

# PSAM 14

Los Angeles, CA, USA

September 2018

## Dynamic Modelling of Severe Accident Management for CANDU Reactors in PSA

INNOVATING THE FUTURE OF ELECTRICITY

KINECTRICS

Alexander Trifanov, Kinectrics, Inc.





# Outline

- Background
- Overview of severe accident progression in CANDU
- Typical SAMG for CANDU
- Approach for modelling of SAMG in PSA
- Conclusions



# Background

## Accident mitigation using Severe Accident Management Guidance (SAMG):

- Symptom-based
- Non-prescriptive as opposed to Emergency Operating Procedures (EOP)
- As many viable mitigating strategies as possible to regain control of the plant
- Consider unusual equipment configurations
- Restore failed equipment
- Use mobile systems (FLEX)
- Timing of accident progression significantly impacts available options

**Difficult to model in PSA using static methods**

# Background



## Static PSA

Mature methodology

Static Event Trees / Fault Trees

Limited set of accident sequences defined by analyst represented by bounding scenarios

Limited use of time history

Well established development process and models easy to quantify on most PCs



## Dynamic PSA

Methodology in development

Dynamic Event Trees Branching

Automatic generation of accident sequences based on accident progression history

Time-dependent process variables

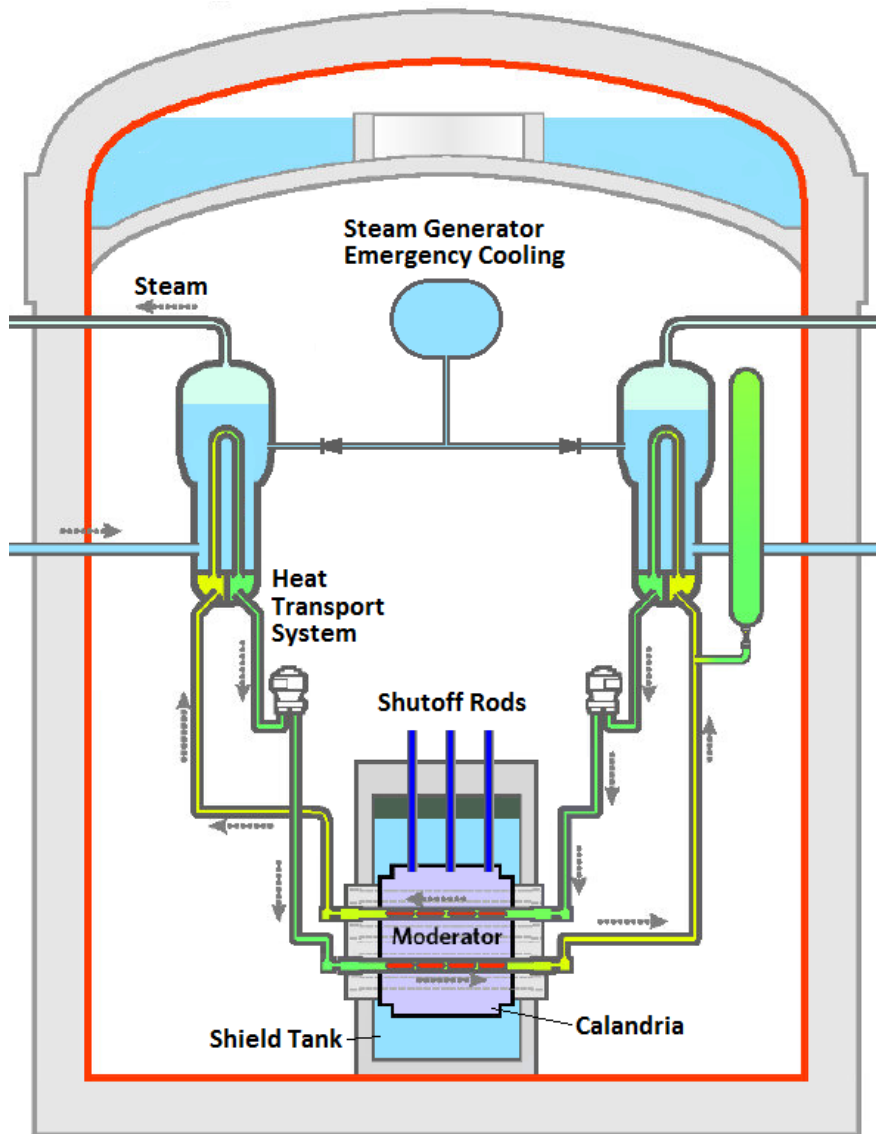
Quantification process requires development of ET branching algorithms and powerful computers



