NARSIS

New Approach to Reactor Safety ImprovementS

Severa:

A New Decision-Support Tool

Marko Bohanec

Jožef Stefan Institute, Department of Knowledge Technologies, Ljubljana, Slovenia

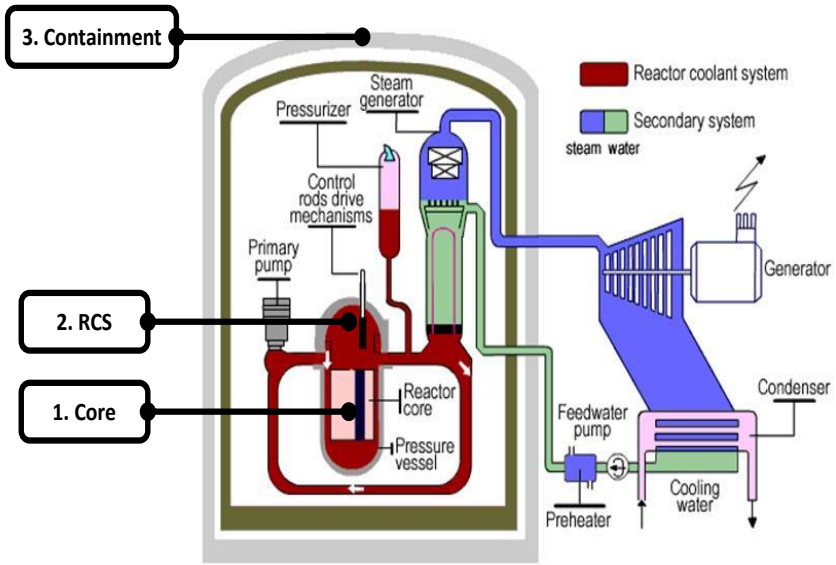
with

Ivan Vrbanić and **Ivica Bašić**, APoSS, System Reliability and Safety Analyses, Zabok, Croatia

Klemen Debelak and **Luka Štrubelj**, GEN energija, d.o.o., Krško, Slovenia

Adem Kikaj, International Postgraduate School Jožef Stefan, Ljubljana, Slovenia

Severe Accidents in NPP



Severe accident:

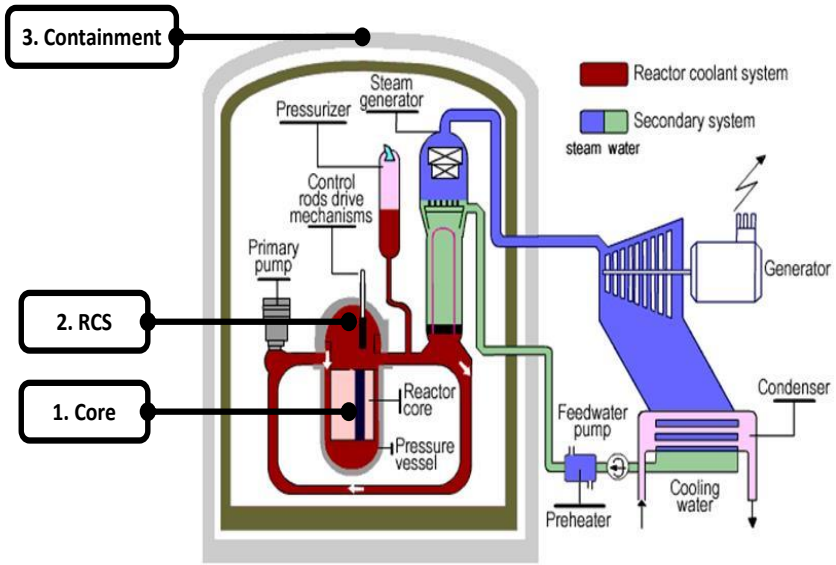
Rare circumstances that can cause:

- Severe core degradation
- Damage to the nuclear fuel, vessel and/or containment
- Release of radioactivity to the environment

Causes:

- *Internal*, e.g. multiple equipment failures
- *External*, e.g. natural hazard(s)

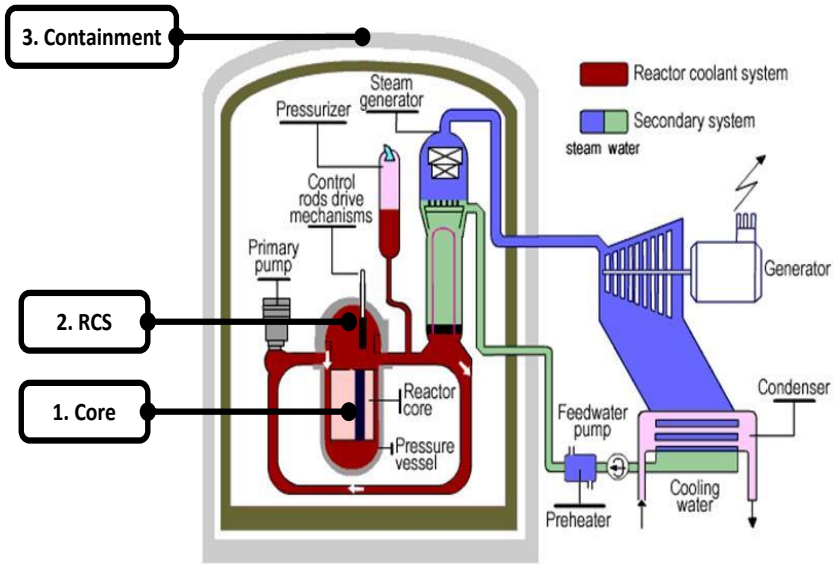
Severe Accident Management



Characteristics:

- Severe accidents are extremely rare
- Require immediate and appropriate response
- Short response time window (minutes or hours at best)
- Overwhelming and uncertain information
- Possible severe consequences
- Difficult and stressful decision-making situation

Severe Accident Management



Severe Accident Management:

- by *Technical Support Center* (TSC)
- according to *Severe Accident Management Guidelines* (SAGs)

Barriers:

1. Reactor Core
2. Reactor Cooling System (RCS)
3. Reactor Containment

Management Objectives:

- Protect barriers
- Prevent radioactive releases to the environment

Severa: Objectives

- A prototype demonstration-level *Decision Support System*
- for *Severe Accident Management*,
- aimed at supporting the *Technical Support Center* (TSC) team
- while managing a severe accident ...
- ... and for training.

- Interactive, responsive and simple to use software
- based on procedures prescribed in selected SAMGs
- using a combination of methods (probability safety assessment, event trees, qualitative multi-criteria models)
- providing essential decision-support information to the TSC team
- in real time.

Severa: Limitations

- Prototype *proof-of-concept* implementation for *demonstration purposes*
- Focused on exploring the *feasibility* of the approach and proposed methods
- Using a reasonably small (but relevant) set of *eight system parameters*
- Considering a subset of *three SAGs* (SAG-1, SAG-2, SAG-3)

Severa: Basic Concepts

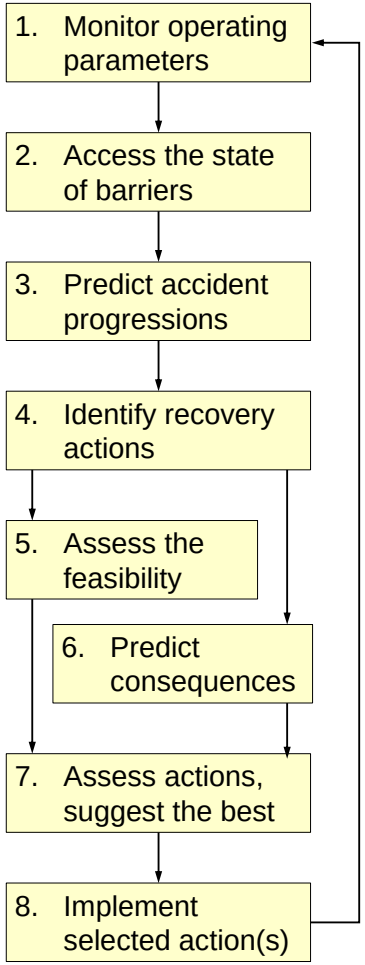
Severa is a *Decision Support System*:

- no decisions made by the software itself,
- it just provides relevant information to human decision-makers.

Provided information:

- What is the current state of NPP barriers?
- What can happen in the future if no actions are undertaken?
- What can be done to resolve the situation?
- What are expected consequences of alternative actions?

