Application of a Dynamic Event Tree Methodology to Loss of CCW/SW Sequences

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SM2A PROJECT, October 2009

1. INTRODUCTION

- Several researching and technical groups have been working in varied nuclear safety areas, resulting from this effort some codes and software packages. The ISA methodology comes up to accomplish these tools to improve the accident analysis in NPP's.
- The global simplified diagram for this new methodology is here presented.

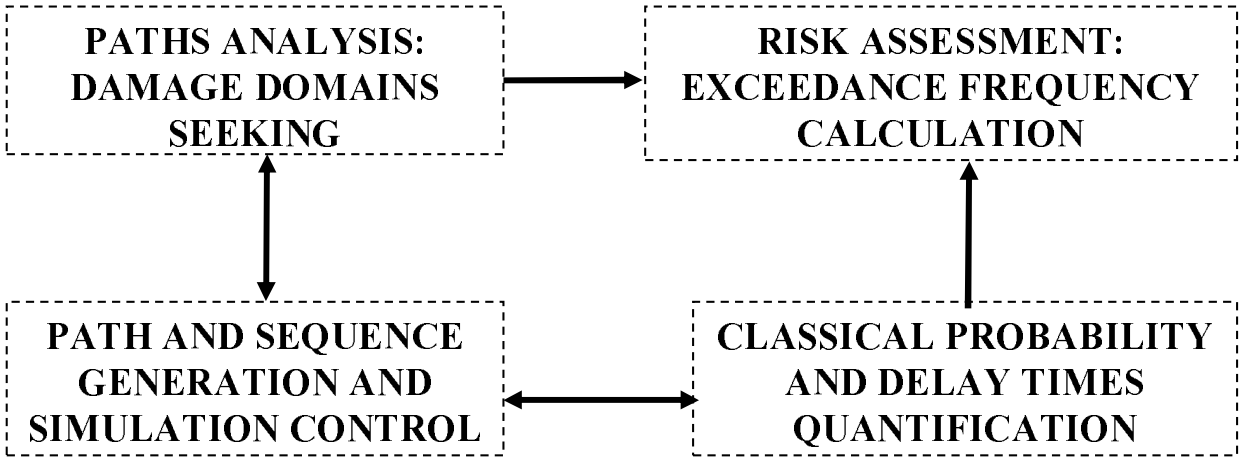


Figure 1: ISA Methodology general diagram

1. INTRODUCTION

- Two analysis levels should be considered in this development. First of all, the lower part of the diagram generates paths and sequences, delineates the dynamic event trees and provides the corresponding times (and their delays) and probabilities to the upper part.
- On the other half of the diagram, the paths analysis module analyzes every path that it is sent by the path and sequence generator in order to perform the sequence damage domain. This development has an enhanced importance because the mathematical techniques used to compute the damage exceedance frequency in the risk assessment module need this damage domain to get a perfect integration region for the damage probability integral.

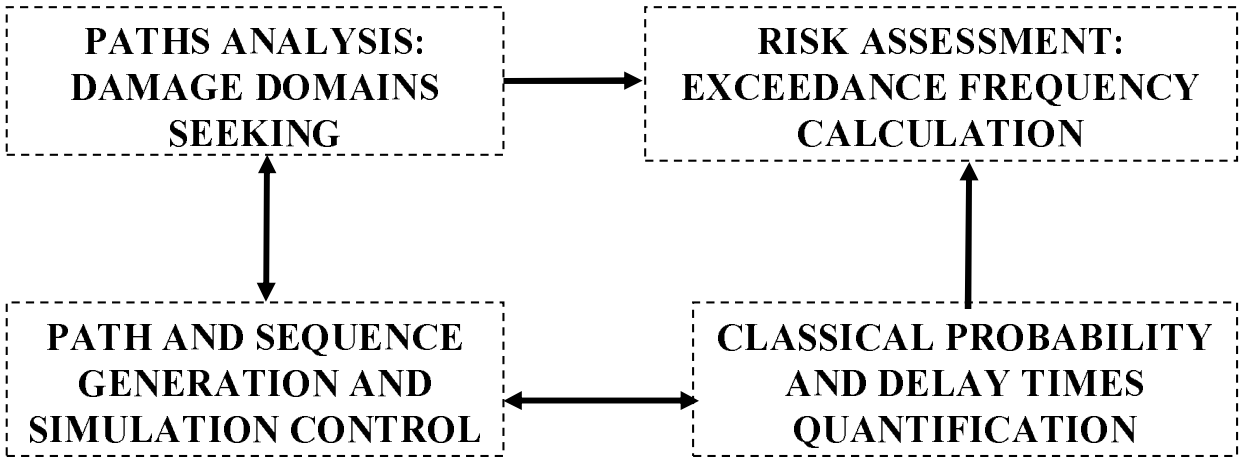


Figure 2: ISA Methodology general diagram

2. PATH AND SEQUENCE GENERATION. Simulation test of the loss of CCW/SW with a SLOCA

Scenario	**Probability**	**Eq. 4-loop area** (m^2) $\rho = 500/700\ kg/m^3$	**Eq. diameter** (m) $\rho = 500/700\ kg/m^3$	**Eq. diameter** (inch) $\rho = 500/700\ kg/m^3$
Sc1	$7.90 \cdot 10^{-1}$	4.80E-05/ 6.72E-05	7.82E-03/ 9.25E-03	3.08E-01/ 3.64E-01
Sc2	$1.44 \cdot 10^{-1}$	1.31E-04/ 1.83E-04	1.29E-02/ 1.53E-02	5.08E-01/ 6.01E-01
Sc3	$5.33 \cdot 10^{-2}$	4.17E-04/ 5.84E-04	2.31E-02/ 2.73E-02	9.08E-01/ 1.07E+00
Sc4	10^{-2}	1.74E-04/ 2.44E-04	1.49E-02/ 1.76E-02	5.86E-01/ 6.94E-01
Sc5	$2.50 \cdot 10^{-3}$	1.10E-03/ 1.54E-03	3.74E-02/ 4.43E-02	1.47E+00/ 1.74E+00

Table 1: Equivalent areas and diameters of SLOCA scenarios

Scenario	Probability
Sc2	$1.44 \cdot 10^{-1}$
Sc3	$5.33 \cdot 10^{-2}$
Sc4	10^{-2}
Sc5	$2.50 \cdot 10^{-3}$
Total	$2.10 \cdot 10^{-1}$

Table 2: SLOCA probability

2. PATH AND SEQUENCE GENERATION. Simulation test of the loss of CCW/SW with a SLOCA

- The selected scenario is Sc3; The 4-loop average area of the break is $5.01 \cdot 10^{-4} cm^2$. The average equivalent diameter is $2.52 \cdot 10^{-2}$m.

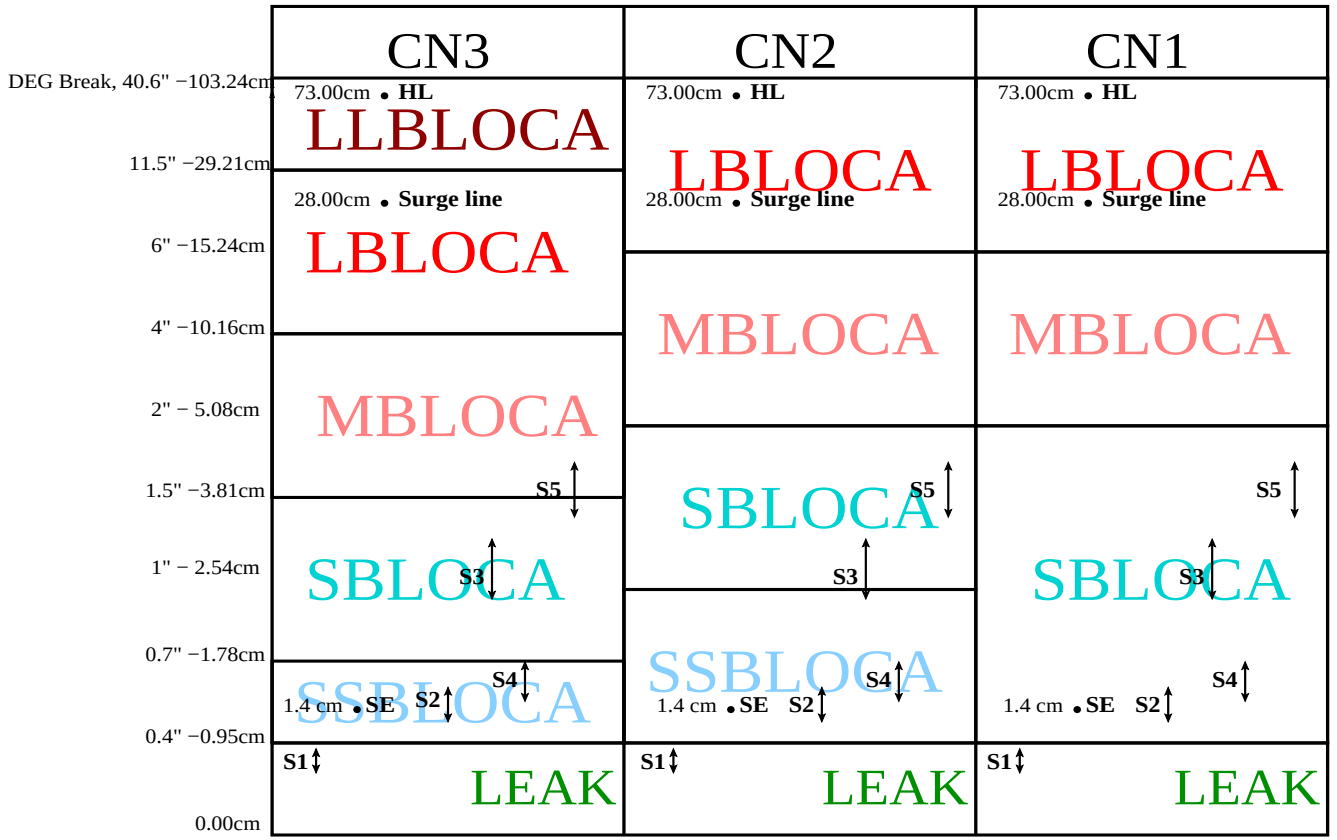
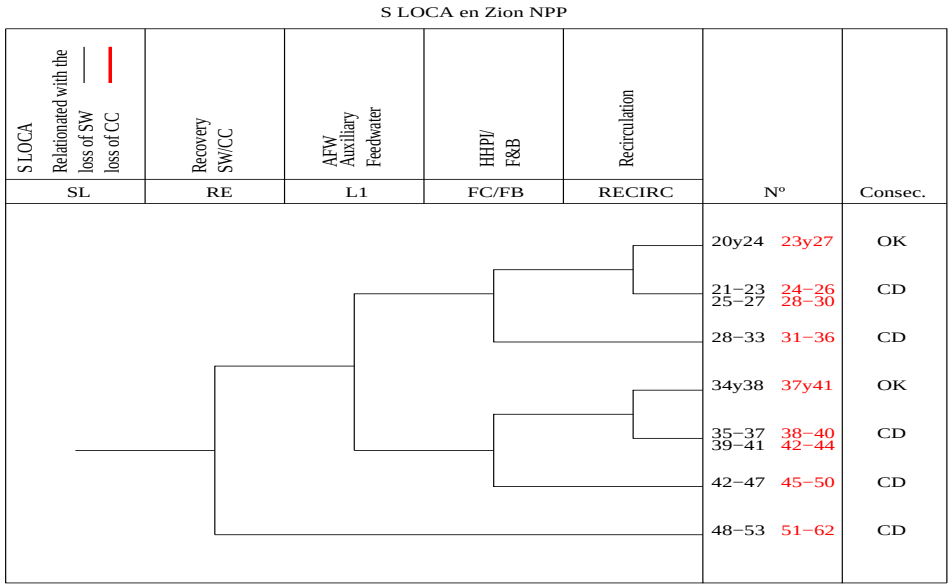


