

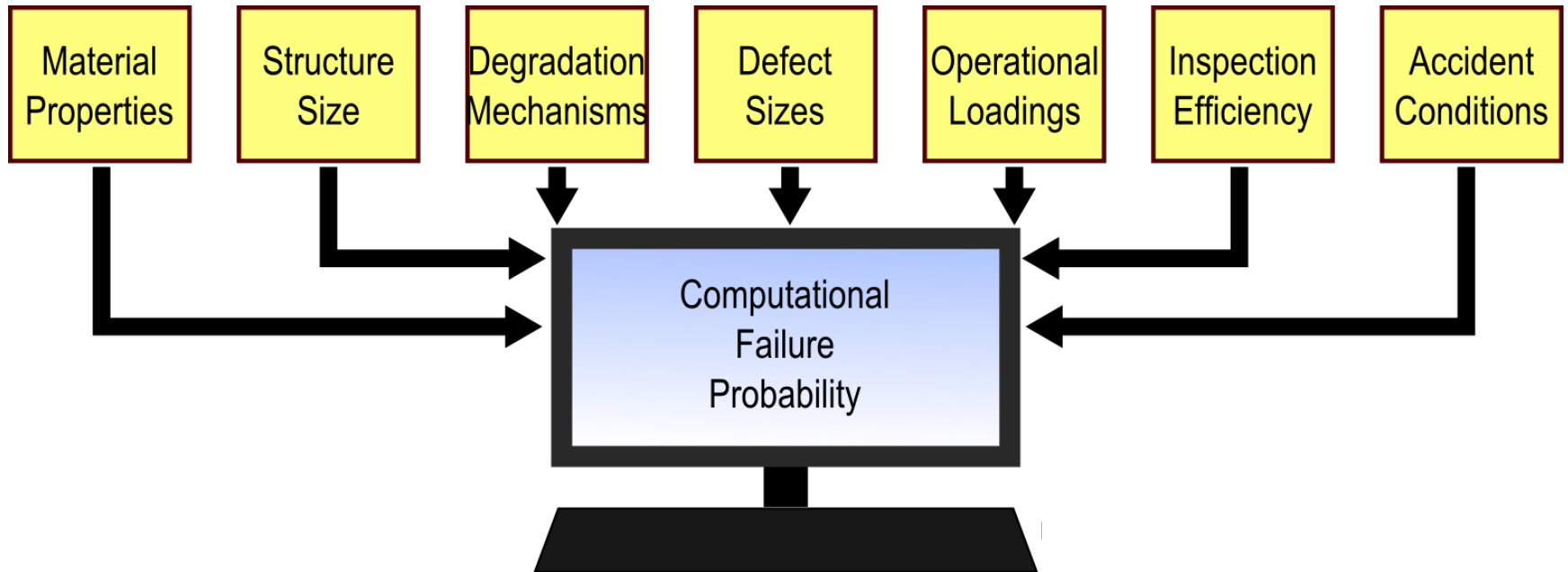
Klaus Heckmann (GRS), Qais Saifi (VTT)

Comparative Analysis of Deterministic and Probabilistic Fracture Mechanical Assessment Tools

Outline

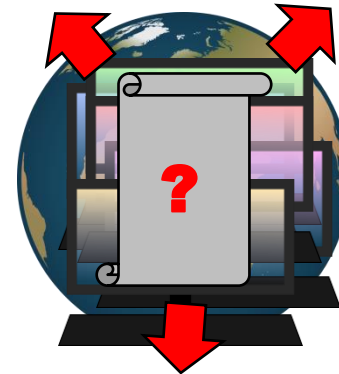
- Probabilistic structure mechanics in nuclear safety
 - Background and scope
- Case study
 - Definition of cases
 - Results: Example and summary
- Comparison of procedures
 - Systematic code examination
 - Identification of relevant ingredients
- Summary, Conclusion, and Outlook

Structural Reliability and Probabilistic Fracture Mechanics in Nuclear Safety



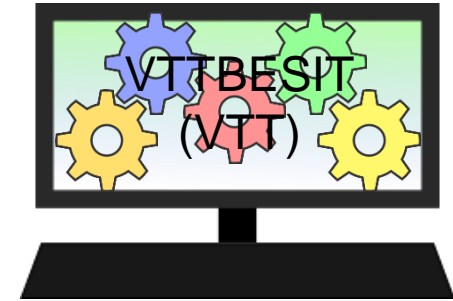
Code Development and International Benchmark Studies

- Several independent developments in different countries
- Benchmark activities for validation
- Typical: Minor, but systematic discrepancies



