Business from technology

RI-ISI Analyses and Inspection Reliability of Piping Systems - RAIPSYS

SAFIR2014 Final Seminar, 20March2015

Otso Cronvall
VTT Technical Research Centre of Finland

CONTENTS OF PRESENTATION

- Introduction
- Assessment of piping failure potential
- Screening criteria and load application methods for probabilistic analyses
- RI-ISI methodologies
- International co-operation

INTRODUCTION - 1

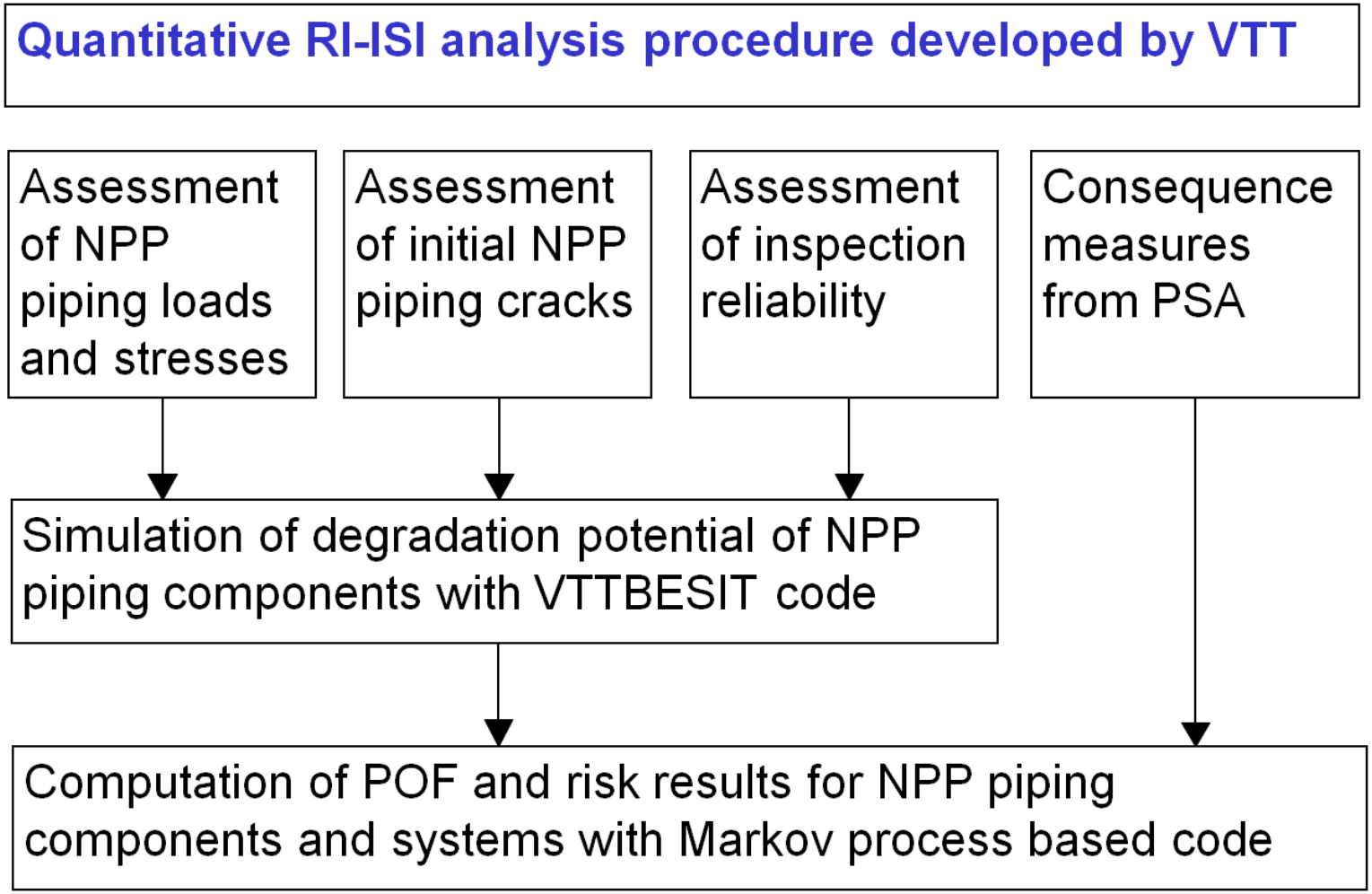
- The overall objective of the RAIPSYS project is to support the implementation of risk informed in-service inspection (RI-ISI) at Finnish NPPs by studying and further developing relevant issues related to RI-ISI.
- The main objectives were the development of structural reliability methods for quantification of piping leak and break probabilities, further development of methods for evaluating inspection capability, further development of RI-ISI analysis methods, as well as strengthening inter-disciplinary readiness to combine structural integrity, non-destructive testing (NDT) and probabilistic safety analysis (PSA) expertise in Finland.
- The project has contributed to international activities, including the participation in the work of the Task Group on Risk (TGR) of the European Network for inspection and Qualification (ENIQ).