Figure 3: Comparisson of the diameters of the break at the Spanish PSAs and the 5 scenarios

2. PATH AND SEQUENCE GENERATION. Simulation test of the loss of CCW/SW with a SLOCA

- The specific objective of this analysis has been to demonstrate the methodology and to check the tool, focusing on an independent verification of the event tree delineation and assessment of realistic EOPs for LOCA plant recovery.



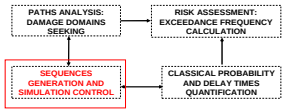


Figure 4: Simplified Loss of CCW/SW E.T. of Zion N.P.P.

2. PATH AND SEQUENCE GENERATION. Simulation test of the loss of CCW/SW with a SLOCA

Header definitions

Header	Description
$SLOCA$	RCP seals failure
$R_L(t)$	Recovery of CCW/SW and LPSI(1/2) available
$R_H(t)$	Recovery of CCW/SW and HPSI(2/4) available
$SG(t)$	Beginning of prymary cooling at 55K/h
A	Accumulators Discharge (4/4)

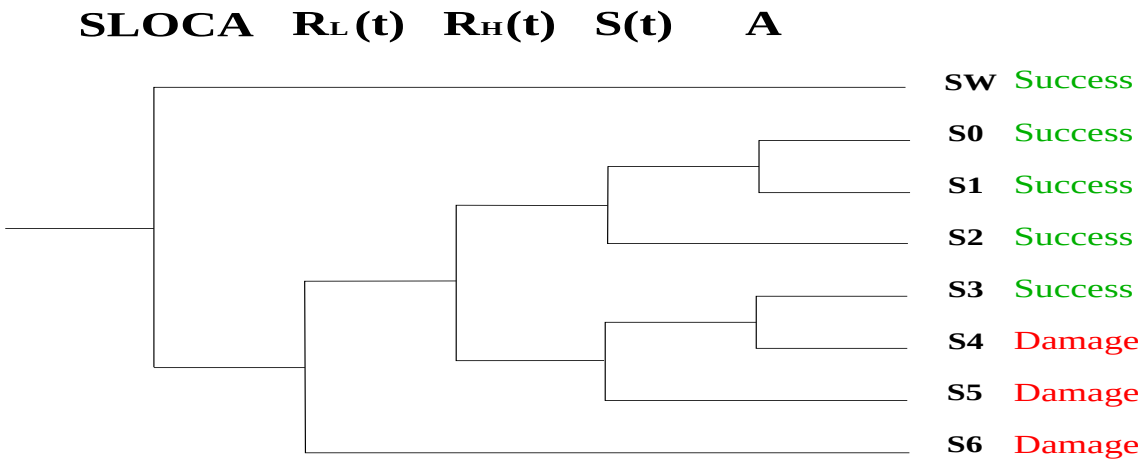


Figure 5: Generic simplified Loss of CCW/SW event tree.

2. PATH AND SEQUENCE GENERATION. Simulation test of the loss of CCW/SW with a SLOCA

- The full scale test application of this integrated software package to the loss of CCW/SW initiating event with a SLOCA of Zion N.P.P. has been performed. The simulation tools used were MAAP, Babieca, SimProc and Dendros.

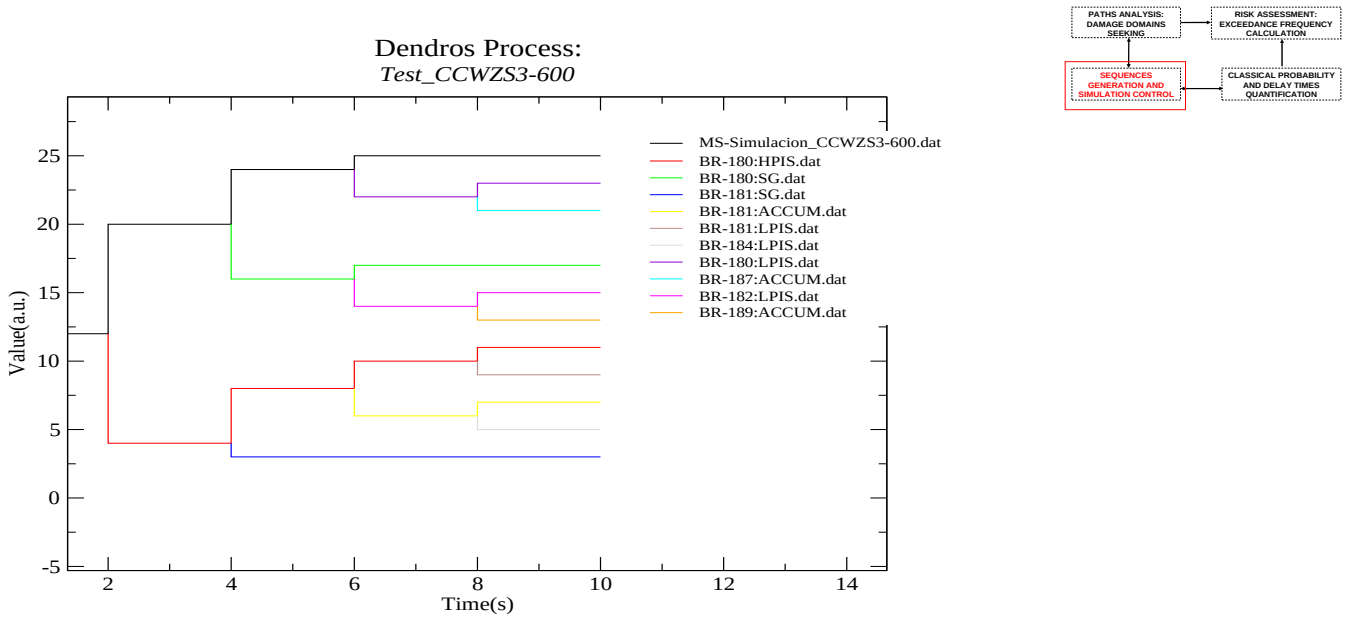
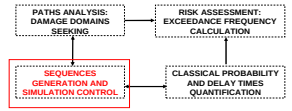


Figure 6: Simulated dynamic event tree. Simulation of the Scenario 3 of the loss of CCW/SW with a SLOCA (SG-600s)(Recovery-0s).

2. PATH AND SEQUENCE GENERATION. Simulation test of the loss of CCW/SW with a SLOCA

Candidate sequences



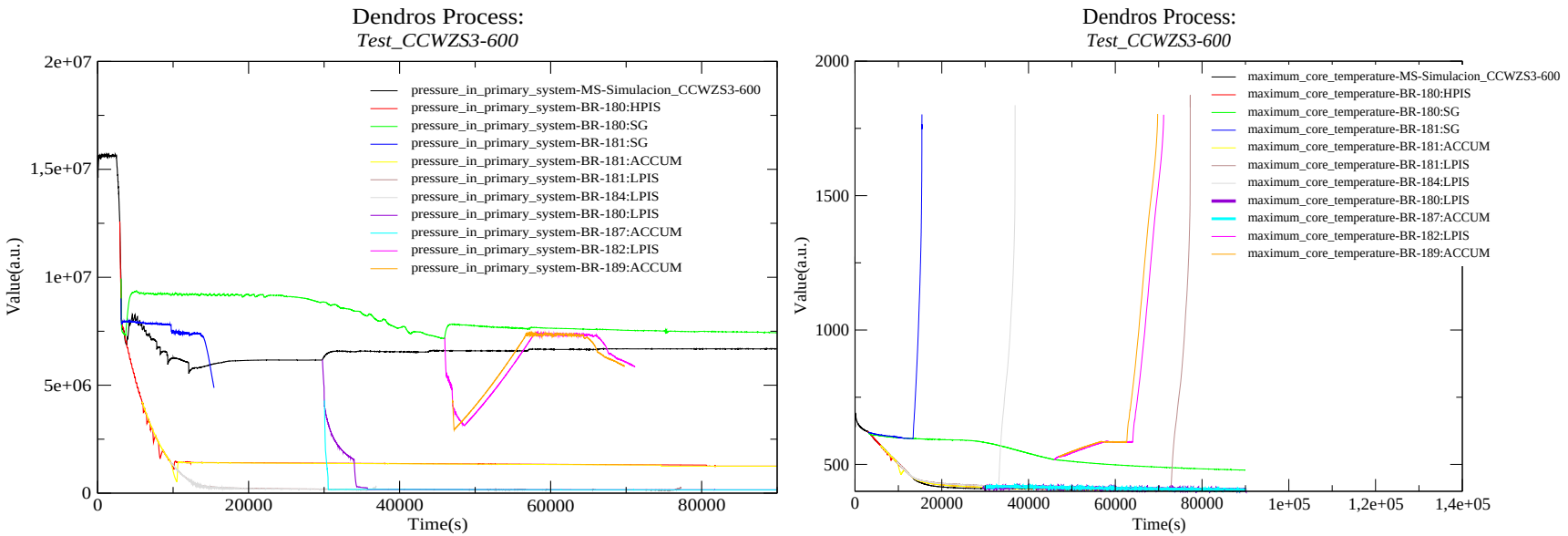


Figure 7: Pressure in the primary system and maximum clad temperature. Loss of CCW/SW with a SLOCA.