# Generic CANDU accident progression



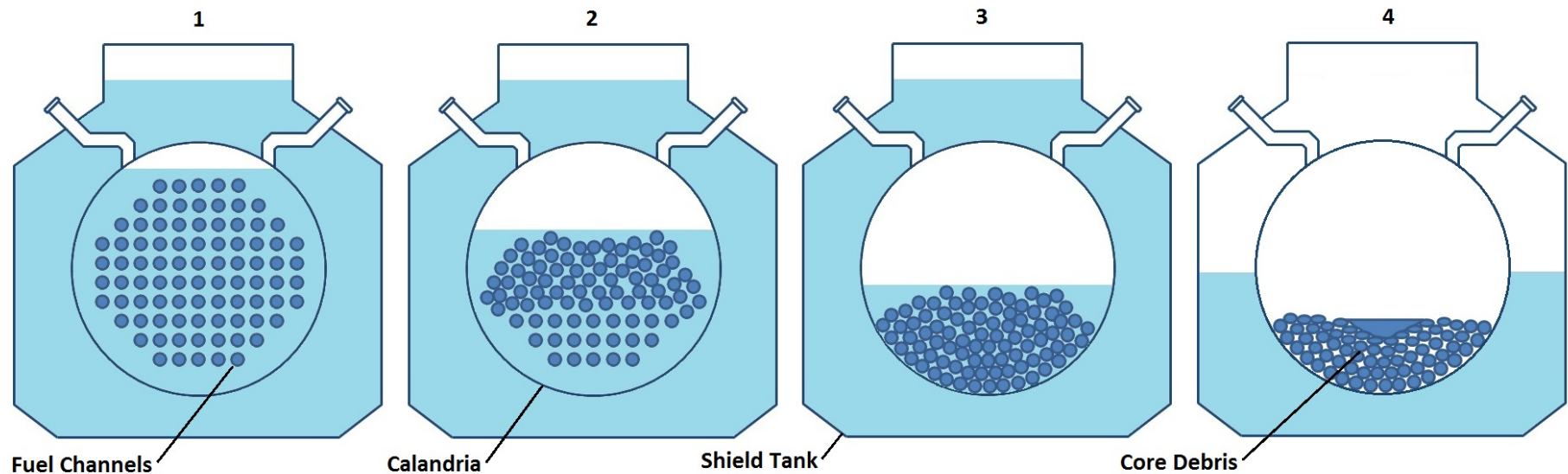
## In case of SBO:



Heat Sink	Time
Steam Generator (SG)	1-2h
SG Emergency Cooling	1-3h
Deaerator inventory drain to SG	4-6h
Primary heat transport boil-off	1-2h
Moderator boil-off	3-6h
Shield tank water boil-off	2-4h

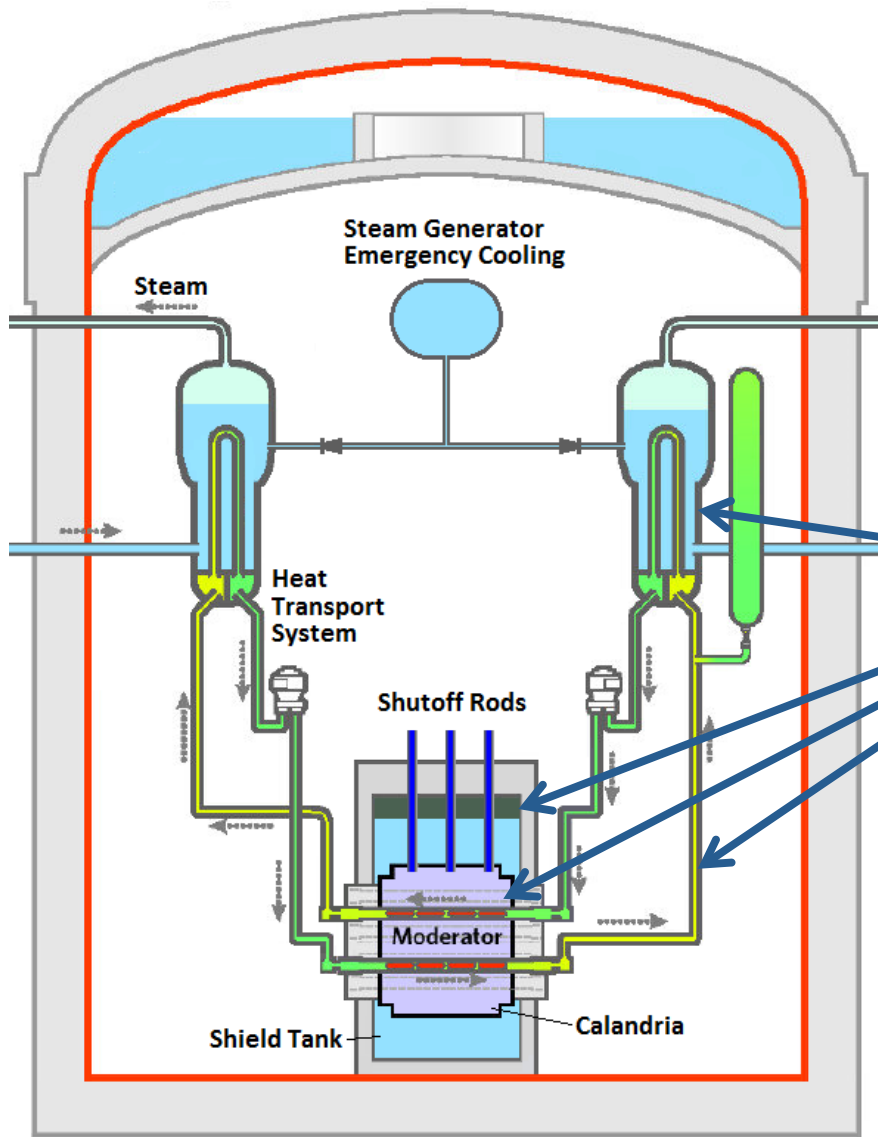
After depletion of all heat sinks, corium would melt through shield tank wall, fall on containment floor and initiate core-concrete interaction