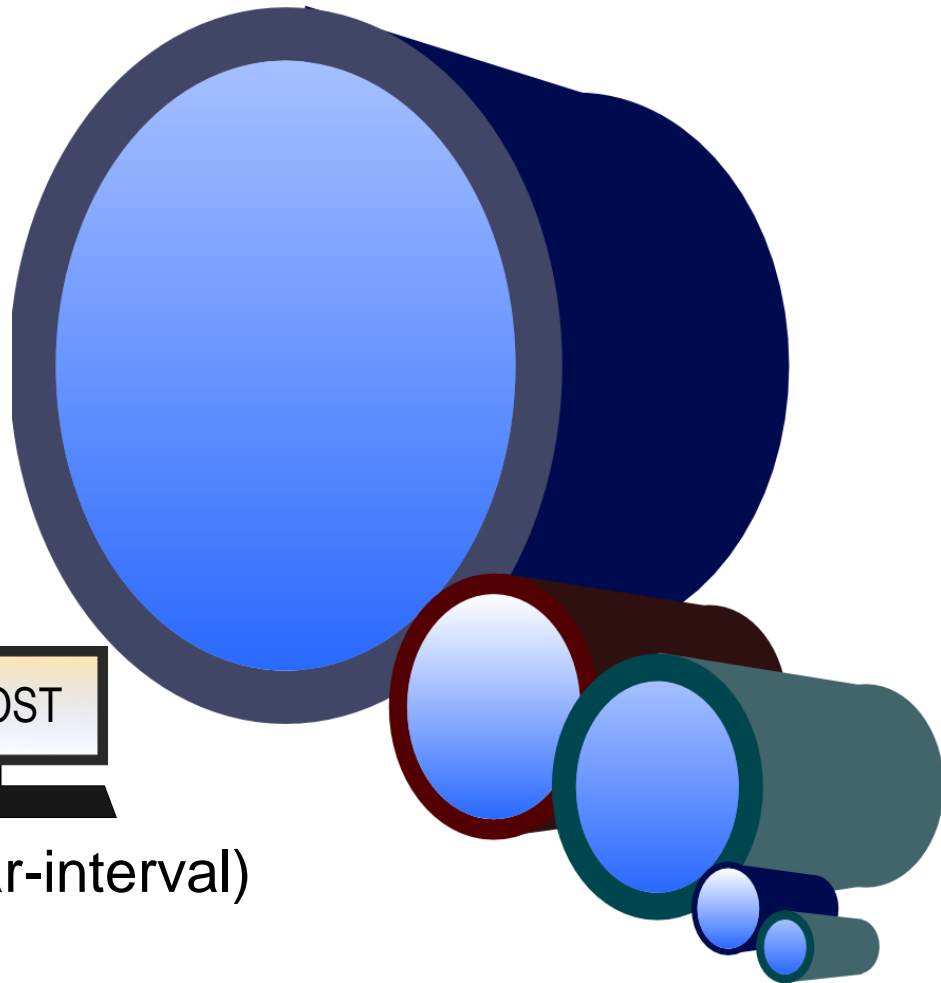
Scope of the Comparative Study

- ETSON objectives & priorities:
 - Development of computer tools for...
 - Reliable component design
 - Robust numerical computation
 - Harmonization of European practices
 - Structural lifetime
 - Ageing assessment
- Scope of the study:
 - Comparative study of computer tools
 - Identification of origins of discrepancies



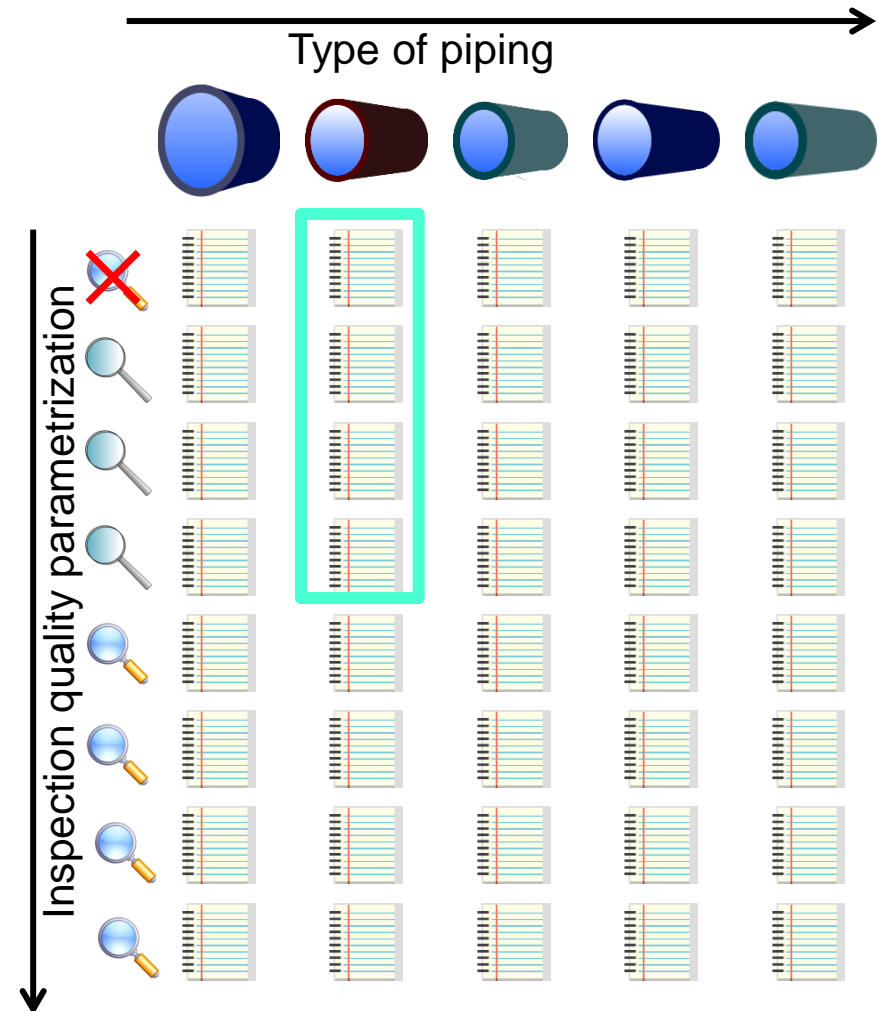
Example Cases

- 5 pipe geometries
 - Crack distributions
- Operational loads
 - PWR
 - BWR
- Damage mechanisms
 - Corrosion
 - Fatigue
- In-service inspections (10-year-interval)
 - Different qualities



