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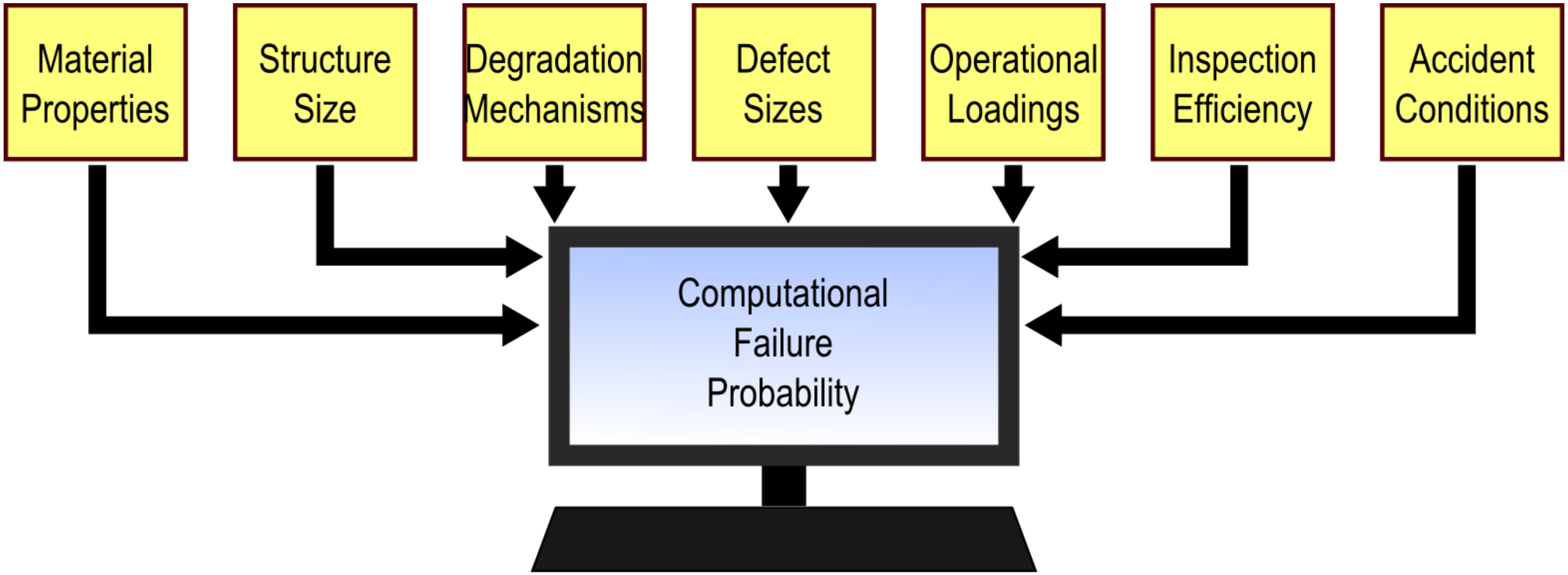
Comparative Analysis of Deterministic and Probabilistic Fracture Mechanical Assessment Tools

Outline

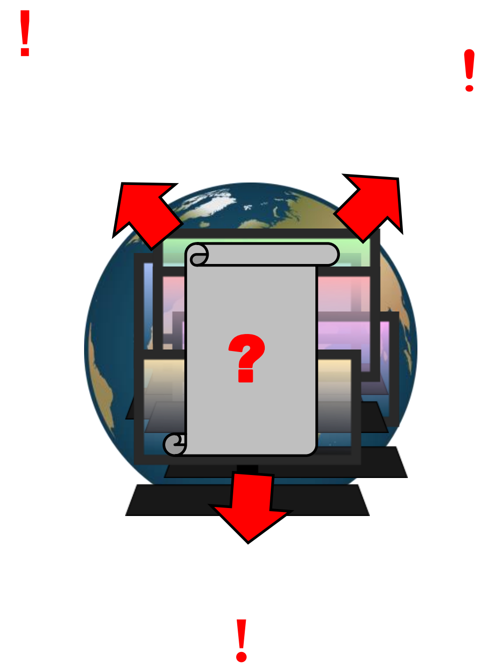
- Probabilistic structure mechanics in nuclear safety
  - Background and scope
- Case study
  - Definition of cases
  - Results: Example and summary
- Comparison of procedures
  - Systematic code examination
  - Identification of relevant ingredients
- Summary, Conclusion, and Outlook