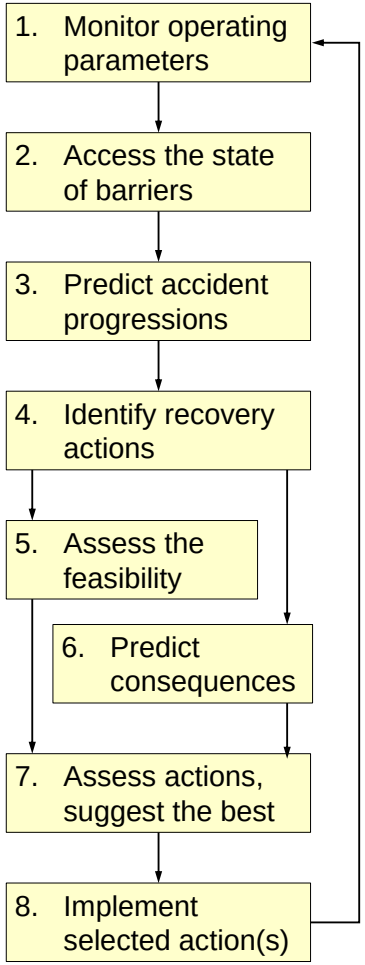
Decision-Support Cycle



- 10-20 minutes per cycle

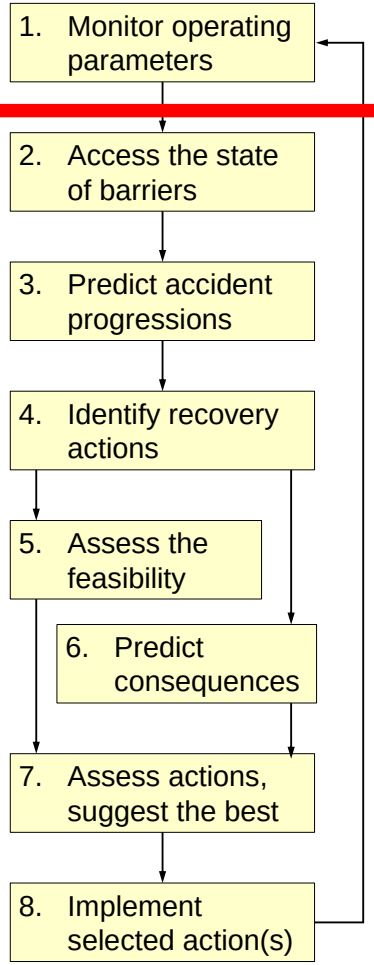
- Steps 1-7 are supported by Severa
- Step 8 is on behalf of the TSC

Severa: Underlying methods



- *Success Trees* (inverse of Fault Trees) to define Success Paths of High-Level Actions
- *Probabilistic Safety Assessment* (PSA) to assess the probability of actions' success in a given time window
- *Qualitative hierarchical multi-criteria rule-based models* (DEX) to assess barrier states and possible developments of the event
- *Accident progression event trees* (APET) to determine NPP hazard damage states and consequently, combined with DEX, to assess expected radioactive releases.

Step 1: Operating Parameters



Input data: Time series of eight parameters

- *Time* [min]

1. **CET**: Core Exit Thermocouples [°C]
2. **SGL**: Steam Generator Level [m]
3. **RPVL**: Reactor Pressure Vessel Level [%]
4. **Prcs**: Reactor Coolant System Pressure [MPa]
5. **Pcont**: Containment Pressure [MPa]
6. **Tcont**: Containment Temperature [°C]
7. **Lcont**: Containment Water Level [m]
8. **H2**: Hydrogen concentration [%]

Severa: Example Use Case

Time series: **SBO#1**

Station Blackout:

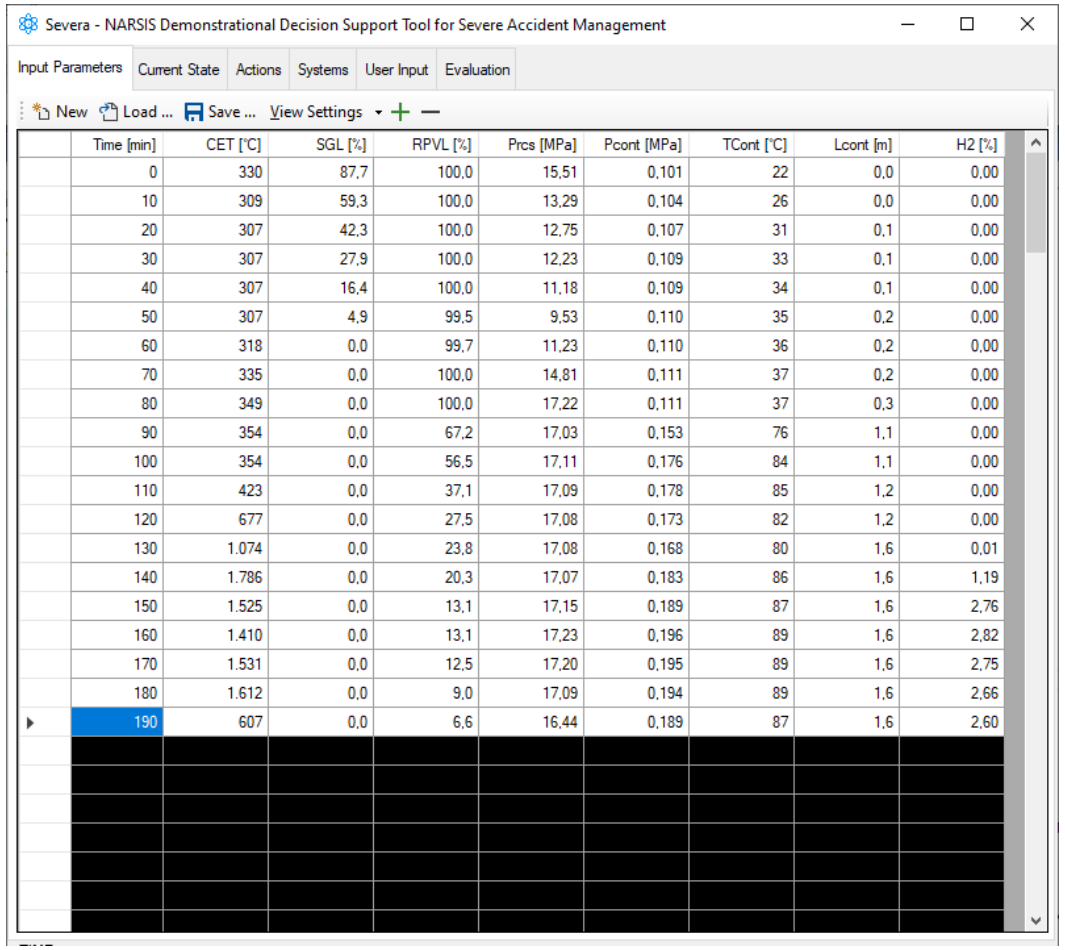
The loss of secondary heat sink caused by loss of all feed-water supplying steam-generators + loss of Reactor Coolant Pump (RCP) seal injection