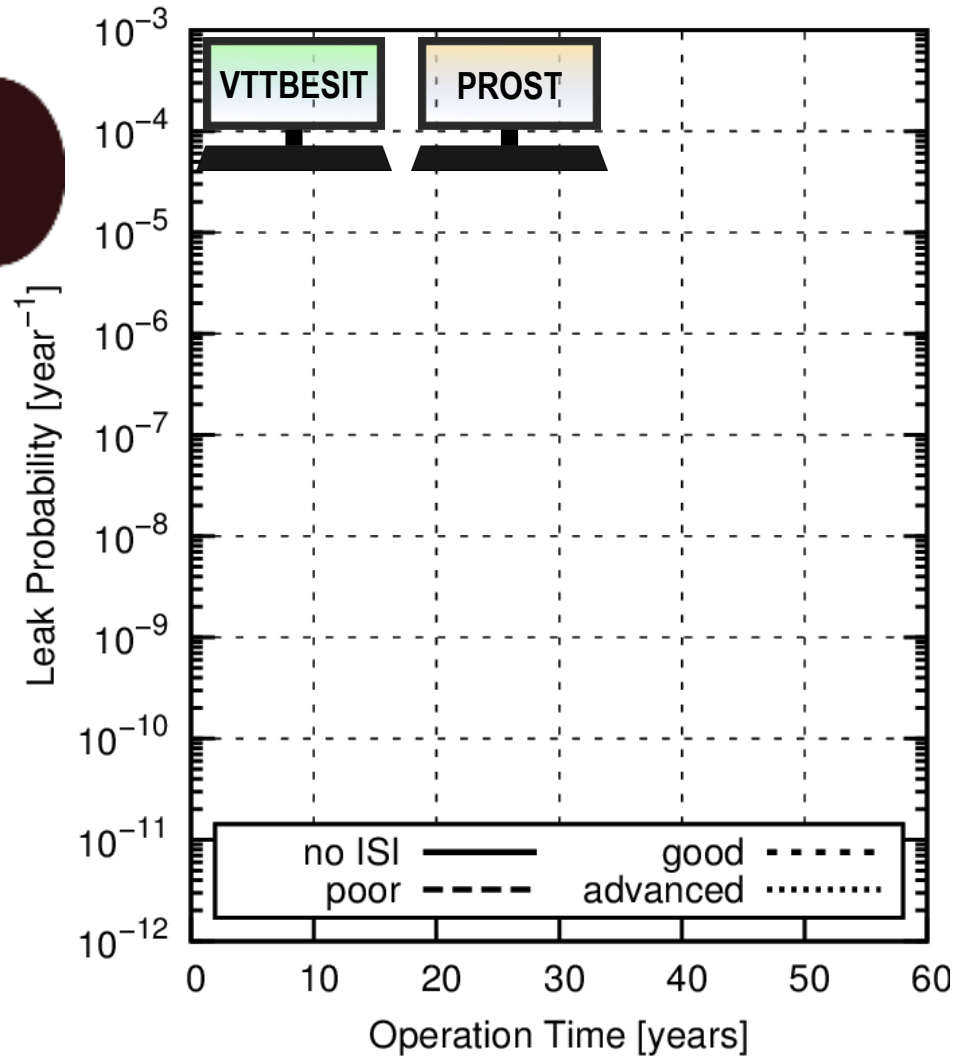
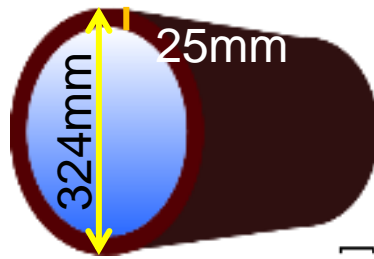
Computational Results

- 5 different piping components
- 7 different inspection qualities + no inspections
- Annual leak probability during operation
- In total ca. 2000 data points per code compared
- Analysis + interpretation



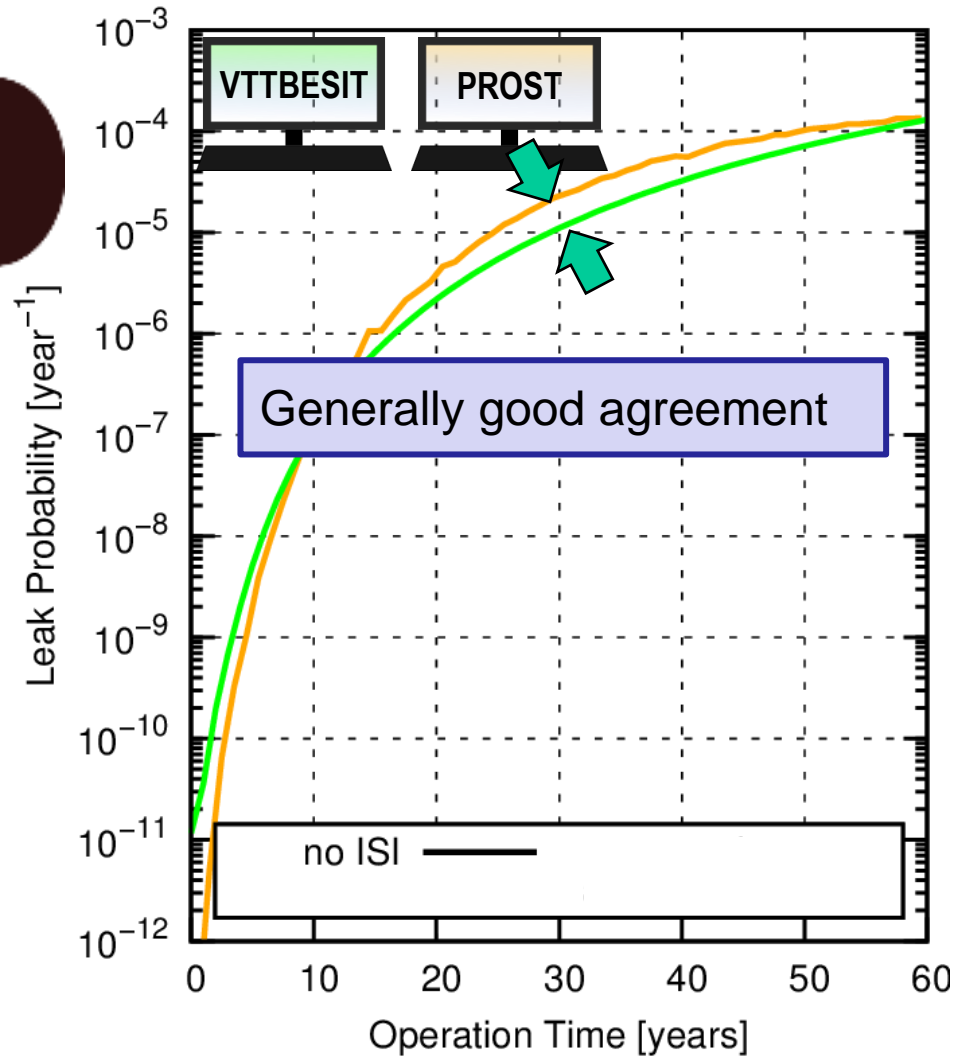
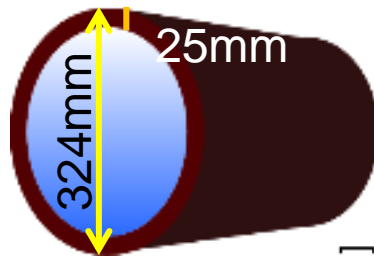
Computational Result (+Example)

