

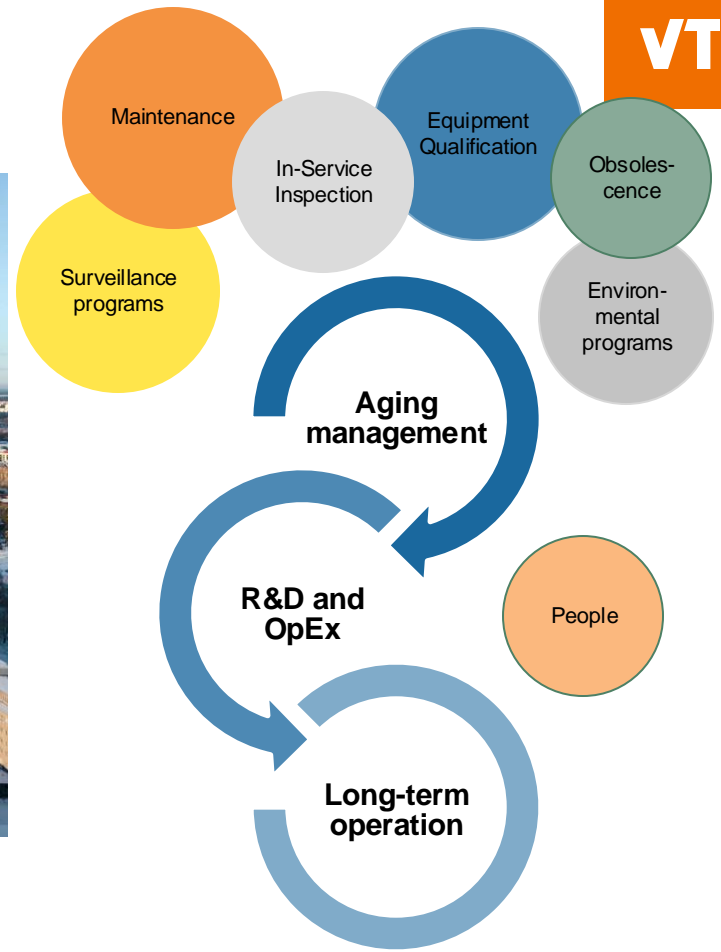
VATTENFALL 

VTT

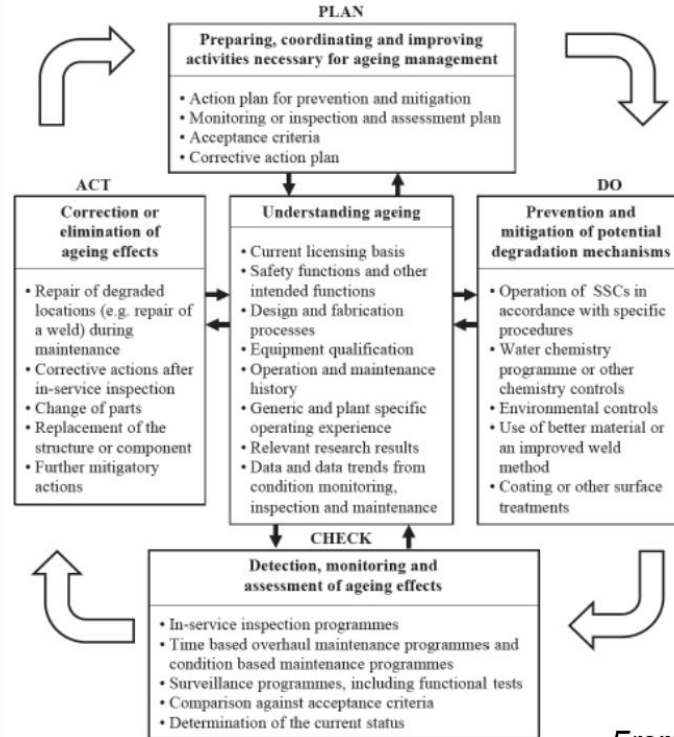
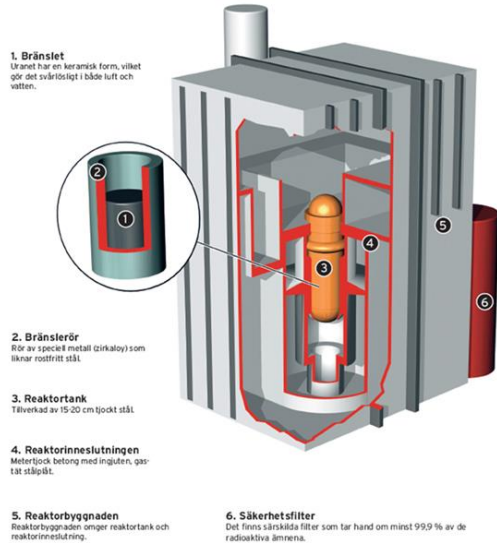
Ensuring the Nordic Material Research Capabilities for Long Term Operation – Focus on RPV and Primary Circuit

