Results of an IDPSA Aimed to Assess the Potential of a Thermally Induced Steam Generator Tube Rupture

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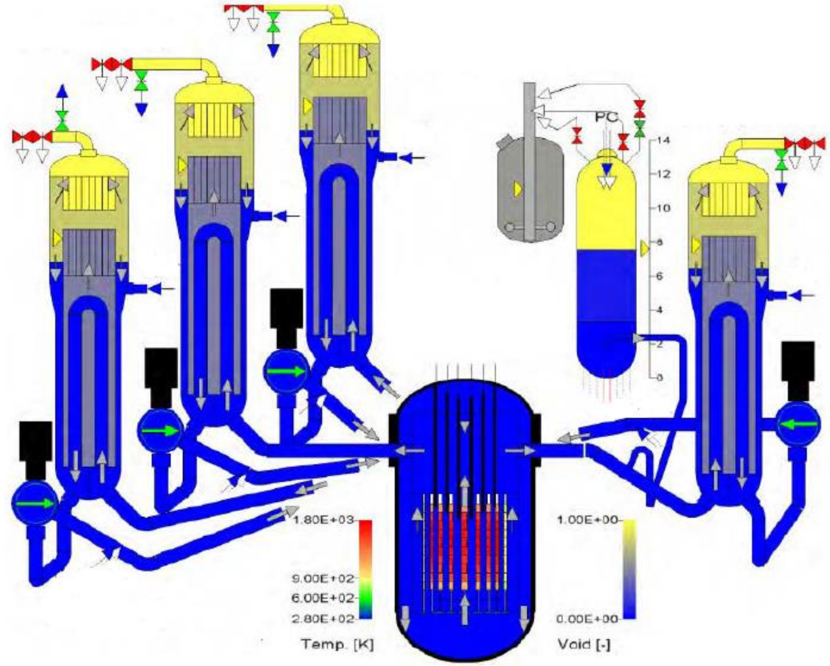
Introduction

- Investigated accident is a high pressure scenario with core melt.
- If an SGTR occurs, the containment is bypassed and fission products may be released directly to the environment.
- The releases may be reduced, if creep ruptures of the main coolant pipe (MCPR) or the surge line (SLR) additionally occur.
  - Fission product retention within the primary system
- MCPR or SLR may even prevent an SGTR and avoid a direct release of fission products.



Introduction

Questions to be answered by the IDPSA study:

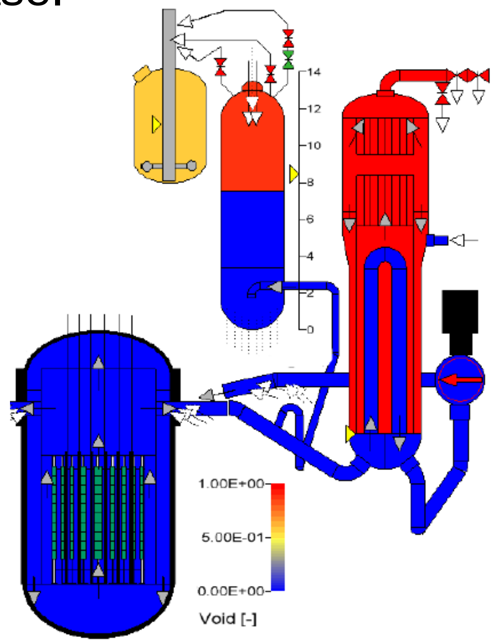
- How likely is an SGTR?
- How likely occurs an SGTR in combination with an MCPR or SLR?
- Is an MCPR or SLR before or after an SGTR?
- Which are the system conditions leading to a rupture at which time?