2. PATH AND SEQUENCE GENERATION. Simulation of the Scenario 3 of the loss of CCW/SW with a SLOCA (SG-600s)(Recovery-0s)

Maximum clad temperature

- To analyze the change of safety conditions, the maximum clad temperature is showed joined to its time occurrence and the limit condition reaching time (if reached).

Sequence	Limit condition time	Time for max. temperature	Max. clad temperature
HS	–	100s	690K
HS$\overline{\text{L}}$A	–	40000s	405K
HS$\overline{\text{LA}}$	–	40000s	405K
H$\overline{\text{S}}$L	–	3100s	620K
H$\overline{\text{S}}$LA	71146	71146	DAMAGED
H$\overline{\text{SLA}}$	69764	69764	DAMAGED
$\overline{\text{H}}$SAL	–	2935s	621K
$\overline{\text{H}}$SA$\overline{\text{L}}$	77276	77276	DAMAGED
$\overline{\text{H}}$S$\overline{\text{A}}$L	–	5869 s	570K
$\overline{\text{H}}$S$\overline{\text{AL}}$	36900	36900	DAMAGED
$\overline{\text{HS}}$	16515	16515	DAMAGED

3. PROBABILITY CALCULATION. Simulation test of the loss of CCW/SW with a SLOCA

System failure probability

Initiator	Frequency (y^{-1})		
Loss of CCW/SW	$2 \cdot 10^{-3}$		

Header	Type of Probability	Failure probability	Distribution function
SLOCA	Stochastic	0.21	Lognormal
Recovery	Stochastic	0.13	Constant/Lognormal
LPSI	Deterministic	10^{-4}	–
HPSI	Deterministic	$2 \cdot 10^{-5}$	–
SG	Stochastic	0.05	Lognormal
A	Deterministic	10^{-3}	–

4. PATH ANALYSIS

- This analysis is completed with the dynamic event tree delineation by an accident code like MAAP:

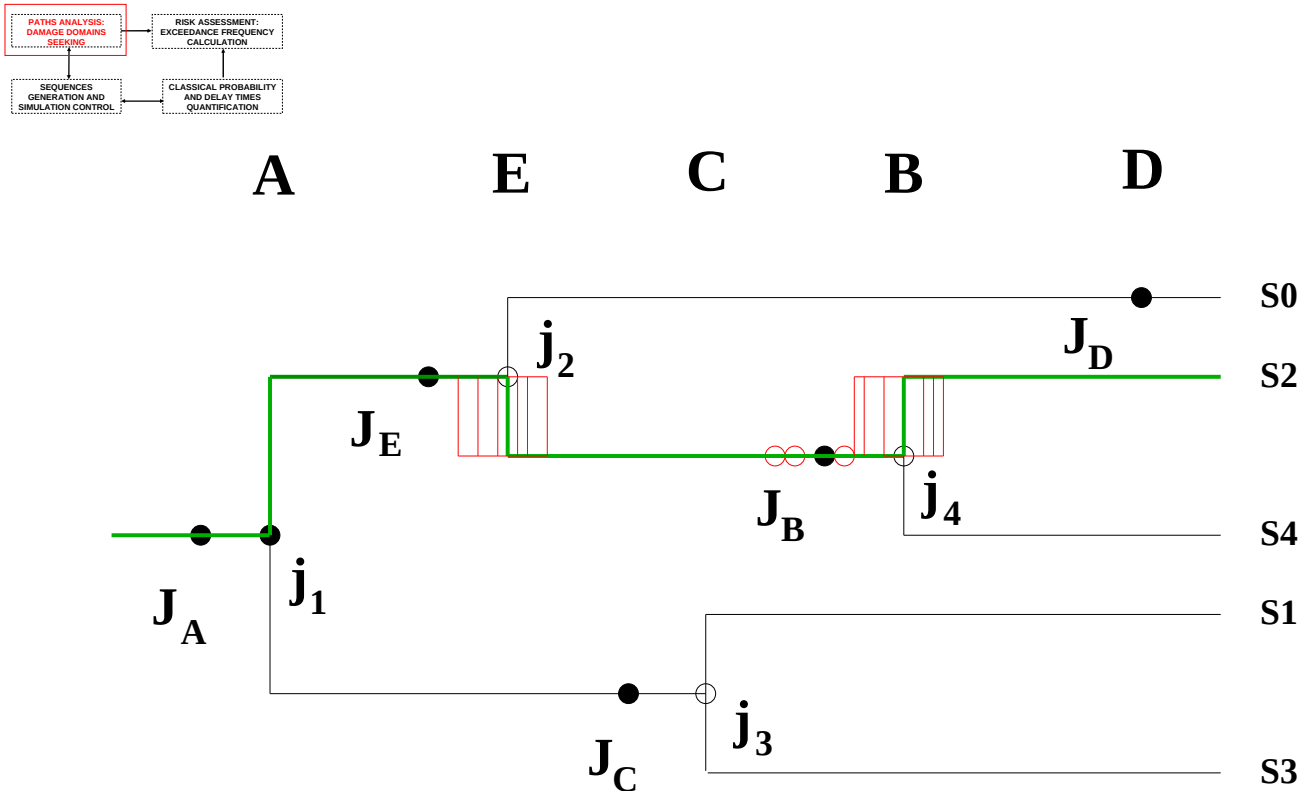


Figure 8: Path damage analysis. Associate event tree.

4. PATH ANALYSIS

- This analysis is completed with the dynamic event tree delineation by an accident code like MAAP:

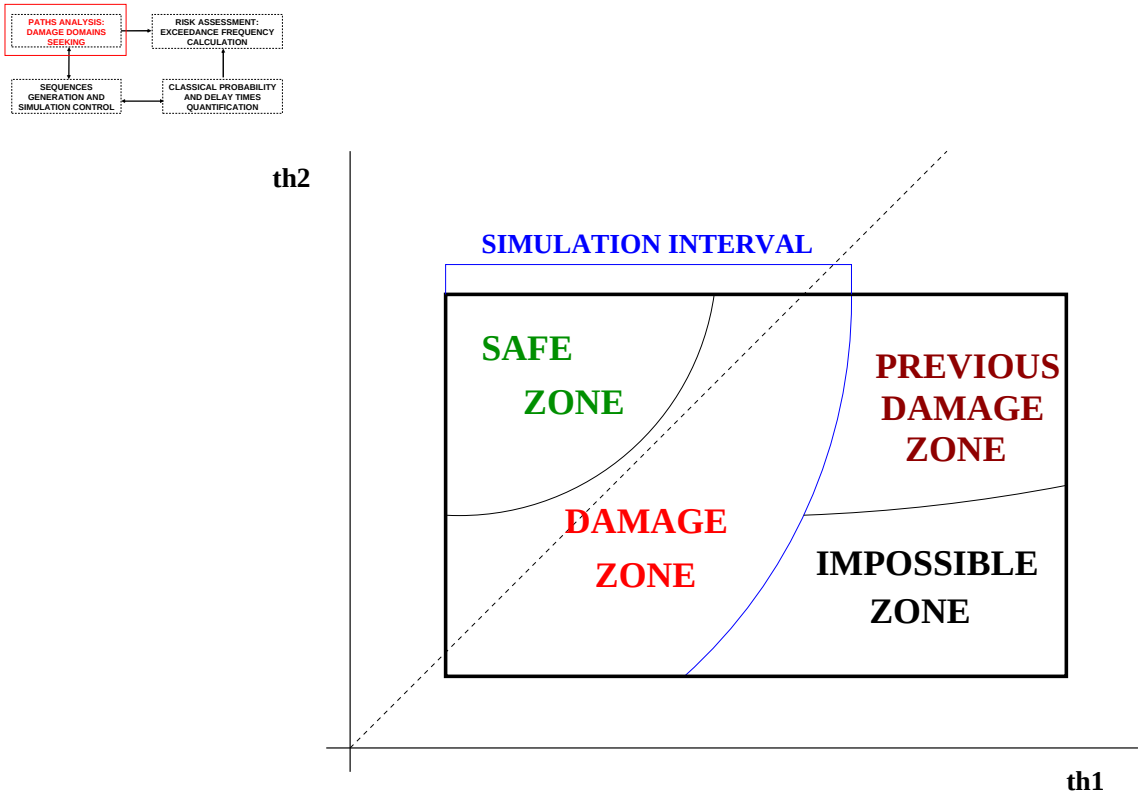
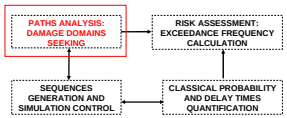


Figure 9: Analysis zones obtained by path analysis.

