency Response Guidelines Network



Emergency Response Guidelines Network



SAMG Interface With Emergency Procedures

Base criterion : ERGs are terminated and SAMGs are entered at onset of core damage

- SAMG is a separate document from the ERGs
- No simultaneous usage of ERGs and SAMG

EOP in effect at the onset of core damage must be :

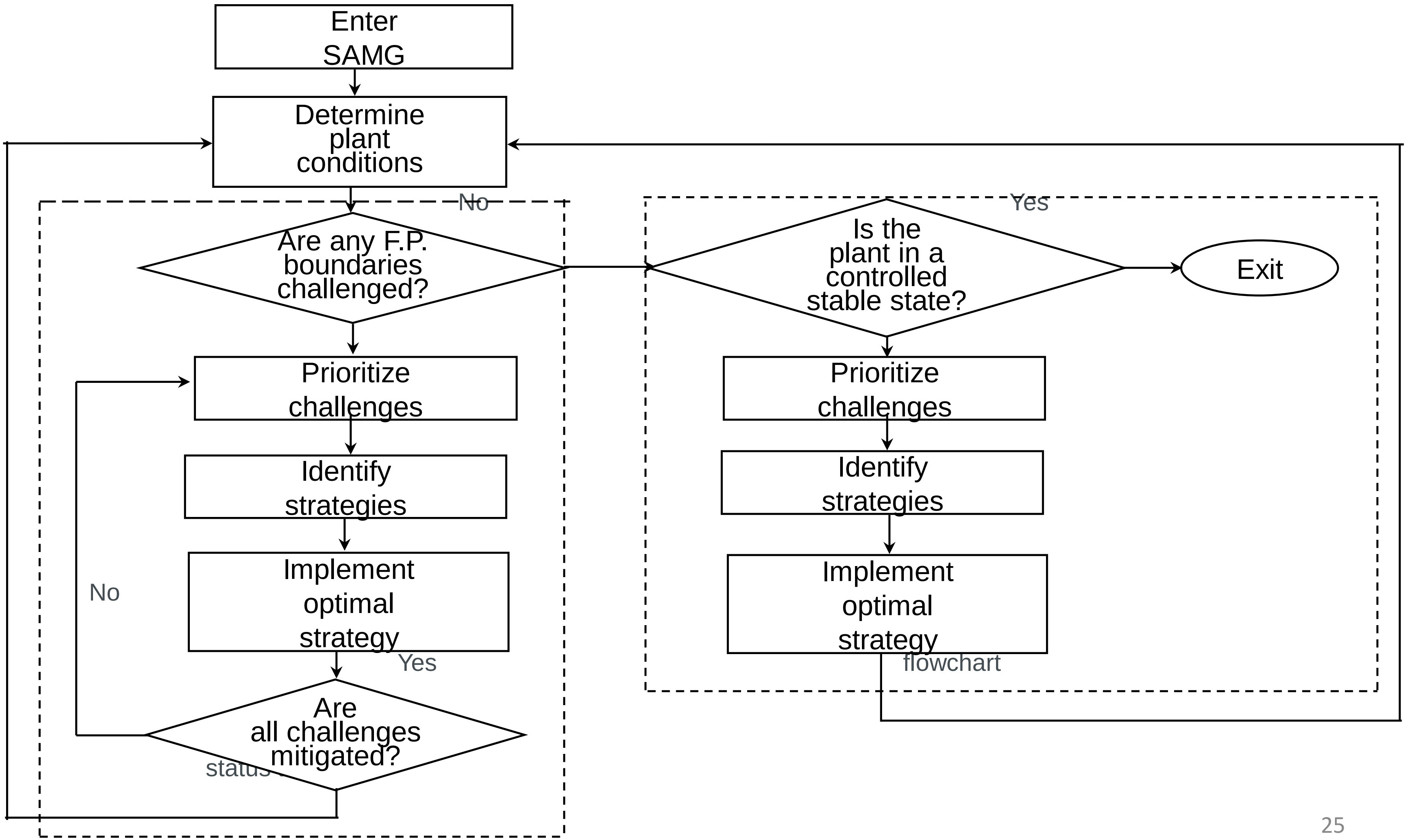
- FR-C.1 (most sequences)
- ECA-0.0 (only accidents with no ac power)
- FR-S.1 (some ATWS events)

Transition to SAMGs based on :

- ⇨ FR-C.1: Core exit temperature > 650 °C, AND all recovery actions have failed
- ⇨ ECA-0.0: Core exit temperature > 650 °C
- ⇨ FR-S.1: Core exit temperature > 650 °C

SAMG Reference Decision Making Process

APoS



SAMG Overview of Components

APoS

Control Room

Severe Accident Control Room Guideline (SACRG-1) Initial Response

Severe Accident Control Room Guideline (SACRG-2) for Transients after the TSC is Functional

Technical Support Center

Diagnostic Flow Chart (DFC)

Severe Accident Guidelines
SAG-1 Inject into the Steam Generators
SAG-2 Depressurize the RCS
SAG-3 Inject into the RCS
SAG-4 Inject into Containment
SAG-5 Reduce Fission Product Releases
SAG-6 Control Containment Conditions
SAG-7 Reduce Containment Hydrogen
SAG-8 Flood Containment

Severe Challenge Status Tree (SCST)