Noora Hytönen, Sebastian Lindqvist VTT
Pål Efsing, Ringhals Ab

04/02/2025 VTT – beyond the obvious



Generating Basis for Continued Operation of the Nordic NPPs

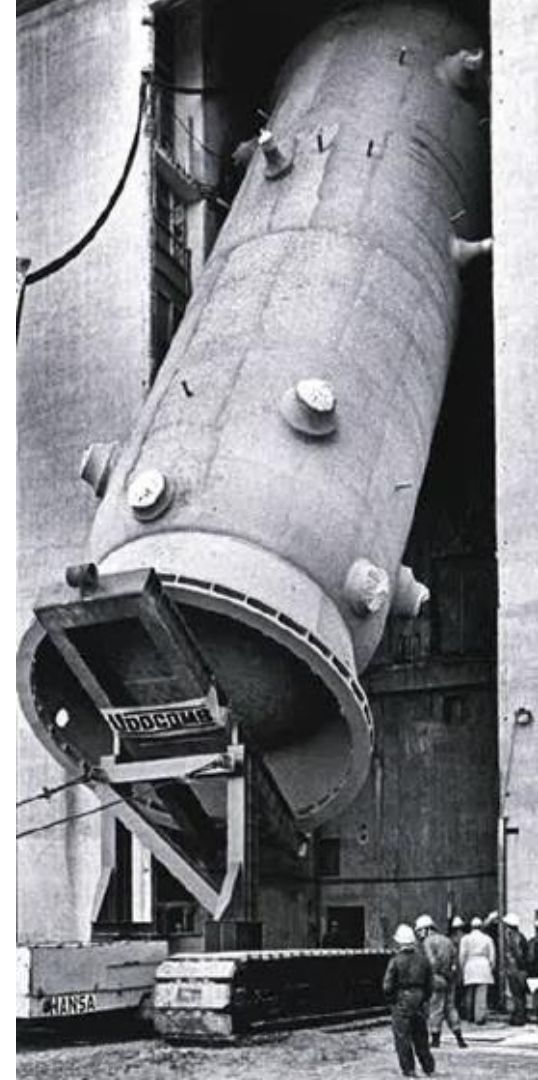


Plan
Do
Check
Act

From IAEA SSG-48

Ensuring Safe LTO: Addressing RPV Material Issues

- RPV irreplaceable component and its durability is a life-time limiting factor in NPP operation
- Thermal and irradiation embrittlement during operation decreases the operation margin
- There are no redundant systems to fulfill the safety functions of the RPV and thus we need to prove its functionality for the entire proposed time of operation



Ageing management of RPV

- 6 BWRs, 2 PWRs, and 2 VVERs are going towards operation beyond the original licensing period in the Nordic
- Necessary to distinguish the operational limiting factors
- There are several knowledge gaps to address:

High-dose mechanical properties

Correctness of the surveillance program vs. actual materials properties

Combined effects of thermal and irradiation induced ageing

Nordic Collaboration in Research

- NKS-BREDA project: Barsebäck Research & Development Arena
- SAFIR2022 BRUTE project: Barsebäck 2 RPV material used for true evaluation of embrittlement
- SAFER2028 BRIGHT project: Barsebäck RPV investigation through thickness
- NKS-RePousses project: Reactor Pressure Vessel LTO Assessment
- FEMMA project: Dissimilar Metal Welds



Nordic Collaboration in Research

- Additional value to the Nordic nuclear community:
 - Improve R&D and Knowledge transfer
 - Workshops, technical meetings
 - Supporting doctoral studies
 - Enabling generational transition
- VTT: Hotcell laboratory at Centre for Nuclear Safety, Mechanical testing on irradiated materials and microstructural investigations
- KTH: Modelling the constrain effect and weakest link probability
- Chalmers: Atom probe tomography for mechanistic understanding of embrittlement
- Ringhals: Operations Experience (OpEx)

Knowledge transfer



Reactor pressure vessel embrittlement seminar for the BREDA – BRUTE project

Place: VTT, CNS building, meeting room Einstein / Kivimiehentie 3, Espoo

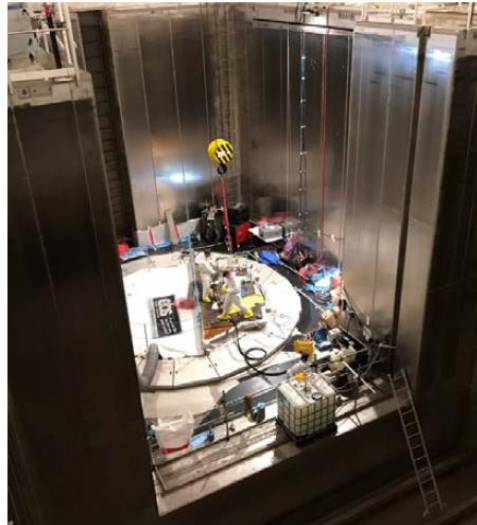
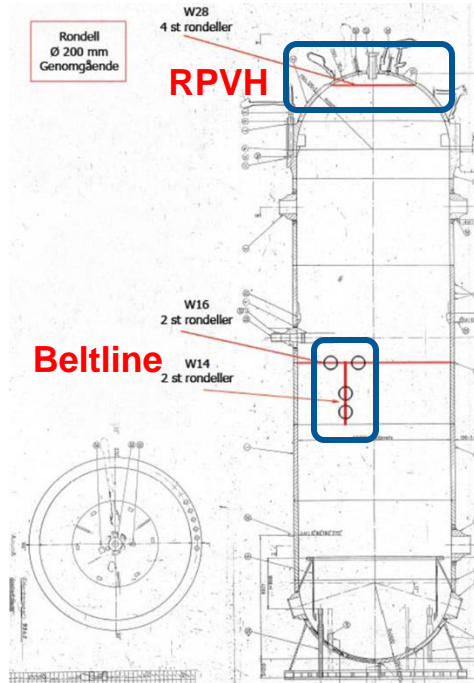
Time: 31 October, 2018

9:00	Opening and welcome	Ulla Ehrnström, VTT
9:10	Expectations for the BREDA project	Jenny Rouden, Ringhals
9:40	The Ringhals RPV story	Jenny Rouden, Ringhals
10:10	Aging and constraint effects of low alloy steels – Magnus Ph.D. Project	Magnus Boösen, KTH
10:40 – 11:00	break	
11:00	Clustering processes during ageing of reactor pressure vessel steels – an atom probe tomography study	Kristina Lindgren, Chalmers
11:30	Review of constraint effect (size effect)	Sebastian Lindqvist, VTT
12:00-13:00	LUNCH	
13:00	Life time assessment of OLI/OI2 RPV's	Antti Kallio, TVO
13:30	Microstructural investigations, possibilities and objectives	Ulla Ehrnström, VTT
14:00	break	
14:30	Surveillance testing procedures	Petteri Lappalainen VTT
15:00	Multi-scale modelling of microstructural evolution in Ringhals RPV welds	Par Olsson, KTH
15:30	Discussion	
16:00	Adjourn	