- BWR condition
- Crack initiation
- Crack distribution
- Stress corrosion cracking



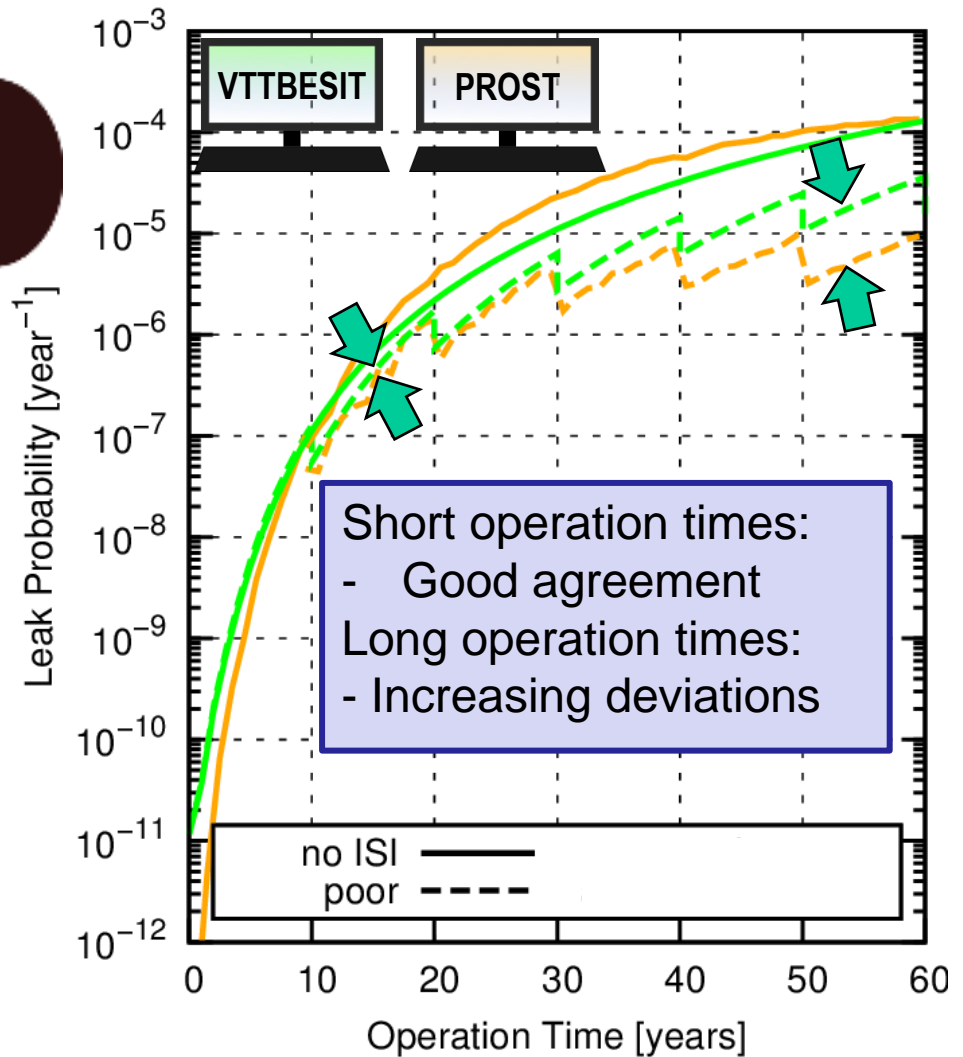
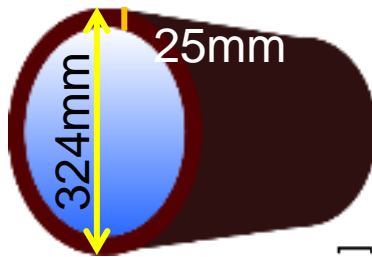
Computational Result (+Example)

- BWR condition
- Crack initiation
- Crack distribution
- Stress corrosion cracking
- No inspections