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

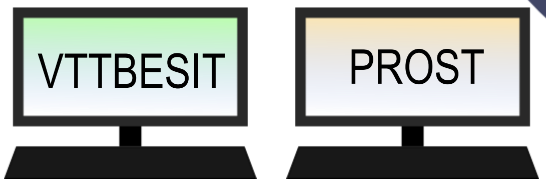


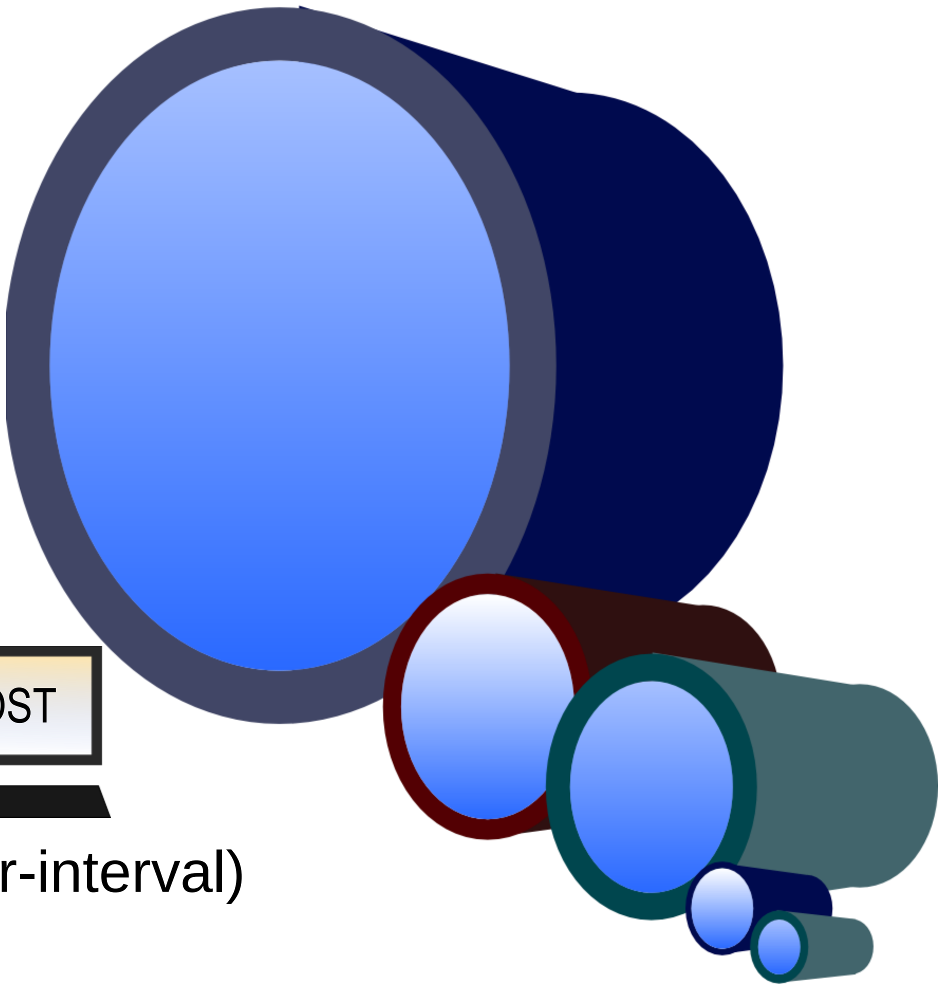
Scope of the Comparative Study

- 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

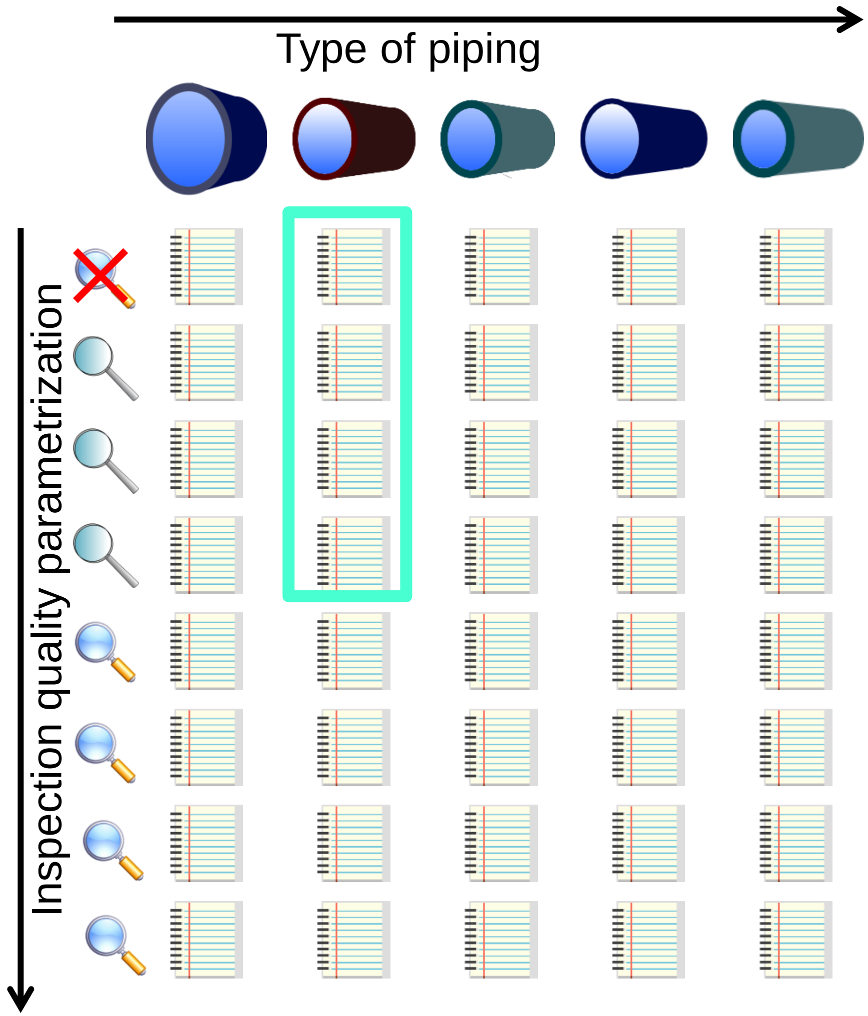




- In-service inspections (10-year-interval)
  - Different qualities

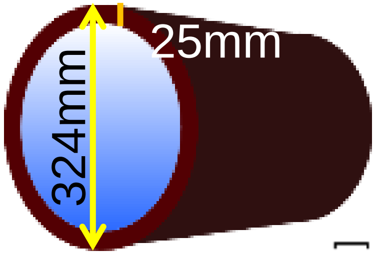
Computational Results