4. PATH ANALYSIS. Simulation test of the loss of CCW/SW with a SLOCA



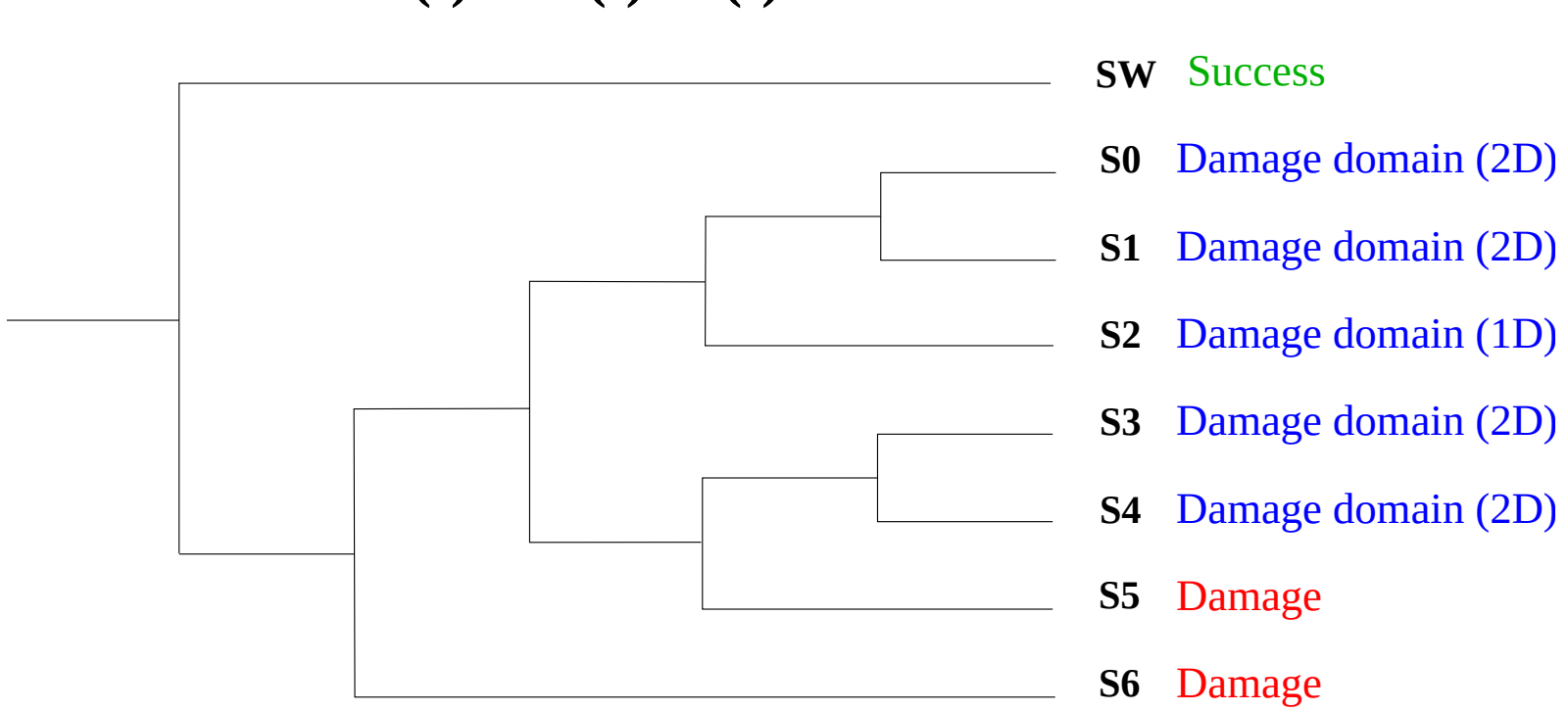
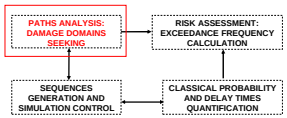


Figure 10: Event tree. Damage domain info.

4. PATH ANALYSIS. Simulation test of the loss of CCW/SW with a SLOCA



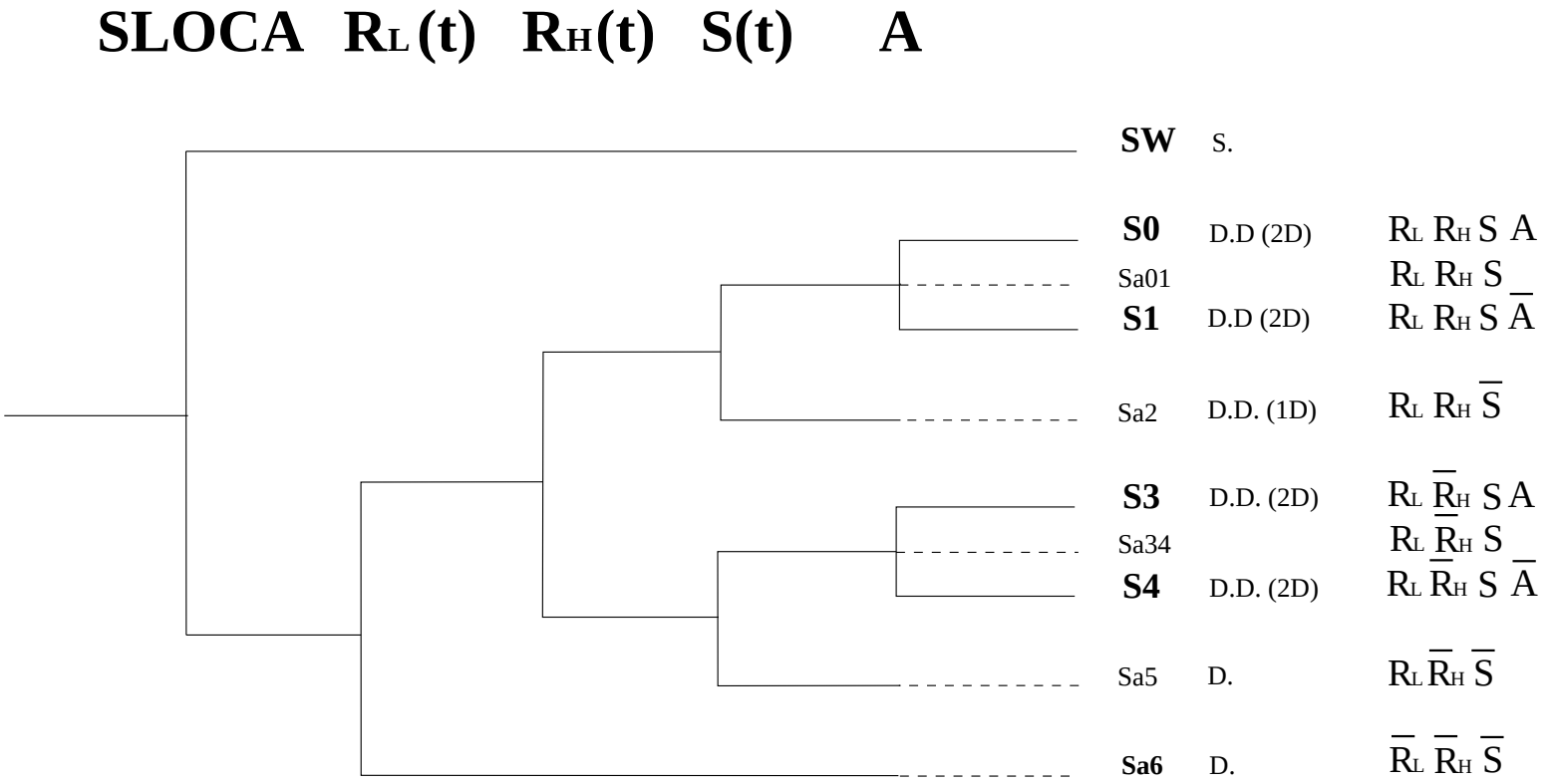


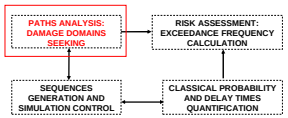
Figure 11: Event tree. Accumulators demand info.

4. PATH ANALYSIS. Simulation test of the loss of CCW/SW with a SLOCA

Sequence frequency

Sequence	Frequency (y^{-1})	Probability
SW	$1.58 \cdot 10^{-3}$	$7.90 \cdot 10^{-1}$
S0	$3.47 \cdot 10^{-4}$	$1.73 \cdot 10^{-1}$
S1	$3.47 \cdot 10^{-7}$	$1.74 \cdot 10^{-4}$
S2	$1.83 \cdot 10^{-5}$	$9.13 \cdot 10^{-3}$
S3	$6.93 \cdot 10^{-9}$	~ 0
S4	$6.94 \cdot 10^{-12}$	~ 0
S5	$3.65 \cdot 10^{-10}$	~ 0
S6	$5.46 \cdot 10^{-5}$	$2.73 \cdot 10^{-2}$