Scenario and aleatory uncertainties

- Initiating event of the accident is a total SBO.
- Since on-site power and emergency diesels are not available, the crew must prepare the 'Bleed & Feed' of the SG.
  - Aleatory uncertainty: Performance of the crew

- Pressure in the SG increases steadily and the main steam relief valves (SRVs) are required to open automatically for partial pressure release.
  - Aleatory uncertainty: Performance of the valves
    - Assumption: Valves open with reduced cross section

- When 'Bleed & Feed' is prepared and specific criteria are fulfilled, the crew has to manually open the SRVs ('Bleed').
  - Aleatory uncertainty: Performance of the crew
    - Assumption: 'Feed' is not carried out



Scenario and aleatory uncertainties

- To limit the pressure on the primary side, the pressurizer valves are cyclically demanded to open and to close.
  - Aleatory uncertainty: Performance of the three pressurizer valves
- When coolant temperature or differential pressure ‘containment - reactor building’ exceeds specific levels, the crew must carry out the primary ‘Bleed & Feed’.
  - Assumption: primary ‘Bleed & Feed’ is not carried out

Additional aleatory uncertainty:

- Degree of SGT degradation (reduction of wall thickness)

  Two degradation classes:
  - ≤ 20 % : 0.96 – 1.2 mm wall thickness
  - 20 - 70 %: 0.36 - 0.96 mm wall thickness

Epistemic uncertainties

- Failure probabilities of the pressurizer valves:
  - Probabilities of independent stuck close/stuck open failures
  - Probabilities of stuck close /stuck open common cause failures
- Transition probabilities of Markov chain applied to assess SGT degradation:
  - Probability of tube degradation proceeding from a degradation class to the next one
- 22 Parameters of the computer code applied for accident simulation:

No.	Parameter Name	Distribution Type
1	time delay RESA signal	Uniform
2	correction factor decay heat	Uniform
3	maximum value of steam pressure	Polygonal Line
4	additional change of set value of maximum steam pressure	Uniform
5	contraction value of steam discharge	Polygonal Line
6	pressure loss in nozzle	Polygonal Line
7	correction factor for opening cross section of pressurizer relief valve	Uniform
8	correction factor for opening cross section of pressurizer safety valves	Uniform
9	correction factor for opening cross section of main steam safety valves	Uniform
10	heat conductivity of UO2	Uniform
11	heat conductivity of ZR	Uniform

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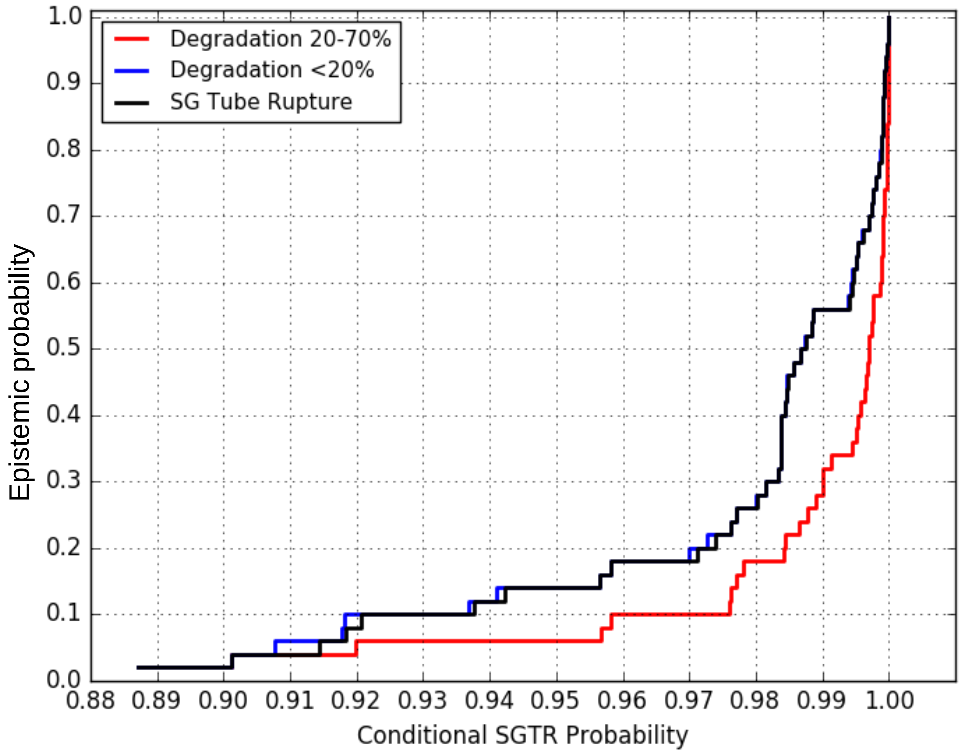
IDPSA tool, computer code and simulations