# Generic CANDU accident progression



- Restoring water supply to steam generators and primary heat transport prevents fuel failure
- Restoring water supply to Calandria prevents core structural disintegration
- Restoring water supply to shield tank prevents core collapse on the Containment floor

# Emergency Mitigating Equipment (FLEX)

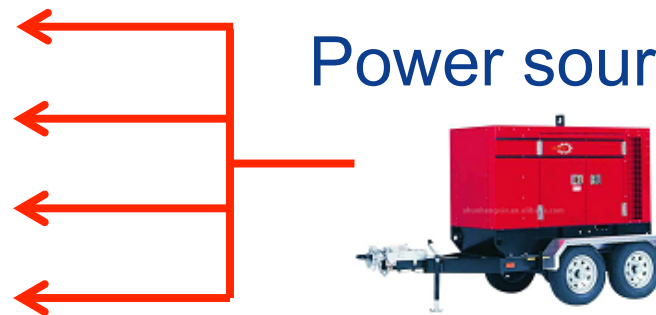


Mobile systems stored off-site  
Flexible configuration

Water source

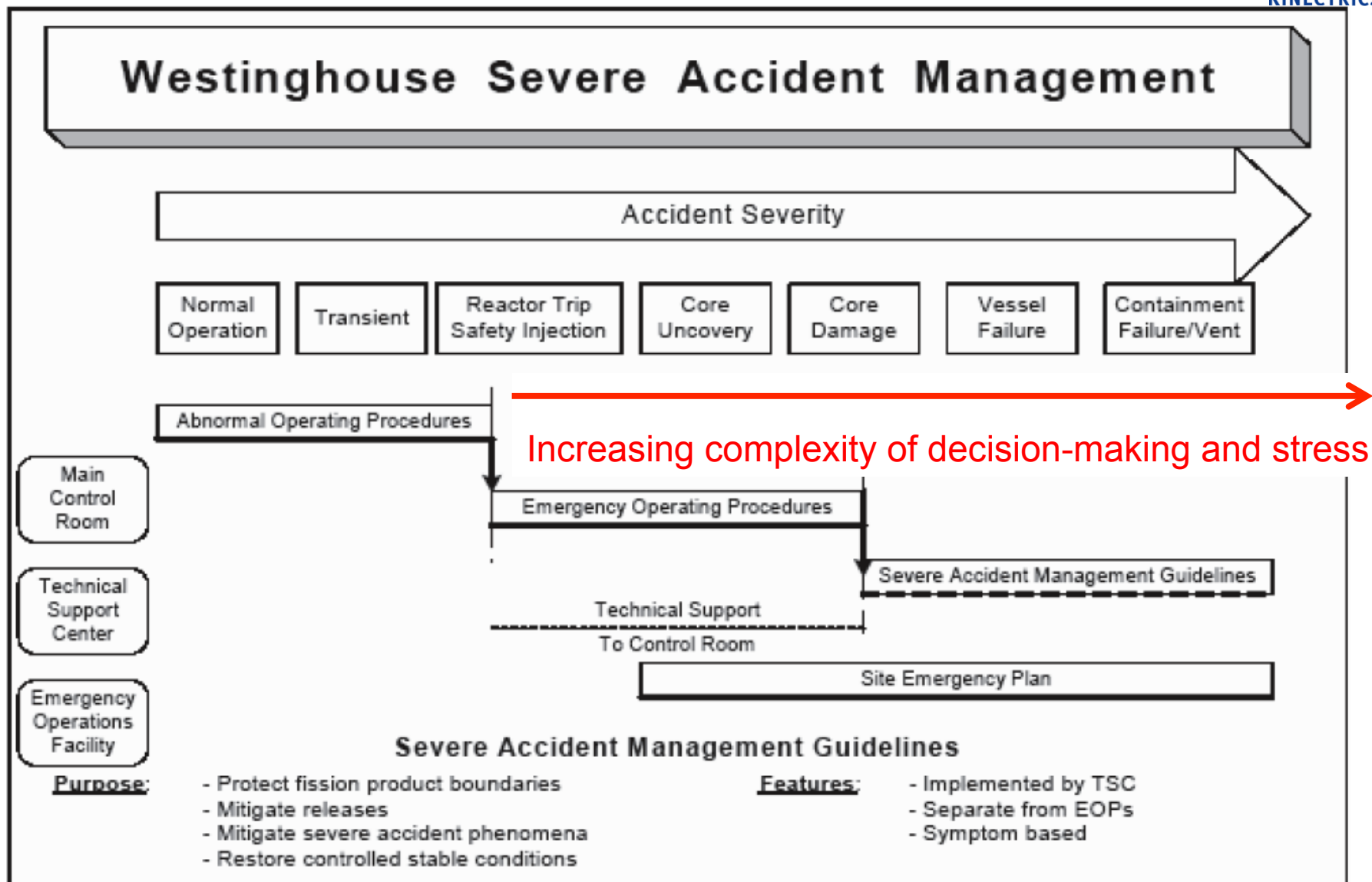


Power source