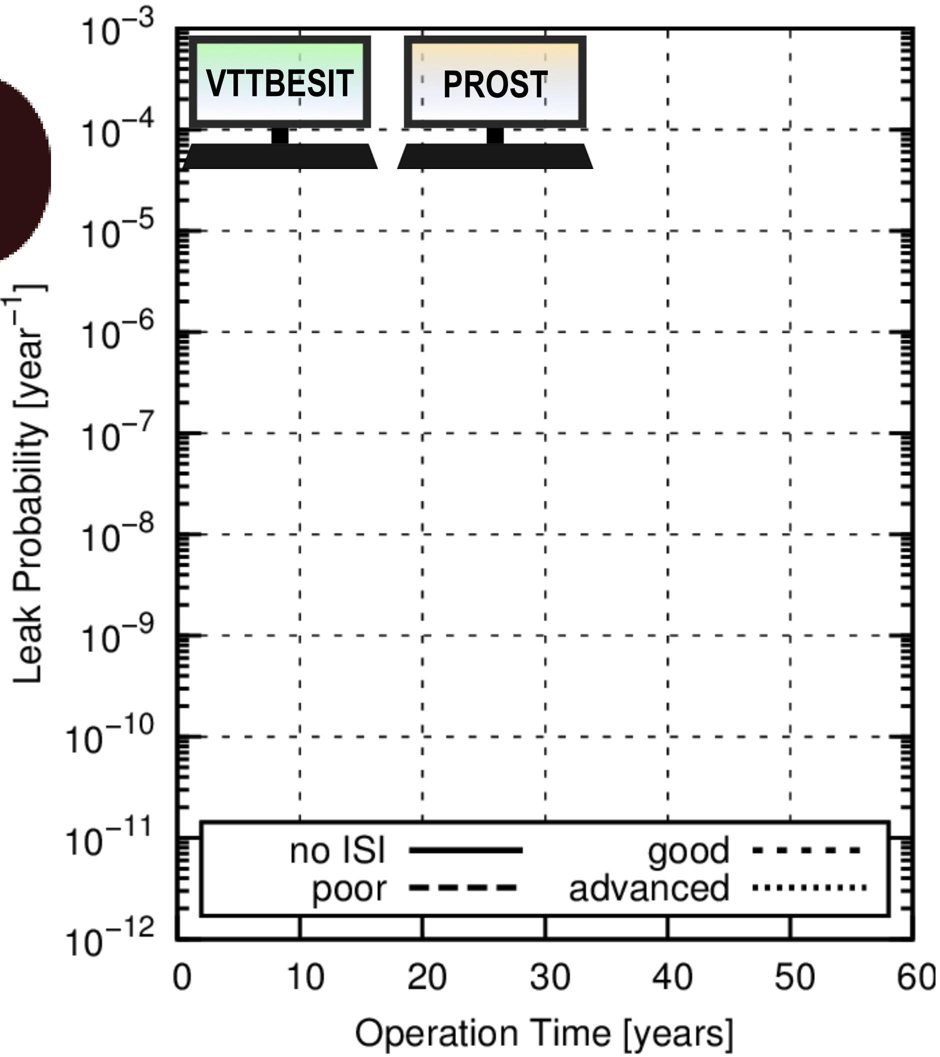
- 5 different piping components
- 7 different inspection qualities + no inspections
- Annual leak probability during operation
- In total ca. 2000 data points per code compared
- Analysis + interpretation



Computational Result (+Example)

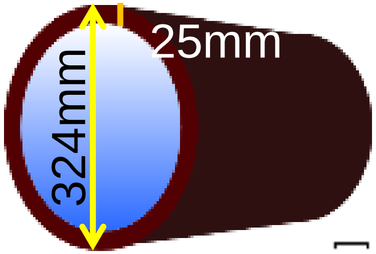
- BWR condition
- Crack initiation
- Crack distribution
- Stress corrosion cracking