Obtained from MELCOR simulations

Modelling as small Loss of Coolant Accident (LOCA) in a cold leg

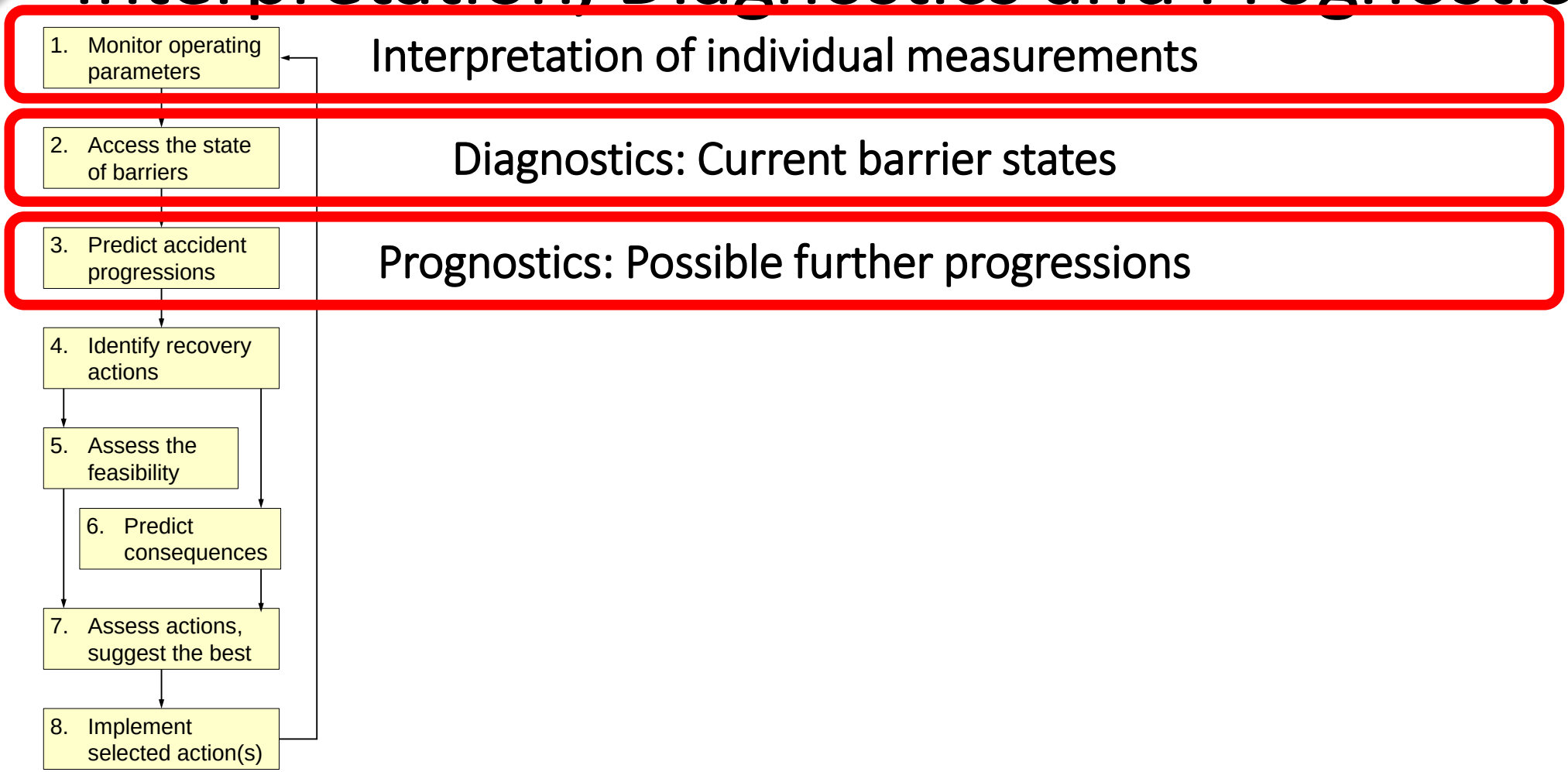
Size: 476 measurements / 10 min

Time span: 4760 minutes [~3.3 days]



Time [min]	CET [°C]	SGL [%]	RPVL [%]	Prcs [MPa]	Pcont [MPa]	TCont [°C]	Lcont [m]	H2 [%]
0	330	87,7	100,0	15,51	0,101	22	0,0	0,00
10	309	59,3	100,0	13,29	0,104	26	0,0	0,00
20	307	42,3	100,0	12,75	0,107	31	0,1	0,00
30	307	27,9	100,0	12,23	0,109	33	0,1	0,00
40	307	16,4	100,0	11,18	0,109	34	0,1	0,00
50	307	4,9	99,5	9,53	0,110	35	0,2	0,00
60	318	0,0	99,7	11,23	0,110	36	0,2	0,00
70	335	0,0	100,0	14,81	0,111	37	0,2	0,00
80	349	0,0	100,0	17,22	0,111	37	0,3	0,00
90	354	0,0	67,2	17,03	0,153	76	1,1	0,00
100	354	0,0	56,5	17,11	0,176	84	1,1	0,00
110	423	0,0	37,1	17,09	0,178	85	1,2	0,00
120	677	0,0	27,5	17,08	0,173	82	1,2	0,00
130	1.074	0,0	23,8	17,08	0,168	80	1,6	0,01
140	1.786	0,0	20,3	17,07	0,183	86	1,6	1,19
150	1.525	0,0	13,1	17,15	0,189	87	1,6	2,76
160	1.410	0,0	13,1	17,23	0,196	89	1,6	2,82
170	1.531	0,0	12,5	17,20	0,195	89	1,6	2,75
180	1.612	0,0	9,0	17,09	0,194	89	1,6	2,66
190	607	0,0	6,6	16,44	0,189	87	1,6	2,60