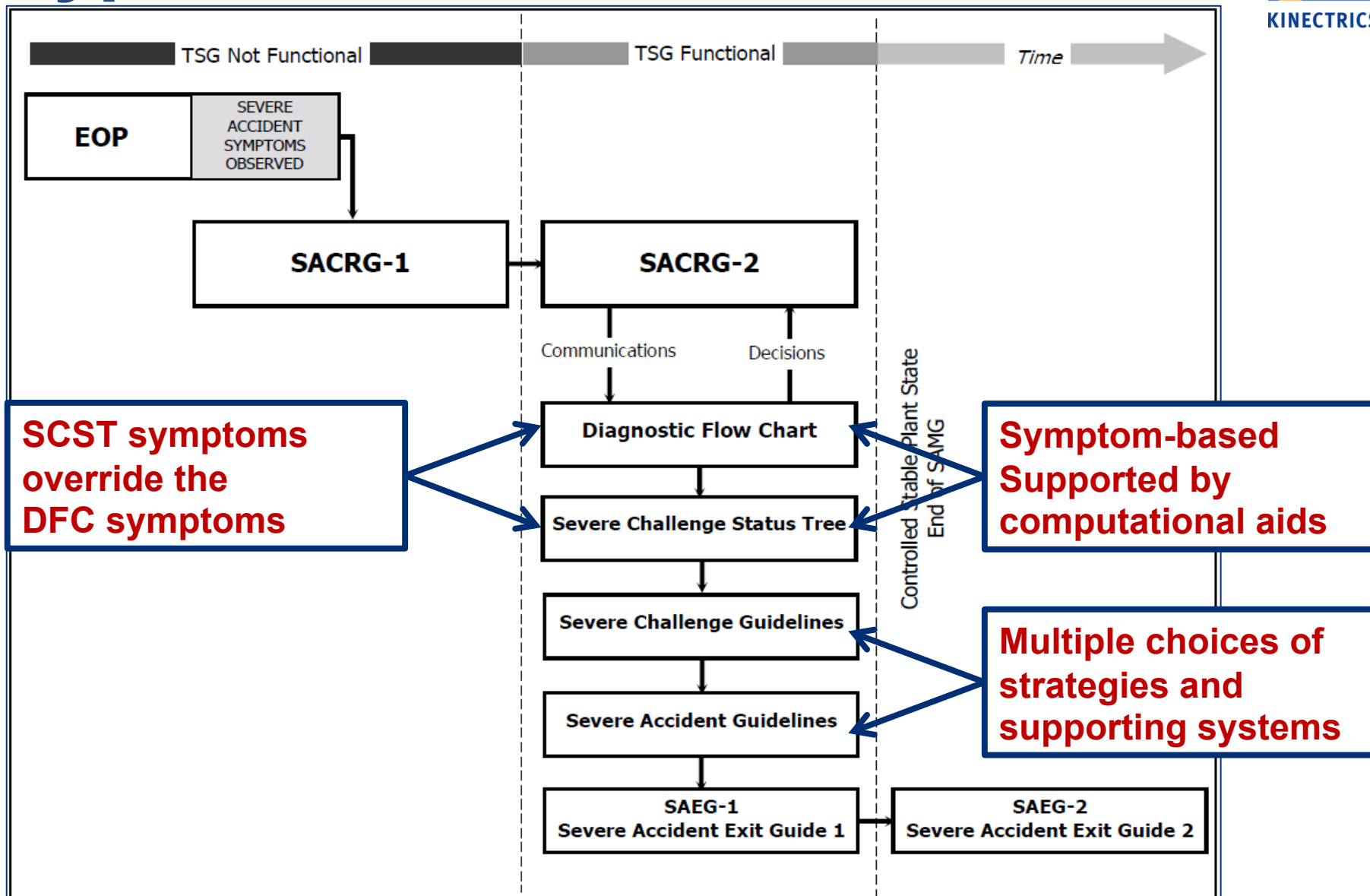


# Typical SAMG for CANDU

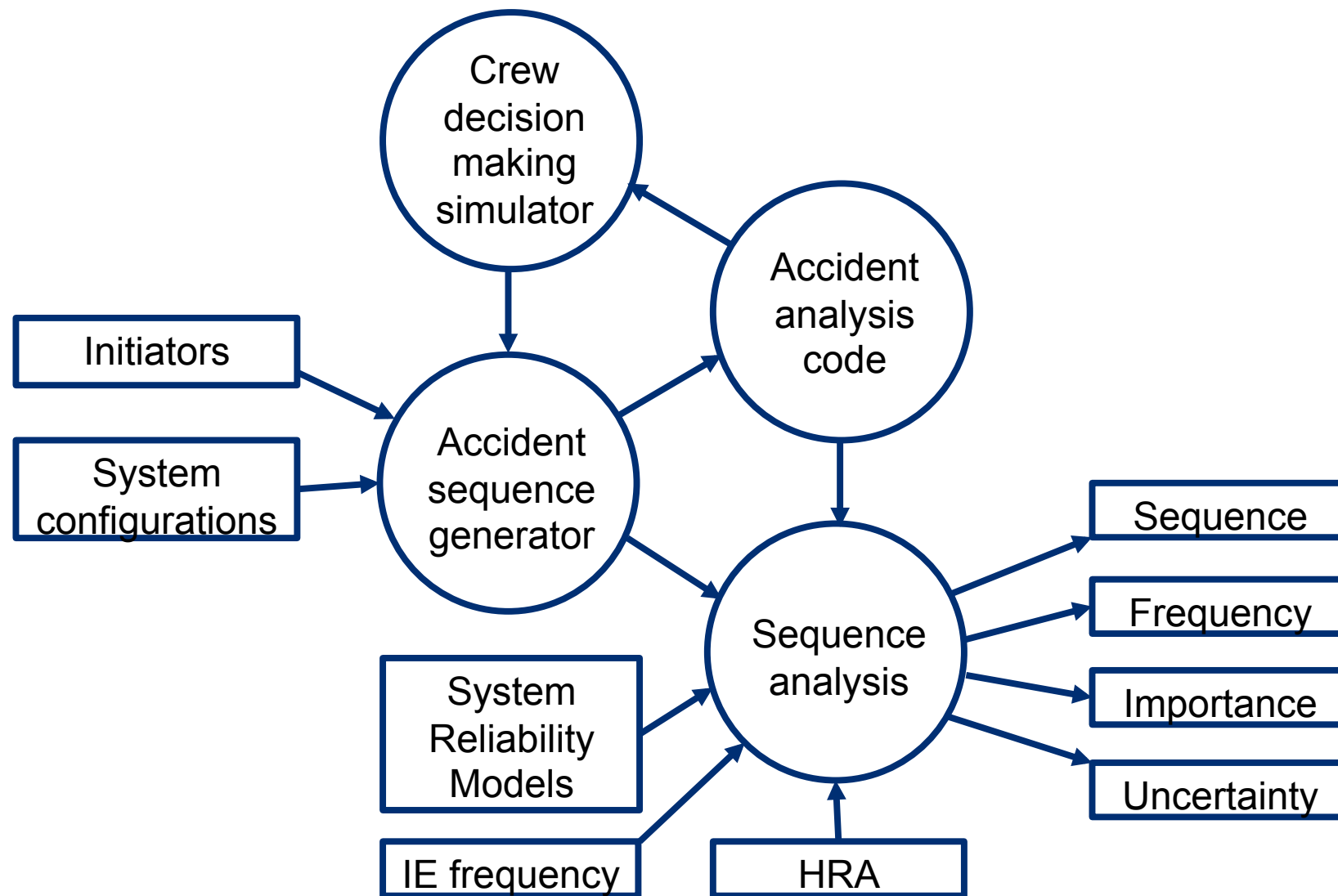




# Typical SAMG for CANDU



# Analysis approach



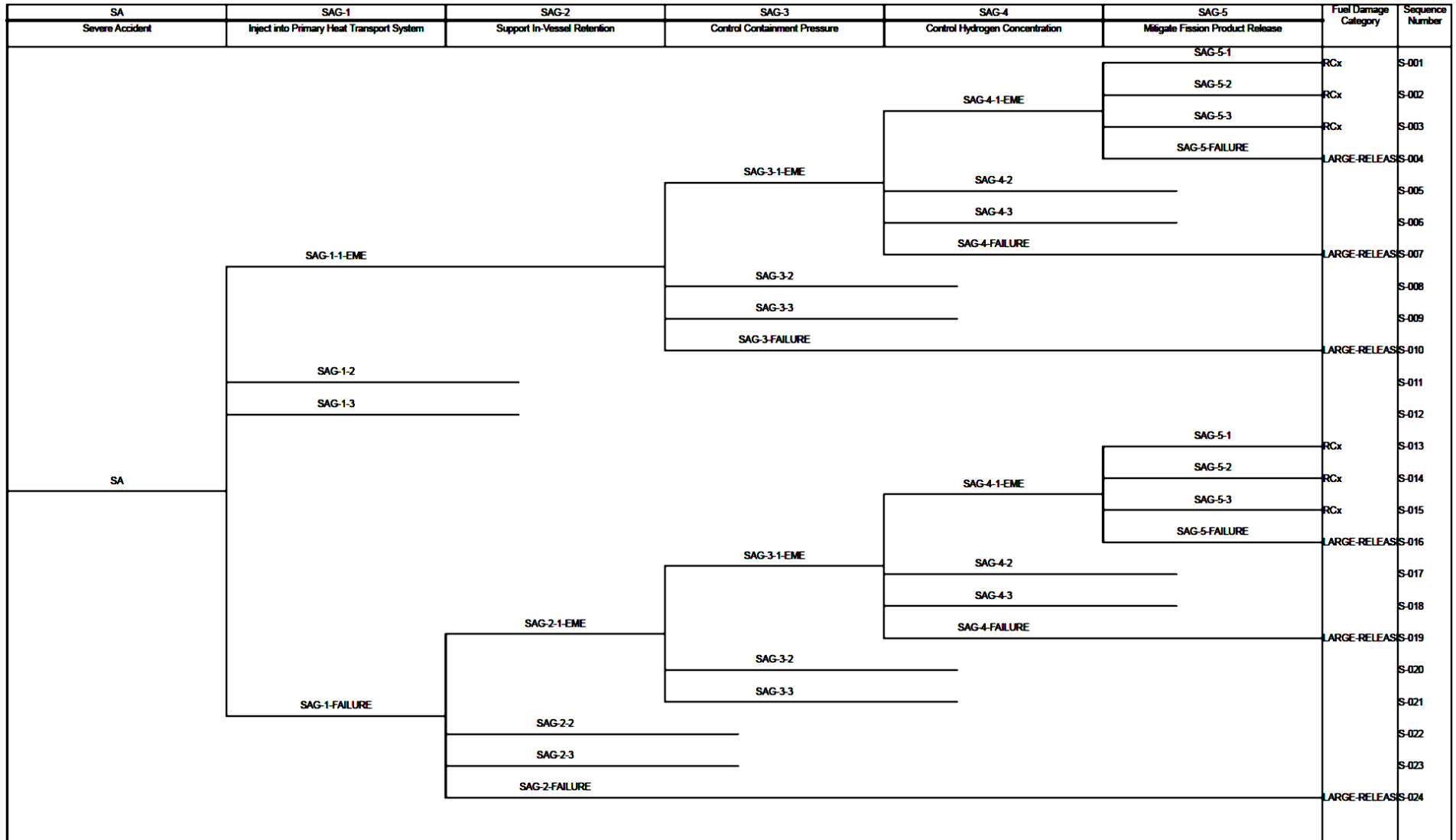
# Simplified ET prior to transition to SAMG