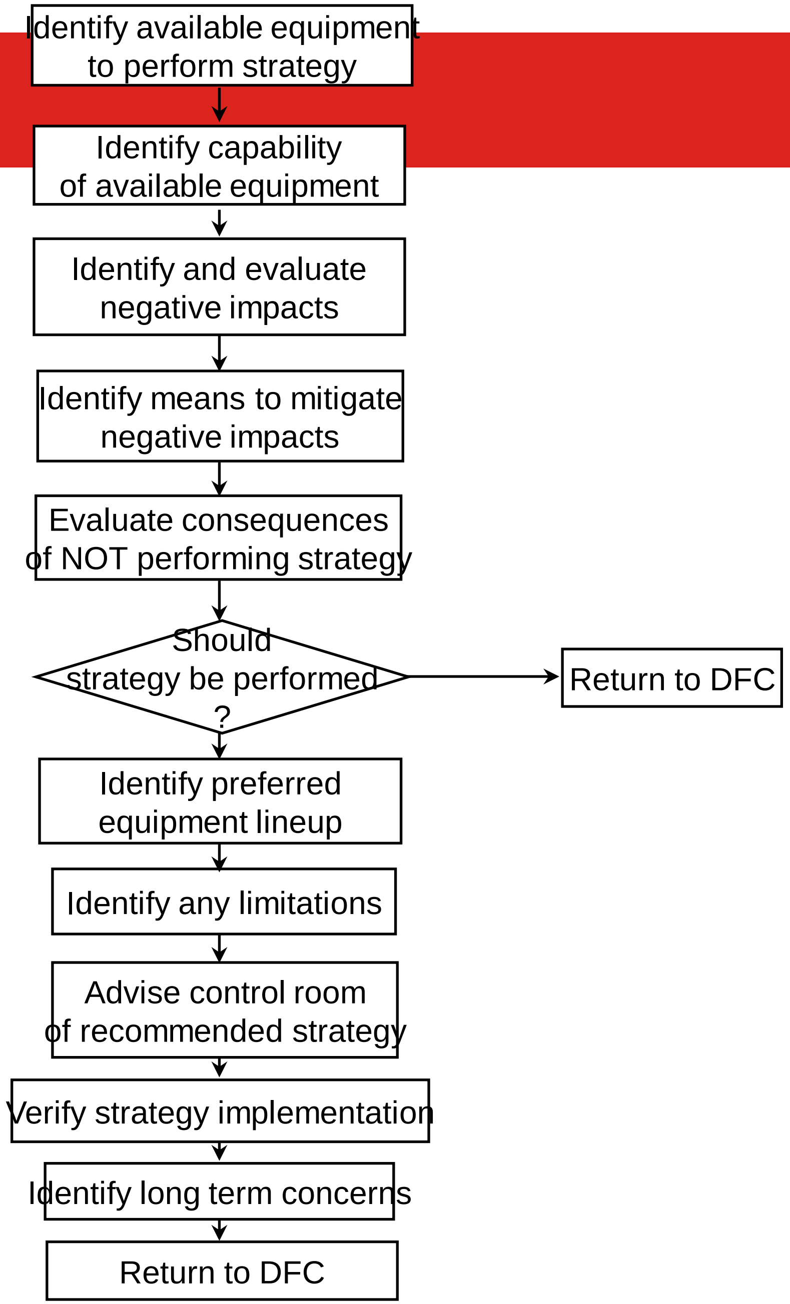
Severe Challenge Guidelines
SCG-1 Mitigate Fission Product Releases
SCG-2 Depressurize Containment
SCG-3 Control Hydrogen Flammability
SCG-4 Control Containment Vacuum

Graphical Computation Aids

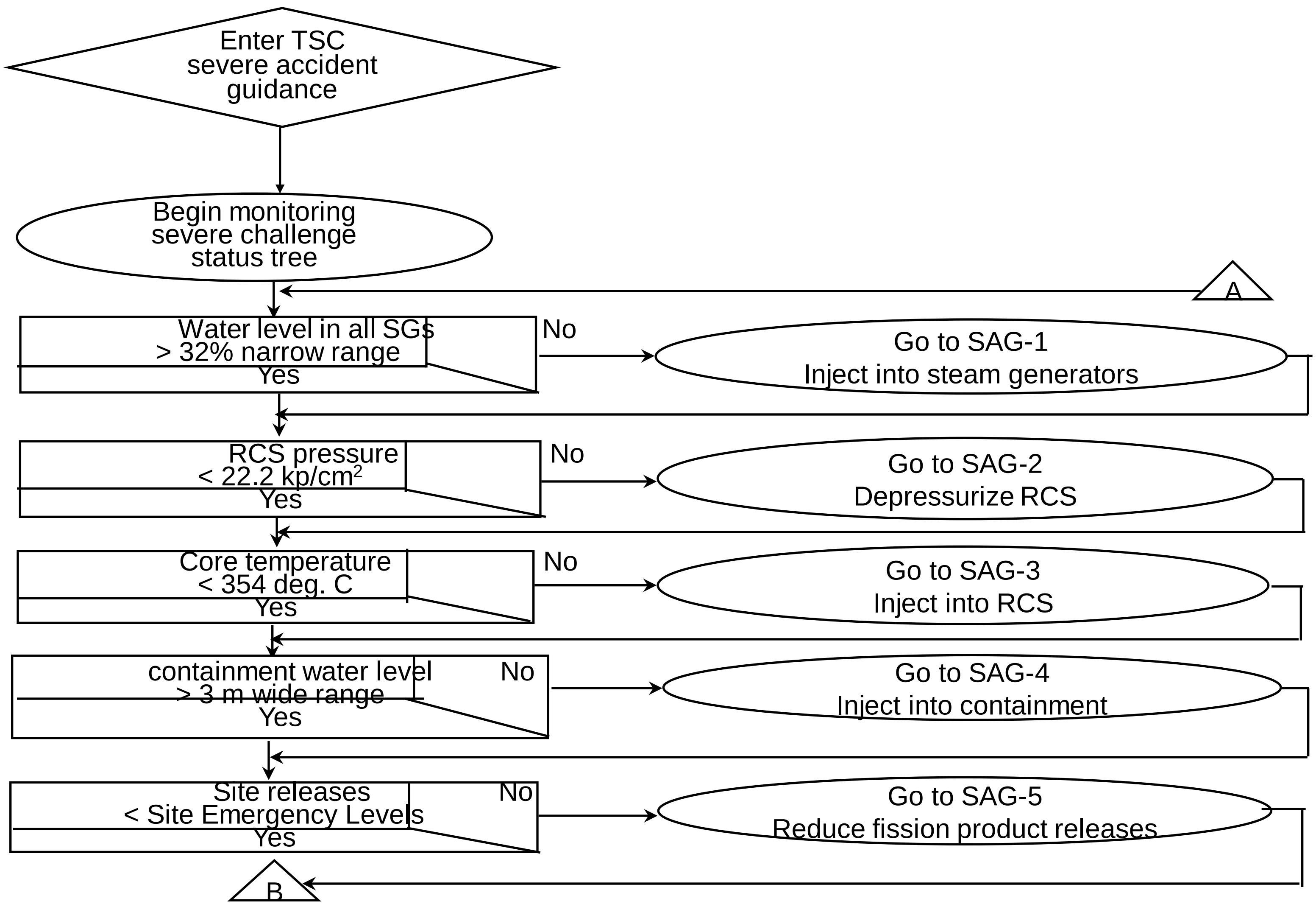
CA-1 RCS Injection to Recover Core
CA-2 Injection Rate for Long Term Decay Heat Removal
CA-3 Hydrogen Flammability in Containment
CA-4 Volumetric Release Rate from Vent
CA-5 Containment Water Level and Volume
CA-6 RWST Gravity Drain
CA-7 Hydrogen Impact when Depressurizing Containment

