Development of Feedwater Line & Main Steam Line Break Initiating Event Frequencies for Ringhals Pressurized Water Reactors

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Lloyd's Register Consulting

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Outline

- Introduction
- Technical approach
- Damage mechanism evaluation
- Equivalent break size (EBS)
- Conditional rupture probability models
- Results
- Conclusions

Introduction

- During the last years LOCA frequencies for the three Ringhals PWR units has been updated piping reliability data from the R-Book.
  - Current version of the R-Book only covers ASME Code Class 1 and 2.
- FWLB and MSLB data however stem from much older data, i.e. WASH-1400.
- Also, during past ten years RI-ISI has been implemented at the PWR units at Ringhals.
- ➢ Desire to have FWLB and SLB frequencies consistent with LOCA frequencies and RI-ISI data.
- Scope of the project was therefore formulated as:
  - Application of state-of-the-art piping reliability models.
  - Use of operating experience data representing current body of industry-wide and plant-specific data
  - Completeness and modelling uncertainty shall be addressed.
  - Ringhals piping integrity management practices and procedures shall be taken into account

Technical approach

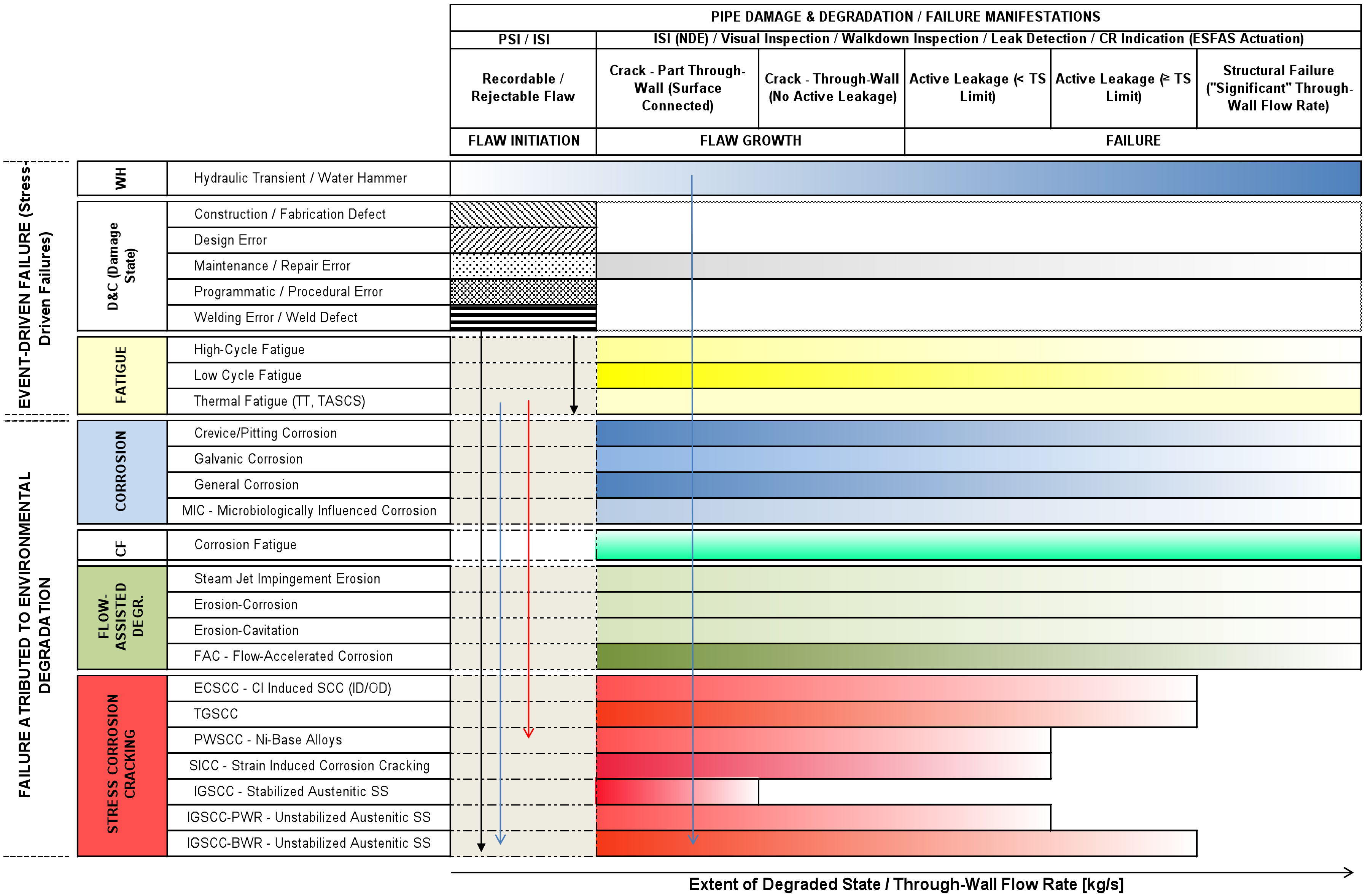
- The technical approach is based on the model expressed by following equations:

$$\rho_{ix} = \sum_{k} \lambda_{ik} P(R_x | F_{ik}) I_{ik} \qquad F(IE_x) = \sum_{i} m_i \rho_{ix}$$