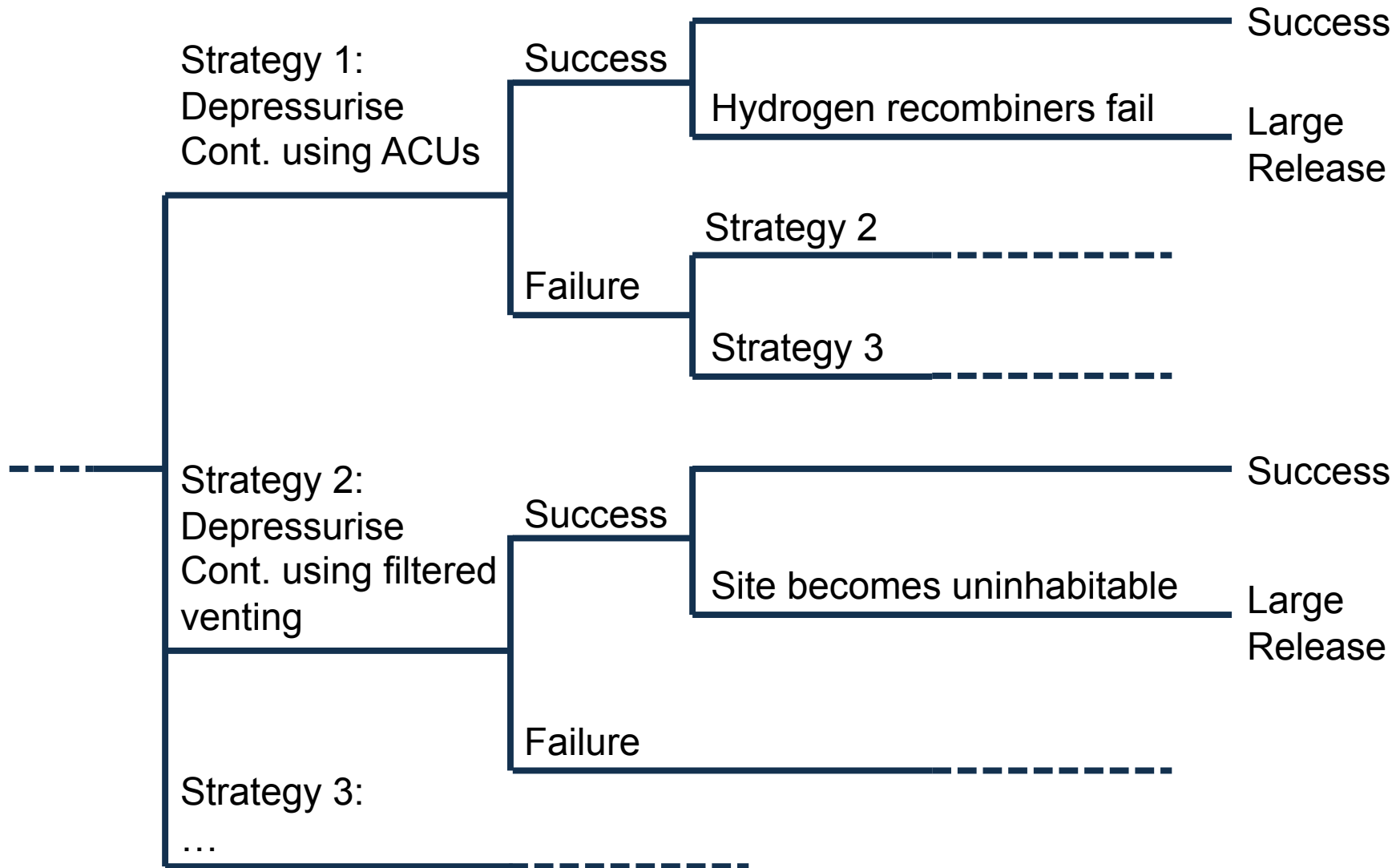
KINECTRICS

TRANS	INT-LOCA	ECI	SD-HS	INT-HS	EME-SG	ECR	EME-PHTS	SAMG	Fuel Damage Category	Sequence Number
Transient with Successful Reactor Shutdown	Interfacing LOCA	Emergency Coolant Injection	Shutdown Heat Sink (Steam Generators, Shutdown Cooling System, Emergency Water)	Interim Heat Sink (Passive supply of water to Steam Generators)	Emergency Mitigating Equipment water supply to Steam Generators	Emergency Coolant Recovery	Emergency Mitigating Equipment water supply to Primary Heat Transport System	Transition to Severe Accident Management Guidance		
								N/A	SUCCESS	S-001
								N/A	SUCCESS	S-002
			SD-HS		EME-SG			9H+	SUCCESS	S-003
				INT-HS				2H+	SA	S-004
								N/A	SUCCESS	S-005
TRANS						ECR		N/A	SUCCESS	S-006
							EME-PHTS	5H+	SA	S-007
								N/A	SUCCESS	S-008
						ECR		N/A	SUCCESS	S-009
							EME-PHTS	5H+	SA	S-010
	INT-LOCA		SD-HS		EME-SG			9H+	SA	S-011
				INT-HS				2H+	SA	S-012
		ECI						1H+	SA	S-013