4. PATH ANALYSIS. Simulation test of the loss of CCW/SW with a SLOCA



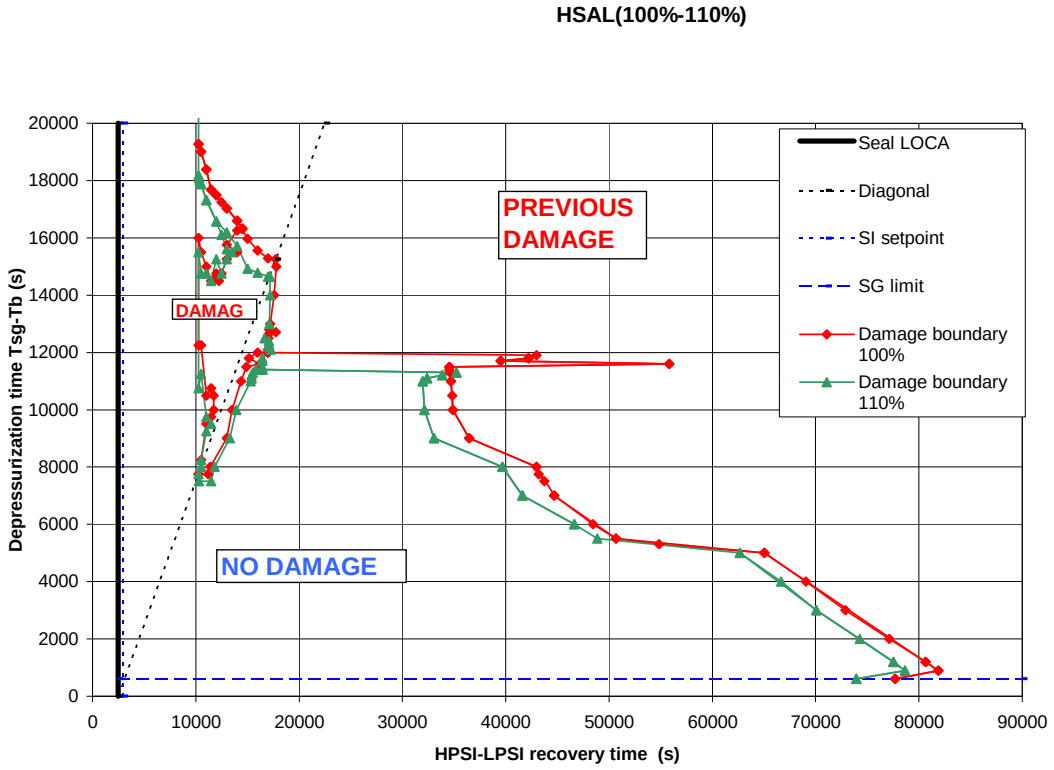
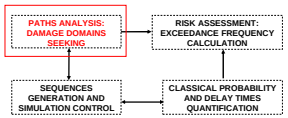


Figure 12: S0 Damage domain at 100% and 110%

4. PATH ANALYSIS.Simulation test of the loss of CCW/SW with a SLOCA



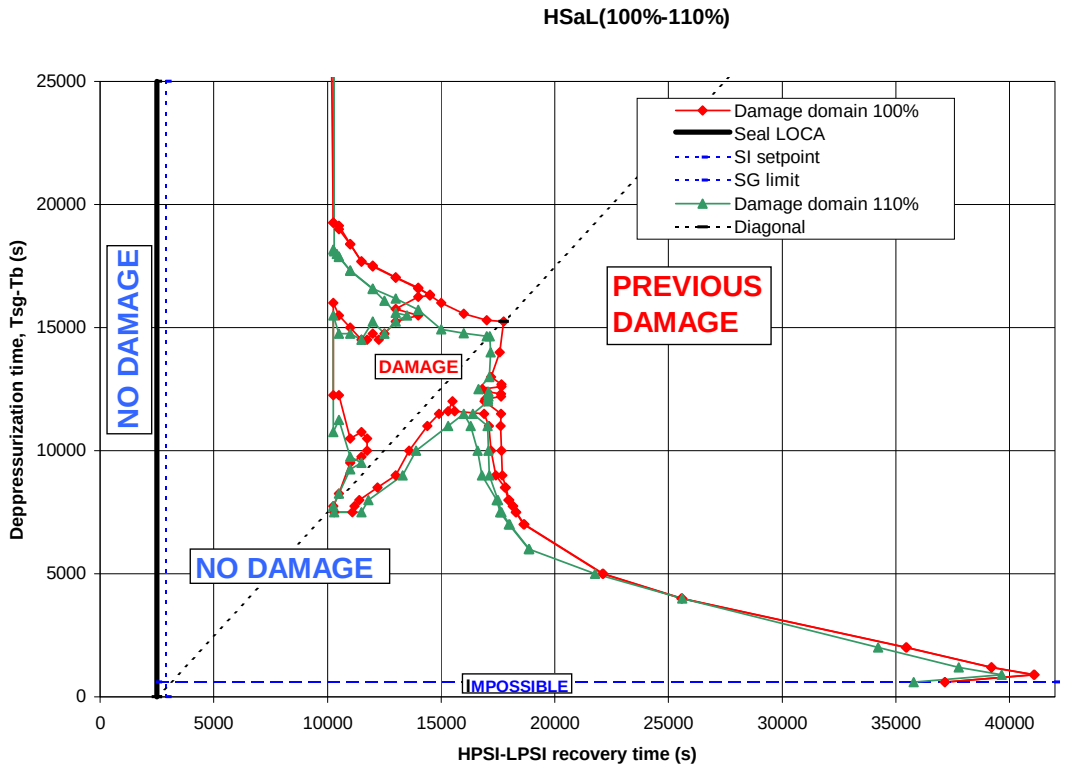
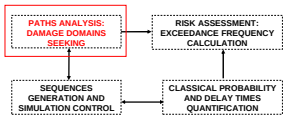


Figure 13: S1 Damage domain at 100% and 110%

4. PATH ANALYSIS. Simulation test of the loss of CCW/SW with a SLOCA



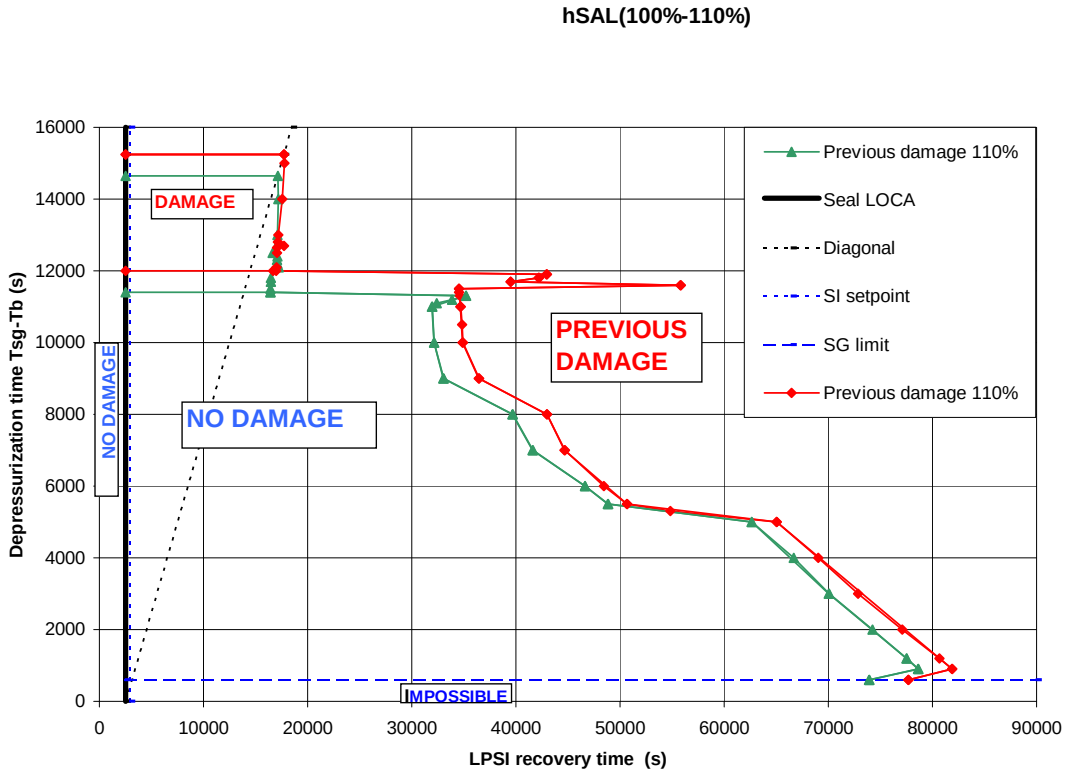
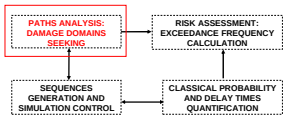


Figure 14: S3 Damage domain at 100% and 110%

4. PATH ANALYSIS. Simulation test of the loss of CCW/SW with a SLOCA



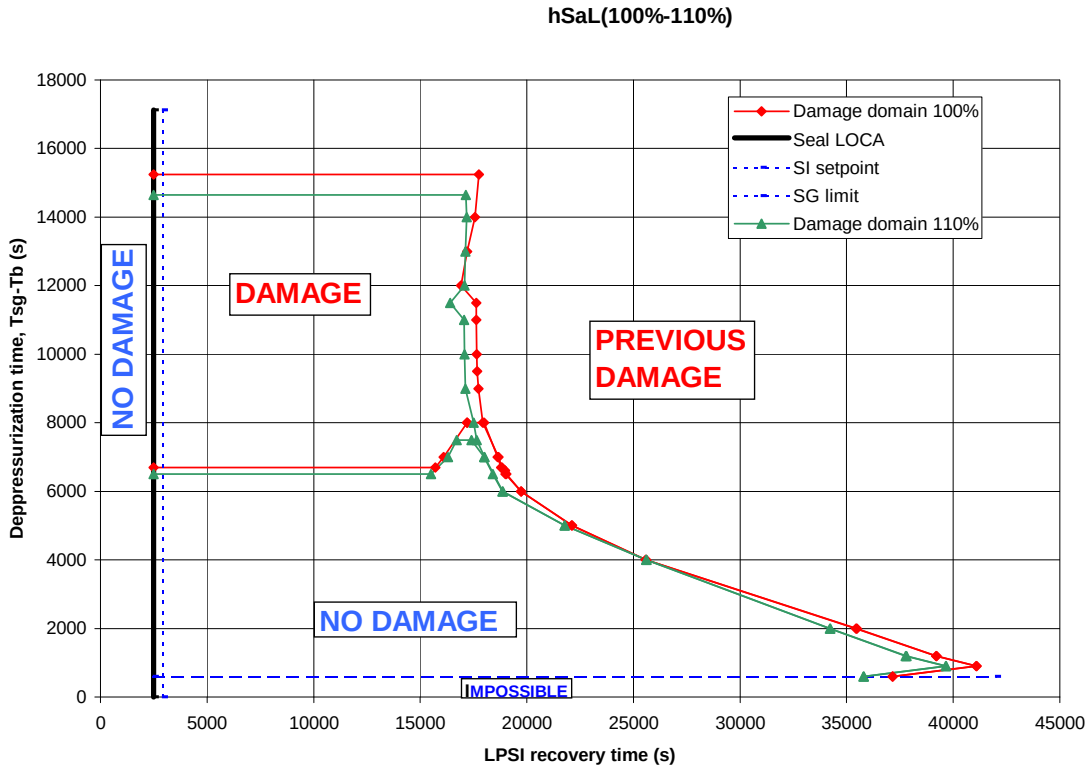
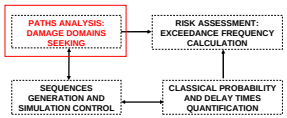