Steps 1-3: Interpretation, Diagnostics and Prognostics

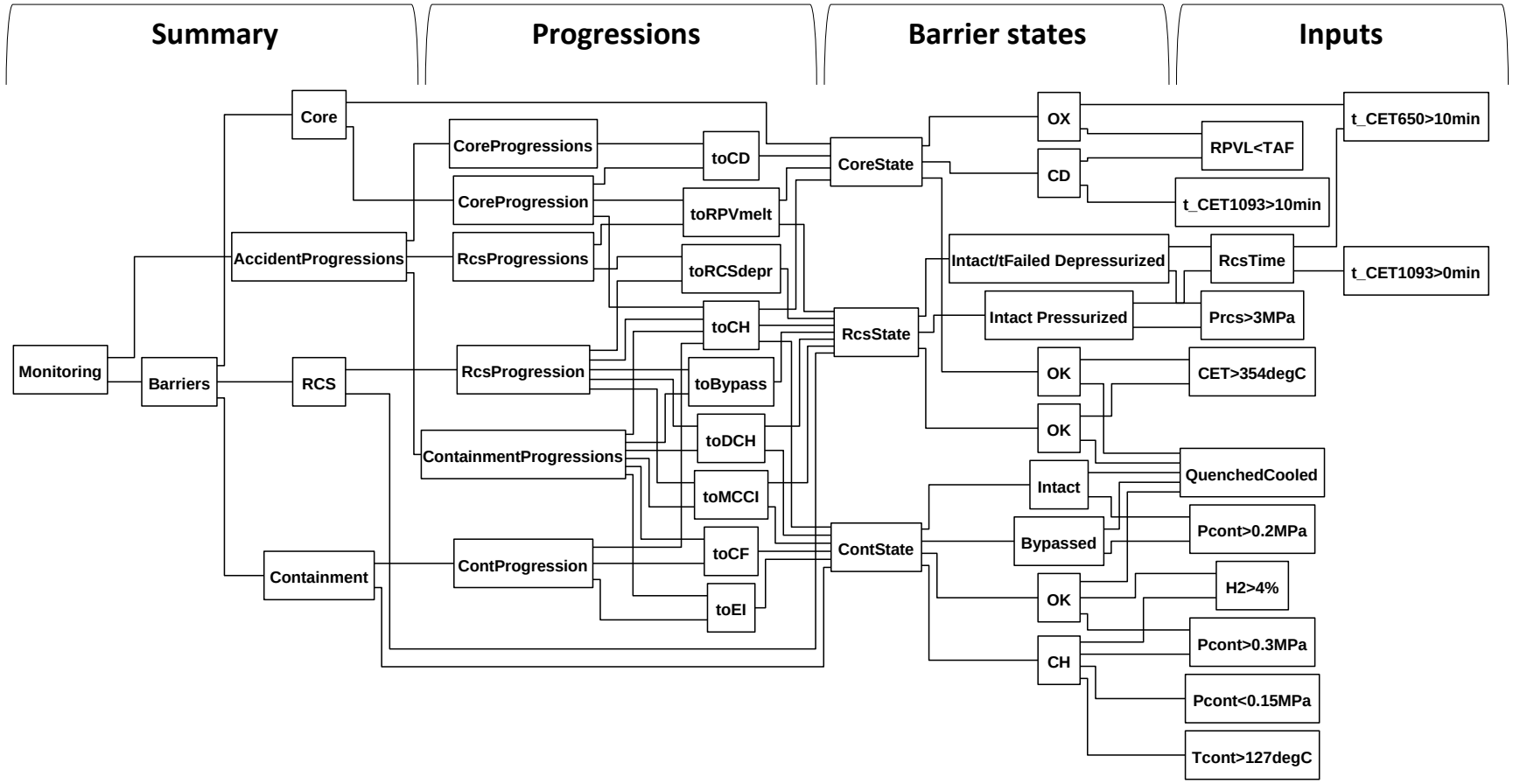


Steps 1-3: Interpretation, Diagnostics and Prognostics

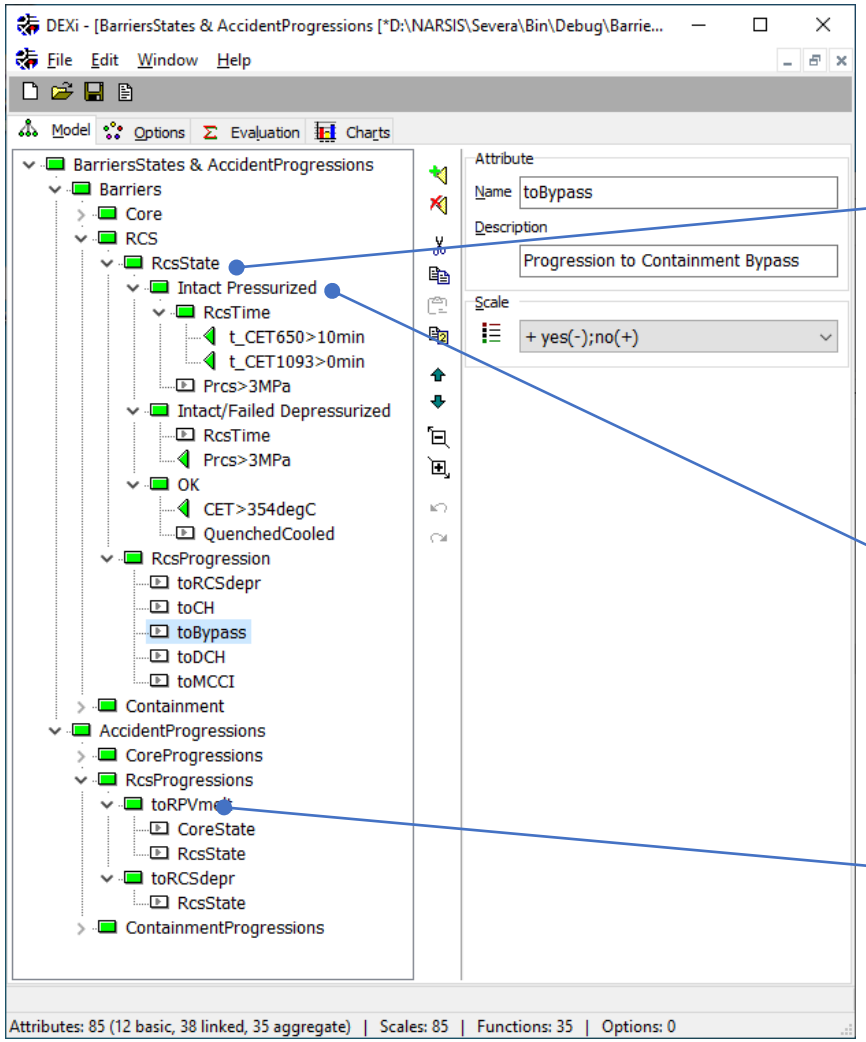
MONITORING and INTERPRETATION								DIAGNOSIS						PROGNOSIS
8 System Parameters								Barrier States						Progress
Time [min]	CET [°C]	SGL [%]	RPVL [%]	Prcs [MPa]	Pcont [MPa]	TCont [°C]	Lcont [m]	H2 [%]	SAGs	Seq Type	Core State	RCS State	Cont State	Possible Progressions
90	354	0,0	67,2	17,03	0,153	76	1,1	0,00			OK	OK	OK	
100	354	0,0	56,5	17,11	0,176	84	1,1	0,00			OK	OK	OK	
110	423	0,0	37,1	17,09	0,178	85	1,2	0,00			OK	OK	OK	
120	677	0,0	27,5	17,08	0,173	82	1,2	0,00	1, 2, 3	High	OK	OK	OK	
130	1.074	0,0	23,8	17,08	0,168	80	1,6	0,00	1, 2, 3	High	OK	OK	OK	
140	1.786	0,0	20,3	17,07	0,183	86	1,6	0,01	1, 2, 3	High	OX	IP	OK	CD, RCSdepr, CH, DCH, Bypass
150	1.525	0,0	13,1	17,15	0,189	87	1,6	0,03	1, 2, 3	High	OX	IP	OK	CD, RCSdepr, CH, DCH, Bypass
160	1.410	0,0	13,1	17,23	0,196	89	1,6	0,03	1, 2, 3	High	CD & OX	IP	OK	RPVmelt, RCSdepr, CH, DCH, Bypass
170	1.531	0,0	12,5	17,20	0,195	89	1,6	0,03	1, 2, 3	High	CD & OX	IP	OK	RPVmelt, RCSdepr, CH, DCH, Bypass
180	1.612	0,0	9,0	17,09	0,194	89	1,6	0,03	1, 2, 3	High	CD & OX	IP	OK	RPVmelt, RCSdepr, CH, DCH, Bypass
190	607	0,0	6,6	16,44	0,189	87	1,6	0,03	1, 2, 3	High	CD & OX	IP	OK	RPVmelt, RCSdepr, CH, DCH, Bypass
200	179	0,0	33,0	0,30	0,294	113	1,6	0,03	1	Low	CD & OX	IFD	OK	RPVmelt, CH, MCCI
210	1.617	0,0	16,3	0,28	0,284	111	1,6	0,03	1, 3	Low	CD & OX	IFD	OK	RPVmelt, CH, MCCI
220	1.747	0,0	12,7	0,27	0,274	109	1,6	0,03	1, 3	Low	CD & OX	IFD	OK	RPVmelt, CH, MCCI
230	1.843	0,0	11,4	0,27	0,265	107	1,6	0,02	1, 3	Low	CD & OX	IFD	OK	RPVmelt, CH, MCCI

Steps 2 & 3: Underlying Model

Qualitative hierarchical multi-criteria rule-based DEX model



The Barriers Model in DEXi



Decision rules RcsState

IFD — Use scale orders — Use weights

	Intact Pressurized	Intact/Failed Depressurized	OK	RcsState
1	yes	yes	no	IFD
2	yes	yes	yes	OK
3	yes	no	no	IP
4	yes	no	yes	OK
5	no	yes	no	IFD
6	no	yes	yes	OK
7	no	no	no	OK
8	no	no	yes	OK

Decision rules Intact Pre...

no

	RcsTime	Prcs>3MPa	Intact Pressurized
1	yes	no	no
2	yes	yes	yes
3	no	no	no
4	no	yes	no

	CoreState	RcsState	toRPVmelt
1	CD & OX;CD	*	yes
2	*	IFD	yes
3	OX;REC;OK	IP	*no*
4	OX;REC;OK	OK	*no*

The Barriers Model in Severa

Severa - NARSIS Demonstrational Decision Support Tool for Severe Accident Management

Input Parameters | Current State | Actions | Systems | User Input | Evaluation

Save ...

Current barrier states and progressions

Current time: 190 min
Last measurement time: 190 min

Input parameters

CET	Core Exit Thermocouples	607	°C
SGL	Steam Generator Level	0,0	%
RPVL	Reactor Pressure Vessel Level	6,6	%
Prcs	Reactor Coolant System Pressure	16,44	MPa
Pcont	Containment Pressure (gauge)	0,189	MPa
Tcont	Containment Temperature	87	°C
Lcont	Containment Water Level	1,6	m
H2	Hydrogen concentration	0,03	%

Entered SAGs

SAG-1	Injection to Steam Generator	since min 120
SAG-2	RCS depressurization	since min 120
Sequence	High pressure	

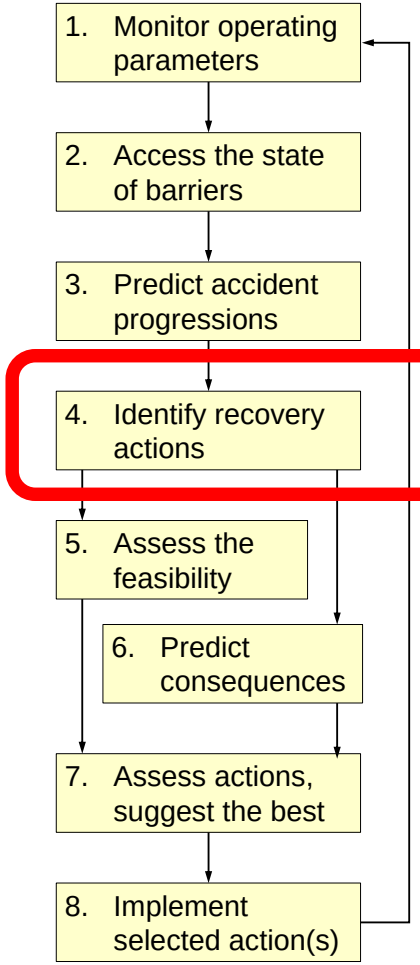
Barrier States

Core	CD & OX
OX	Cladding Oxidation
CD	Core Damage
OK	not OK
RCS	IP
Intact Pressurized	Intact Pressurized
OK	not OK
Containment	OK
Bypassed	Bypassed Containment
Progression(s)	
RPVmelt	Progression to RPV melt-through
RCSdepr	Progression to RCS sudden depressurization -> containment bypa
CH	Progression to Containment Challenge
DCH	Progression to Direct Containment Heating, steam explosion pote
Bypass	Progression to Containment Bypass

BarriersStates & AccidentProgressions	yes
| **Barriers**	yes
| | **Core**	yes
| | | **CoreState**	CD & OX
| | | | **OX**	yes
| | | | | t_CET650>10min	yes
| | | | | RPVL<TAF	yes
| | | | **CD**	yes
| | | | | t_CET1093>10min	yes
| | | | | *RPVL<TAF*	yes
| | | | **OK**	no
| | | | | CET>354degC	yes
| | | | | QuenchedCooled	no
| | | | | *t_CET650>10min*	yes
| | | **CoreProgression**	yes
| | | | ***toCD***	no
| | | | ***toCH***	yes
| | | | ***toRPVmelt***	yes
| **RCS**	yes
| | | **RcsState**	IP
| | | | **Intact Pressurized**	yes
| | | | | **RcsTime**	yes
| | | | | | *t_CET650>10min*	yes
| | | | | | t_CET1093>0min	yes
| | | | | Prcs>3MPa	yes
| | | | **Intact/Failed Depressurized**	no
| | | | | ***RcsTime***	yes
| | | | | *Prcs>3MPa*	yes
| | | | **OK**	no
| | | | | *CET>354degC*	yes
| | | | | *QuenchedCooled*	no
| | | **RcsProgression**	yes
| | | | ***toRCSdepr***	yes
| | | | ***toCH***	yes
| | | | ***toBypass***	yes
| | | | ***toDCH***	yes
| | | | ***toMCCI***	no
| **Containment**	yes
| | | **ContState**	OK
| | | | **Intact**	no
| | | | | Pcont>0.2MPa	no
| | | | | *QuenchedCooled*	no
| | | | **Bypassed**	yes