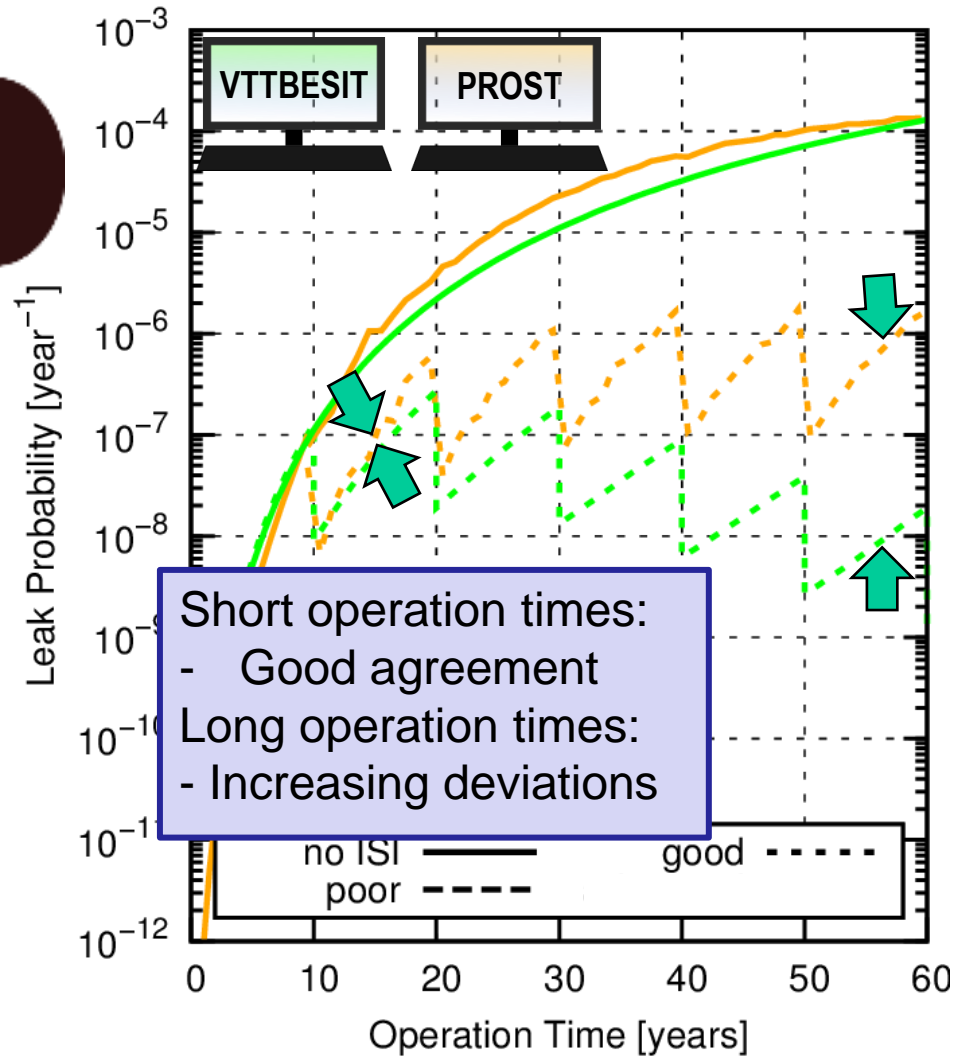
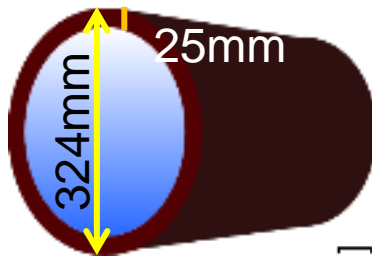
Computational Result (+Example)

- BWR condition
- Crack initiation
- Crack distribution
- Stress corrosion cracking
- No inspections
- Inspection Qualities
 - Poor



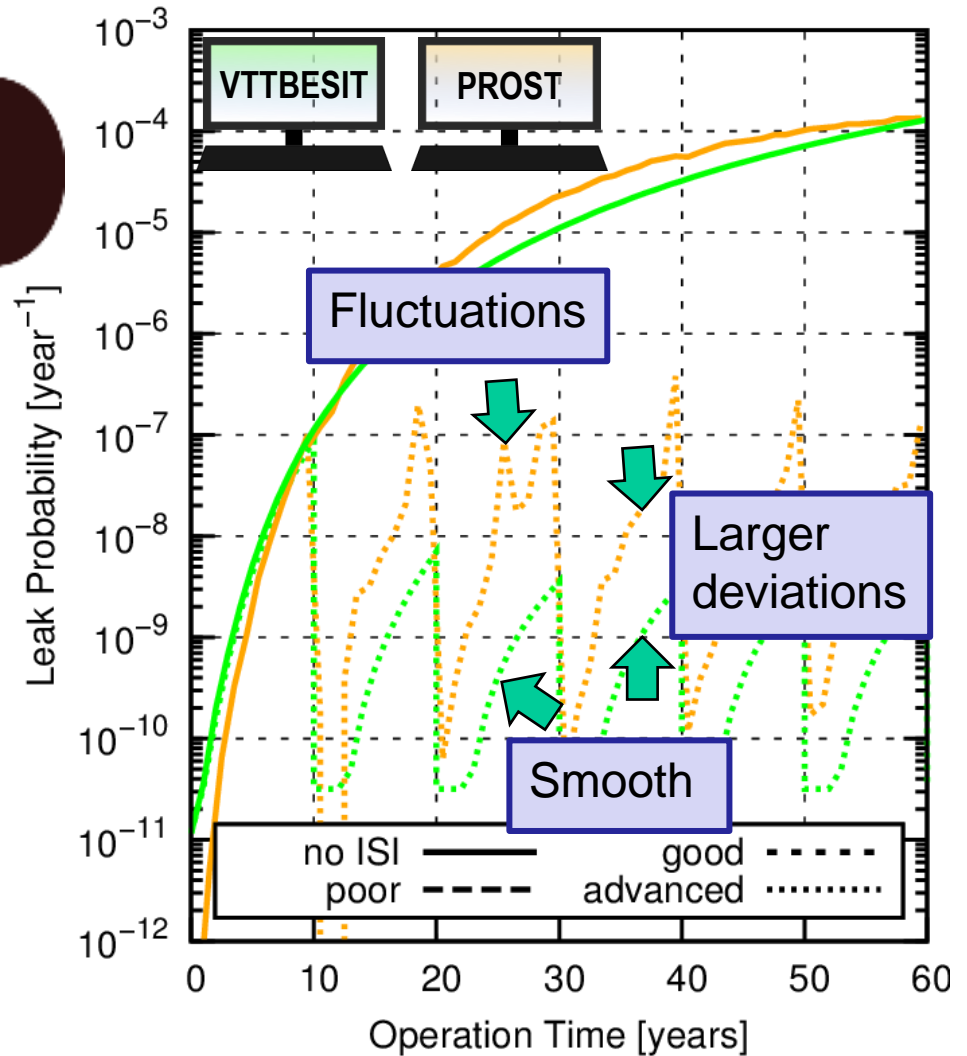
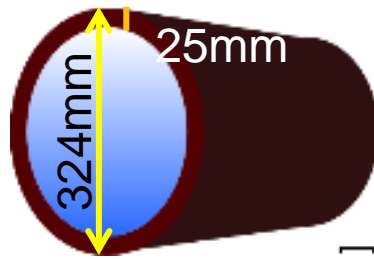
Computational Result (+Example)