Figure 15: S4 Damage domain at 100% and 110%

4. PATH ANALYSIS. Simulation test of the loss of CCW/SW with a SLOCA



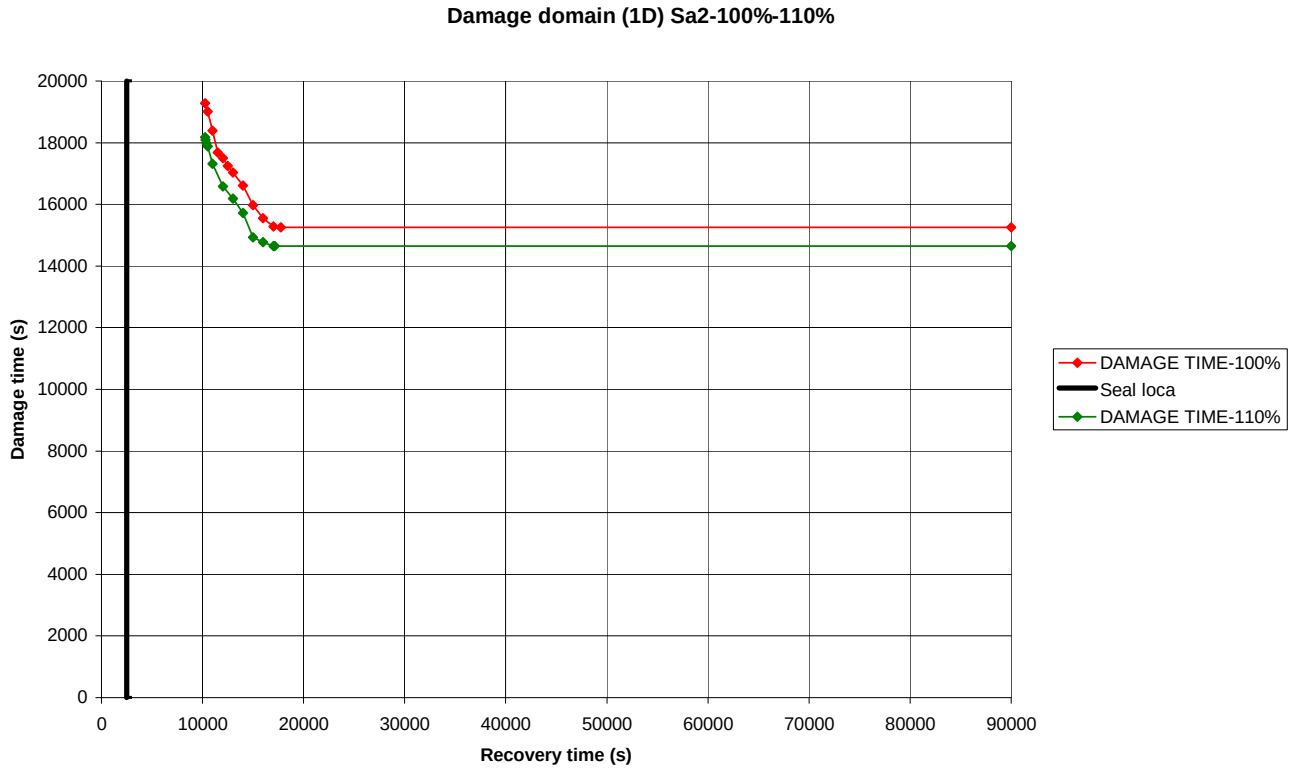
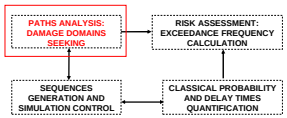


Figure 16: Sa2 Damage domain (1D) at 100% and 110%

4. PATH ANALYSIS. Simulation test of the loss of CCW/SW with a SLOCA



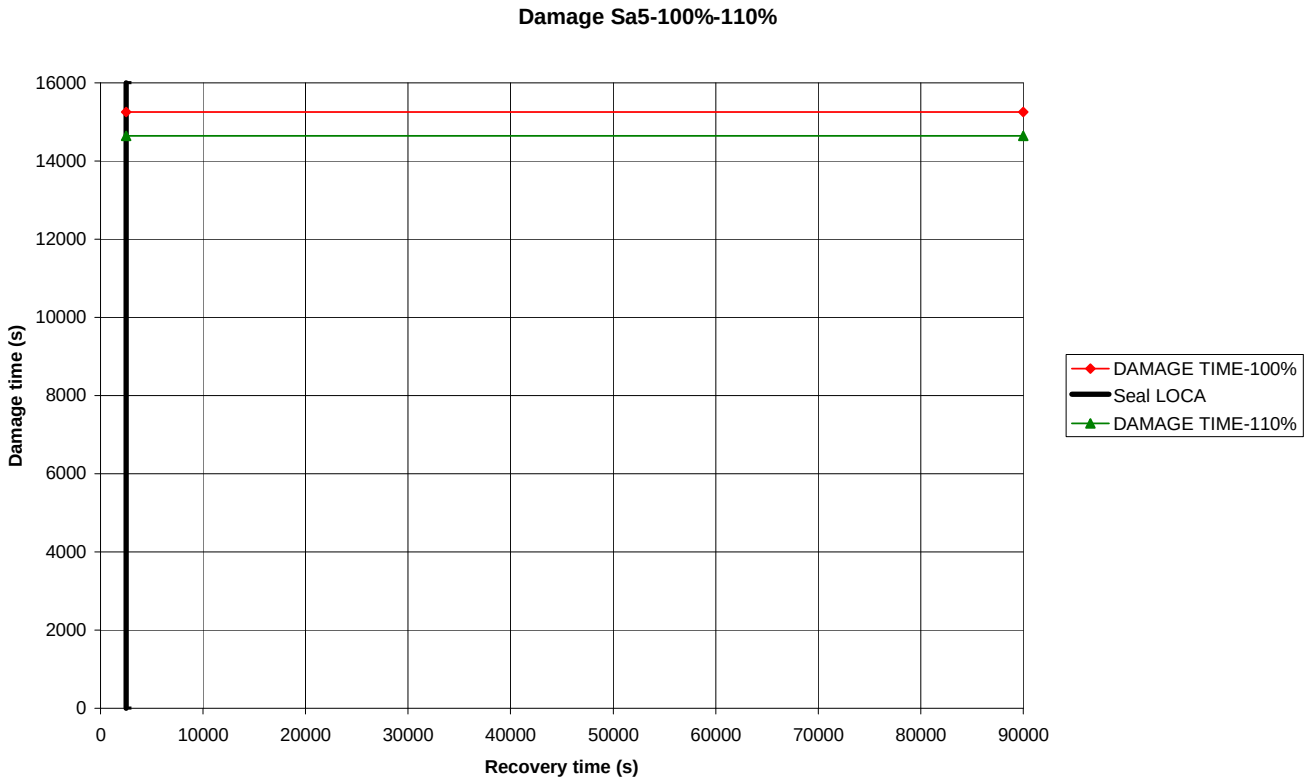
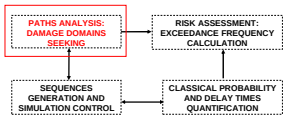


Figure 17: Sa5 Damage at 100% and 110%

4. PATH ANALYSIS. Simulation test of the loss of CCW/SW with a SLOCA



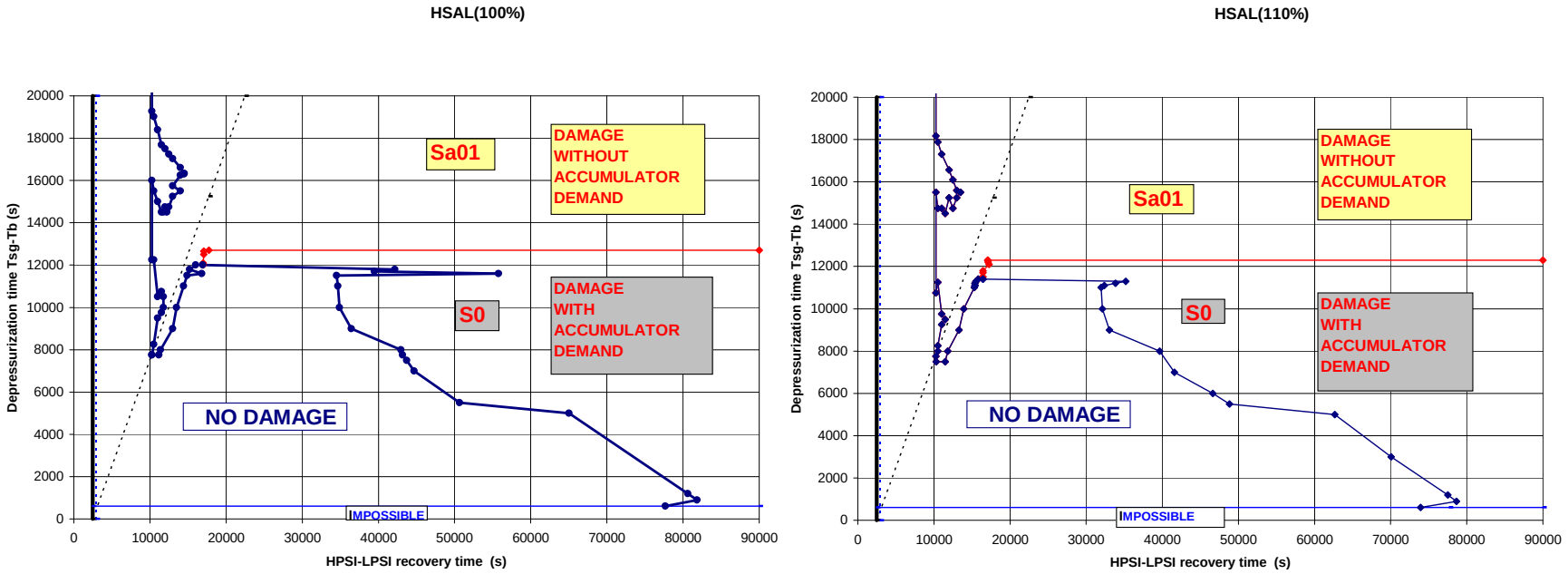
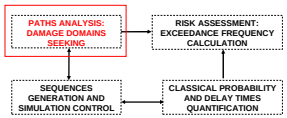