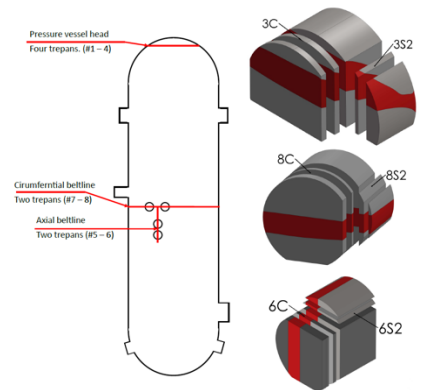
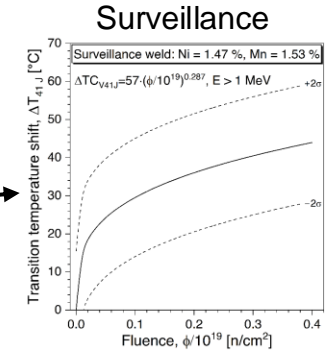
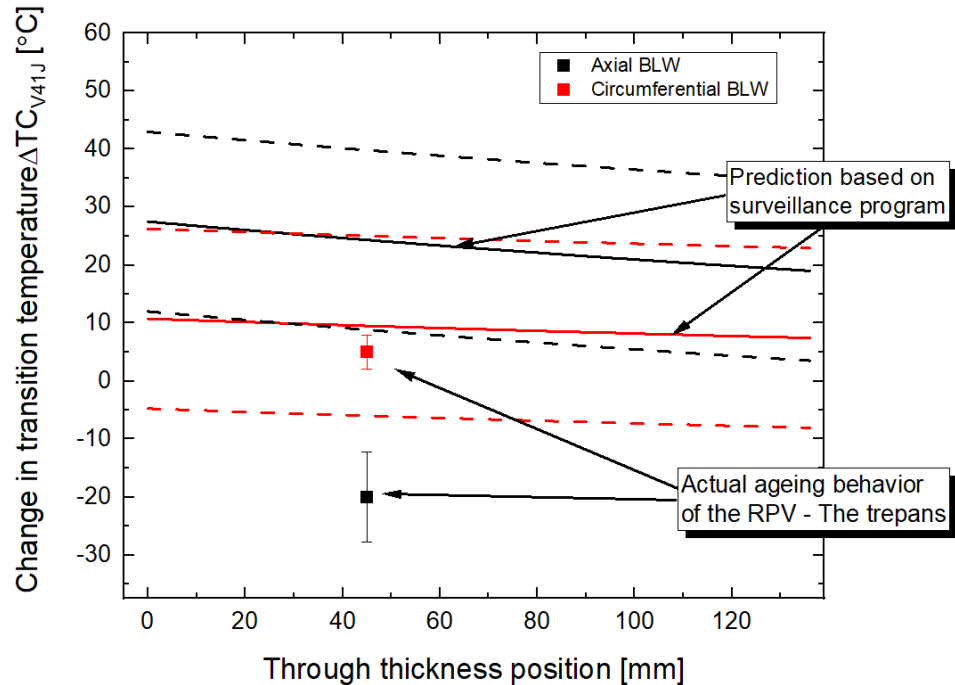
BREDA–BRUTE–BRIGHT

- A unique possibility was created through the decommissioning of the Barsebäck 2 NPP → Use of harvesting to enable knowledge building
- BREDA (2016-2022) launched in Sweden
- SAFIR2022 BRUTE (2018-2022) and SAFER2028 BRIGHT (2023-2025) on performing the mechanical testing and microstructural characterisation at VTT, Finland
- Objectives the three knowledge gaps mentions earlier
 - Comparison between results from the plant and from the surveillance program
 - Effect of thermal aging on low alloy steels at BWR operating temperatures
 - High-dose surveillance material evaluations
- + The use of miniature mechanical test samples to allow for update of the surveillance programs for LTO