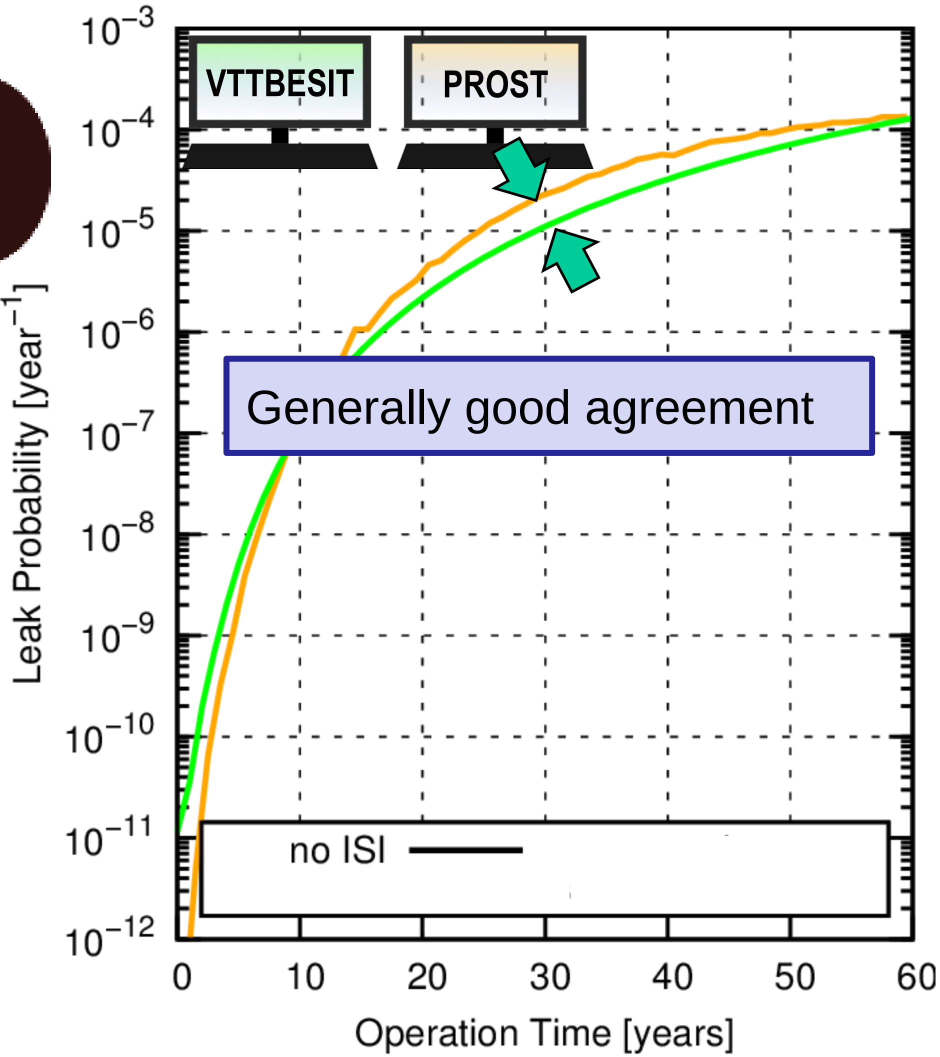




Computational Result (+Example)

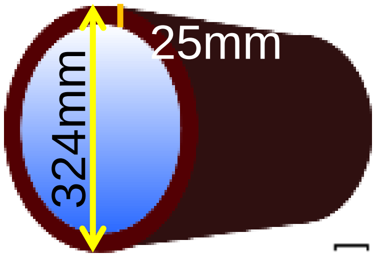
- BWR condition
- Crack initiation
- Crack distribution
- Stress corrosion cracking
- No inspections

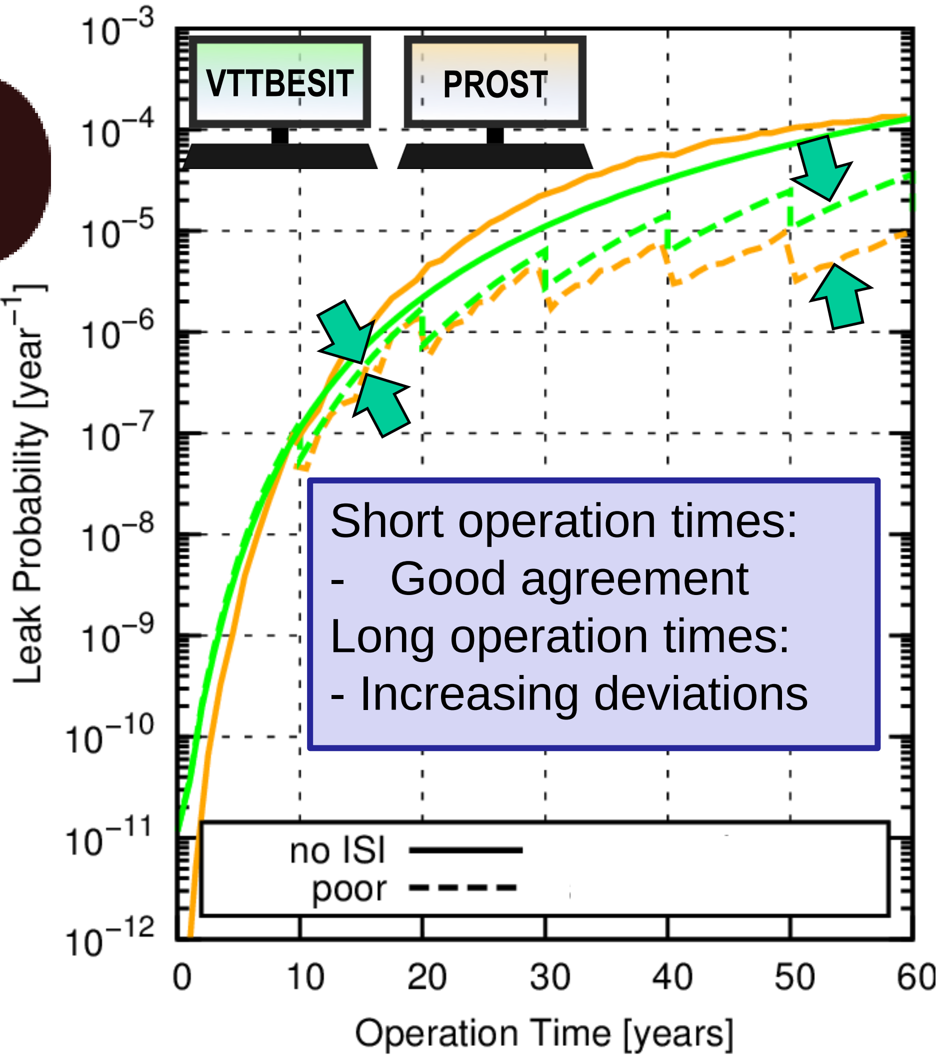




Computational Result (+Example)

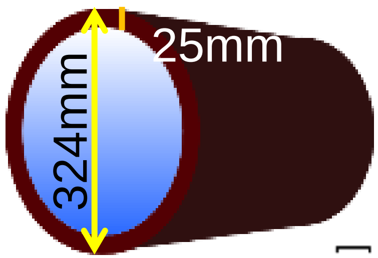
- BWR condition
- Crack initiation
- Crack distribution
- Stress corrosion cracking
- No inspections
- Inspection Qualities
  - Poor