INTRODUCTION - 2

- In Finland, the use of risk-informed methodology in planning new ISI programs is a regulatory requirement, and both domestic utilities are developing RI-ISI programs for the existing plants.
- The ISI programs for new OL3 and Fennovoima units will also consider risk insights.
- This presentation is divided into four main parts, which are:
  - Assessment of piping failure potential,
  - Screening criteria and load application methods for probabilistic piping degradation analyses,
  - RI-ISI methodologies, and
  - International co-operation.
- This presentation describes the main results achieved in the RAIPSYS project, more detailed results are documented in written scientific journal articles, conference articles, VTT research reports and international research publications.

INTRODUCTION - 3

- Analysis flow with probabilistic VTTBESIT & Markov application:



ASSESSMENT OF PIPING FAILURE POTENTIAL - 1

Further development of probabilistic VTTBESIT - 1:

- Research work on structural reliability analysis methods at VTT has resulted in further development of a probabilistic fracture mechanics (PFM) based analysis tool VTTBESIT.
- VTTBESIT has been developed by the Fraunhofer-Institut für Werkstoffmechanik (IWM), Germany, and by VTT.
- VTTBESIT allows quick computation of the Mode I stress intensity factor (SIF-I) values along the crack front and, based on this, the simulation of the crack growth.
- The accuracy of VTTBESIT was improved by developing and implementing a more accurate crack growth increment computation procedure.
- This procedure takes into account the crack growth potential in all computation points along the crack front, whereas the earlier procedures consider it only in one or two crack front points.

ASSESSMENT OF PIPING FAILURE POTENTIAL - 2

Further development of probabilistic VTTBESIT - 2:

- In the new procedure, the semi-elliptic area corresponding to the next crack size is computed first, by taking into account all crack growth vectors along the crack front, see Figure 1.
- Then, the shape of this area is determined from the relation of the through wall and parallel to wall surface components of the crack growth vectors.