- BWR condition
- Crack initiation
- Crack distribution
- Stress corrosion cracking
- No inspections
- Inspection Qualities
 - Poor
 - Good



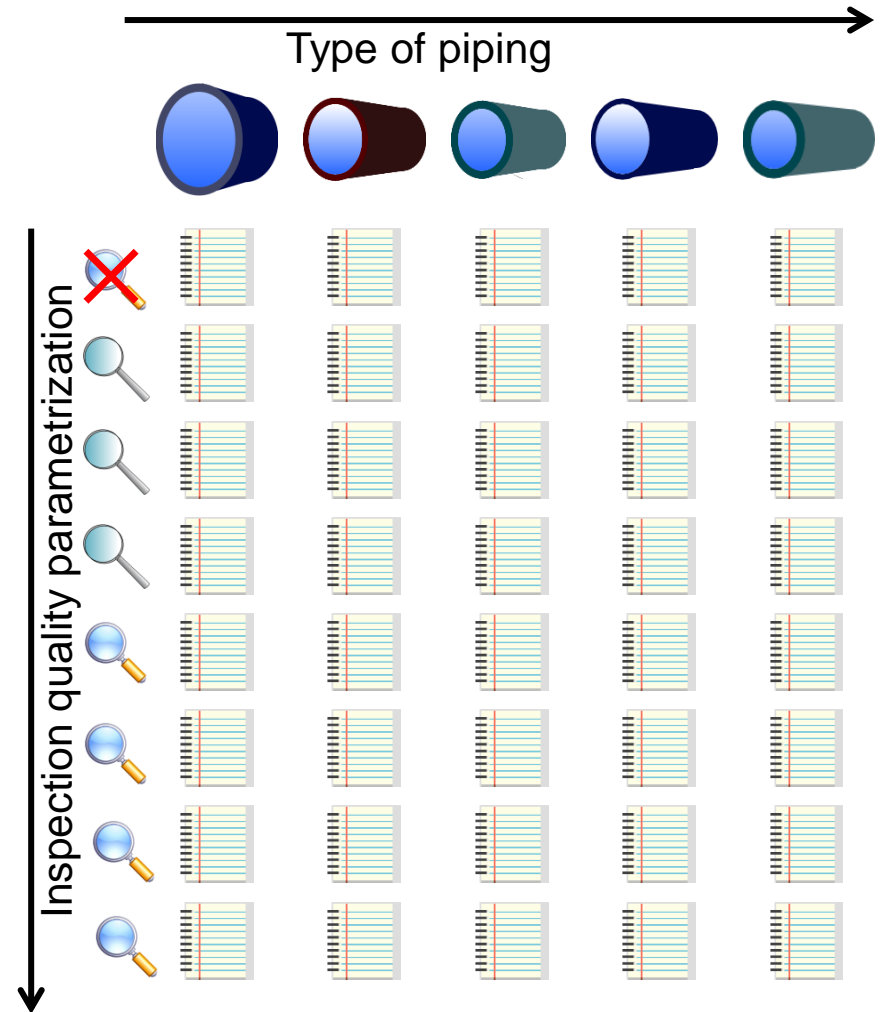
Computational Result (+Example)

- BWR condition
- Crack initiation
- Crack distribution
- Stress corrosion cracking
- No inspections
- Inspection Qualities
 - Poor
 - Good
 - Advanced