SAEG-1 TSC Long Term Monitoring Activities

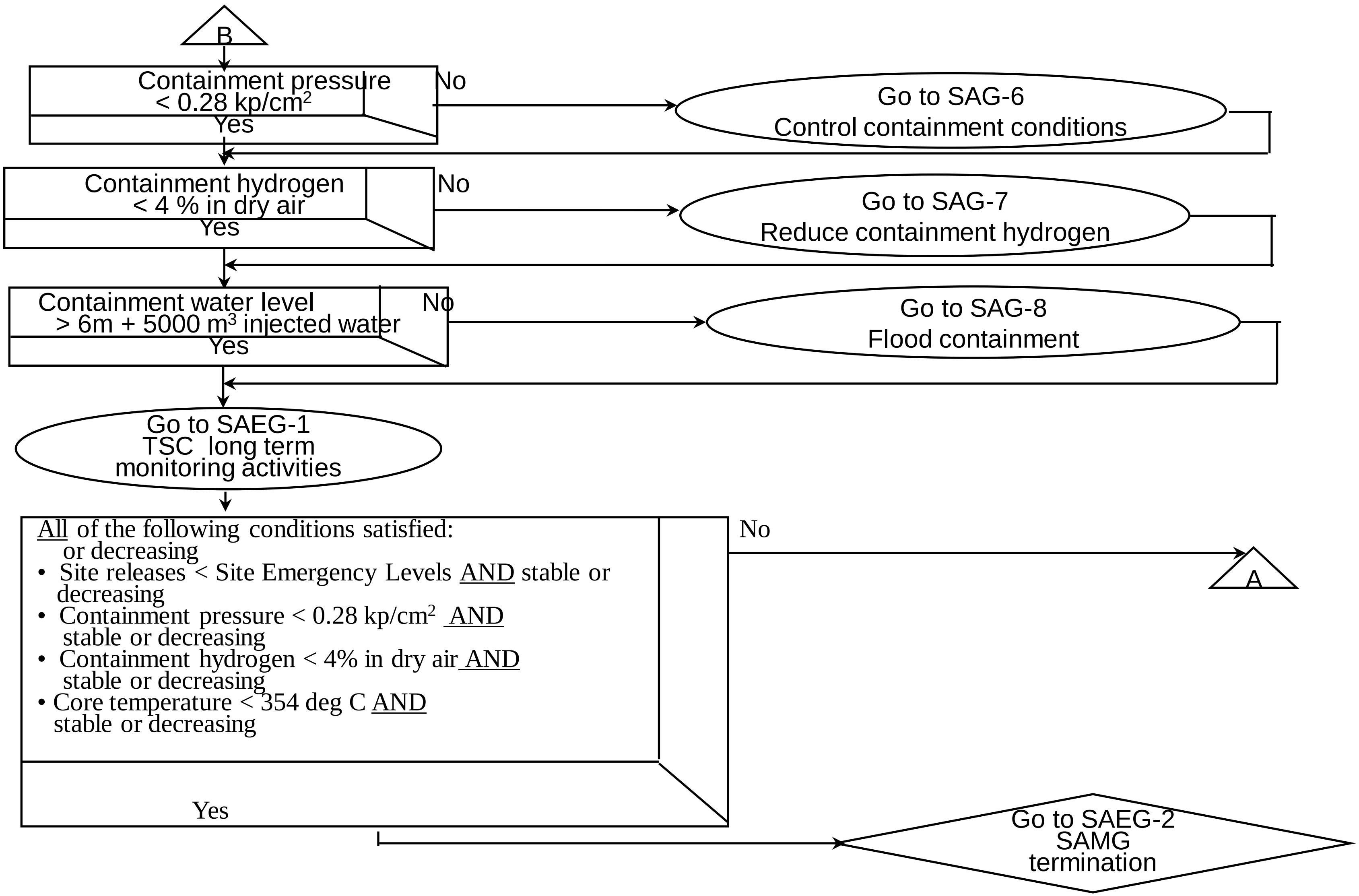
SAEG-2 SAMG Termination


Identify available equipment to perform strategy
Identify capability of available equipment
Identify and evaluate negative impacts
Identify means to mitigate negative impacts
Evaluate consequences of NOT performing strategy
Should strategy be performed ?
Return to DFC
Identify preferred equipment lineup
Identify any limitations
Advise control room of recommended strategy
Verify strategy implementation
Identify long term concerns
Return to DFC

TSC Diagnostic Flow Chart



TSC Diagnostic Flow Chart



Plant specific SAMG

Development of plant specific SAMG can be based on Owner Groups (e.g. PWROG) generic guidelines:

- Generic Strategies defined (an action /set of actions) to be taken; a challenge that is to be mitigated, and the equipment that will be used);
- Many steps needed to developed plant specific procedures (development of plant specific background documentation, procedures, implement required changes in EP,..)

WOG Generic SAMG Implementation

- Review of WOG Generic SAMG applicability;
- Development of plant-specific SAMG setpoint;
- Development of plant-specific computational aids;
- Review of EOPs to incorporate transitions to SAMG;
- Writing of plant-specific control room SACRGs;
- Writing of plant-specific TSC guidance, including SAGs, SCGs, DFC, SCST, and SAEGs;

Background Documents - Strategies

Purposes were:

- Identify if all **generic strategies** are applicable to NEK - can successfully be applied;