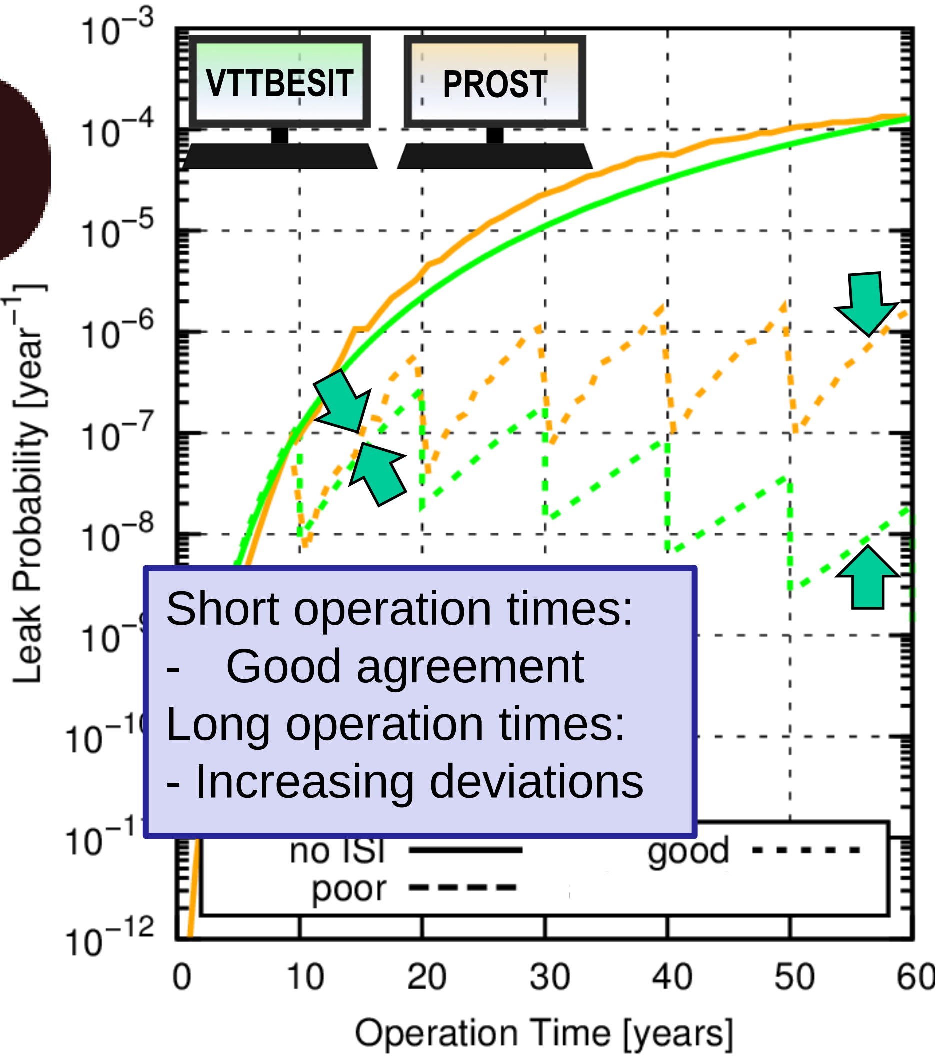




Computational Result (+Example)

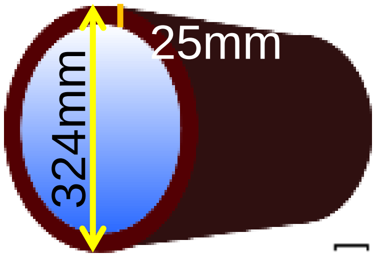
- BWR condition
- Crack initiation
- Crack distribution
- Stress corrosion cracking
- No inspections
- Inspection Qualities
  - Poor
  - Good