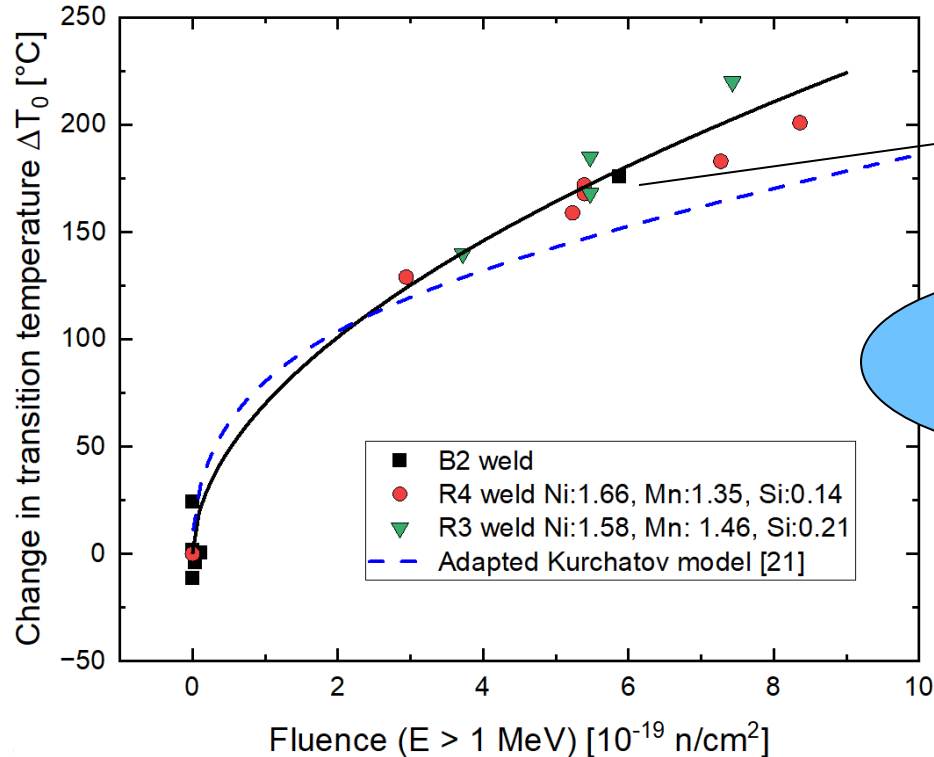
Extraction of trepans from B2



The surveillance program describes the ageing of the RPV operated for 28 years



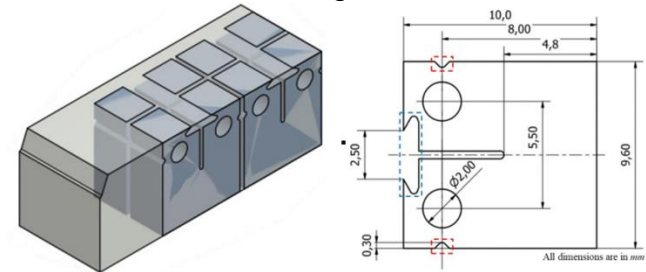
In the high-fluence region, the Barsebäck 2 weld embrittlement is similar to Ringhals 3 and 4



The fluence is equivalent to approximately 300 years of BWR operation and 60-80 years of PWR operation

