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Classical Event Tree Analysis and Dynamic Event Tree Analysis for High Pressure Core Melt Accidents in a German PWR

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Introduction

This presentation intends to explain two different approaches to evaluate the risk-dominant issue of primary system depressurisation in case of a high pressure core melt accident.

GRS has performed a PSA level 2 for a 1400 MWe PWR of the “Konvoi” type

- methodology is similar to NUREG-1150
- based on detailed accident simulations, but these are limited in number
- event tree set up and branching probabilities based on expert judgement
- accident management measures taken into account in PSA level 1 and 2

About 26% of all plant damage states have high primary pressure. The depressurization before RPV failure is an important risk reducing issue.

This issue has been adressed by two methods:

- Classical event tree analysis
- Dynamic event tree analysis

Classical event tree analysis

Large event tree (similar to the NUREG-1150-study)

- starting point: core begins to melt (plant damage states - PDS)
- end point:: final plant status including release to environment
- Properties of PDS (e.g. pressure) determined by PSA level 1
- Uncertainties in accident progression represented by branching points
- Branching probabilities (stochastic uncertainties) determined by expert judgement
- Uncertainties of knowledge (epistemic) modelled by Monte Carlo simulation

Dynamic event tree analysis

Large number of integral code runs (MELCOR), each run associated with a different probability (see companion paper by Peschke, Sonnenkalb)

- starting point: initiating event (here limited to SBO)
- end point: 12000s (or earlier RPV failure)
- stochastic uncertainties (aleatory) have been taken into account associated with the MELCOR runs -> generation of a sample of Dynamic Event Trees
- State of knowledge uncertainties (epistemic) not considered (lack of ressources)

Three different ways for depressurisation have been taken into account in both approaches

Delayed manual depressurisation according to emergency procedure

Manual depressurisation is due before core melt, but might be delayed, so that it becomes effective after core melt begins.

Failure of primary piping due to elevated temperature at system pressure

The core degradation process generates very hot gases passing through the primary piping. Combined with the high pressure, this could lead to a failure.

Stuck open safety valve

During core degradation, the safety valves operate beyond their design basis. There is an elevated failure probability.

Delayed manual depressurisation

Classical event tree analysis

- Success probability for manual depressurisation between PDS and 3000 s after PDS has been determined by PSA level 1 methods for each PDS.
- Success probabilities are rather low, because previously (before PDS) the depressurisation was not successful.

Dynamic event tree analysis

- Depressurisation before and after PDS is handled consistently
- MELCOR process data determine time when signal to depressurise is generated (between 4500 s and 6100 s after initiating event).
- Time needed by operators to depressurise is a distribution between 300 s and 3600 s

Failure of primary piping due to elevated temperature

Classical event tree analysis

- failure temperature in hot leg determined by finite element analysis is between 1093 K and 1118 K (uniform distribution)
- maximum temperature in hot leg is correlated to hydrogen production. Based on MELCOR results and expert judgement: 1050 K … 1350 K
- other potential failure locations (surge line, steam generator tubes) are not significant

Dynamic event tree analysis

- state of knowledge uncertainty of failure temperature for reactor coolant line is given as a uniform distribution between 1023 and 1103 K.
- In the calculations only the mean value of 1063 K was considered as failure temperature of the reactor coolant line (Epistemic uncertainties have not been analyzed in this MCDET-analysis).

Stuck open safety valve

Classical event tree analysis

- temperature in pressurizer before core relocation does not significantly exceed design value -> no failure in this phase
- temperature in pressurizer short after core relocation is much higher than design value (up to 1000 K)-> failure possible, large uncertainty, failure assumed in 50 % of all Monte Carlo simulations.

Dynamic event tree analysis

- Each failure mode (stuck open; stuck close) of the safety valves is explicitly considered in the Dynamic Event Tree analysis
- The probability distributions of the respective failure modes depend on the demand cycles the valves have seen during their operating history.
- The time and demand cycle, at which each of the safety valves stuck open or close, were randomly sampled for each dynamic event tree, respectively.