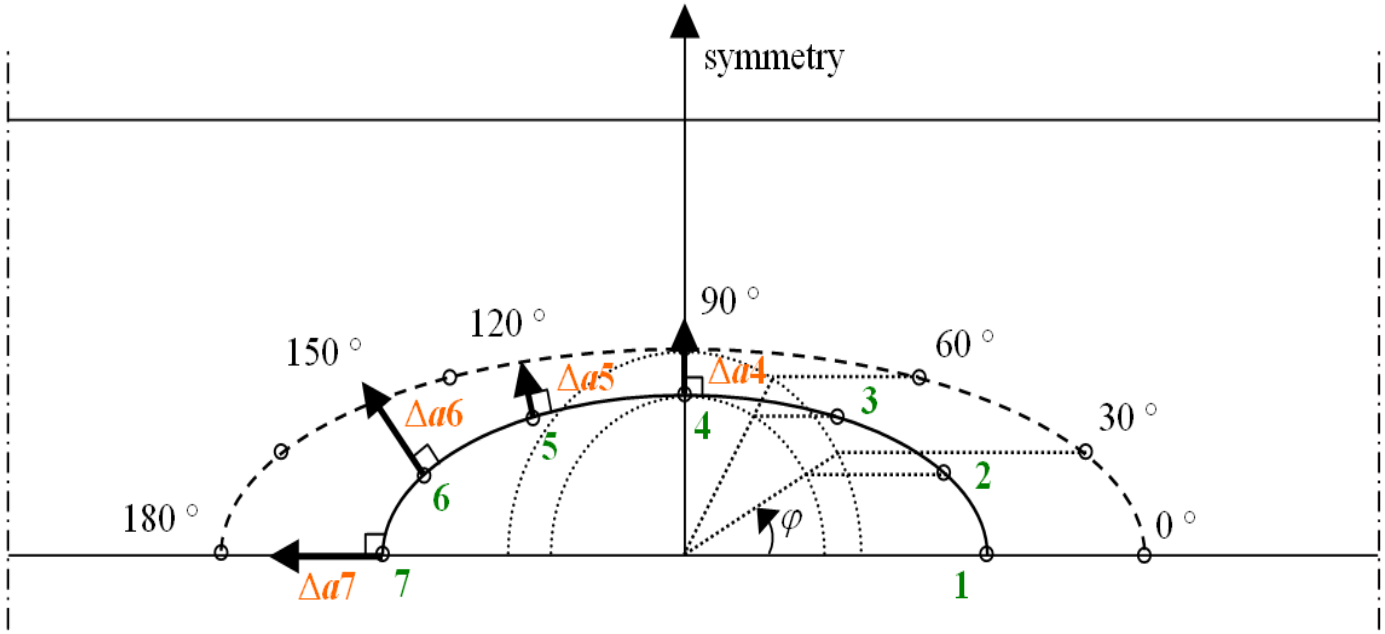


Figure 1. Crack postulate with local crack growth vectors.

ASSESSMENT OF PIPING FAILURE POTENTIAL - 3

Further development of discrete Markov model - 1:

- In 2013, the existing discrete stationary Markov model was developed further by expanding it with non-stationary analysis capabilities.
- The non-stationary Markov chain method calculates separate degradation matrices for given time intervals, whereas the existing stationary Markov chain considers the whole NPP time in operation as a homogeneous process, by using a single degradation matrix for this time span.
- Markov analysis tool takes now better into account the different ageing phases of NPP piping systems, which can e.g. follow the bath tube curve.
- For the time being, the two implemented non-stationary time interval options are:
  - 1) 0 – 10, 10 – 40, 40 – 60 years, and
  - 2) 0 – 20, 20 – 40, 40 – 60 years.
- More accurate pipe leak & break probability results can be obtained with the developed non-stationary Markov model.

ASSESSMENT OF PIPING FAILURE POTENTIAL - 4

Further development of discrete Markov model - 2:

- Figure 2 shows break probability results for a pipe weld with outer diameter and wall thickness of 170 mm and 11.0 mm, respectively, while the considered degradation mechanism is SCC, and inspection interval is 3 y.