| | | | **Bypassed**	yes
| | | | | *Pcont>0.2MPa*	no
| | | | | *QuenchedCooled*	no
| | | | **CH**	no
| | | | | Pcont>0.3MPa	no
| | | | | Tcont>127degC	no
| | | | | Pcont<0.15MPa	no
| | | | | H2>4%	no
| | | | **OK**	yes
| | | | | *Pcont>0.3MPa*	no
| | | | | *H2>4%*	no
| | | | | *QuenchedCooled*	no
| | | **ContProgression**	yes
| | | | ***toCH***	yes
| | | | ***toEI***	no
| | | | ***toCF***	no
| **AccidentProgressions**	yes
| | **CoreProgressions**	no
| | | **toCD**	no
| | | | ***CoreState***	CD & OX
| | **RcsProgressions**	yes
| | | **toRPVmelt**	yes
| | | | ***CoreState***	CD & OX
| | | | ***RcsState***	IP
| | | **toRCSdepr**	yes
| | | | ***RcsState***	IP
| | **ContainmentProgressions**	yes
| | | **toCH**	yes
| | | | ***CoreState***	CD & OX
| | | | ***RcsState***	IP
| | | | ***ContState***	OK
| | | **toDCH**	yes
| | | | ***RcsState***	IP
| | | | ***ContState***	OK
| | | **toMCCI**	no
| | | | ***RcsState***	IP
| | | | ***ContState***	OK
| | | **toCF**	no
| | | | ***ContState***	OK
| | | **toBypass**	yes
| | | | ***RcsState***	IP
| | | **toEI**	no
| | | | ***ContState***	OK

Step 4: High-Level Actions



High-level actions (HLAs)

A subset of three HLAs:

- **HLA1**: Inject into SG (SAG-1)
- **HLA2**: Depressurize the RCS (SAG-2)
- **HLA3**: Inject into the RCS (SAG-3)

Step 4: Recovery Actions

1. Monitor operating parameters
2. Access the state of barriers
3. Predict accident progressions
4. Identify recovery actions
5. Assess the feasibility
6. Predict consequences
7. Assess actions, suggest the best
8. Implement selected action(s)

Representing/Defining Recovery Actions

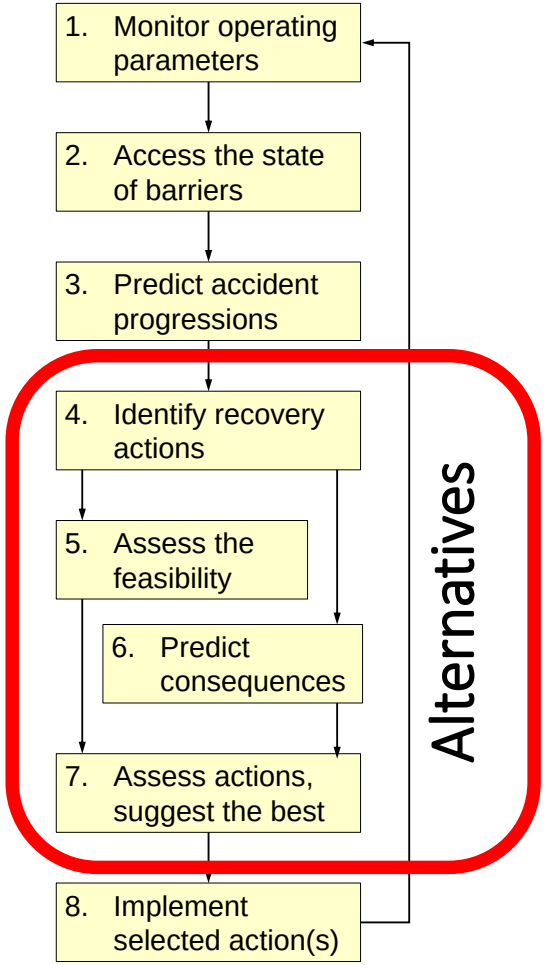
Severa - NARSIS Demonstrational Decision Support Tool for Severe Accident Management

Input Parameters | Current State | Actions | Systems | User Input | Evaluation

Edit

HLA	Succ Path	Description	Elements	Adequacy	Status	Started	Ended	Success
HLA1		High Level Action 1: Inject into Steam Gen...			Triggered at 120, duration 70 ...			
	SP11	Injection by Auxiliary Feedwater	AFW	1	Triggered			
	SP12	Depressurize SG to DEC SG shutoff by SG...	SGPORV; DECSG	0,9	Triggered			
	SP13	Depressurize SG to DEC SG shutoff by DE...	DECSGPORV; DECSG	0,8	Triggered			
	SP14	Depressurize SG to FLEX SG shutoff by S...	SGPORV; FLEXSG	0,7	Triggered			
	SP15	Depressurize SG to FLEX SG shutoff by D...	DECSGPORV; FLEXSG	0,6	Triggered			
HLA2		High Level Action 2: Depressurize the Rea...			Triggered at 120, duration 70 ...			
	SP21	Depressurize RCS from secondary side by ...	SGPORV; SGINV	1	Triggered			
	SP22	Depressurize RCS from secondary side by ...	DECSGPORV; SGINV	0,9	Triggered			
	SP23	Depressurize RCS from primary side by PR...	PRPORV	1	Triggered			
	SP24	Depressurize RCS from primary side by DE...	DECPRPORV	0,9	Triggered			
HLA3		High Level Action 3: Inject into the Reacto...			Triggered at 120, duration 70 ...			
HLA3I		Phase 1: Injection			Triggered at 120, duration 70 ...			
	SP3I1	Injection into RCS using LPSI Pumps	LPSI	1	Triggered			
	SP3I2	Injection into RCS using DEC SI Pumps	DECSI	0,9	Triggered			
	SP3I3	Injection into RCS using FLEX Pump(s)	FLEXRCS	0,7	Triggered			
	SP3I4	Injection into RCS using HPSI Pumps	HPSI	1	Triggered			
HLA3R		Phase 2: Recirculation			Unavailable			
	SP3R1	Recirculation by LPSI Pumps	LPSI; SMPLPSI	1	Unavailable			
	SP3R2	Recirculation by DEC SI	DECSI; SMPLPSI	0,9	Unavailable			
	SP3R3	Recirculation by FLEX Pump(s)	FLEXRCS; SMPFLEX	0,7	Unavailable			
HLAC1		Containment: Spray			Triggered at 0, duration 190 min			
	SPC1	Containment: Spray	SP	1	Triggered			
HLAC2		Containment: Reactor Containment Fan Co...			Triggered at 0, duration 190 min			
	SPC2	Containment: Reactor Containment Fan Co...	RCFC	1	Triggered			

Steps 4-7: Decision Alternatives



Alternative:

- defined in terms of availability of plant systems for coping with accidents
- represented by a vector of Time-Delay values

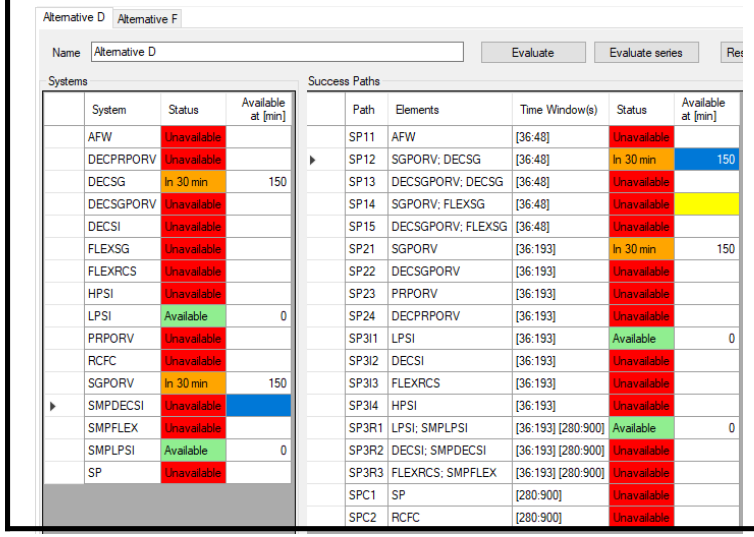
System	Status	Available at [min]
AFW	Unavailable	
DECPRPORV	Available	0
DECSG	Available	0
DECSGPORV	Available	0
DECSI	Unavailable	
FLEXSG	In 20 min	20
FLEXRCS	Available	0
HPSI	Available	0
LPSI	Available	0
PRPORV	Available	0
RCFC	Available	0
SGPORV	Available	0
SMPDECSI	Available	0
SMPFLEX	Available	0
SMPLPSI	Available	0
SP	Available	0

Step 4: Decision Alternatives

1. Monitor operating parameters
2. Access the state of barriers
3. Predict accident progressions
4. Identify recovery actions
5. Assess the feasibility
6. Predict consequences
7. Assess actions, suggest the best
8. Implement selected action(s)

Defining Decision Alternatives in Terms of Available Systems

Altrernative D	Alternative F
Use Design-Based Equiment Later	Use Flexible Equipment Sooner