Accident progression after depressurisation

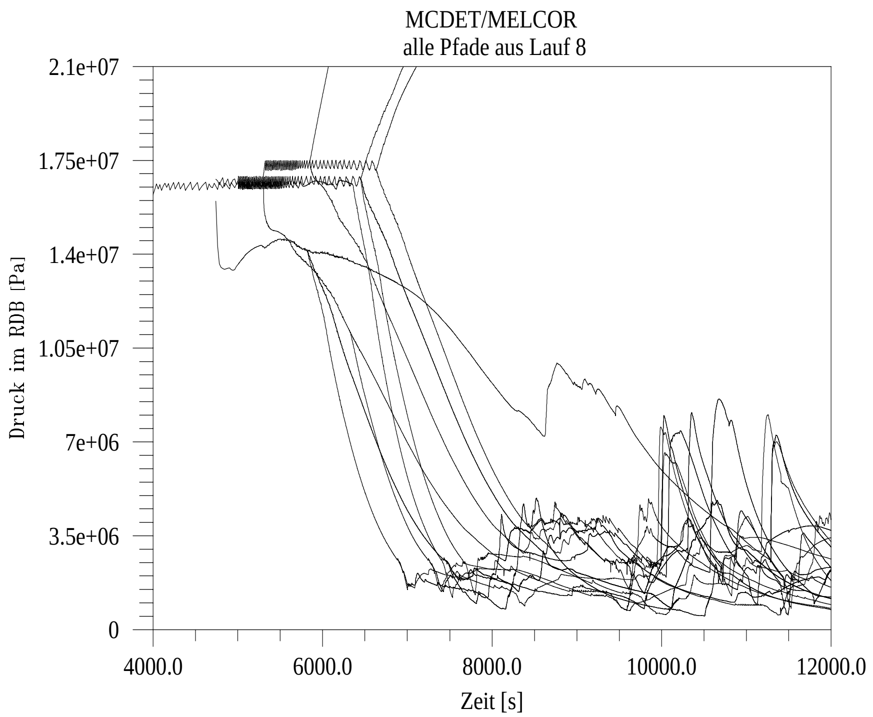
Classical event tree analysis

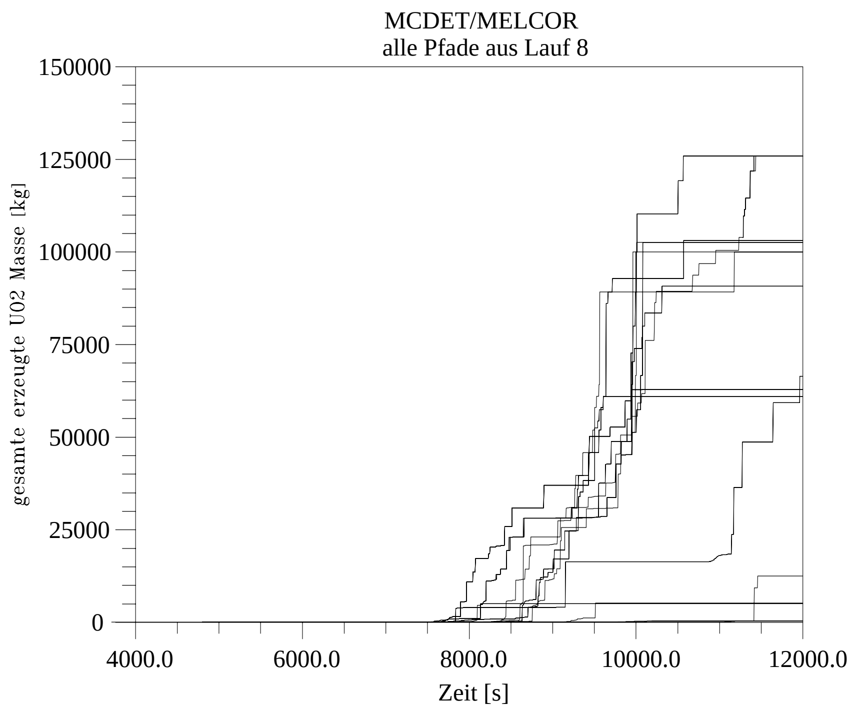
- availability of HP and LP ECCS is part of PDS attributes
- flooding of core is assumed if ECCS is available and RPV pressure lower than pressure head of pumps
- probability for retention of partly molten core estimated by expert judgement based on MELCOR analyses.

Dynamic event tree analysis

- time and probability for restoration of HP and LP ECCS availabilty determined for each MELCOR run
- flooding of core calculated by MELCOR for each run
- retention of partly molten core calculated by MELCOR for each run

Dynamic event tree analysis:
Example for results of a part of the simulations





Pressure in RPV

Molten fuel mass

Results for SBO with high pressure at beginning of core melt

Classical event tree analysis

- probability for high pressure RPV failure:	0.10
- probability for low pressure RPV failure:	0.76
- probability for corium retention in core region:	0.01
- probability for corium retention in lower plenum:	0.13

Dynamic event tree analysis

- probability for high pressure RPV failure:	0.018
- probability for low pressure RPV failure:	0.815
- probability for corium retention in core region:	0.068
- probability for corium retention in lower plenum:	0.099

Summary and conclusions (1)

A comparison of assumptions and results for the conventional event tree analysis and the dynamic event tree analysis is given.

The comparison is limited to accident sequences from incipient core melt under high pressure until RPV-failure.

Assumptions of the manual depressurization, of safety valve failure, failure of primary piping due to elevated temperature are given for each of the respective methods.

Given the uncertainties involved, the overall results show a rather good agreement, while details vary considerably.

Summary and conclusions (2)

In addition to the conventional Event Tree method, future research in PSA Level 2 should explore the advantages of Probabilistic Dynamics methods, because they allow a much more detailed analysis.

Specific issues, where the confidence in expert judgment is low, may be analyzed by advanced methods of Probabilistic Dynamics.

The results obtained can then be used in future PSA work and an improvement of the quality of a PSA is to be expected.