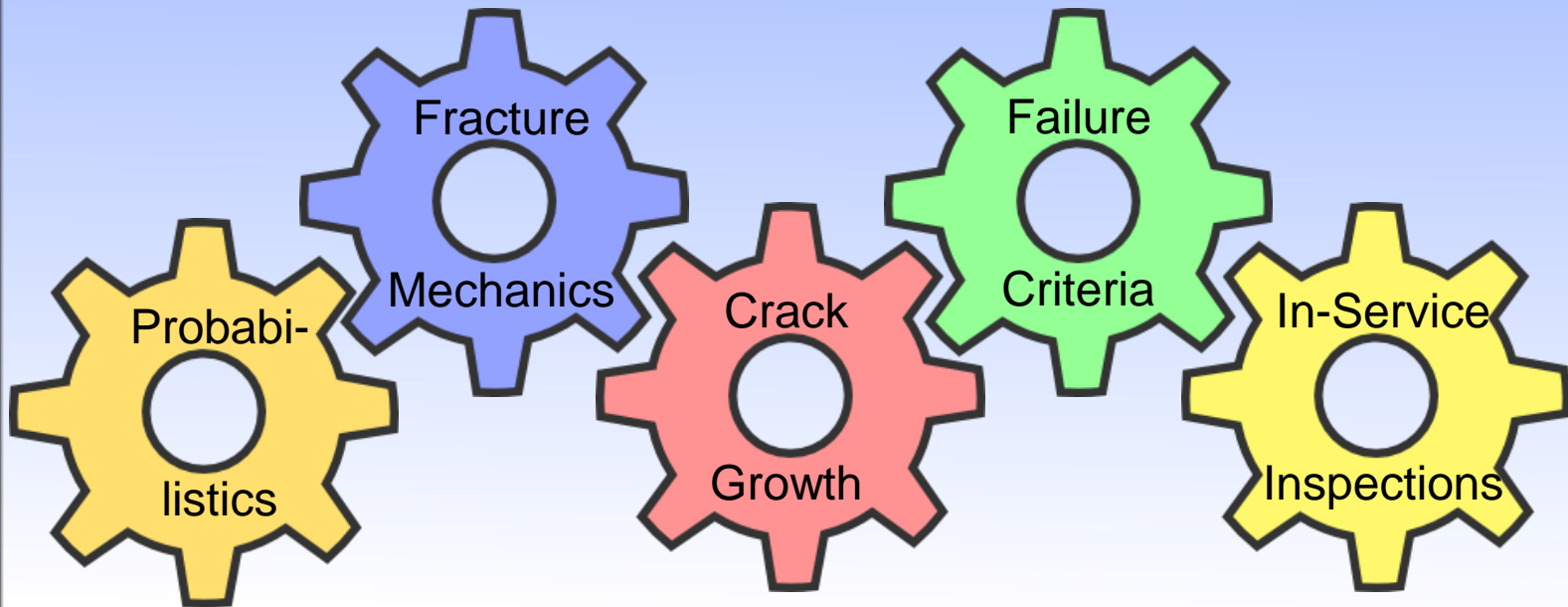
Summary of Trends

- No inspections:
 - Generally good agreement
- Inspections:
 - Small deviations
 - Realistic qualities
 - Short operation times
 - Increasing deviations
 - High qualities
 - Long operation times
- Smooth vs. fluctuating curves



VTTBESIT / PROST

Comparison of Procedures

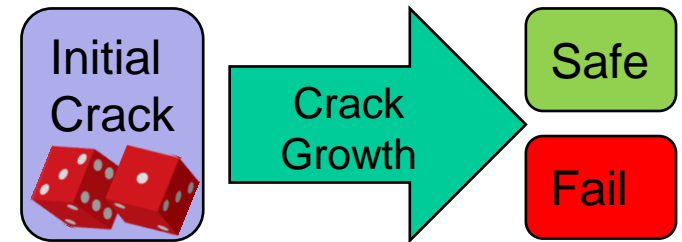


Probabilistics and Random Sampling



- PROST

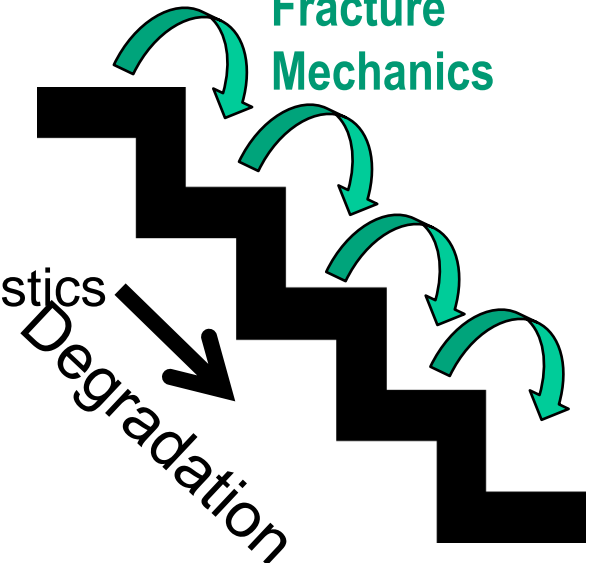
- Probabilistic fracture mechanics
- All parameters distributed
- Monte Carlo / importance sampling
- Scattering for small leak probabilities



Probabilistic
Fracture
Mechanics

- VTTBESIT

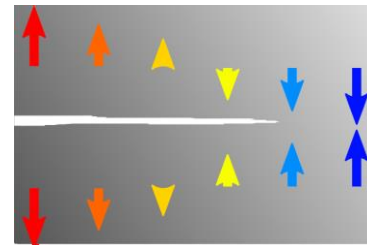
- Discrete degradation states
- Transition between states via probabilistics
- Initial crack size: distributed
- Other (e.g. material): non-distributed



Ageing & Fracture Mechanics: Stresses & K-Factors



- Stress variations
 - Influence of strong residual stresses in particular cases



- Stress intensity factors K

- Analytical K-solutions
- Range of validity exceeded for particular cases



	Range					
Relative Wall Thickness t/r_i	0.1-0.25	0.33	0.26	0.16	0.18	0.17
Mean Initial Crack Aspect Ratio c_0/a_0	1-10	3	3	6	18.9	77.8