Figure 18: S0 Damage domain with/without accumulator demand at 100% and 110%

4. PATH ANALYSIS. Simulation test of the loss of CCW/SW with a SLOCA



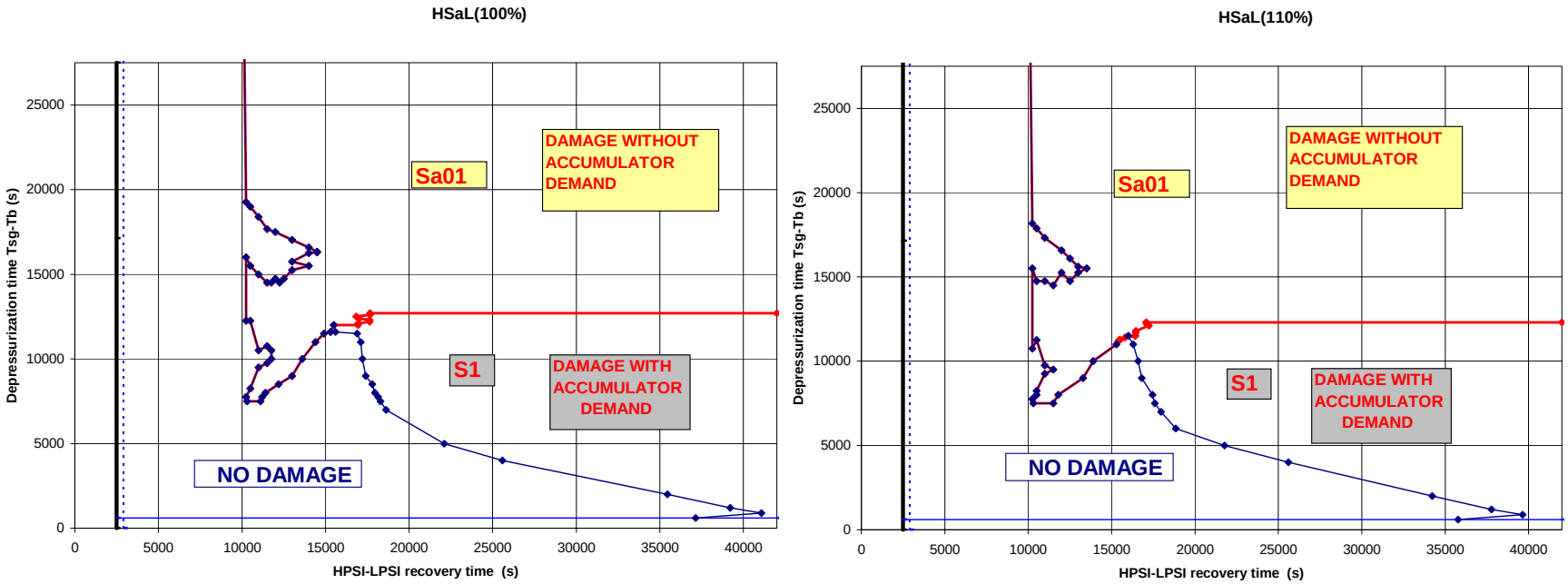
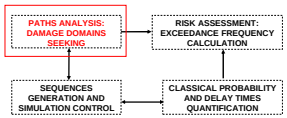


Figure 19: S1 Damage domain with/without accumulator demand at 100% and 110%

4. PATH ANALYSIS. Simulation test of the loss of CCW/SW with a SLOCA



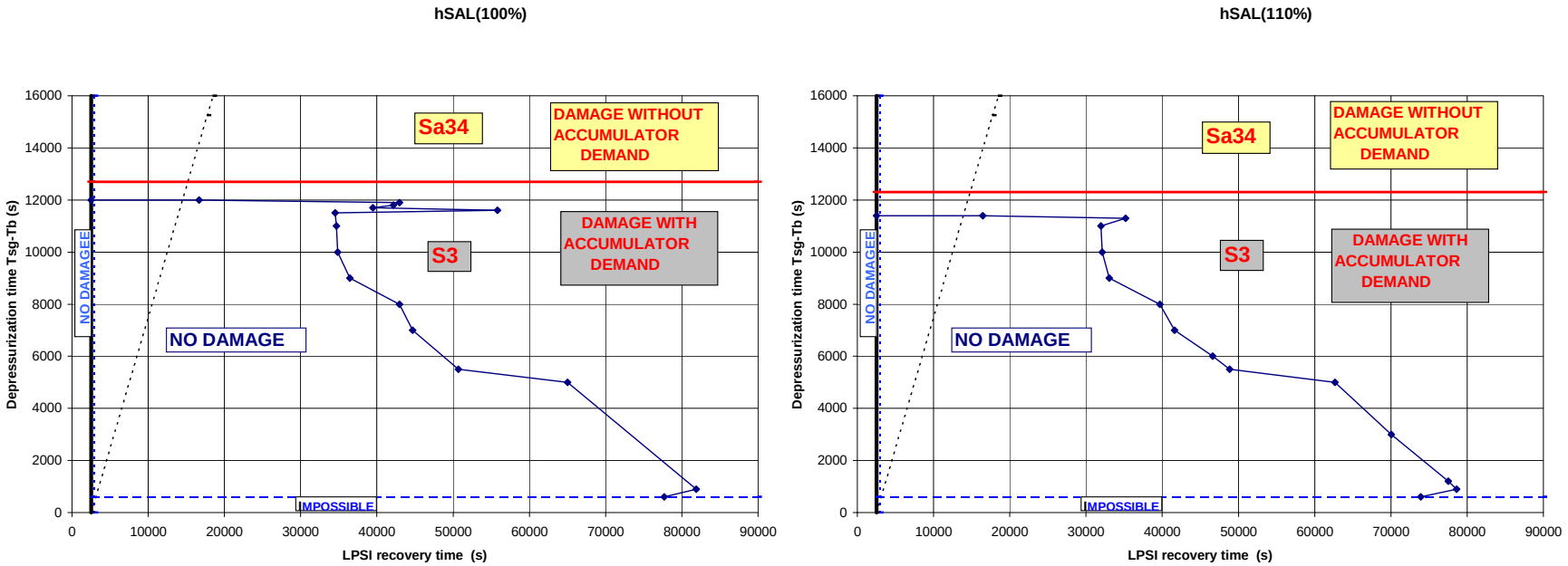
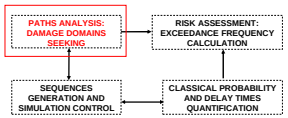


Figure 20: S3 Damage domain with/without accumulator demand at 100% and 110%

4. PATH ANALYSIS. Simulation test of the loss of CCW/SW with a SLOCA



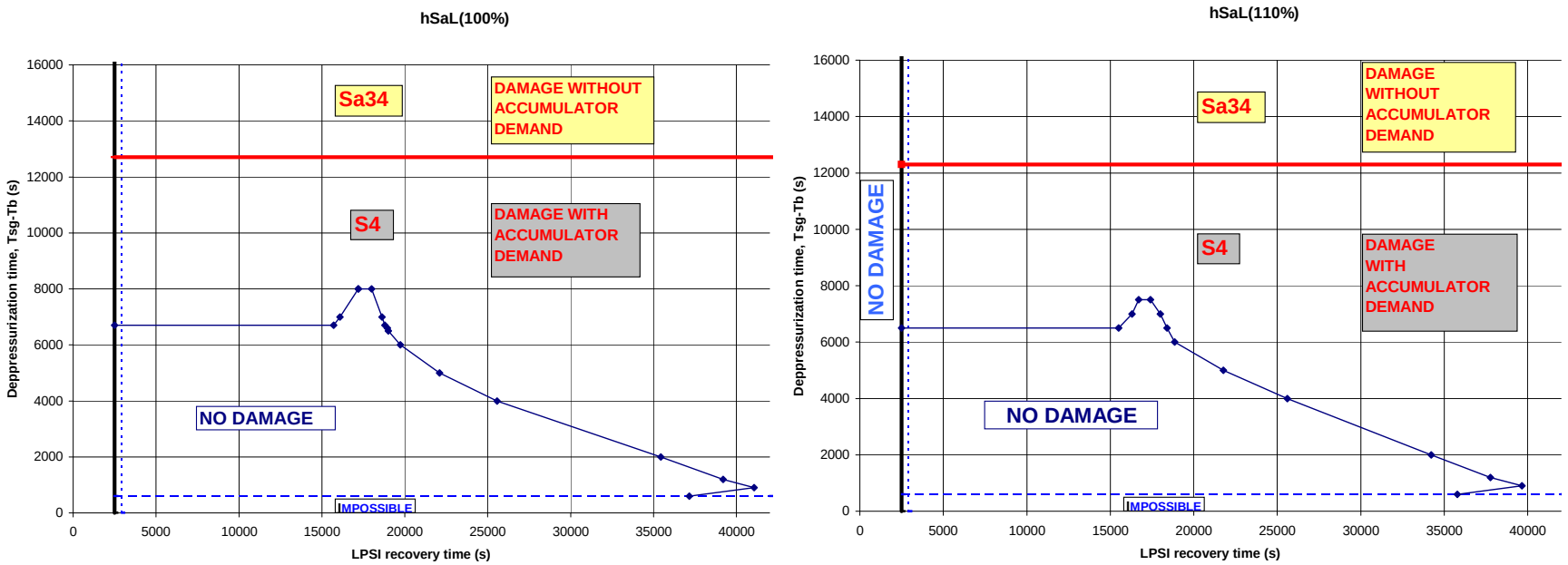
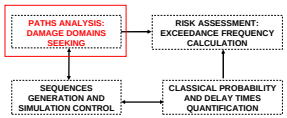