- IDPSA study was carried out with MCDET in combination with
  - its add-on Crew Module for generating time-dep. human action sequences
  - the code ATHLET-CD for accident simulation
- 100 dynamic event trees (DETs) were generated with different values for epistemic & aleatory variables.
- Sequences were calculated up to maximally 20000 s (~5.6 h).
- When an MCPR or SLR occurred, a simulation run was stopped automatically.
- 4216 different sequences were generated in total.

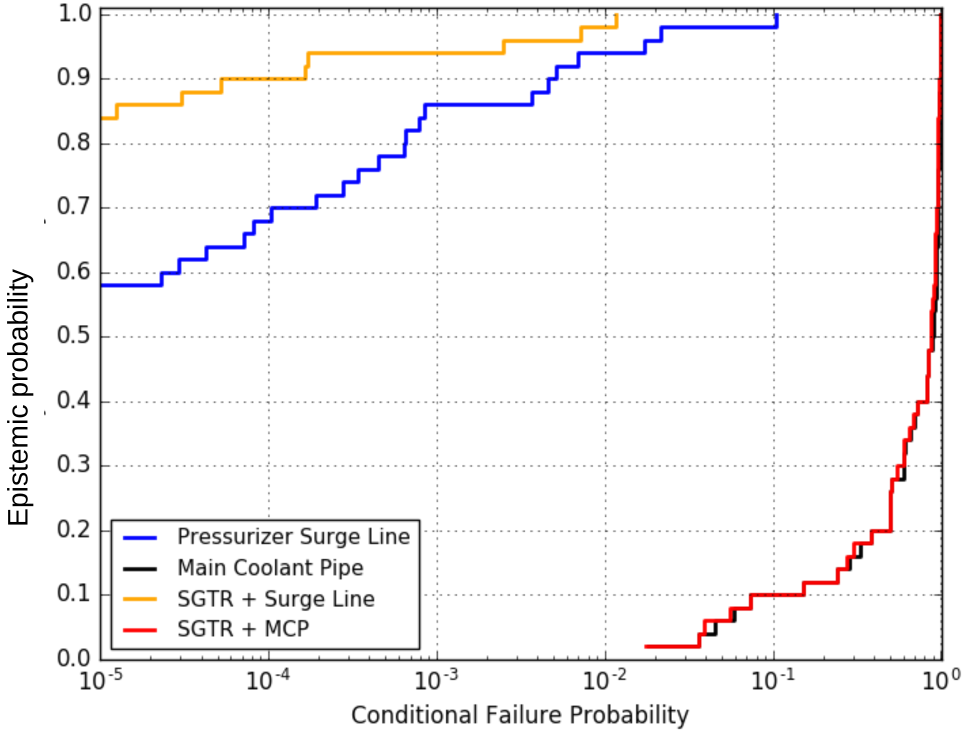
Epistemic Uncertainty of the Likelihood of an SGTR



Likelihood relates to SGTR without preceding MCPR or SLR.

- Range: 0.883 – 1.00
- Median: ~ 0.987
- SGT degradation > 20%:
  - Median: ~ 0.997

Epistemic Uncertainties of the Likelihoods of MCP and SL ruptures



Likelihood (MCPR):

- Median: ~ 0.8
- 10%-quantil: > 0.1

Likelihood (SLR) :