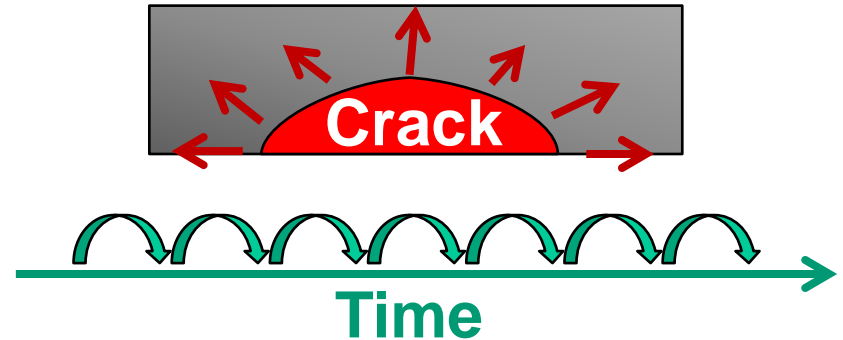
- Different extrapolation procedures

Crack Growth: Velocity & Numerics



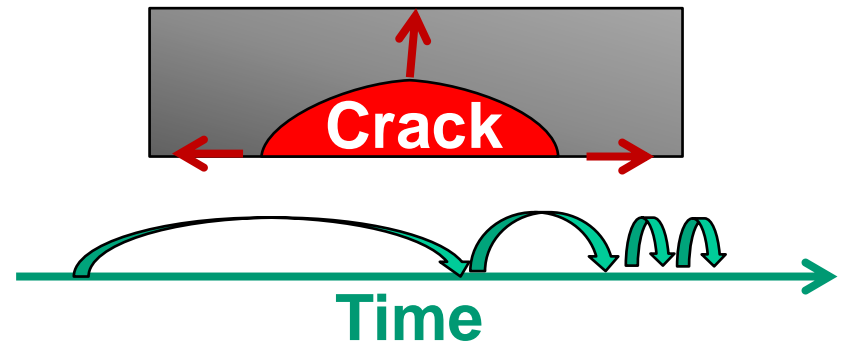
- VTTBESIT

- Growth along crack front
- Fixed integration step size



- PROST

- Growth in depth & length
- Adaptive step size control

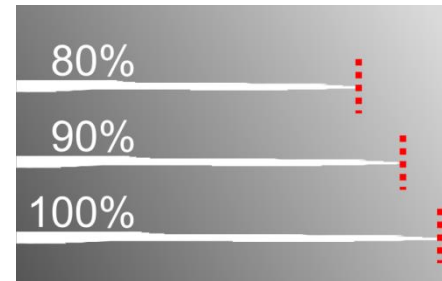


Failure Criteria: Thresholds and Material Properties



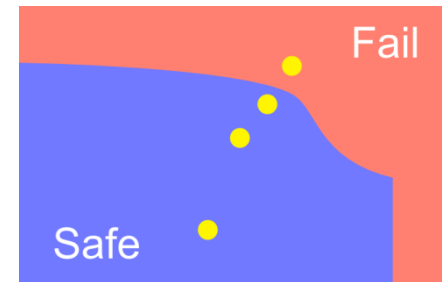
- Failure criteria

- Geometric criteria: $a/t=80\%$, 90% , 100%
- Failure assessment diagram (FAD)



- Material properties

- Consideration of Scatter (y/n)



- Analysis & comparison

- Consistent choice of VTTBESIT + PROST
- Minor influence of different failure criterion
- Neglectable influence of uncertainties in material parameters

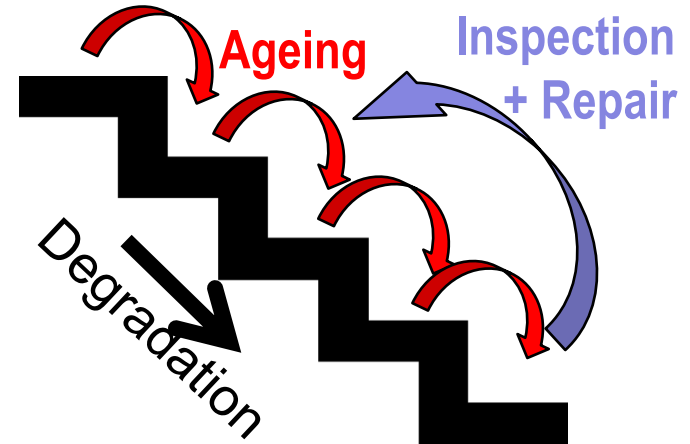


In-Service Inspections



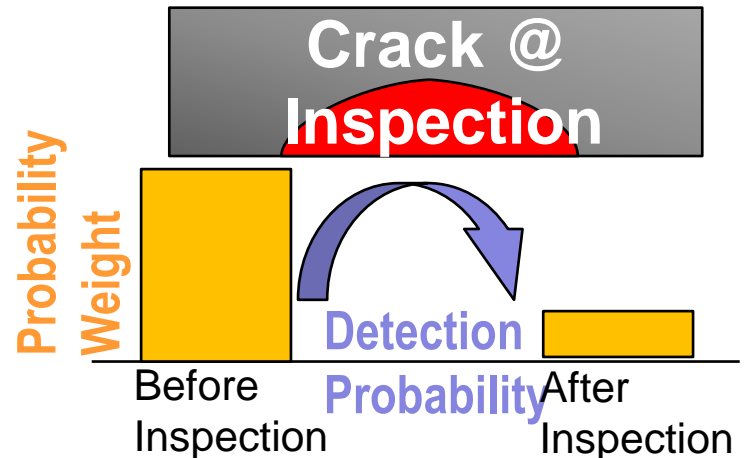
- VTTBESIT

- Inspections via Transition from Degradation States
- Markov Chain Model



- PROST

- Inspections via Interruption of Crack Growth Simulation
- Reduction of Probability Weight



Summary, Conclusion, and Outlook



- Collaborative comparative investigation
- Results of both partners widely in good agreement
 - Coherence in safety relevant topics (fracture + failure)
- Identifications of origins of gaps in particular cases
 - Different methods for consideration of in-service inspections
- Most deviations between results well understood
- Codes suitable for integrity assessment of components
- Results used for further code development
- Contribution to harmonization of European practices