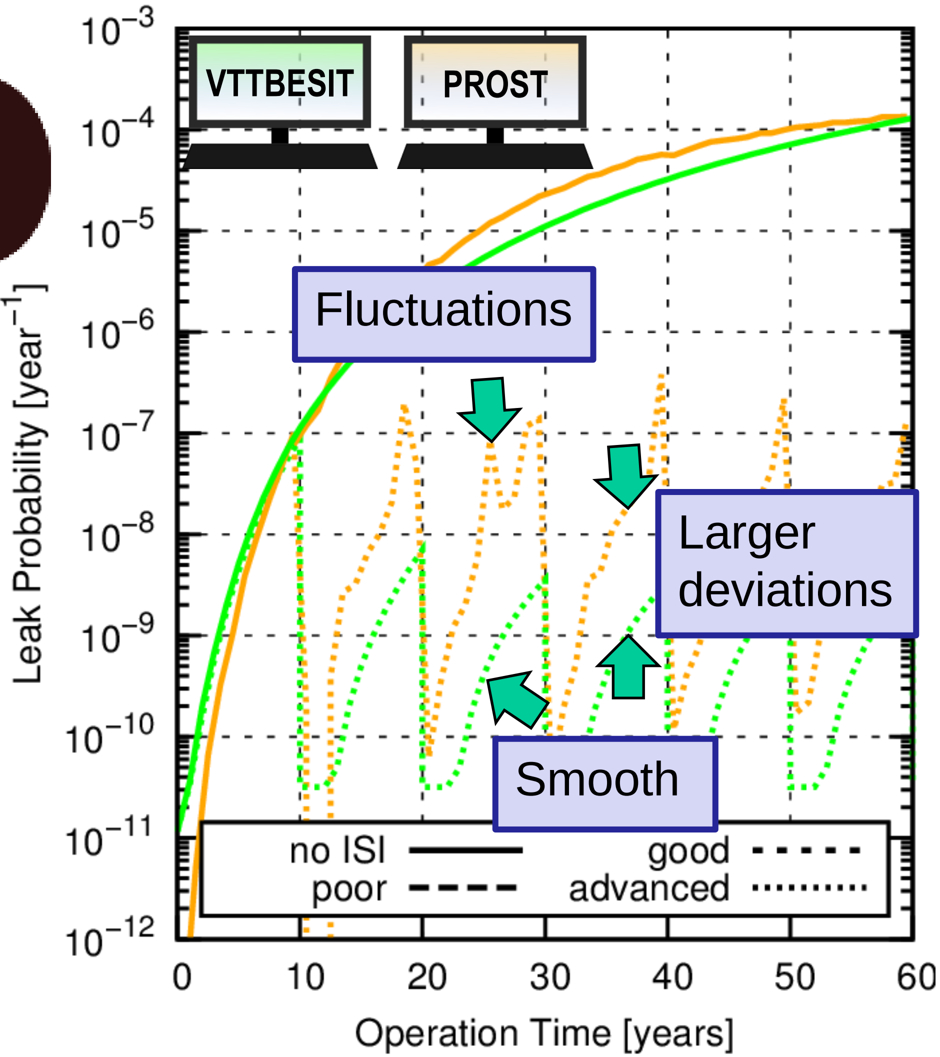




Computational Result (+Example)

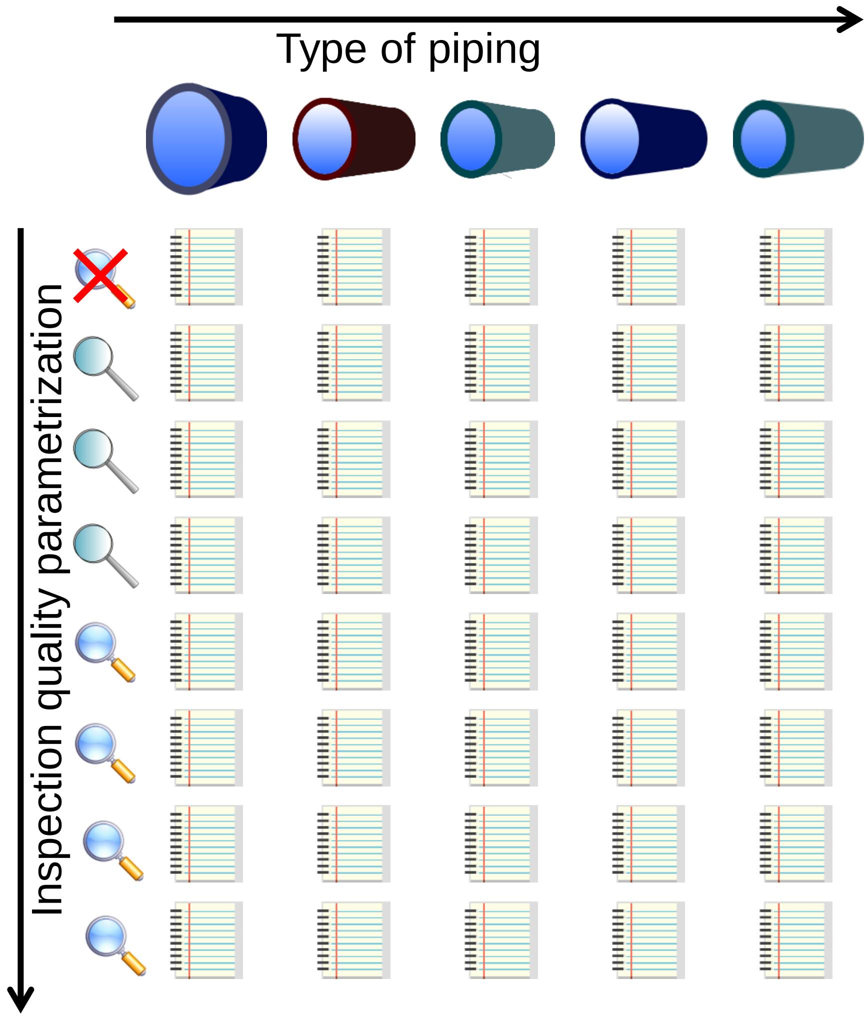
- BWR condition
- Crack initiation
- Crack distribution
- Stress corrosion cracking
- No inspections
- Inspection Qualities
  - Poor
  - Good
  - Advanced