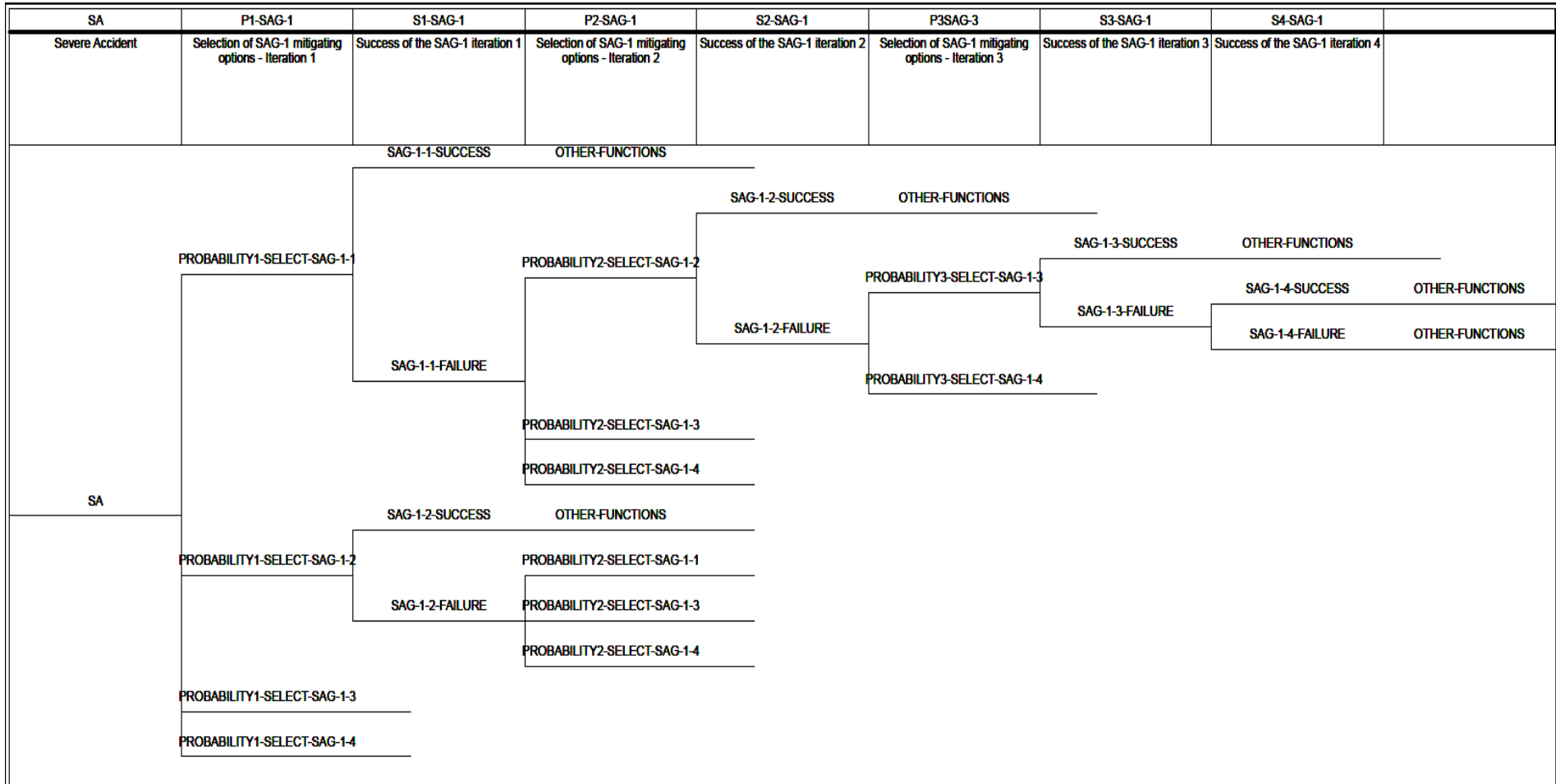
# Simplified severe accident ET



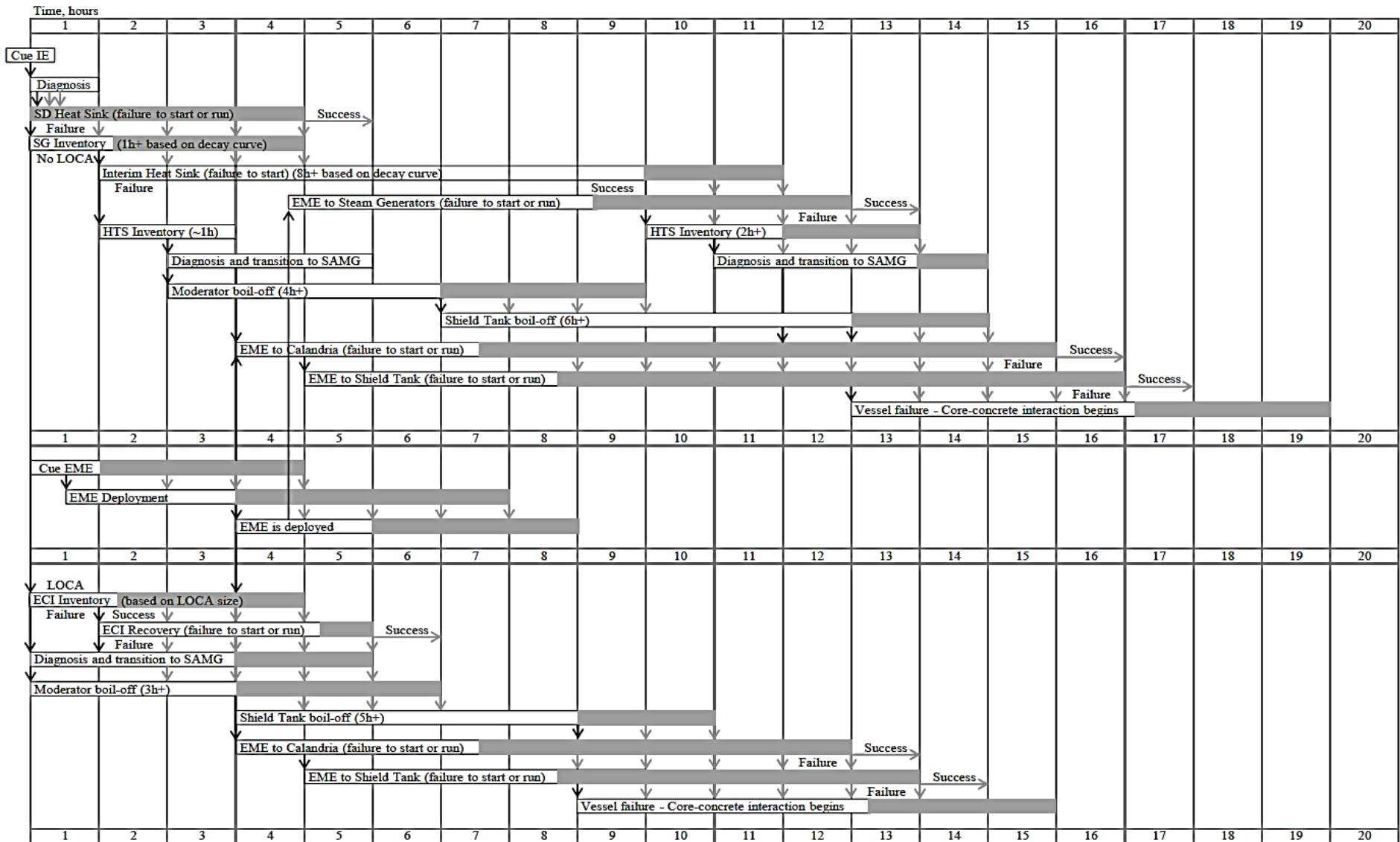
# Simplified severe accident ET



# Potential branching of SAMG mitigation



# Dynamic presentation of accident progression







# Conclusions

- SAMG are difficult to incorporate in PSA using static models
  - Cues, mitigating options, and likelihood of success significantly depend on the timing and phenomena of accident progression
  - SAMG actions have positive and negative effects
  - There are multiple options
- Dynamic modelling can generate families of ETs based on parameters predicted by the coupled deterministic model
- ET branching algorithm is relatively complex
  - Potentially contradictive and overriding symptoms
  - Decision making by the crew to select strategy and equipment
  - Use of FLEX
  - Potential restoration of failed equipment
  - Impact of plant condition degradation on operator performance
- Need significant computational capability



# Thank you for Attention!

## Questions?