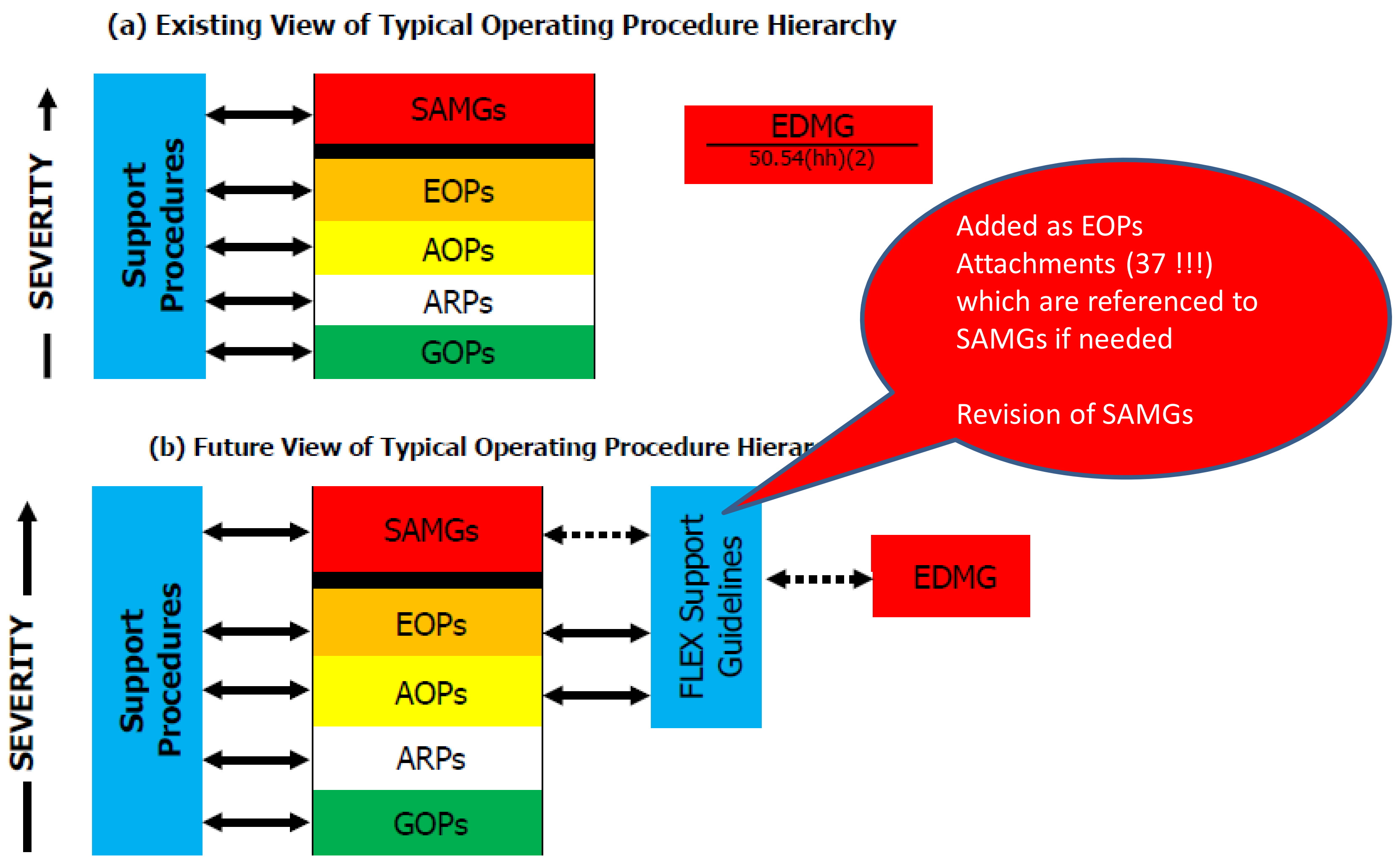
  Accident Management measures or strategies may be PREVENTIVE (delay or prevent core damage) or MITIGATIVE (mitigate core damage and protect fission product boundaries) or BOTH

  SAMG

- Verify if **IPE insights are addressed** in generic strategies;

- Identify the plant **specific capabilities** (equipment that will be used), action to be taken to mitigate the challenge

Implementation of NEI 12-06 (FLEX)



- The Pressurized Water Reactor Owner's Group (PWROG) is in the process of upgrading the generic Severe Accident Management Guidelines (SAMGs)
  - Phase I (completed 2013): Each vendor generic SAMG was upgraded to include key Fukushima lessons learned that could be included without unnecessary delay
  - Phase II (completed 2015): Integration of the three vendor generic SAMGs into one generic Pressurized Water Reactor (PWR) SAMG

- Phase I Scope: Update the three individual vendor generic SAMGs to include updates from the Electric Power Research Institute (EPRI) Technical Basis Report (TBR) update
  - Addition of Spent Fuel Pool (SFP) SAMG
  - Addition of Aux. Building Ventilation Strategies
  - Guidance related to the use of Raw Water (e.g., saltwater, river water, dirty water, etc.)
  - Guidance related to containment venting

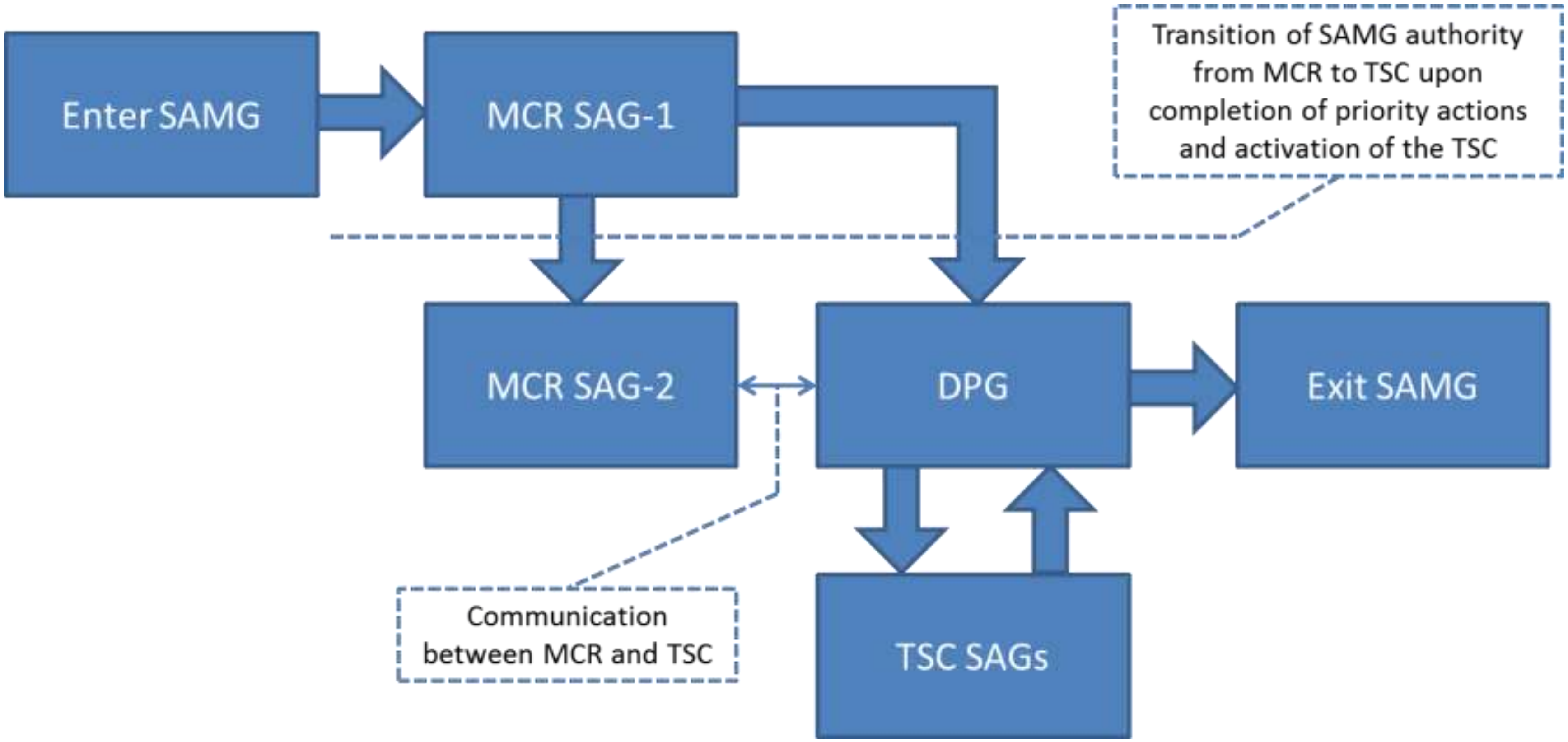
Insights from Development of the Combined PWR SAMG