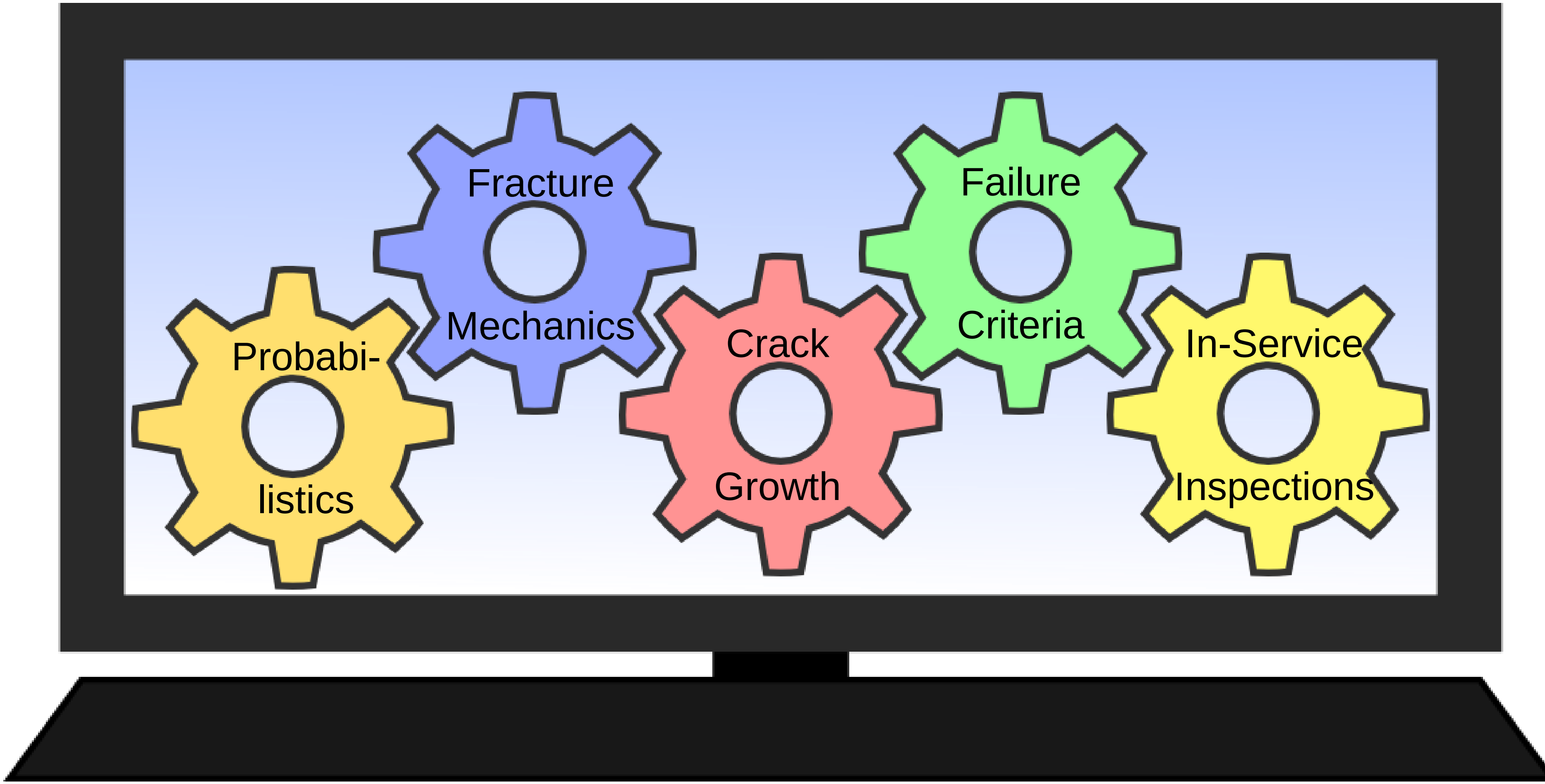


Summary of Trends

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

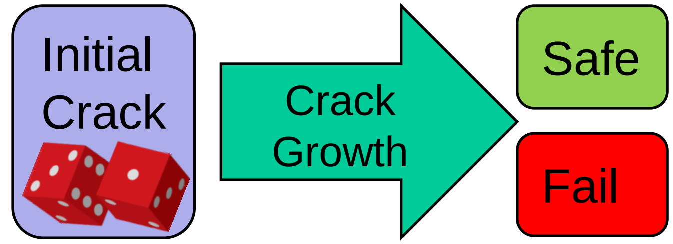


VTTBESIT / PROST
Comparison of Procedures

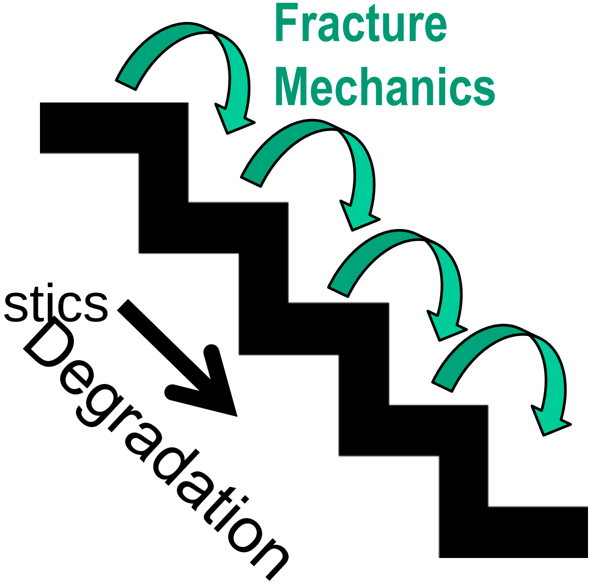


Probabilistics and Random Sampling

- PROST
  - Probabilistic fracture mechanics
  - All parameters distributed
  - Monte Carlo / importance sampling
  - Scattering for small leak probabilities
- VTTBESIT
  - Discrete degradation states
  - Transition between states via probabilistics
  - Initial crack size: distributed
  - Other (e.g. material): non-distributed

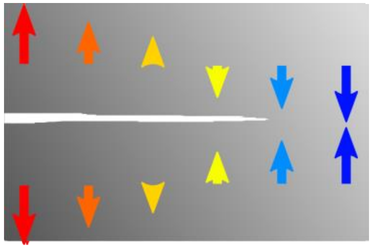


Probabilistic Fracture Mechanics

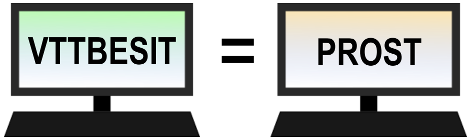


Ageing & Fracture Mechanics: Stresses & K-Factors

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



- Stress intensity factors K
  - Analytical K-solutions



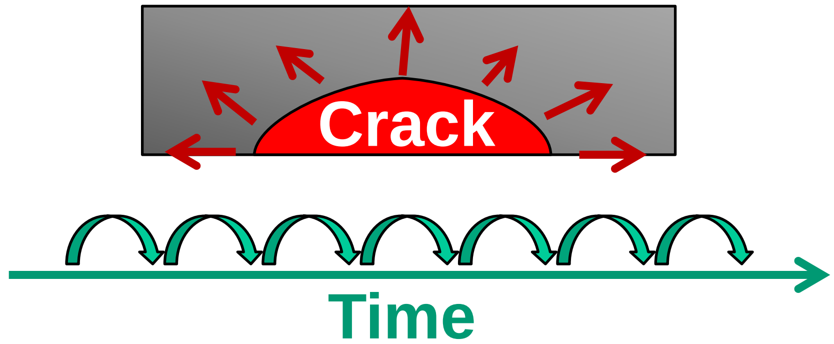
  - Range of validity exceeded for particular cases