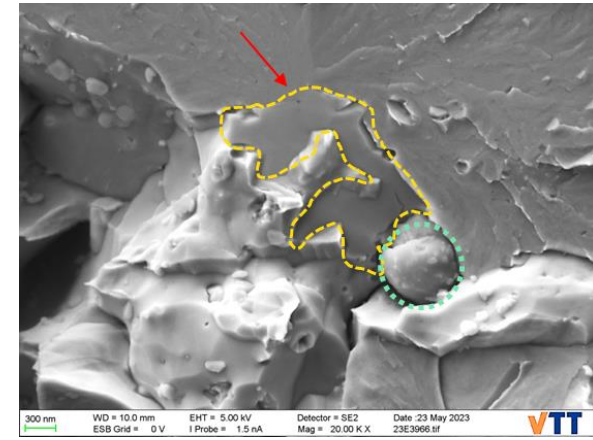
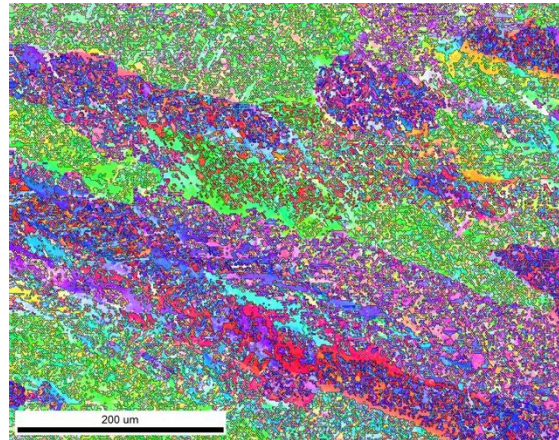
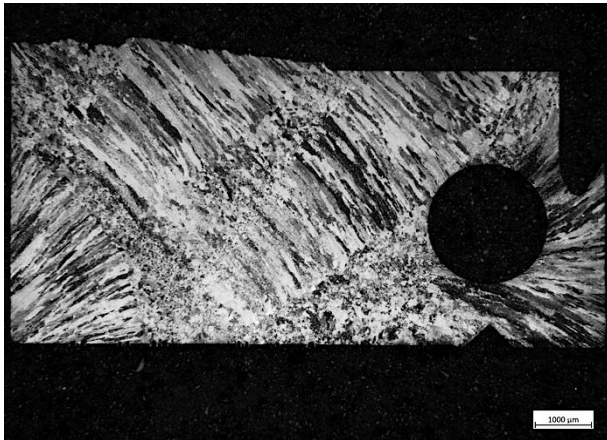
Surveillance weld located in a high flux position in the core region

Based on fracture toughness measurements



Finding weakest links in the material – Understanding ageing

- Increasing the mechanistic understanding of brittle fracture initiation and microstructure after thermal ageing and neutron irradiation
 - Fracture surface analysis
 - Microstructural evolution through thermal ageing and irradiation
 - Identifying microstructural features that initiate a brittle fracture
 - Differentiating welding metallurgical effects from operation ageing effects



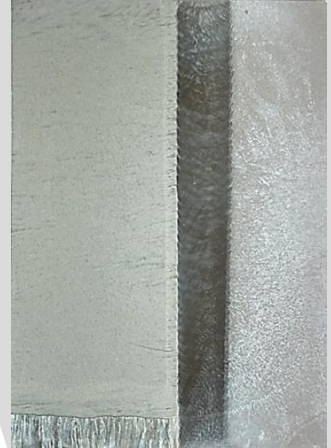
Barsebäck RPV investigations activities

Activities	Number of items
Impact toughness test	88
Fracture toughness test	120
Fractography samples	132
Research reports	40
Scientific publications	11
Seminars and technical meetings	13
Conference presentations	10
Doctoral theses	6

Nordic Collaboration on Dissimilar Metal Welds (DMWs)

- FEMMA (2020-2022) and FEMMA+ (2023-2027) projects coordinated by VTT
- Involvement of Finnish and Swedish utilities and authorities
 - TVO, STUK
 - Ringhals, OKG, Chalmers, SSM
- Main challenge in DMWs is the mismatch between two dissimilar metals; crystallographic mismatch, welding induced residual stresses, and susceptibility to stress corrosion cracking

Narrow-gap weld



Double-buttering repair weld



Collaborative Innovations and Knowledge Build-up for Life After 60

Potential to further enhance RPV life-time evaluations

- Solutions for diminishing volume of representative materials
- Focus on fine-tuning the evaluation procedures accounting for transferability, to have a more precise estimate on operation margin and remaining life-time
- Improved mechanistic understanding of material behaviour at high doses
- Competence build-up and knowledge management together on all levels: Research institutions, Authorities, and Utilities



Thank you! Kiitos! Tack!

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