- Phase II Scope: Develop a common generic PWR SAMG includes the best features of the three individual SAMG products
  - Provides consistency for Nuclear Regulatory Commission (NRC) oversight
  - Provides efficiency for future updates
  - Provides effective basis for sharing plant-to-plant experience and assistance
- Phase II scope includes
  - Generic Guidelines
  - Generic Training
  - Generic Validation
  - Generic Scenario Templates

Insights from Development of the Combined PWR SAMG

- The generic PWR SAMG includes a number of enhancements not in the Phase I generic SAMGs
  - Enhanced integration with other procedures and guidance
    - Transitions between Emergency Operating Procedures (EOPs), Extensive Damage Mitigation Guidelines (EDMGs), FLEX Support Guides (FSGs)
    - Common handbook of accident management capabilities
  - Review of Boiling Water Reactor Owner's Group Severe Accident Management products
    - Instrumentation guidance
  - Attention to NRC identified deficiencies
    - Multi-unit events
    - Decision-maker guidance
  - Feedback from drills and exercises based on the existing SAMGs, including:
    - Additional guidance for delayed Technical Support Center (TSC)
    - Simplification of some knowledge based decisions to prevent paralysis
  - Guidance for a severe accident originating from plant shutdown conditions

Insights from Development of the Combined PWR SAMG



Insights from Development of the Combined PWR SAMG

- Additional Main Control Room (MCR) guidance was added to the SAMGs to include priority actions that should be done for all severe accidents
  - Inject water into the steam generators
  - Depressurize the Reactor Coolant System (RCS)
  - Inject water into the RCS
  - Inject water into containment

- Once the priority actions are performed, the MCR will determine if the TSC has been activated

- Additional MCR guidance was added for the time period after the TSC has been activated
  - Provide feedback to TSC on knowledge from MCR

- Some of the major changes to the TSC guidance include:
  - A Diagnostic Process Guideline (DPG) that directs the TSC to a specific guideline for each critical plant parameter
    - Multiple color-coded thresholds for each parameter allows for a prioritization of actions based on plant conditions
  - Step-wise guidance in each guideline
    - Identify evaluation and implementation price
    - Rule-based priorities and preferred methods where appropriate
    - Increased evaluation bases
    - Simplified Computational Aid usage

Insights from Development of the Combined PWR SAMG

Highest Priority

DATE:________ TIME:________		RED	ORANGE	YELLOW	GREEN	TREND (Circle One)
SG Level	Setpoint		LESS THAN L01		GREATER THAN L01	↑ STABLE ↓
Go to SAG-1	Actual					
RCS Pressure	Setpoint		GREATER THAN P02		LESS THAN P02	↑ STABLE ↓
Go to SAG-2	Actual					
Core Temperature	Setpoint		GREATER THAN T01		LESS THAN T01	↑ STABLE ↓
Go to SAG-3	Actual					
Containment Water Level	Setpoint		LESS THAN L02	BETWEEN L02 and L04	GREATER THAN L04	↑ STABLE ↓
Go to SAG-4	Actual					
Containment Pressure	Setpoint	GREATER THAN P01	BETWEEN P01 and P03	LESS THAN P04	BETWEEN P03 and P04	↑ STABLE ↓
Go to SAG-5	Actual					
Containment Hydrogen Concentration	Setpoint	GREATER THAN H01		BETWEEN H01 and H02	LESS THAN H02	↑ STABLE ↓
Go to SAG-6	Actual					
Site Release Level	Setpoint	GREATER THAN R01	BETWEEN R01 and R02		LESS THAN R02	↑ STABLE ↓
Go to SAG-7	Actual					
SFP Water Level	Setpoint		LESS THAN L03	BETWEEN L03 and L05	GREATER THAN L05	↑ STABLE ↓
Go to SAG-8	Actual					

Lowest Priority

Insights from Development of the Combined PWR SAMG

- To ensure a systematic and logical method of severe accident mitigation, the basic format of the Westinghouse Severe Accident Guides (SAGs) has been chosen for the PWR SAMG

- To facilitate rapid response, a set of immediate priority actions are executed at the onset of a severe accident

- The evaluation bases scope and level of detail are being increased
  - Various tools are being developed to facilitate rapid decision making

Insights from Development of the Combined PWR SAMG

- The Phase I SAMG update incorporated Fukushima lessons learned into the three vendor specific SAMGs without significant modification to their format