Alternative D | Alternative F

Name: Alternative D

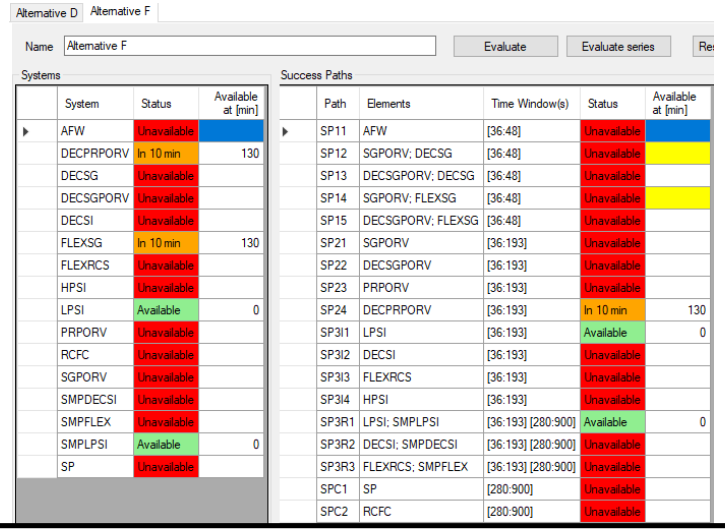
Evaluate | Evaluate series | Res

Systems

System	Status	Available at [min]
AFW	Unavailable	
DECPRPORV	Unavailable	
DECSG	In 30 min	150
DECSGPORV	Unavailable	
DECSI	Unavailable	
FLEXSG	Unavailable	
FLEXRCS	Unavailable	
HPSI	Unavailable	
LPSI	Available	0
PRPORV	Unavailable	
RCFC	Unavailable	
SGPORV	In 30 min	150
SMPDECSI	Unavailable	
SMPFLEX	Unavailable	
SMPLPSI	Available	0
SP	Unavailable	

Success Paths

Path	Elements	Time Window(s)	Status	Available at [min]
SP11	AFW	[36:48]	Unavailable	
SP12	SGPORV; DECSG	[36:48]	In 30 min	150
SP13	DECSGPORV; DECSG	[36:48]	Unavailable	
SP14	SGPORV; FLEXSG	[36:48]	Unavailable	
SP15	DECSGPORV; FLEXSG	[36:48]	Unavailable	
SP21	SGPORV	[36:193]	In 30 min	150
SP22	DECSGPORV	[36:193]	Unavailable	
SP23	PRPORV	[36:193]	Unavailable	
SP24	DECPRPORV	[36:193]	Unavailable	
SP3I1	LPSI	[36:193]	Available	0
SP3I2	DECSI	[36:193]	Unavailable	
SP3I3	FLEXRCS	[36:193]	Unavailable	
SP3I4	HPSI	[36:193]	Unavailable	
SP3R1	LPSI; SMPLPSI	[36:193] [280:900]	Available	0
SP3R2	DECSI; SMPDECSI	[36:193] [280:900]	Unavailable	
SP3R3	FLEXRCS; SMPFLEX	[36:193] [280:900]	Unavailable	
SPC1	SP	[280:900]	Unavailable	
SPC2	RCFC	[280:900]	Unavailable	



Alternative D | Alternative F

Name: Alternative F

Evaluate | Evaluate series | Re

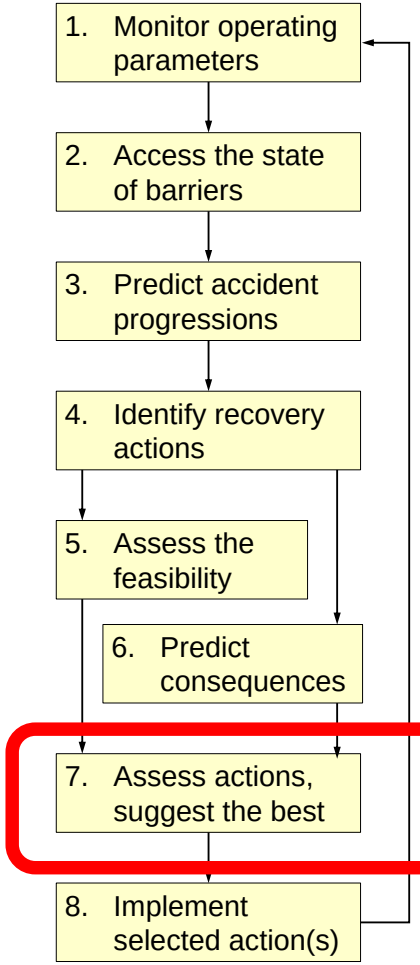
Systems

System	Status	Available at [min]
AFW	Unavailable	
DECPRPORV	In 10 min	130
DECSG	Unavailable	
DECSGPORV	Unavailable	
DECSI	Unavailable	
FLEXSG	In 10 min	130
FLEXRCS	Unavailable	
HPSI	Unavailable	
LPSI	Available	0
PRPORV	Unavailable	
RCFC	Unavailable	
SGPORV	Unavailable	
SMPDECSI	Unavailable	
SMPFLEX	Unavailable	
SMPLPSI	Available	0
SP	Unavailable	

Success Paths

Path	Elements	Time Window(s)	Status	Available at [min]
SP11	AFW	[36:48]	Unavailable	
SP12	SGPORV; DECSG	[36:48]	Unavailable	
SP13	DECSGPORV; DECSG	[36:48]	Unavailable	
SP14	SGPORV; FLEXSG	[36:48]	Unavailable	
SP15	DECSGPORV; FLEXSG	[36:48]	Unavailable	
SP21	SGPORV	[36:193]	Unavailable	
SP22	DECSGPORV	[36:193]	Unavailable	
SP23	PRPORV	[36:193]	Unavailable	
SP24	DECPRPORV	[36:193]	In 10 min	130
SP3I1	LPSI	[36:193]	Available	0
SP3I2	DECSI	[36:193]	Unavailable	
SP3I3	FLEXRCS	[36:193]	Unavailable	
SP3I4	HPSI	[36:193]	Unavailable	
SP3R1	LPSI; SMPLPSI	[36:193] [280:900]	Available	0
SP3R2	DECSI; SMPDECSI	[36:193] [280:900]	Unavailable	
SP3R3	FLEXRCS; SMPFLEX	[36:193] [280:900]	Unavailable	
SPC1	SP	[280:900]	Unavailable	
SPC2	RCFC	[280:900]	Unavailable	

Step 7: Assesment of Alternatives



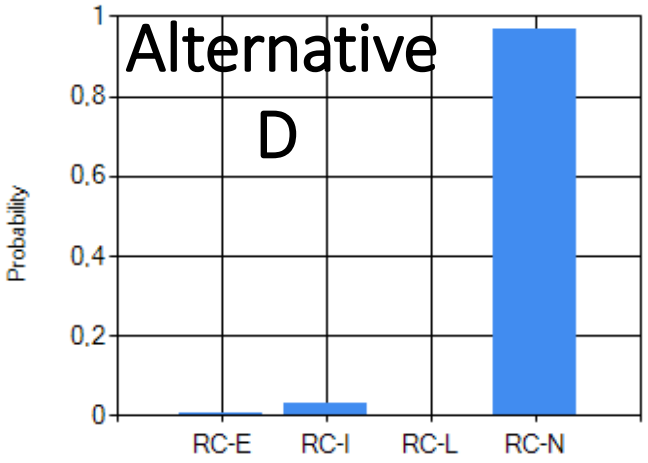
Expected *consequences of actions* are assessed using probability distributions of *radioactive release categories:*

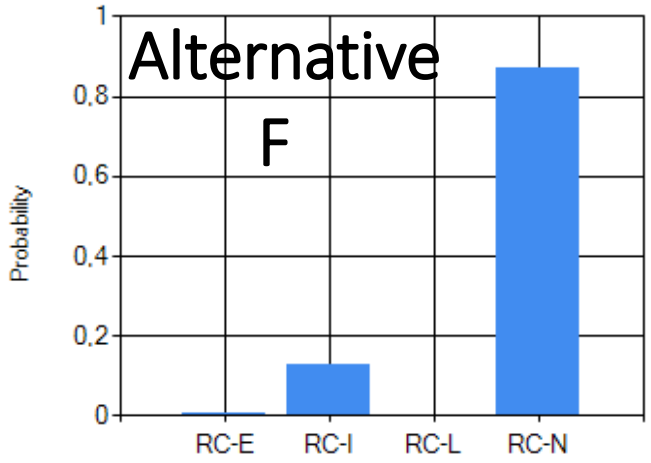
- **RC-E**: Early containment failure and radioactivity release (hours)
- **RC-I**: Intermediate (about a day)
- **RC-L**: Late (several days)
- **RC-N**: Long-term concern

Assessment of alternatives

Step 7: Assesment of Alternatives

1. Monitor operating parameters
2. Access the state of barriers
3. Predict accident progressions
4. Identify recovery actions
5. Assess the feasibility
6. Predict consequences
7. Assess actions, suggest the best
8. Implement selected action(s)