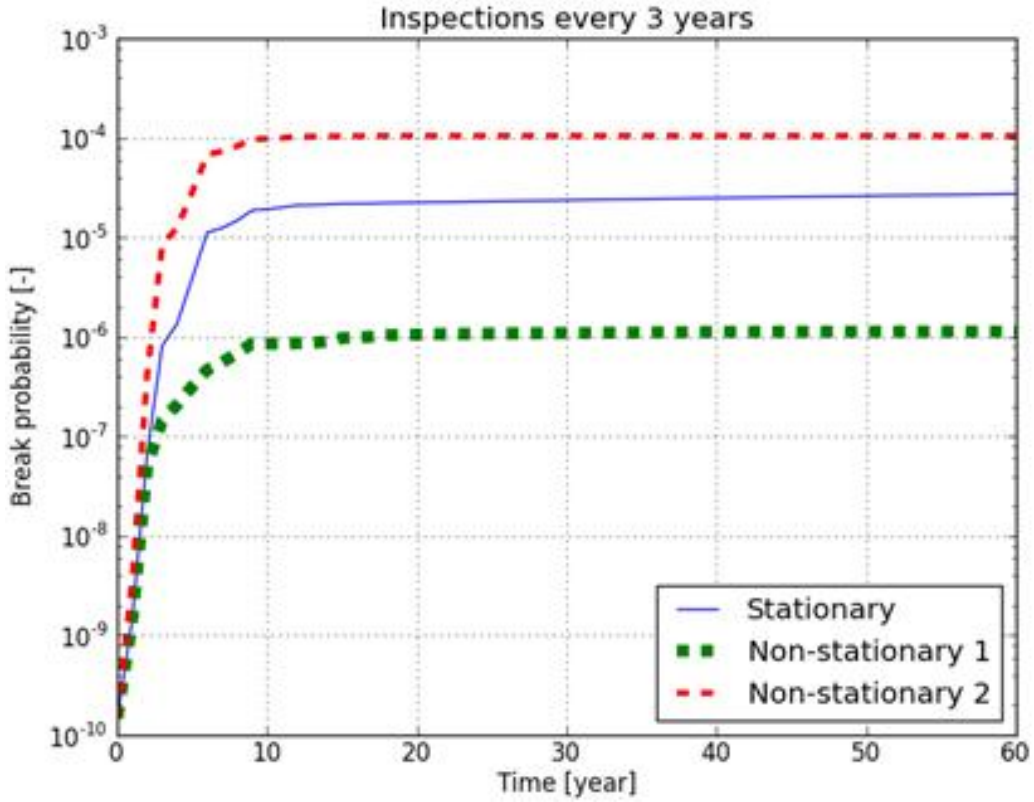


Figure 2. Break probability results for a pipe weld.

ASSESSMENT OF PIPING FAILURE POTENTIAL - 5

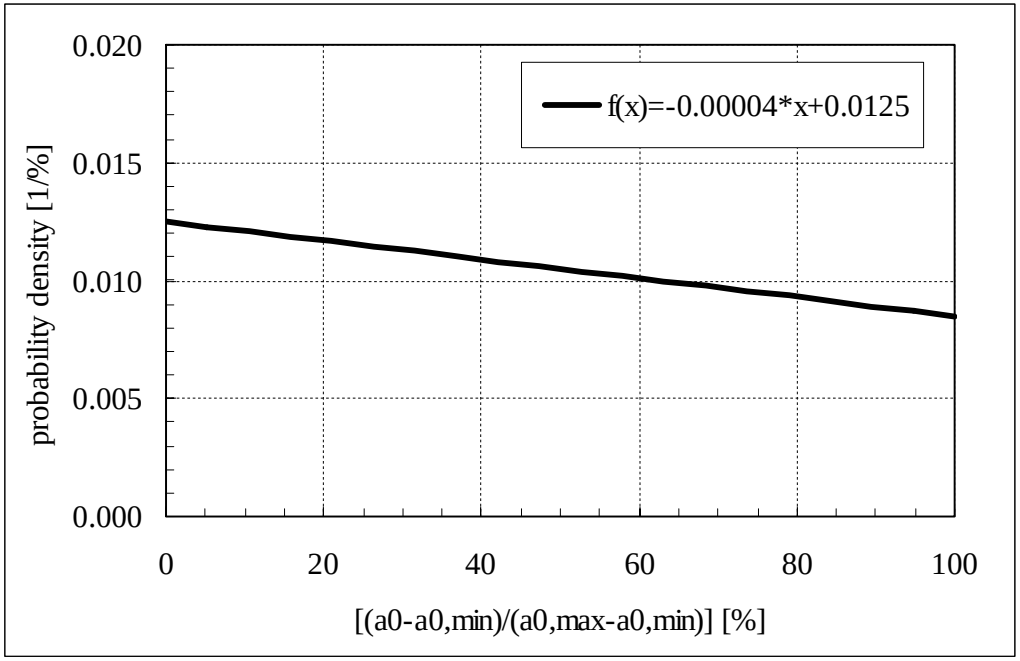
Convolution integral method for pipe break probabilities:

- To expand the analysis capabilities, the convolution integral method for computation of pipe break probabilities was implemented in 2012.
- The method combines crack intitiation probability and growth probabilities.
- Unlike the Markov models, the convolution method does not have any assumptions about the form of the probability distributions, and consequently these distributions can be arbitrary.
- The method allows the use of multiple probability distributions, due to which an arbitrary number of degradation states can be modelled.
- In 2014, the convolution integral based procedure was developed further, by taking into account the effect of inspections and considering more degradation states.
- The convolution method is feasible for computation of pipe break probabilities, and is also promising from the viewpoint of further development.