- ≤ 0.1
- Median: < 10^{-5}

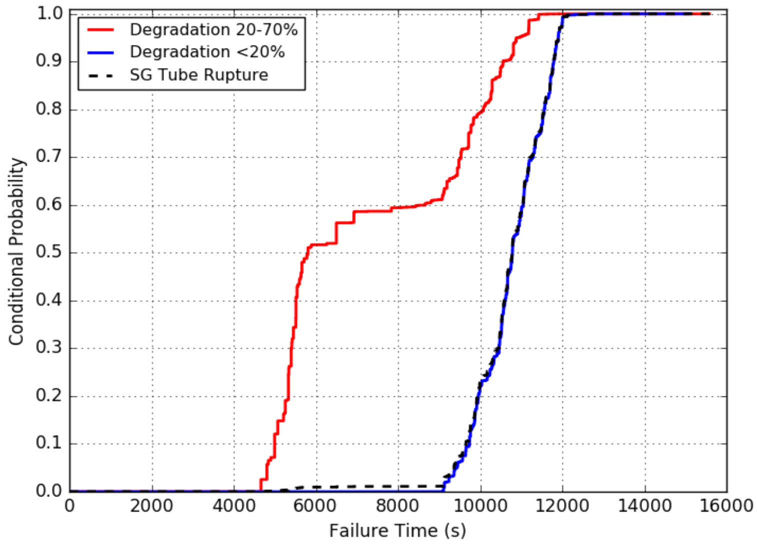
Likelihood (SGTR & MCPR) = Likelihood (MCPR)

- ➢ MCPR after SGTR

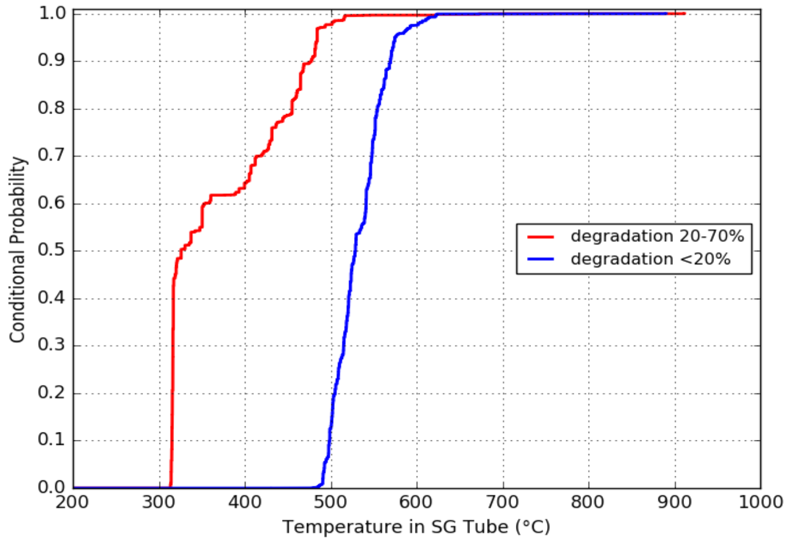
Likelihood (SGTR & SLR) ≠ Likelihood (SLR)