- Where:
  - F(IE) - Frequency of pipe break of size *x*
  - *m* - Number of pipe components of type *i.*
  - ρ - Frequency of rupture of component type *i* with break size *x*
  - λ - Failure rate per "location-year" for pipe component type *i* due to failure mechanism *k*
  - *P(R|F)* - Conditional probability of rupture of size *x* given failure of pipe component type *i* due to damage or degradation mechanism *k*

Damage mechanism evaluation

- The causes of pipe failure (e.g., loss of structural integrity) are attributed to damage or degradation mechanisms.
- In piping reliability analysis, two classes of failure are considered:
  - Event-Driven Failures; e.g. vibration, water hammer, operator failure
  - Failures Attributed to Environmental Degradation defined by unique sets of conjoint requirements that include operating environment, material and loading conditions, e.g. SCC.
- The source of all piping service experience data supporting this study is the proprietary PIPExp Database.
  - “Parent database” of the OPDE (2002-2011) and CODAP (2011-2014) databases
- In piping reliability, a "failure" is any degraded condition that necessitates repair or replacement.
- The high-level database summary on next slide is used to formulate specifications for a quantitative analysis of pipe failure parameters.


PIPE DAMAGE & DEGRADATION / FAILURE MANIFESTATIONS
PSI / ISI
ISI (NDE) / Visual Inspection / Walkdown Inspection / Leak Detection / CR Indication (ESFAS Actuation)
Recordable / Rejectable Flaw
Crack - Part Through-Wall (Surface Connected)
Crack - Through-Wall (No Active Leakage)
Active Leakage (< TS Limit)
Active Leakage (≥ TS Limit)
Structural Failure ("Significant" Through-Wall Flow Rate)
FLAW INITIATION
FLAW GROWTH
FAILURE
EVENT-DRIVEN FAILURE (Stress-Driven Failures)
WH
Hydraulic Transient / Water Hammer
D&C (Damage State)
Construction / Fabrication Defect
Design Error
Maintenance / Repair Error
Programmatic / Procedural Error
Welding Error / Weld Defect
FATIGUE
High-Cycle Fatigue
Low Cycle Fatigue
Thermal Fatigue (TT, TASCS)
FAILURE ATRIBUTED TO ENVIRONMENTAL DEGRADATION
CORROSION
Crevice/Pitting Corrosion
Galvanic Corrosion
General Corrosion
MIC - Microbiologically Influenced Corrosion
CF
Corrosion Fatigue
FLOW-ASSISTED DEGR.
Steam Jet Impingement Erosion
Erosion-Corrosion
Erosion-Cavitation
FAC - Flow-Accelerated Corrosion
STRESS CORROSION CRACKING
ECSCC - Cl Induced SCC (ID/OD)
TGSCC
PWSCC - Ni-Base Alloys
SICC - Strain Induced Corrosion Cracking
IGSCC - Stabilized Austenitic SS
IGSCC-PWR - Unstabilized Austenitic SS
IGSCC-BWR - Unstabilized Austenitic SS
Extent of Degraded State / Through-Wall Flow Rate [kg/s]

Damage mechanism evaluation

- The process of estimating reliability parameters begins by performing a systematic degradation mechanism (DM) evaluation of all pipe segments within the evaluation boundary.
- Based on the EPRI RI-ISI methodology, and the damage and degradation mechanisms specified there, a set of damage mechanisms to be evaluated was identified:
  - FAC – Flow-Accelerated Corrosion (FW)
  - LDIE – Liquid Droplet Impingement Erosion (FW/SL)
  - TASCS – Thermal Stratification Cycling & Striping (FW)
  - LC-FAT – Low-Cycle Fatigue & Pressure (FW/SL)
  - SH – Steam hammer (SL)
  - WH – Water hammer (SL)
  - VF – Vibration fatigue (VF)

Equivalent break size (EBS)