ASSESSMENT OF PIPING FAILURE POTENTIAL - 6

Development of new estimates for SCC induced initial cracks:

- New estimates for depth and length of SCC induced initial circumferential cracks were developed in 2011, see Figure 3 below.
- Recursive method based on fracture mechanics and statistical curve fitting was used, as applied on Swedish SCC crack data.



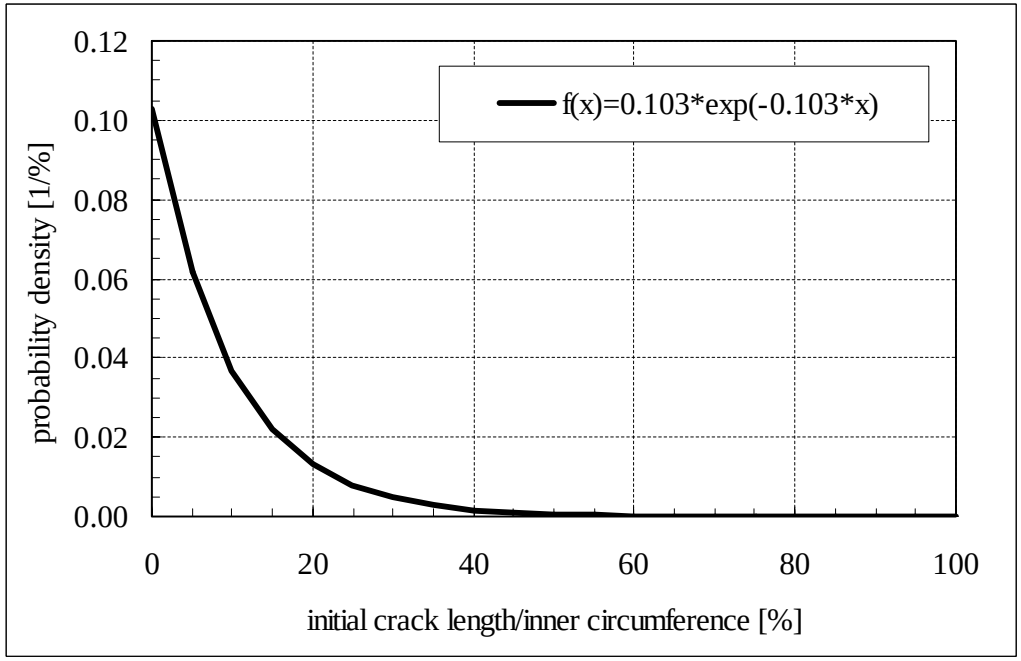


Figure 3. PDFs for probabilistic depth (a_0) and length (l_0) of initial SCC cracks.

SCREENING CRITERIA AND LOAD APPLICATION METHODS - 1

Screening criteria for probabilistic piping degradation analyses:

- As NPP piping component failure probabilities are usually very low, calculation of them can be tedious and require pipe component specifically several or even hundreds of thousands of deterministic simulations.
- The SIF and SIF range threshold values can be used as screening criteria for the onset of SCC and fatigue induced crack growth, respectively.
- The main result of the study carried out in 2013 is a collection of threshold data concerning these degradation mechanisms.
- The SIF and SIF range values describe the intensity of the loading and loading range at the crack front, respectively.
- When these values are below some specified threshold values, the crack growth should not start and the cases with such input data can be excluded from the computational analyses.

SCREENING CRITERIA AND LOAD APPLICATION METHODS - 2

Load application methods for probabilistic piping degradation analyses:

- In 2014, a study was carried out on collection, review and development of cyclic loading methods applicable to probabilistic fatigue induced crack growth analyses of NPP piping components.
- The scope of this study concerns mainly thermal high-cycle loading.
- The covered documents are codes and rules of a number of countries using nuclear energy, as well as fitness-for-service procedures and scientific literature.
- The developed new straightforward method for application of cyclic loading was compared to THERFAT Level 2 method in a computational example concerning fatigue induced crack growth in a representative NPP piping Tee.
- Both as a function of time and of load cycles, the crack growth rate through wall is more than twice faster with the THERFAT Level 2 method than with the VTT approach.