Figure 21: S4 Damage domain with/without accumulator demand at 100% and 110%

4. PATH ANALYSIS. Simulation test of the loss of CCW/SW with a SLOCA



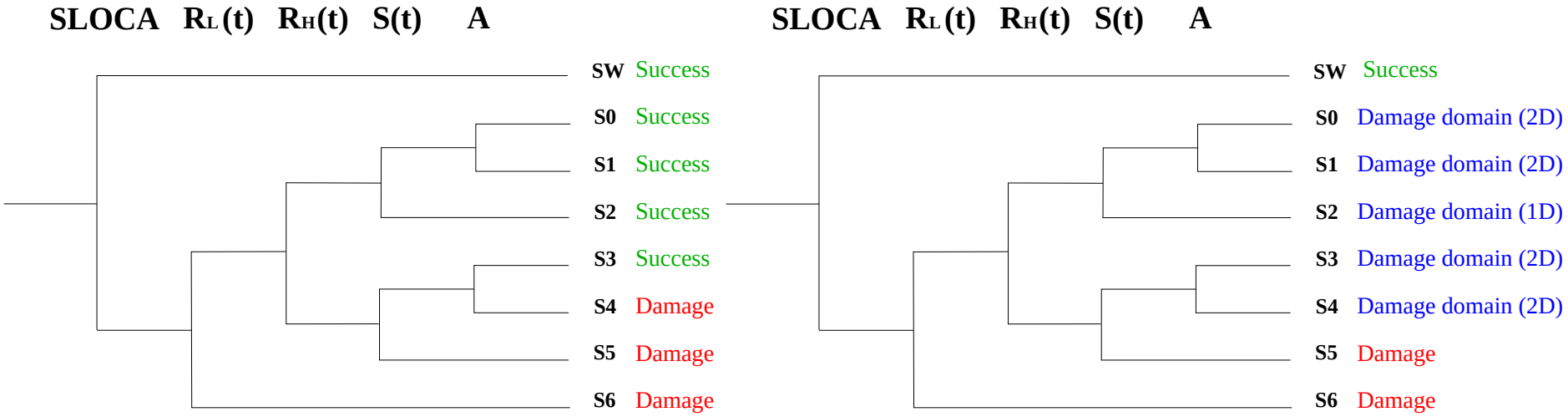
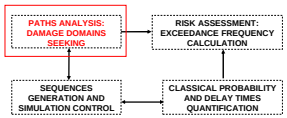


Figure 22: Comparison between general simplified event tree and the one obtained in the simulation.

5. RISK ASSESSMENT. Simulation test of the loss of CCW/SW with a SLOCA



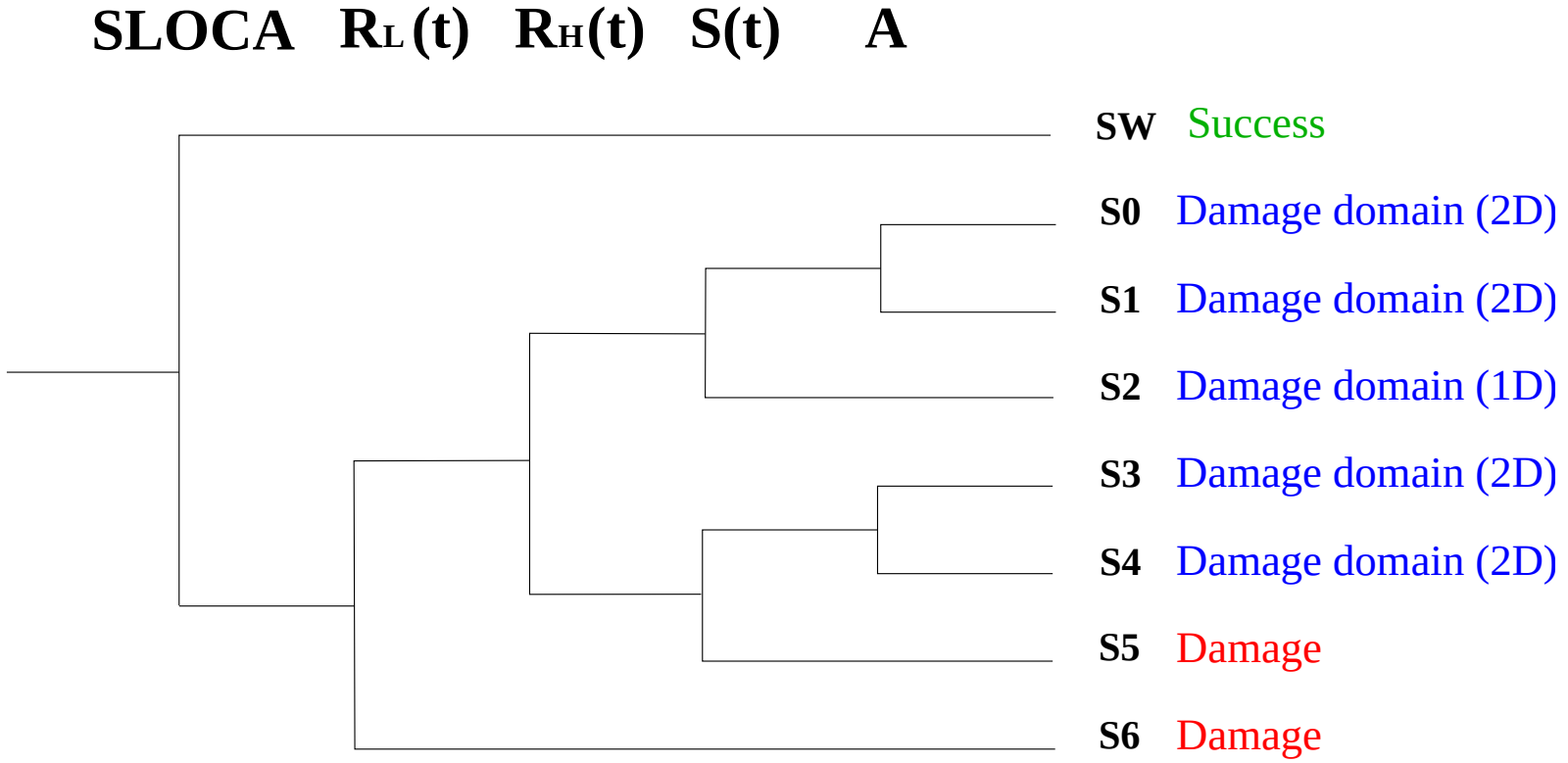


Figure 23: Event tree. Damage domain info.

5. RISK ASSESSMENT. Simulation test of the loss of CCW/SW with a SLOCA

Sequence	Frequency (y^{-1})	Exceedance damage frequency (y^{-1})	Conditional probability
SW	$1.58 \cdot 10^{-3}$	0	0
S0	$3.47 \cdot 10^{-4}$	$7.80 \cdot 10^{-7}$	$2 \cdot 10^{-3}$
S1	$3.47 \cdot 10^{-7}$	$3.47 \cdot 10^{-9}$	10^{-2}
S2	$1.83 \cdot 10^{-5}$	$2.01 \cdot 10^{-6}$	$1.1 \cdot 10^{-1}$
S3	$6.93 \cdot 10^{-9}$	~ 0	–
S4	$6.94 \cdot 10^{-12}$	~ 0	–
S5	$3.65 \cdot 10^{-10}$	~ 0	–
S6	$5.46 \cdot 10^{-5}$	$5.46 \cdot 10^{-5}$	1

Table 3: Final results for exceedance damage frequency at 100%

5. RISK ASSESSMENT. Simulation test of the loss of CCW/SW with a SLOCA

- Taking into account only damage sequences with f$>10^{-6}(y^{-1})$

Sequence	Conditional probability (100%)	Conditional probability (110%)	Damage frequency (y^{-1}) (100%)	Damage frequency (y^{-1}) (110%)	Damage frequency (y^{-1}) increase
S0	$2.25 \cdot 10^{-3}$	$2.86 \cdot 10^{-3}$	$7.80 \cdot 10^{-7}$	$9.92 \cdot 10^{-7}$	$2.12 \cdot 10^{-7}$
S2	$1.10 \cdot 10^{-1}$	$1.10 \cdot 10^{-1}$	$2.01 \cdot 10^{-6}$	$2.01 \cdot 10^{-6}$	0
S6	1	1	$5.46 \cdot 10^{-5}$	$5.46 \cdot 10^{-5}$	0
TOTAL			$5.74 \cdot 10^{-5}$	$5.76 \cdot 10^{-5}$	$2.12 \cdot 10^{-7}$

Table 4: Final results for exceedance damage frequency at 100% and 110%

- The increase in the relative damage frequency due to the increase of 10% in the power is $3.68 \cdot 10^{-3}$

$$\frac{\Delta\varphi_{damage}}{\varphi_{damage}} = \frac{2.12 \cdot 10^{-7}}{5.74 \cdot 10^{-5}} = 3.68 \cdot 10^{-3}$$

6. CONCLUSIONS

- A brief overview of Integrated Safety Analysis new methodology status and simulation packages has been presented. The code accomplishment permits a complete and improved accident transient analysis. The scope of this set of tools is to perform independent assessments in technical support for PSA safety cases.

  The application at the comparison of the exceedance damage frequency at the power of 100% and at 110% for Loss of CCW/SW on the scenario 3 has a result of a very small increase of relative damage frequency.

7. ACKNOWLEDGMENTS

- ACKNOWLEDGMENTS: This work is funded by Consejo de Seguridad Nuclear.

Thank you for your attention!