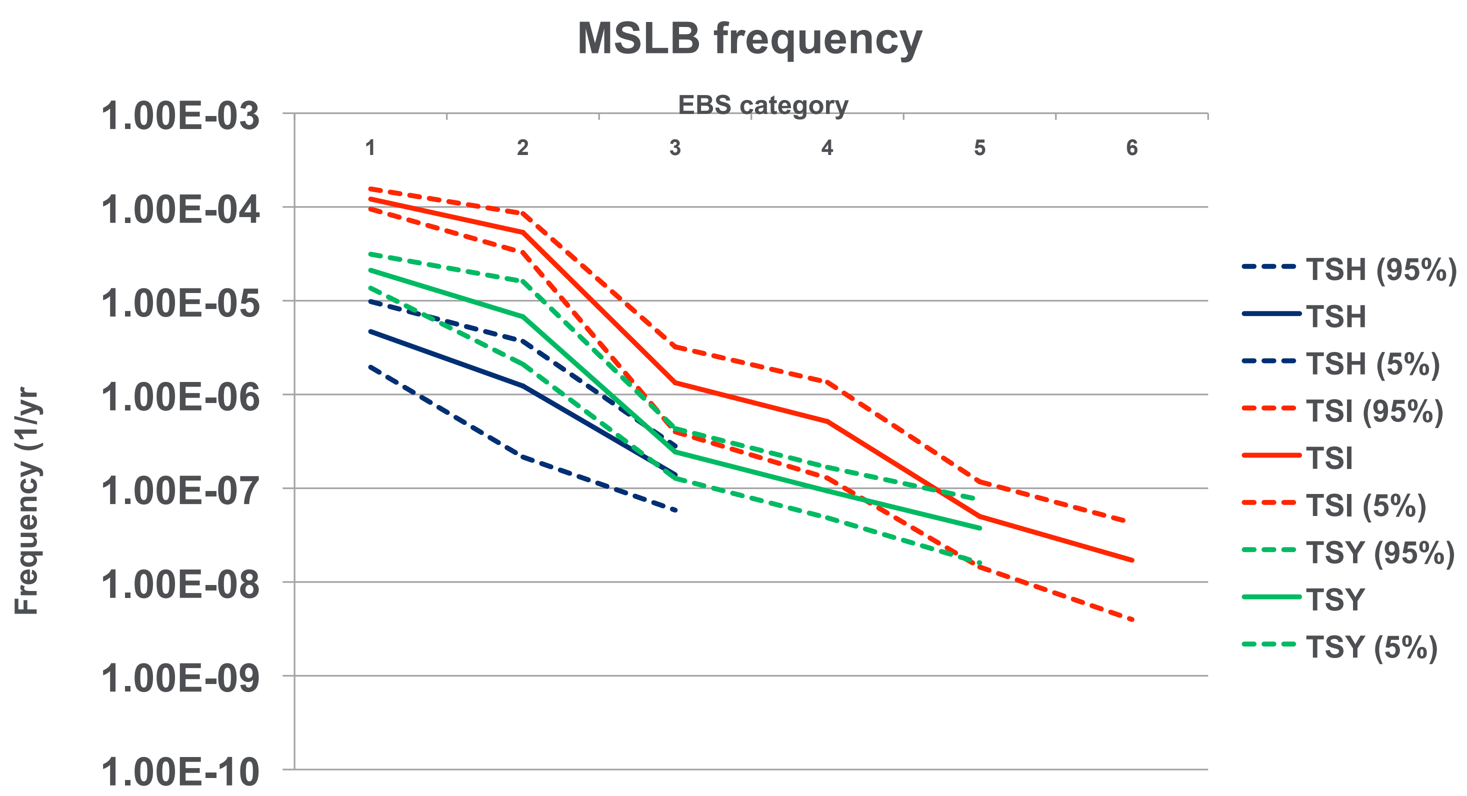
- Another technical consideration is the correlation of IE frequencies with equivalent break sizes as required by a PSA model.
- The break sizes to be considered range from minimum break sizes that requires some kind of actuation up to a double-ended guillotine break.
- Break sizes were divided into the following categories:

Category	>EBS (mm)	Liquid Flow Rate (kg/s)[1]
1	13	10
2	38	75
3	76	300
4	152	1200
5	356	6250
6	762	28600