RI-ISI METHODOLOGIES - 1

- The effect of loads, initial flaw size and inspections to NPP piping risks was examined in 2011-2014, with probabilistic VTTBESIT & Markov application.
- As an example, analyses & results from 2013 are presented.
- Analysis input data - 1:
  - one BWR pipe weld cross-section, with base material as SA376 TP304,
  - SCC as the considered degradation mechanism, with rate equation used in the computations; da/dt = C×(KI^n), where a is crack depth, t is time and C & n are material and environment specific parameters,
  - flaw postulate: semi-elliptic circumferential surface crack,
  - operational BWR conditions as the considered process loads, with pressure of 70 bar and temperature of 286 °C,
  - three sets of PDFs for sizes of initial cracks and four distributions for WRSs,
  - inspection intervals; 3 years,10 years, no inspections,
  - assumed time in operation is 60 years.

RI-ISI METHODOLOGIES - 2

- Analysis input data - 2:

Pipe size	**Outer diameter [mm]**	**Wall thickness [mm]**
FRESH	323.85	17.45
Initial crack sizes by	**Cause for crack initiation**	**Median crack depth [mm]**
Simonen & Khaleel	fabrication	1.4 … 2.7 (*)
NURBIT distribution	SCC	1.0
VTT distribution	SCC	0.5
WRSs by/from	**Maximum value [MPa]**	**Minimum value [MPa]**
FRESH	270	-100
ASME	200	-200
R6 Method, Rev. 4	320	120
SSM handbook	260	-100
POD from	**Scope**	**NDT quality options**
NUREG/CR-3869	intergranular SCC, austenitic stainless steels and ferritic steels	advanced, good, poor, of which good is used here
CCDP value	**No. of degradation states**	**Time in operation [year]**
0.00001	10 or 8 (*)	60

(*) depends on wall thickness.