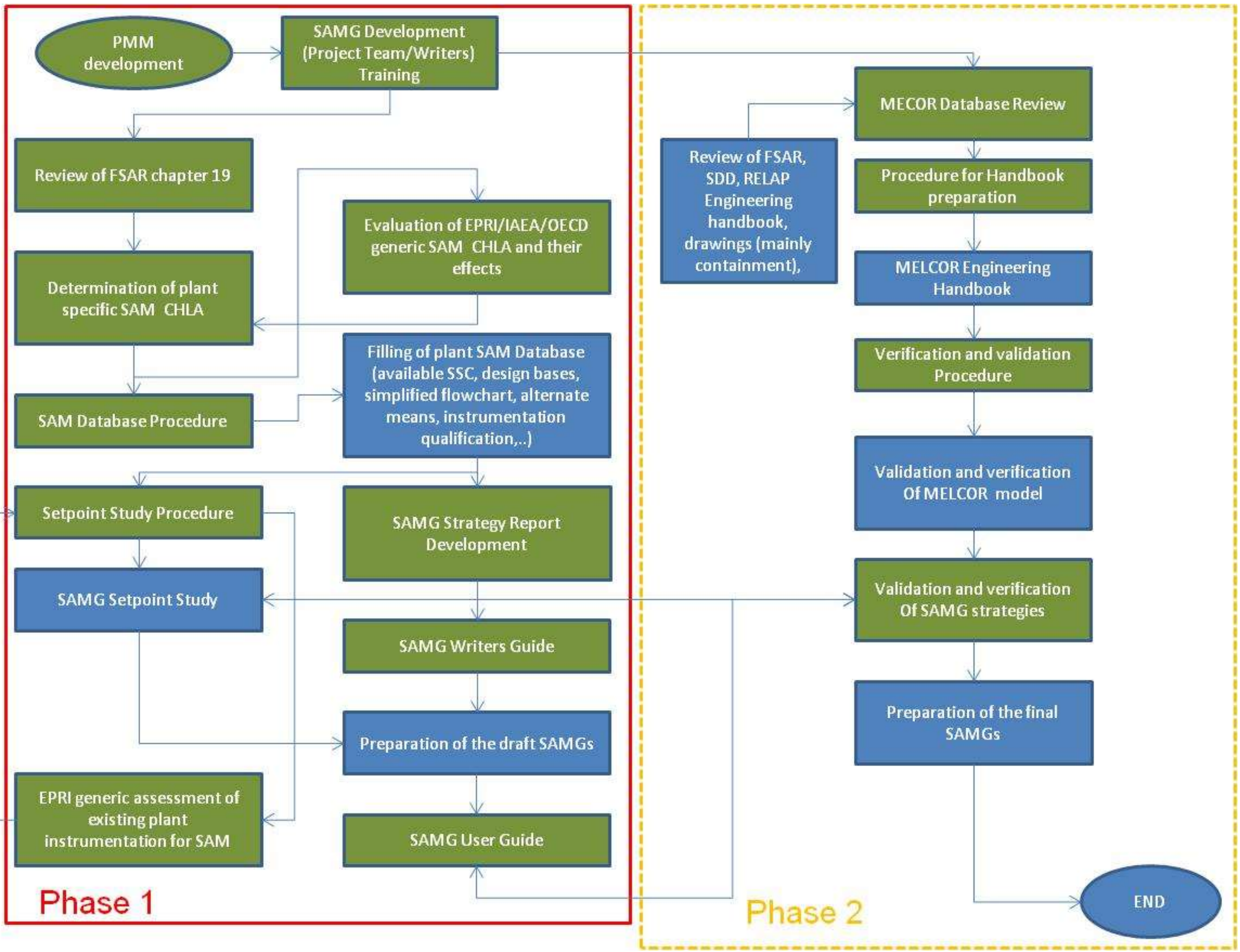
- The Phase II product, i.e., the PWR SAMG, combines the three PWR vendor's generic SAMGs into a single generic SA mitigation methodology that will further improve SA management

Conclusions

Development of plant specific SAMG should cover:

- The current worldwide state of the art in severe accident research including experimental and analytical efforts;
- Plant specific capabilities (structures, systems, components) and strategies assessment including FLEX capability NEI 06-12;
- Generic and specific PSA insights assessment;
- However, even **that certain changes and revision of SAMGs and SEOPs were introduced by post Fukushima WENRA stress tests evaluations**
  - **PARs, PCFV, new ECR, additional LP SIS pump, mobile RHR HX (MHX), etc**

Option without PSA Level 2 and Deterministic Severe Accident Analyses



Option without PSA Level 2 and Deterministic Severe Accident Analyses

- There is no need to cope with generic format (AREVA, Westinghouse, GE, etc.)
  - SAMGs are guidelines not procedures
  - Guidelines could be given in the format of logical symptom oriented diagrams with associated tables (advantages vs. disadvantages of mitigative measures)

- Evaluation of already identified and documented generic severe accident management candidate high level actions (CHLA) strategies and mitigate system/structure/component (SSCs) (based on OECD, IAEA and EPRI Severe Accident Management Guidance Technical Basis Reports (TBR) in comparison with subjected NPP design, available SSCs and its applicability

Option without PSA Level 2 and Deterministic Severe Accident Analyses

- Definition of transition
- SAMG for MCR (should be similar to FR-C1)
- SAMG for Spent Fuel Pool (not available in generic SAMG, important issue from Fukushima point of view)
- SAMG for shutdown (e.g. loss of SRH on mid-loop operation)
- Alternative means (mobile equipment FLEX) usage:
  - Different fire protection pumps
  - Fast connections to the systems (e.g. injection into SGs)
  - Source of waters (e.g. amount for flooding the containment to protect cavity floor from MCCI OR even flooding the Rx cavity to the top of acctive fuel to establish external cooling)

APoS

Supporting Accident Analysis (generic & plant specific)

- **Generic Severe Accident evaluation were performed for pilot (reference) plant** not directly applicable for every plant (usually no sensitivity runs and modeled actions) . The **WOG SAMG** reference plant is basically a **4-loop HP** plant with system design features similar to current **Westinghouse-design plants** (mainly SNUPPS).

- E.g. in determining the actions which should be taken in generic SACRG-1, the consideration is limited to those actions in the **first "hour" after core damage** has begun for **large LOCA events** and **ATWS events**. Information from IPEs and generic severe accident analyses for large LOCA and ATWS core damage accident sequences provides the basis for defining the challenges to the containment fission product boundaries during this time frame.

Supporting Accident Analysis (generic & plant specific)