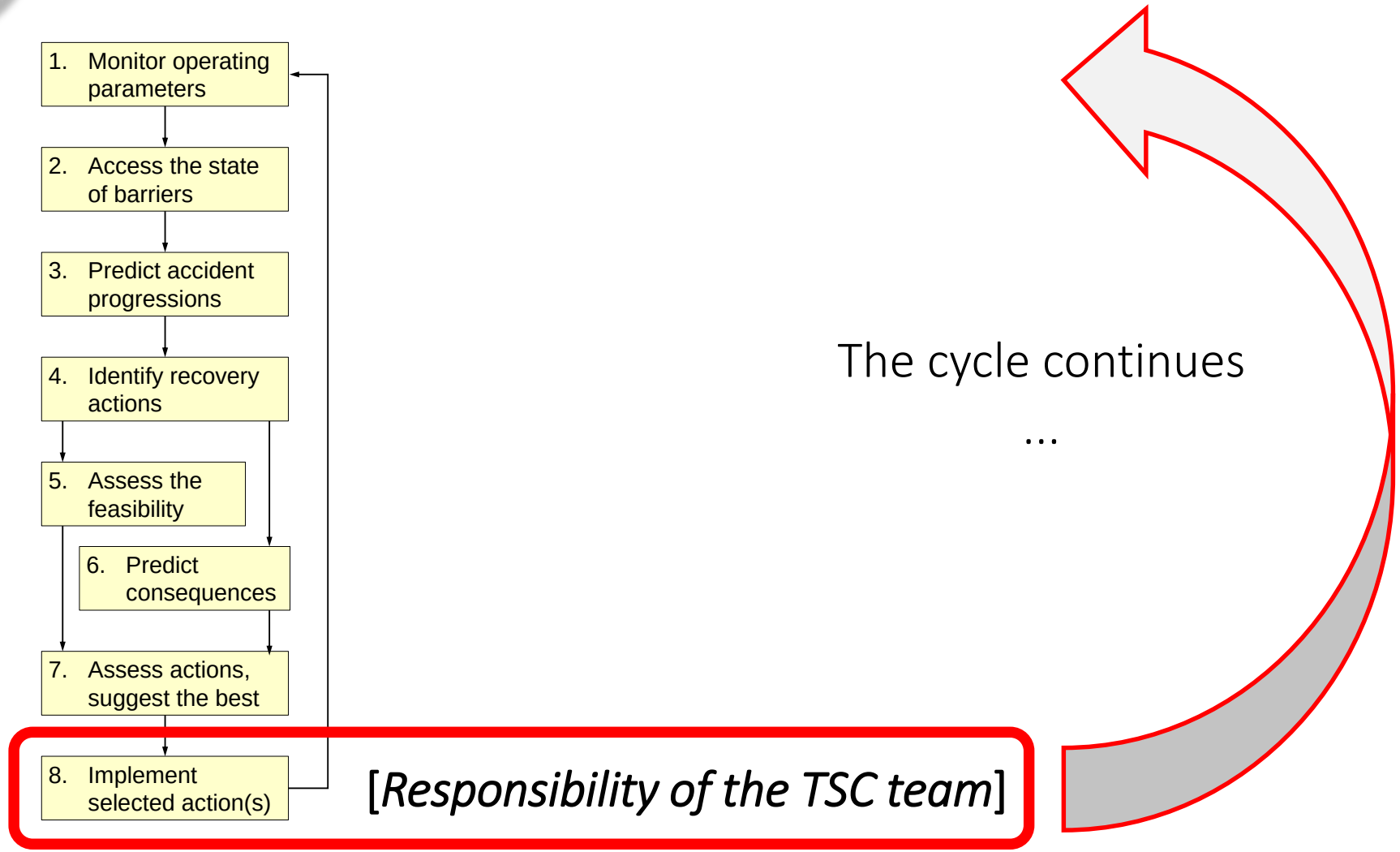




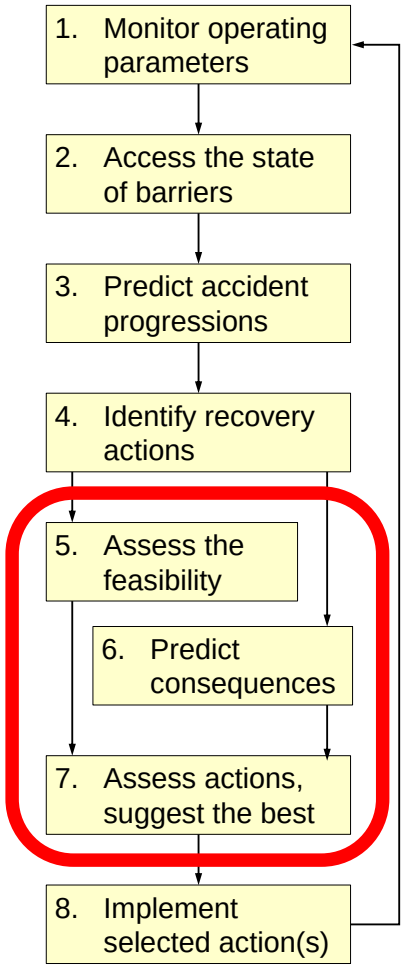
RC-E: Early release (hours)
RC-I: Intermediate (~ 1 day)
RC-L: Late (several days)
RC-N: Long-term concern

Assessment of alternatives

Step 8: Choosing and Implementing Actions

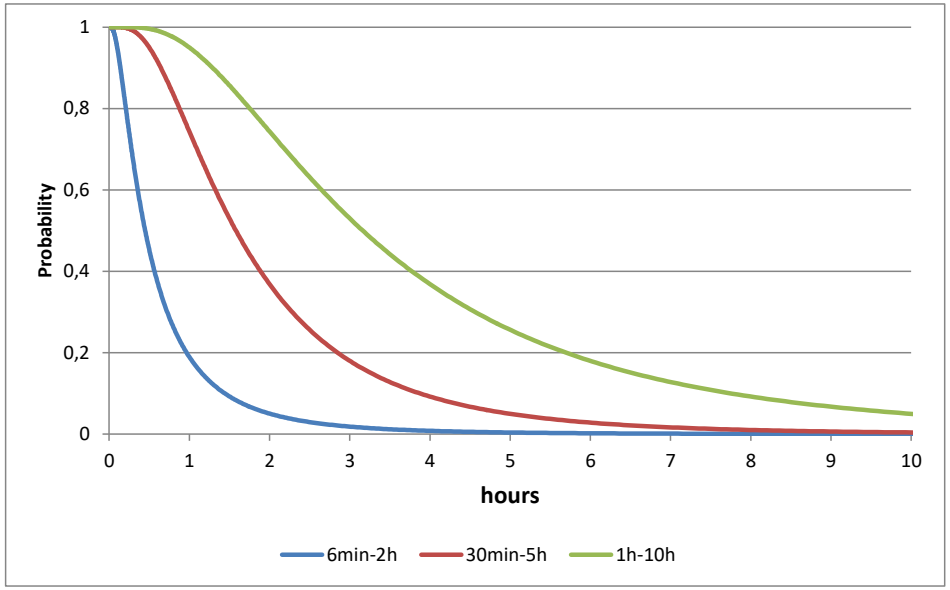


Steps 5-7: Assess Alternatives



Probabilistic Assessment of Actions' Success

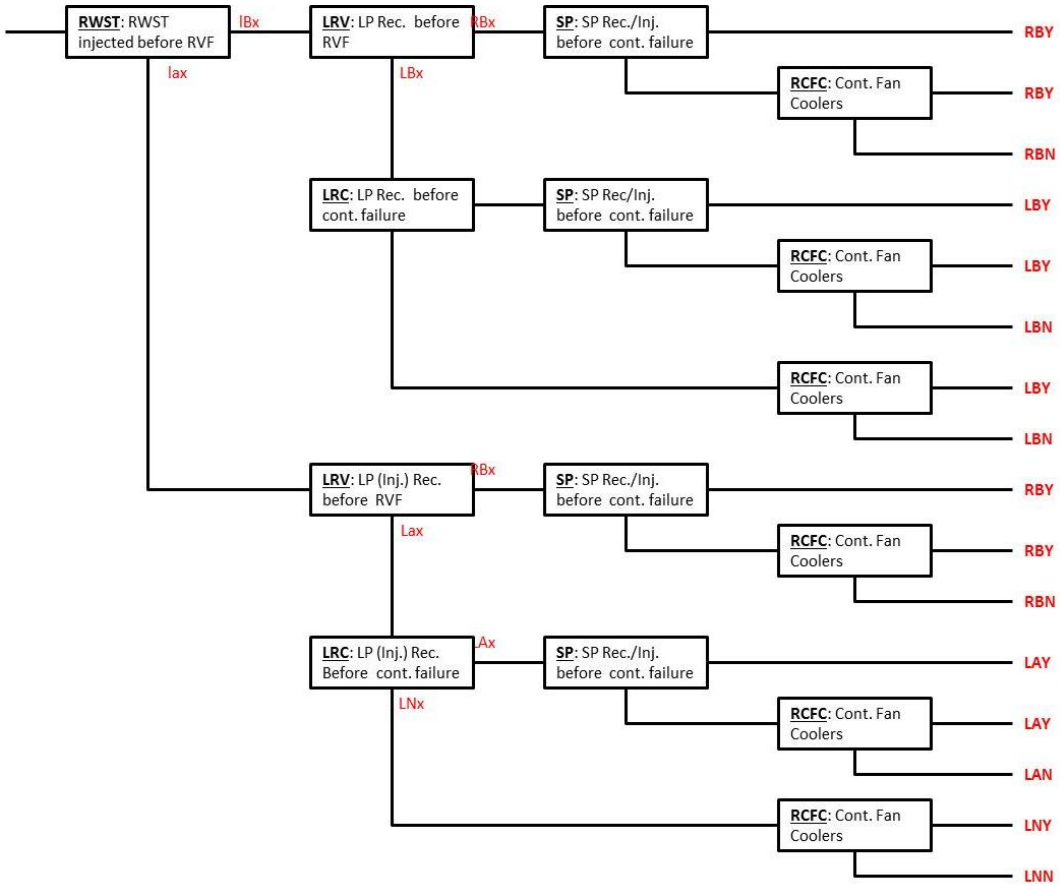
- Each activity has a "success window": 95th percentile and 5th percentile success times
- Expected action success is estimated by cumulative lognormal distribution depending on T_{05} and T_{95}