	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

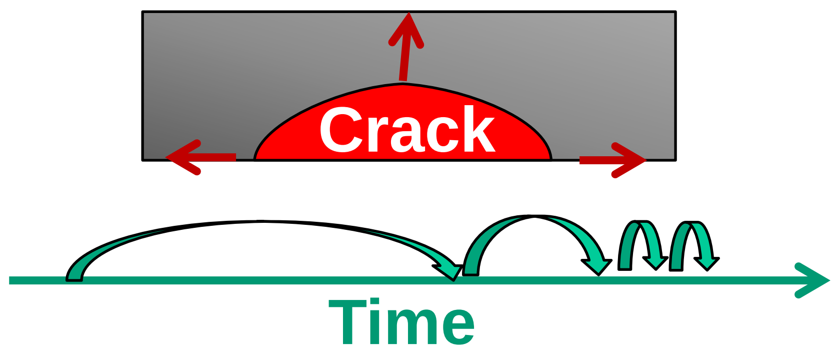
  - Different extrapolation procedures

Crack Growth: Velocity & Numerics

- VTTBESIT
  - Growth along crack front
  - Fixed integration step size

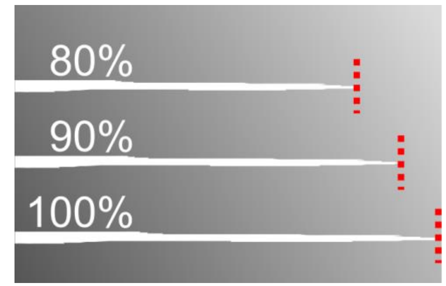


- PROST
  - Growth in depth & length
  - Adaptive step size control

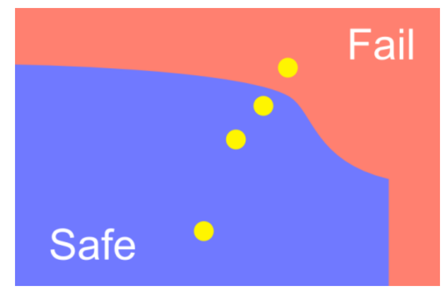


Failure Criteria: Thresholds and Material Properties

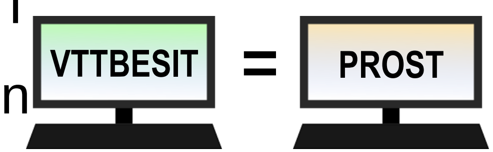
- Failure criteria
  - Geometric criteria: a/t=80%, 90%, 100%
  - Failure assessment diagram (FAD)



- Material properties
  - Consideration of Scatter (y/n)

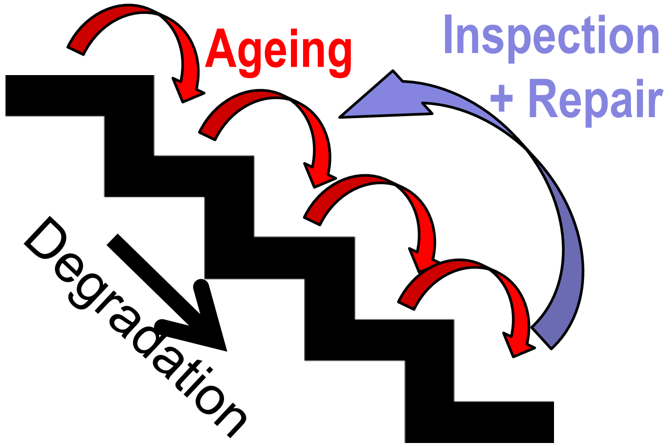


- Analysis & comparison
  - Consistent choice of VTTBESIT + PROST
  - Minor influence of different failure criterion
  - Neglectable influence of uncertainties in material parameters

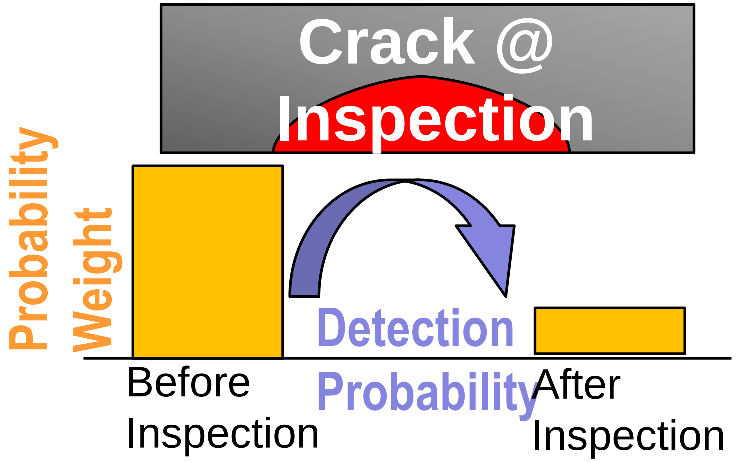


In-Service Inspections

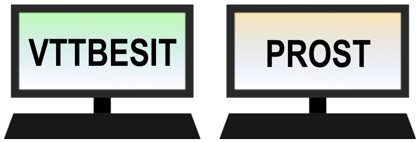
- VTTBESIT
  - Inspections via Transition from Degradation States
  - Markov Chain Model



- 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