Conditional rupture probability models

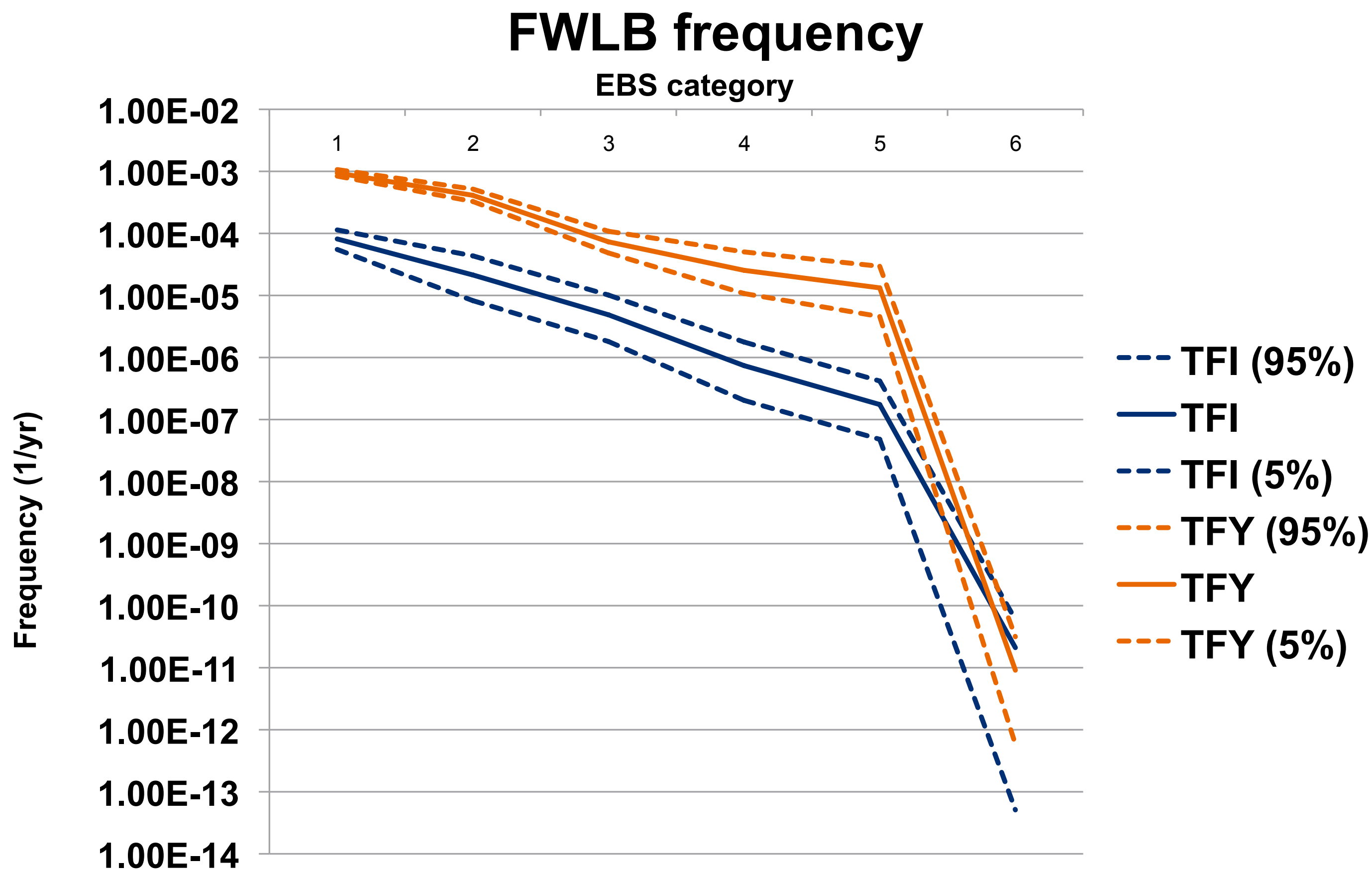
- For certain combinations of material, loading conditions and degradation susceptibility, sufficient service experience exists to support direct CRP estimation.
  - As an example, extensive data exists on FAC-induced pipe rupture
- For other types of degradation mechanisms (DMs), only “precursor data” is available.
  - Service experience data is limited to observations of rejectable non-through-wall flaws and minor through-wall flaws
- The approach taken was to utilize service experience insights and results from the expert elicitation documented in NUREG-1829 for all DMs except FAC.
- The expert elicitation NUREG-1829 synthesizes inputs from experts representing two schools of thought :
  - one based on statistical analysis of service data and simple models,
  - and another based on probabilistic fracture mechanics approaches

Results



MSLB frequency
EBS category
1
2
3
4
5
6
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
Frequency (1/yr
TSH (95%)
TSH
TSH (5%)
TSI (95%)
TSI
TSI (5%)
TSY (95%)
TSY
TSY (5%)

Results



FWLB frequency
EBS category
1
2
3
4
5
6
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
1.00E-08
1.00E-09
1.00E-10
1.00E-11
1.00E-12
1.00E-13
1.00E-14
Frequency (1/yr)
TFI (95%)
TFI
TFI (5%)
TFY (95%)
TFY
TFY (5%)

Conclusions

- Comparison between existing and updated frequencies show that:
  - Mean value for TFI (FWLB) have not changed much
  - Mean values for TSH/TSY (MSLB) is significantly smaller
  - Mean values for TSI (MSLB) and TFY (FWLB) have increased

- Possible sensitivity cases:
  - Vibration fatigue is most dominant DM to TFY (FWLB)
    - VF may be changed to LC-FAT instead since VF should be applied to small diameter piping only
  - Flow-Accelerated Corrosion is second most dominant DM to TFY (FWLB)
    - Consideration not taken to replacement of steam generators

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