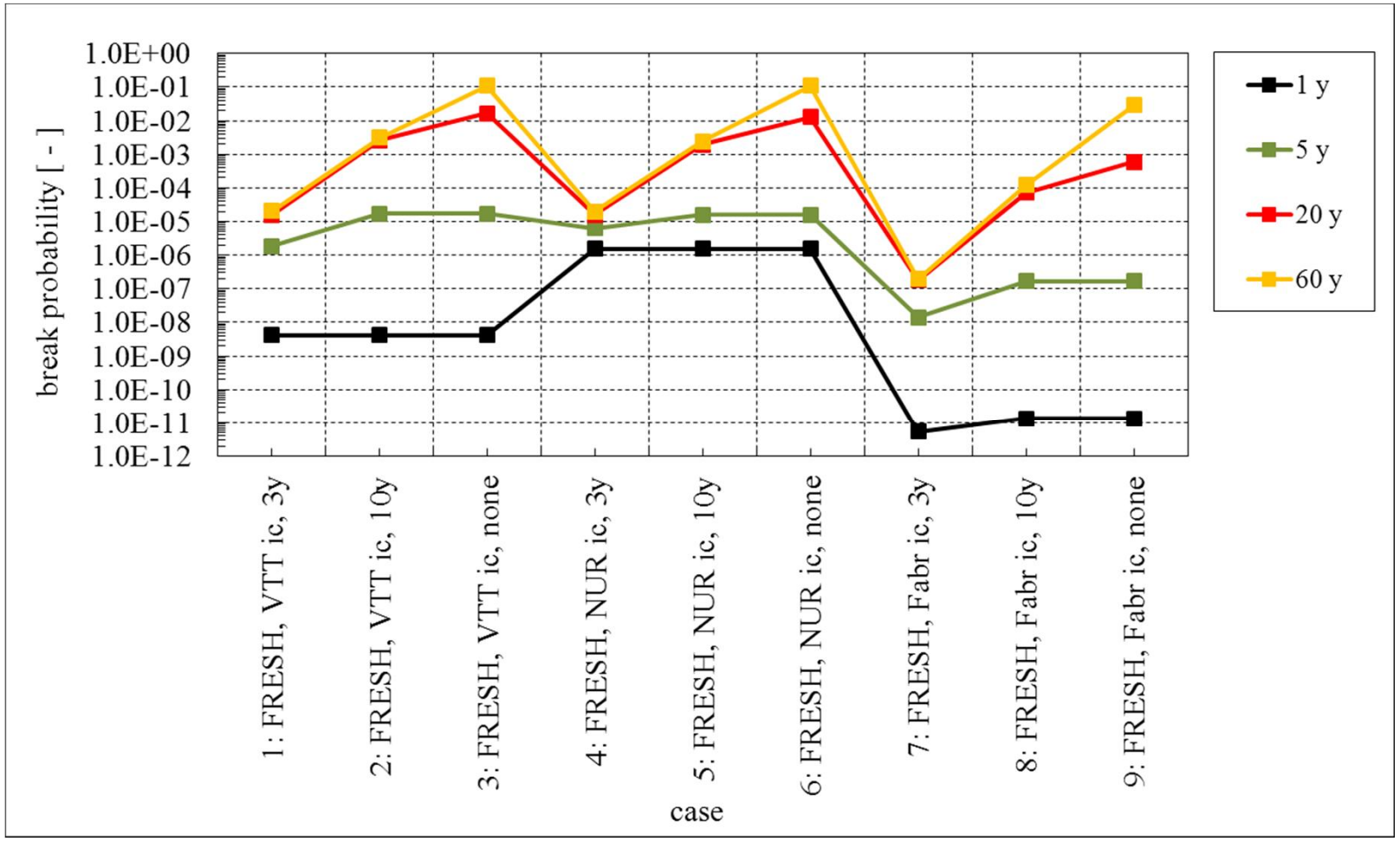
RI-ISI METHODOLOGIES - 3

- List of analysis cases:

Case no.	Cross-section	Initial crack sizes	WRSs according to	Inspection interval
1	FRESH	VTT	FRESH	3 years
2	FRESH	VTT	FRESH	10 years
3	FRESH	VTT	FRESH	No inspections
4	FRESH	NURBIT	FRESH	3 years
5	FRESH	NURBIT	FRESH	10 years
6	FRESH	NURBIT	FRESH	No inspections
7	FRESH	Fabrication flaws	FRESH	3 years
8	FRESH	Fabrication flaws	FRESH	10 years
9	FRESH	Fabrication flaws	FRESH	No inspections
10	FRESH	VTT	ASME	3 years
11	FRESH	VTT	ASME	10 years
12	FRESH	VTT	ASME	No inspections
13	FRESH	VTT	R6 Method, Rev. 4	3 years
14	FRESH	VTT	R6 Method, Rev. 4	10 years
15	FRESH	VTT	R6 Method, Rev. 4	No inspections
16	FRESH	VTT	SSM handbook	3 years
17	FRESH	VTT	SSM handbook	10 years
18	FRESH	VTT	SSM handbook	No inspections