Steps 5-7: Assess Alternatives

1. Monitor operating parameters
2. Access the state of barriers
3. Predict accident progressions
4. Identify recovery actions
5. Assess the feasibility
6. Predict consequences
7. Assess actions, suggest the best
8. Implement selected action(s)

Basic representation: Accident Progression Event Tree (APET)



Steps 5-7: Assess Alternatives

1. Monitor operating parameters
2. Access the state of barriers
3. Predict accident progressions
4. Identify recovery actions
5. Assess the feasibility
6. Predict consequences
7. Assess actions, suggest the best
8. Implement selected action(s)

APET implemented as a DEX Model

- **Release**
  - **APET**
    - **Main**
      - *HP*
      - *PRZR*
      - *SGFW*
      - *SGRV*
      - *CRSGFW*
      - *CRSGSR*
      - *CRSGPR*
      - *CRSG*
    - **SUB1**
      - *RWST*
      - *LRV*
      - *LRC*
      - *SP*
      - *RCFC*
    - **SUB2**
      - *RWST*
      - *LRC*
      - *SP*
      - *RCFC*

	Main	SUB1	SUB2	APET
1	SUB1	RBY	*	RBY
2	SUB1	RBN	*	RBN
3	SUB1	LBY	*	LBY
4	SUB1	LBN	*	LBN
5	SUB1	LAY	*	LAY
6	SUB1	LAN	*	LAN
7	SUB1	LNY	*	LNY
8	SUB1	LNN	*	LNN
9	SUB2	*	HBY	HBY
10	SUB2	*	HBN	HBN
11	SUB2	*	HAY	HAY
12	SUB2	*	HAN	HAN
13	SUB2	*	HNY	HNY
14	SUB2	*	HNN	HNN
15	RC-E	*	*	RC-E

	RWST	LRV	LRC	SP	RCFC	SUB1
1	*	yes	*	*	yes	RBY
2	*	yes	*	yes	*	RBY
3	*	yes	*	no	no	RBN
4	yes	no	*	*	yes	LBY
5	yes	no	yes	yes	*	LBY
6	yes	no	no	*	no	LBN
7	yes	no	*	no	no	LBN
8	no	no	yes	*	yes	LAY
9	no	no	yes	yes	*	LAY
10	no	no	yes	no	no	LAN
11	no	no	no	*	yes	LNY
12	no	no	no	*	no	LNN

	RWST	LRC	SP	RCFC	SUB2
1	yes	*	*	yes	HBY
2	yes	yes	yes	*	HBY
3	yes	no	*	no	HBN
4	yes	*	no	no	HBN
5	no	*	yes	yes	HAY
6	no	yes	*	yes	HAY
7	no	yes	yes	*	HAY
8	no	no	yes	no	HAN
9	no	yes	no	no	HAN
10	no	no	no	yes	HNY
11	no	no	no	no	HNN

Conclusion (1/2)

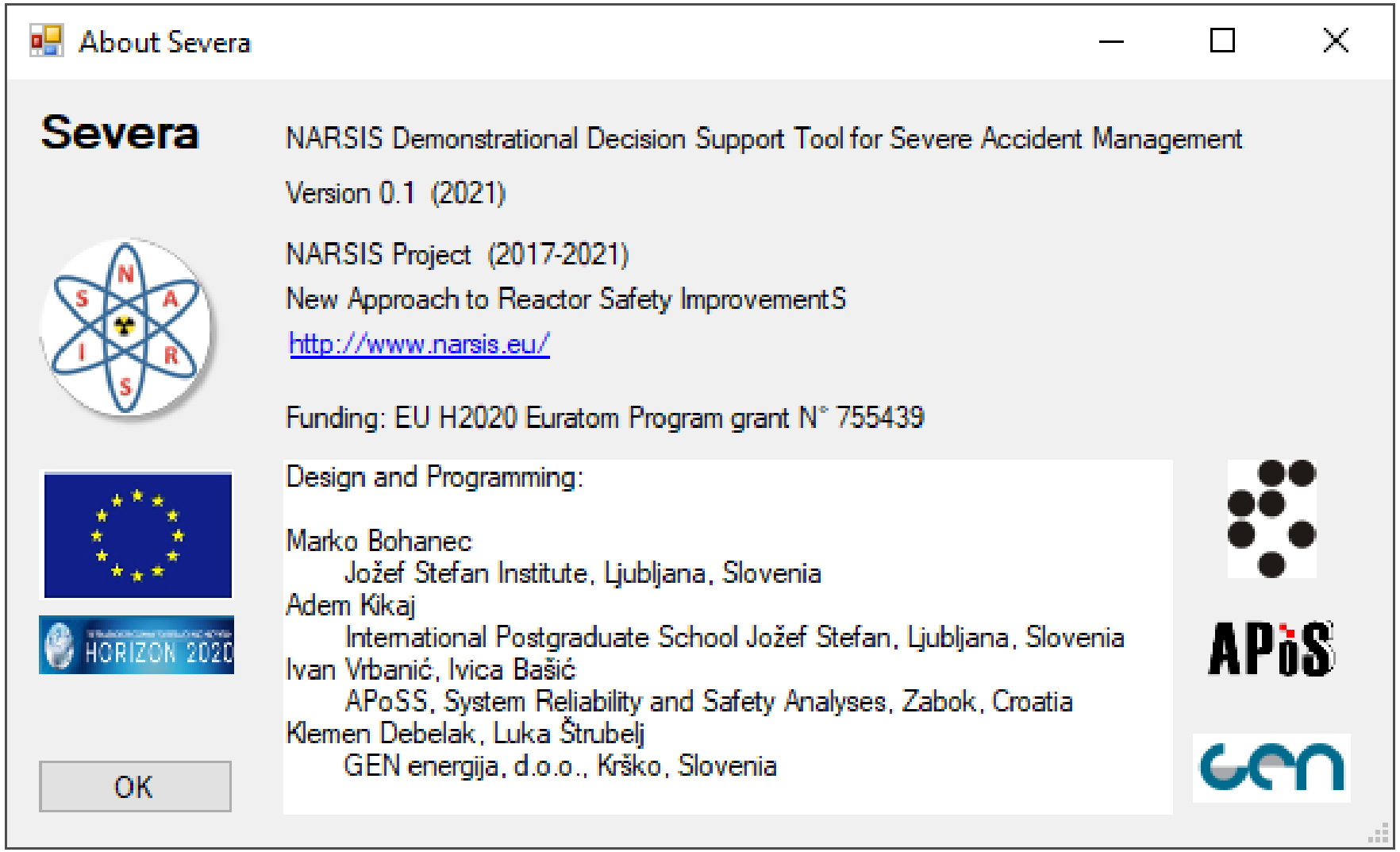
- **Goal**
  - Demonstrating the feasibility of decision-support tools, using PSA and decision modelling
- **Novelty**
  - Operationalization of SAMGs in real time
  - Focusing on decision-support needs of the TSC
  - Using/integrating a variety of modelling techniques (DEX, APET, PSA)
- **Limitations**
  - Prototype proof-of-concept software
  - Limited set of measured parameters
  - Subset of SAGs
  - Accuracy is expected to drop as the event proceeds

Conclusion (2/2)

- Contributions
  - Supporting of the TSC in an extremely difficult, stressful and often unclear decision situation
  - A training tool for TSC team members
  - Providing timely and best available information about the barriers and potential future events
  - Operationalization of SAMGs for a specific situation
  - Reducing the risk of inappropriate decisions

Further Work

- Perpetual testing of the *diagnostic part* [hard to obtain data and expertise]
- Improving the static table of RC probability distributions [currently suitable for early stages of the accident]
- Gradually adding the missing SAGs and plant systems
- Further assessment in educational/training sessions
- Formulating the requirements and resources for integration in a real NPP
- Improving methods and tools for this type of problems, e.g., “Dynamic DEX”



Thank you!

Marko Bohanec

marko.bohanec@ijs.si