- ➢ SLR before or after SGTR

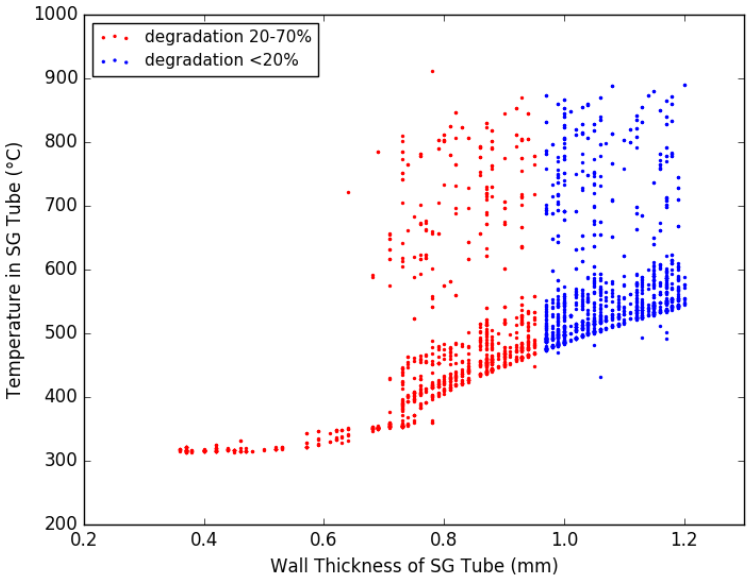
Distribution of SGTR Time



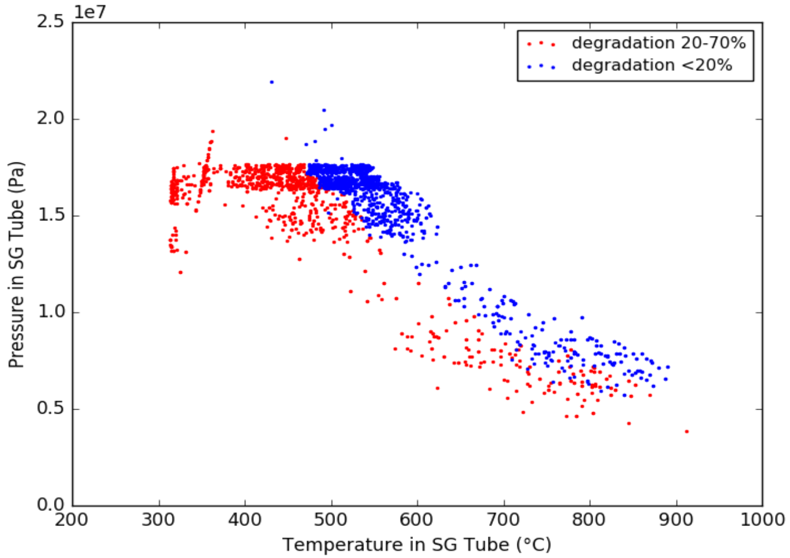
Distribution of the Temperature at SGTR Time



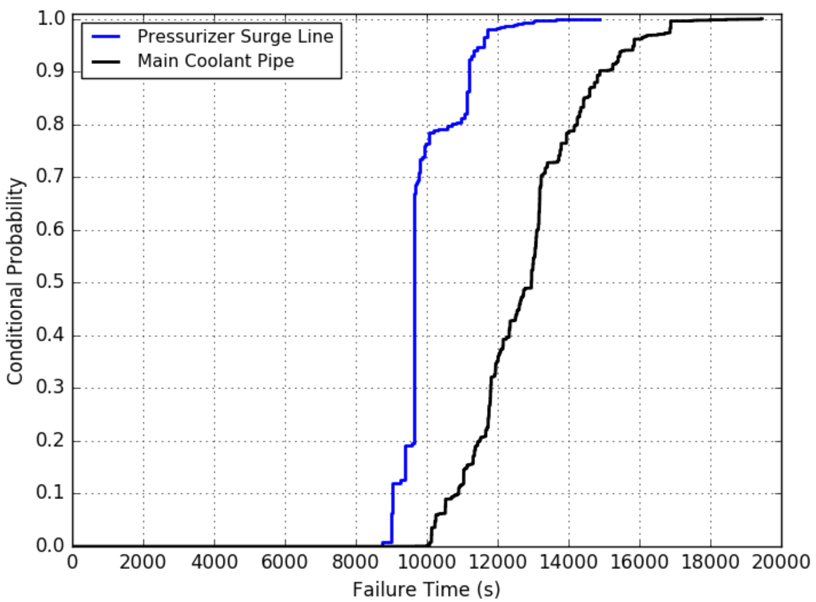
Temperature at SGTR & SGT Wall Thickness