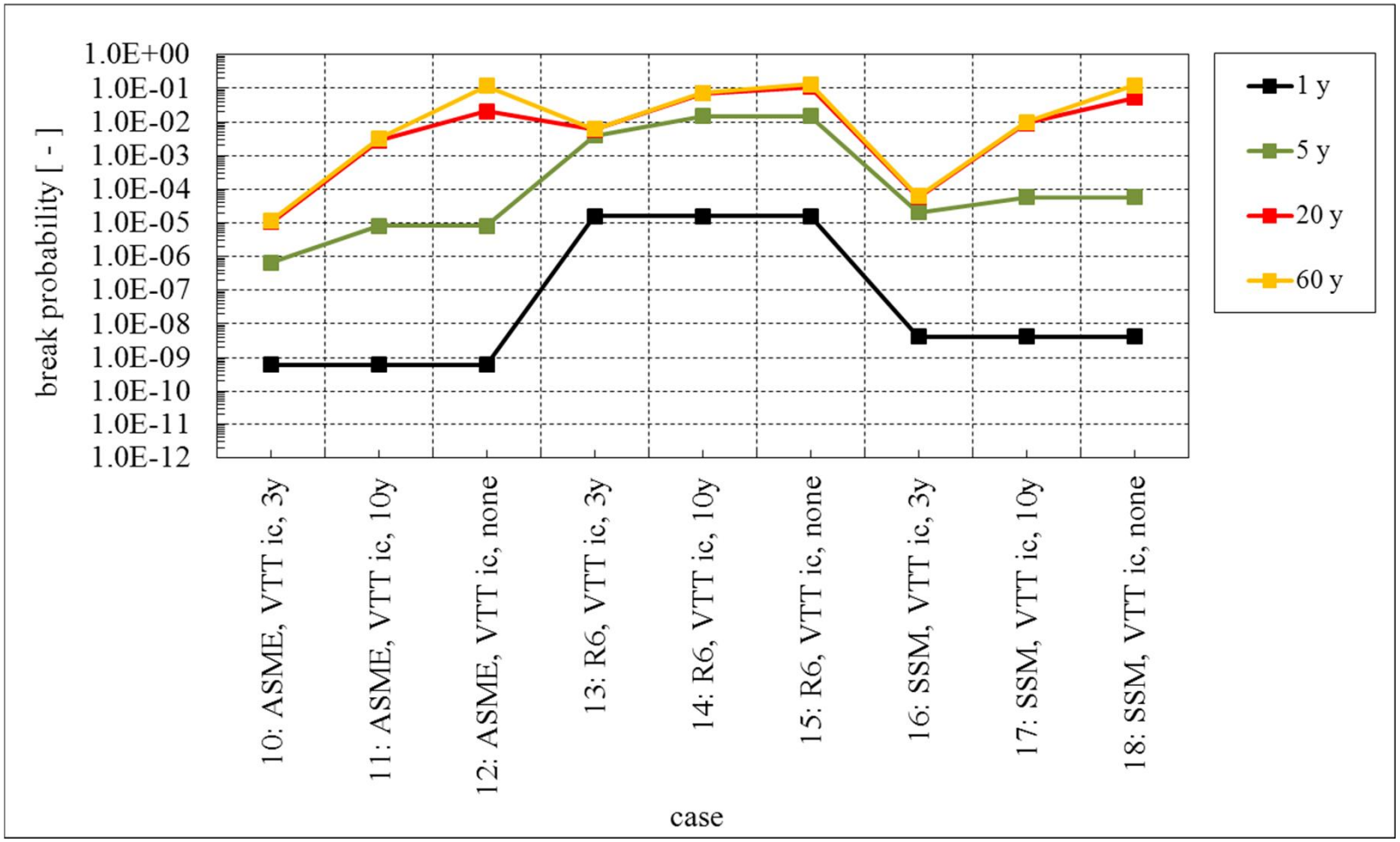
RI-ISI METHODOLOGIES - 4

- Comparison of pipe break probabilities after 1, 5, 20 and 60 years in operation for FRESH weld cross-section, for cases 1-9:



RI-ISI METHODOLOGIES - 5

- Comparison of pipe break probabilities after 1, 5, 20 and 60 years in operation for FRESH weld cross-section, for cases 10-18:



RI-ISI METHODOLOGIES - 6

- Conclusions:
- According to the analysis results, the magnitude of the loading has the biggest effect on the NPP pipe component leak/break probabilities.
- The WRS recommendations in the fitness-for-service guidelines are always conservative, often overly so.
- It is recommended to simulate the WRSs with an applicable FE analysis code, as such WRSs do not include unnecessary conservatism.
- Presently, such challenging and advanced FE simulations require additional capabilities, as to be developed by the code user.
- The effect of initial crack size to leak/break probabilities is significant at early phase of plant lifetime, but decreases considerably as the NPP ages.
- As for the effect of inspections, they clearly decrease the resulting pipe leak/break probabilities => it is recommended to include them to the computations.

INTERNATIONAL CO-OPERATION

- Through RAIPSYS project VTT has actively participated in the work of the ENIQ TGR, which is nowadays NUGENIA Technical Area 8 (TA8).
- The TGR works towards developing European best practices for RI-ISI methodologies.
- The participation to TGR work includes contributing to ENIQ consensus documents, position/discussion documents and technical reports as well as participating the ENIQ TGR meetings.
- The main reporting contribution by VTT to ENIQ TGR has been for:
  - ENIQ TGR discussion document: RI-ISI – Lessons Learned from Application to European Nuclear Power Plants,
  - ENIQ TGR Report: European Framework Document for Risk-Informed In-Service Inspection.
- Through RAIPSYS project VTT has also participated in the activities of NUGENIA Technical Area 1 (TA1), Plant safety and risk assessment.

VTT creates business from technology