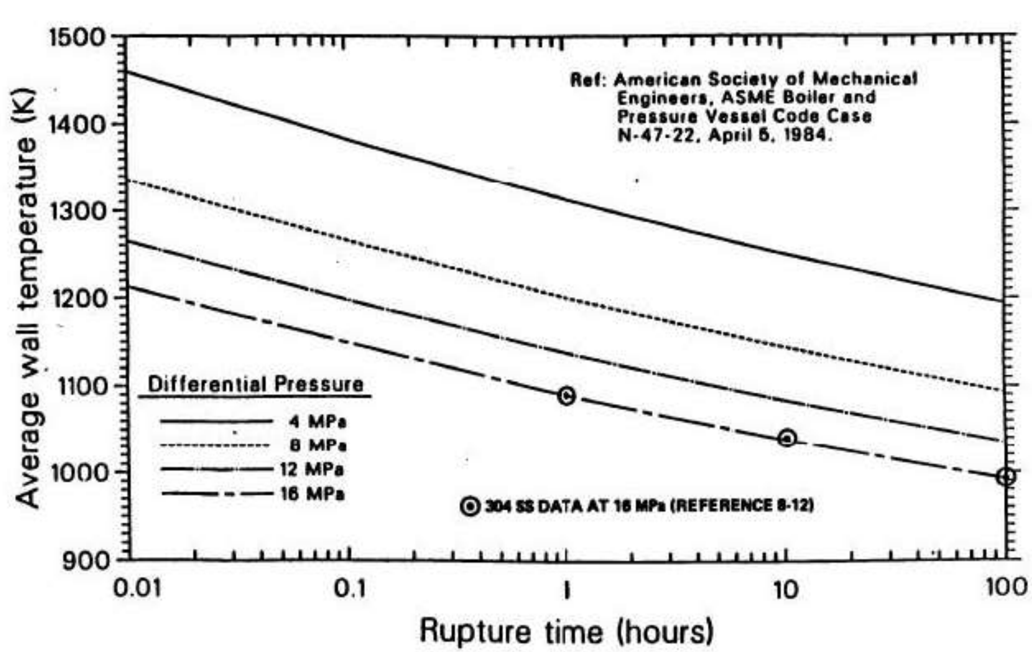
- **Generic Severe Accident evaluation** (e.g. WOG Background for SAG1 „Inject to SG") is often just referred to analysis documented in **EPRI TBR**: „2.2.3 Creep Rupture of SG Tubes", „The TBR contains an appendix (**Volume II, Appendix I**) discussing **the creep rupture of RCS components during a severe accident.** **Figure I.2** of this appendix provides the relationship between tube temperature, RCS-SG differential pressure, and the time until tube rupture for Inconel 600 SG tubes in an as-fabricated state. Plant Specific analyses (either by MAAP or MELCOR, etc.) provide the flexibility for sensitivity cases:
  - Changing the input file the parameters related to the creep failure (either for SG u-tubes, RPV or HL pipe) can be changes and analysis profile and time sequence compared

MAAP 4.0.5 model of creep failure is based on observation of Larson-Miller parameter:

$$LMP=T_R(A+\log_{10} \times t_{rh})$$

Where:

- LMP = Larson-Miller parameter
- T_R = temperature (K)
- t_{rh} = rupture time (hours), and
- A = best fit parameter, different for each material



Average Wall Temperature vs. Time for Hot Leg Pipe Creep Rupture (Larson-Miller Correlation)

Deterministic Analysis of Severe Accidents Phenomena – example CREEP failure and influence on SAMG

Analysis	HL pipe	SG Pipe	
	HL temperature > 1100K	Time with T> 850K	Time with T > 1100 K
Seabrook			
Base Case	N/A	< 10 min	N/A
No core blockage	> 30 min	> 40 min	< 10 min
Loop seal clear	N/A	< 10 min	N/A
Ringhals			
Base Case	N/A	N/A	N/A
No core blockage	N/A	N/A	N/A
Delayed RV failure	> 10 min	N/A	N/A

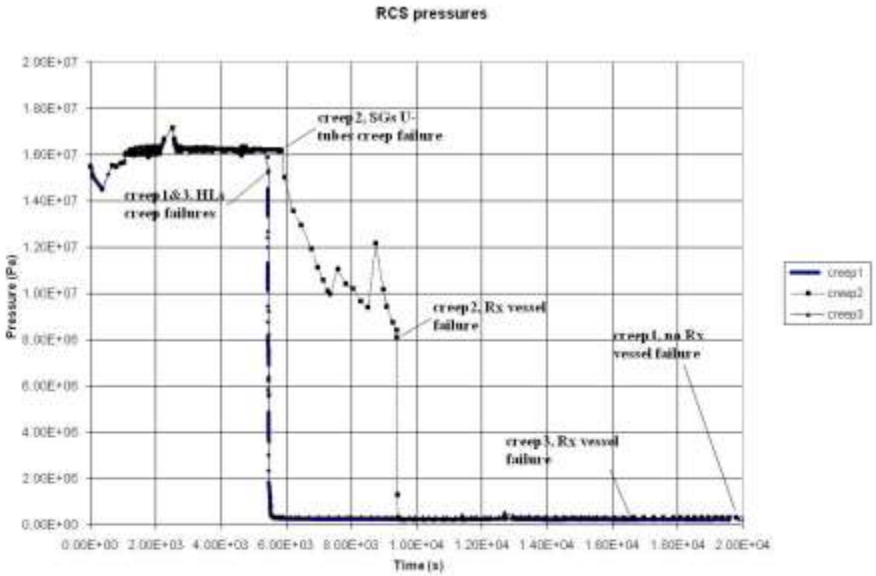
Deterministic Analysis of Severe Accidents Phenomena – example CREEP failure and influence on SAMG

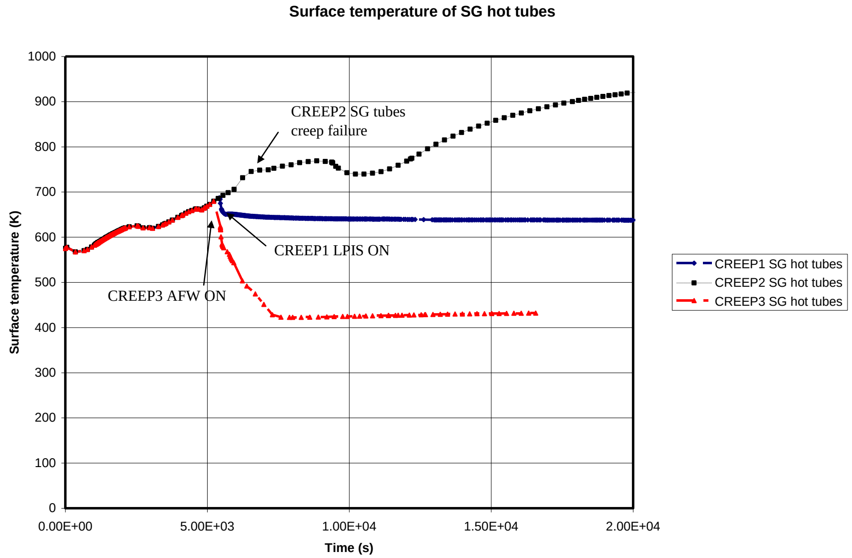
Analyses of 3 LOAF cases:

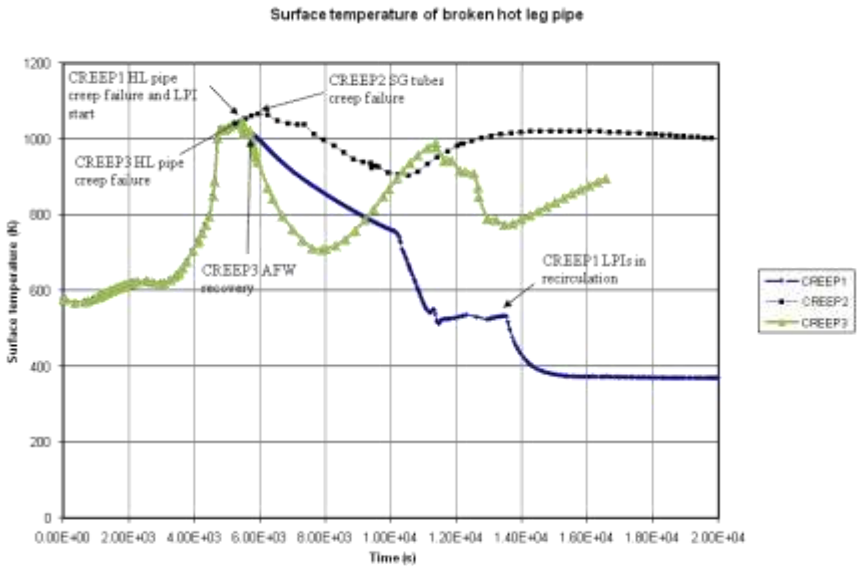
- LPI recover just before HLs creep failure (CREEP1)
- HLs creep failures prevented by user intervention (CREEP2)
- user intervention to favorize SG tubes creep failure, recovery of AFW (CREEP3)

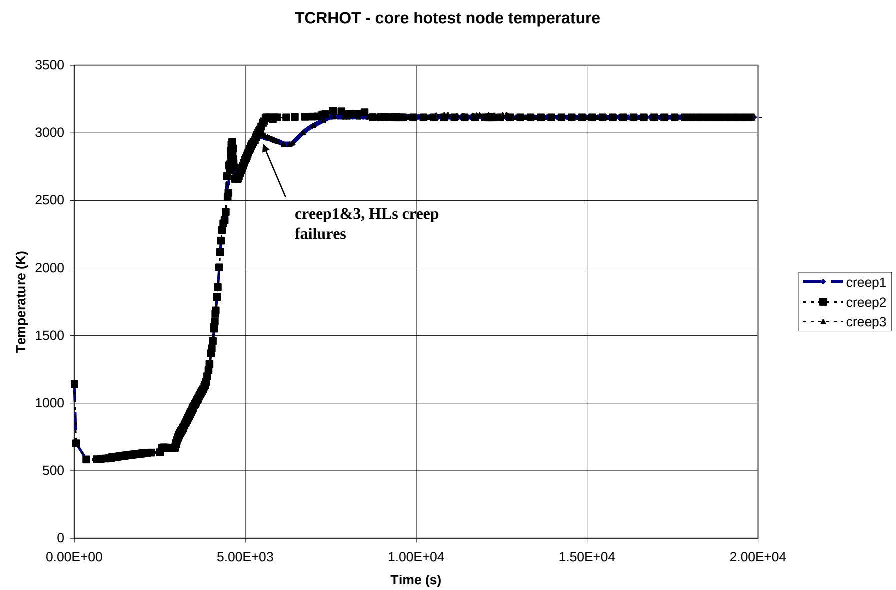
Deterministic Analysis of Severe Accidents Phenomena – example CREEP failure and influence on SAMG

APoS









Potential Questions from Regulator

Availability of important support functions as well as possibility of their restoration

- AC/DC capability for essential SSCs and critical safety function should be assesed together with possible alternatives (existing alternative sources + portable devices + FLEX connection)
  - Special attention to diagnostic instrumentation
- Water sources for makeup of SG and RCS should be evaluated togetger with alternative paths and sources for prolonged severe time window (4h, 24h, 72h...)
  - Special attention for long term cooling of RCS and containment
- Compressed Air for essential valves necessary for establishment of critical safety function
  - Special attention for containment isolation valve or PRZR PORV and SG PORVs

Potential Questions from Regulator

Plant initial operating mode, as accidents can develop in operating modes where one or more fission product barriers could already be lost at the beginning of the accident;

- At begining of transient MCR is ,due to degraded fission barriers, is in SEOP FRPs (typicaly FR C-1 and with CET above 650degC transfered to SACRG
- When TCS become operable – switch to SAMG
- SAMGs are guidelines not procedures – few SAMGs can be executed in paralel
  - DFC and SCST should be monitored: when one of fission product barrier is lost one prioritized SCG is executed according to User Guide

Potential Questions from Regulator

Adequacy of a strategy in the given domain; Some strategies can be adequate in the preventive domain, but not as relevant in the mitigatory domain due to changing priorities

- SAMGs are guidelines not procedures and for each strategy the positive and negative aspects should be carefully assessed but decision making process should be assured not to stuck in the long assessment (limiting time during severe accident before corium degradation and Rx vessel failure)
- Adequacy of proposed HCLA could be evaluatde during validation proces

Potential Questions from Regulator

The difficulty of ~~developing~~ executing several strategies in parallel

- SAMGs are not procedures – guidelines:
  - Few SAGs strategies can be executed simultaneously (but prioritization should be performed based on time&staff&SSC available) observing and monitoring the critical safety fanction parameters
  - Only one SCG strategy can be executed alone
- User Guide should be developed
- This is important issue for the verification/validation and training

Potential Questions from Regulator

Long-term implications or concerns of implementing the strategies (e.g. unavailability of coolant for later use)

– Should be addresed in strategy for the establishing the necessary support systems
    - AC/DC capability for essential SSCs and critical safety function should be assesed together with possible alternatives (existing alternative sources + portable devices + FLEX connection)
    - Water sources for makeup of SG and RCS should be evaluated togetger with alternative paths and sources for prolonged severe time window (4h, 24h, 72h...)
    - Compressed Air for essential valves necessary for establishment of critical safety function

Regulator Review Role

Regulator Options

- Development of specific Regulatory Review Guide (RRG) based on IAEA guides (NS-G-2.15, SRS32(SAMG), SRS48(SEOP), Services Series No.9, etc.)
  - Review the SAMG development and maintenance process, documentation, update, implementation of findings after drills and excercise,...
- Organizing the IAEA RAMP mission or other kind of independent review
- Participate in execution of drills and excercise

- Do not forget: Responsibility of safety during DBA and SA is in NPPs, Regulatory Body approval of SAMG is not recommended due to sharing responsibility if something is wrong.

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Questions?
Comments?

Thanks for your attention!