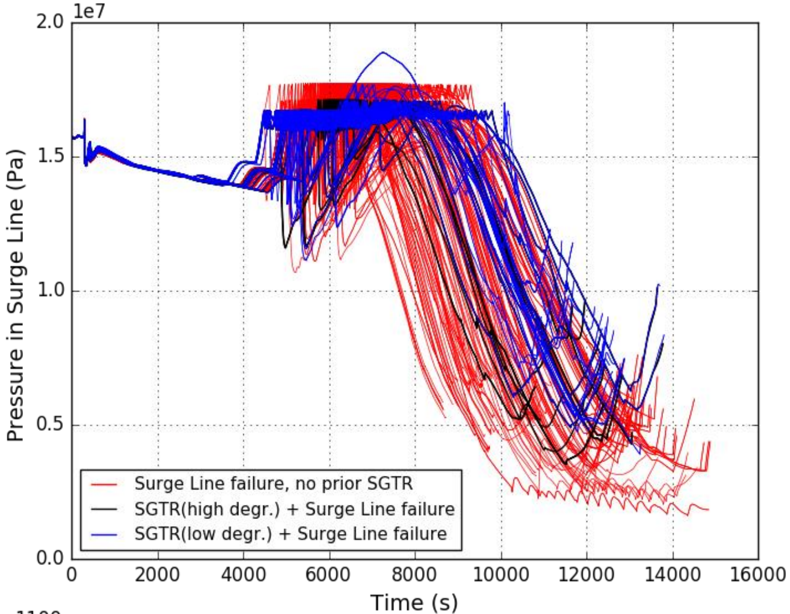
Pressure & Temperature at SGTR Time

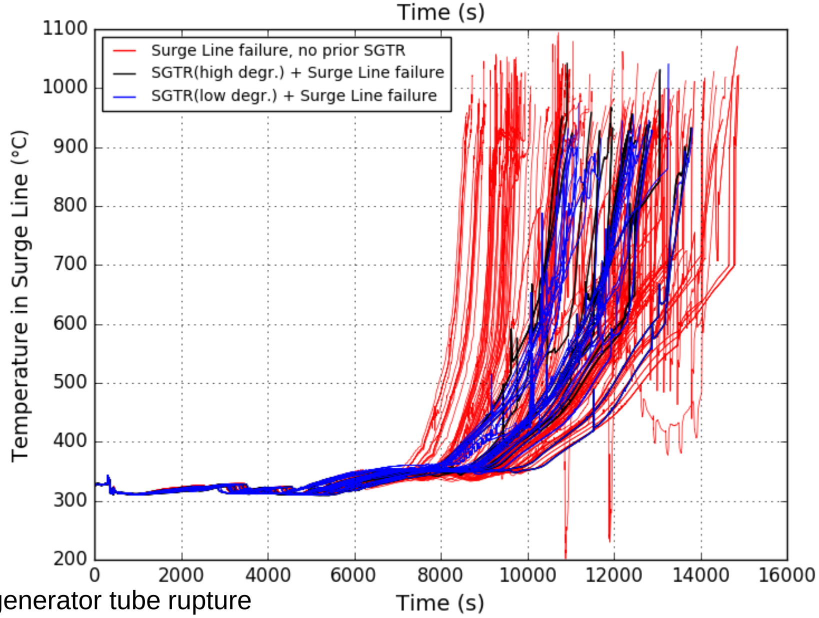


Distributions of MCP & SL Rupture Times



Pressure & Temperature leading to SLR





SLR time < MCPR time

SLR occurs at

- a temperature > 900°C
- a pressure < 12 MPa
- caused by pressurizer valves failed in stuck open mode

Conclusions

- Presented IDPSA study can be considered as a complementary analysis to the classical PSA Level 2.
- It provided useful information on the potentials of creep ruptures in a high pressure scenario:
  - High likelihood of an SGTR without a preceding MCPR or SLR.
  - High likelihood of a subsequent MCPR.
  - Only small likelihood of an SLR.
  - SLR may occur before or after an SGTR and is caused by a pressurizer valve failed in stuck open mode.
  - SGTR (degradation ≤ 20 %, wall thickness: ≥ 0.96 mm) is most likely thermally induced.
  - SGTR (degradation > 40 %, wall thickness: < 0.72 mm) is most likely induced by high pressure differential.

Outlook

- Next investigations will be focused on the identification of the main influencing factors on the results:
  - timing of human actions?
  - stuck close / stuck open failures of the pressurizer valves and resp. failure times?
  - model uncertainties?

- Additional investigations will address the countermeasures which may prevent an SGTR or mitigate its consequences.
  - At what time and at which system states the implementation of additional feeding options may be effective?
- MCDET will be further developed, so that the existing DETs can be easily enhanced and the DET simulations can be continued.