Studsvik

NEA
Nuclear Energy Agency

SMILE PROJECT
Studsvik Material Integrity Life Extension project

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OUTLINE

- SMILE Project in General
  - Project organization
  - The need – approach to meet the need
  - Project structure

- Technical Overview
  - Highlights
  - Data on decommisioned Swedish reactors
  - Materials
  - Examinations and testing

SMILE PROJECT ORGANIZATION

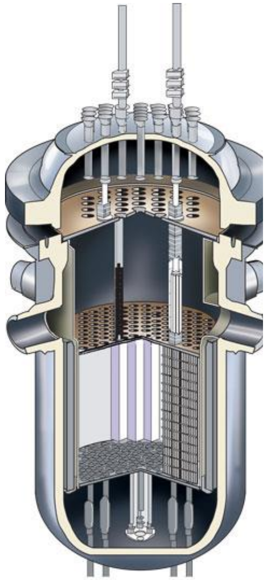
- SMILE, a cooperative Studsvik/OECD/NEA project that will connect experts from all over the world, creating a forum for knowledge transfer between organizations and age generations
- Five year project with a budget of ~17 MEuro
- Studsvik - Operating agent
- Started in January 2021
- Organizations from 8 countries

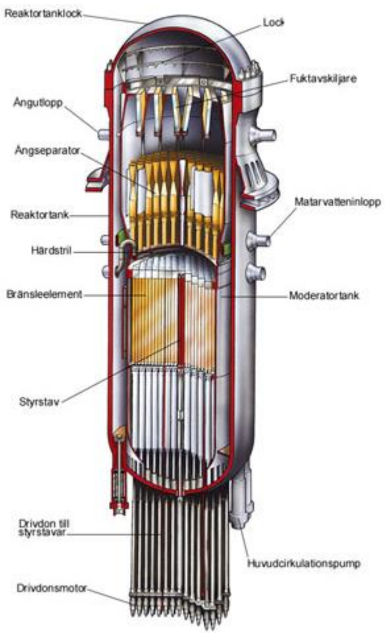
THE NEED

- Light Water Reactors are in general designed for 40 years

- Many LWR operators aim for life extension
  - 60 years
  - 80 years
  - ?? years

- In support of life extension programs, all BWR and PWR reactor operators need
  - Data on aging effects
  - Understanding of aging phenomena
  - Models predicting aging effects
  - Arguments





- Authorities/regulators need data and understanding to evaluate license renewal applications

APPROACH TO MEET THE NEED

- SMILE is a project that supports LWR operators and authorities worldwide in plant ageing management
- The main objective is to provide critical data and mechanistic understanding of materials ageing mechanisms in support of plant ageing management, life extension programmes and operating licence renewals
- The experimental approach leverages a unique opportunity to harvest components and materials from Swedish LWRs that have recently shut down.

OVERVIEW OF THE SMILE PROJECT

Management Board

Project Manager

Customer Relations

Internal Expert Group

Project Assistant

Task 1
Materials Library

Task 2
RPV LAS Irradiation and Thermal Embrittlement

Task 3
SS Core Support Structures and Internals

Task 4
Austenitic pressure boundary alloys

SMILE MEMBERS PRIORITIZATION

Task 1
Materials Library

- **Subtask 1.1** Acquisition of materials
- **Subtask 1.2** Documentation of all harvested materials
- **Subtask 1.3** Calculations

Task 2
RPV LAS irradiation & thermal embrittlement

- **Subtask 2.1** Irradiation embrittlement
- **Subtask 2.2** Thermal ageing embrittlement
- **Subtask 2.3** Stability in service of casting and forging anomalies
- **Subtask 2.4** SCC tests in simulated reactor coolants

Task 3
SS core support structures and internals

- **Subtask 3.1** Irradiation embrittlement including SS welds
- **Subtask 3.2** IASCC and corrosion fatigue susceptibility
- **Subtask 3.3** CASS and weld thermal ageing with irradiation effects

Task 4
Austenitic pressure boundary alloys

- **Subtask 4.1** DMW and SS welds; SCC resistance in BWRs and PWRs
- **Subtask 4.2** Alloy 690/152/52 PWSCC resistance and thermal stability in PWRs
- **Subtask 4.3** Fatigue in BWR and PWR reactor coolants

High priority

Medium priority

Low priority

Limited interest

SMILE TASKS AND SUBTASKS

Task 1
Materials Library

- **Subtask 1.1**
  Acquisition of materials
- **Subtask 1.2**
  Documentation of all harvested materials
- **Subtask 1.3**
  Calculations

Task 2
RPV LAS irradiation & thermal embrittlement

- **Subtask 2.1**
  Irradiation embrittlement

Task 3
SS core support structures and internals

- **Subtask 3.1**
  Irradiation embrittlement including SS welds
- **Subtask 3.2**
  IASCC and corrosion fatigue susceptibility

Task 4
Austenitic pressure boundary alloys

- **Subtask 4.1**
  DMW and SS welds; SCC resistance in BWRs and PWRs
- **Subtask 4.2**
  Alloy 690/152/52 PWSCC resistance and thermal stability in PWRs

FUEL AND MATERIALS TECHNOLOGY

Transports

Microscopy & Analysis

Active metals laboratory

Pool facilities

Hot cell laboratory

Corrosion lab

SMILE – TECHNICAL HIGHLIGHTS

- SMILE addresses aging mechanisms of structural materials used in the primary coolant systems of LWRs
  - Focus on high-priority knowledge gaps identified in e.g., the EPRI (Electric Power Research Institute) materials damage matrix (MDM) studies
  - Based on methodologies for materials aging management, such as the EPRI Issue Management Tables (IMTs), and the IAEA International Generic Ageing Lessons Learned (IGALL)
- SMILE leverages a unique opportunity to examine and test materials harvested from Swedish reactors decommissioned after 40+ years of operation
- SMILE includes examination and testing of e.g.:
  - Highly irradiated wrought stainless steel and weld metal after 40+ years in service
  - Alloy 690 and Alloy 52 weld metal from the world's second oldest replacement steam generator(1989) and oldest RPV head (1995)
  - RPV steel from very low dose, to very high dose, including archive material, as well as BMI nozzles

DATA ON DECOMMISSIONED SWEDISH REACTORS

	Oskarshamn 1	Oskarshamn 2	Ringhals 2
Vendor	ASEA-ATOM	ASEA-ATOM	Westinghouse
Reactor type	BWR	BWR	PWR – 3 loop
Operation	1972-2017	1974-2013	1975-2019
EFPY	~28.2	~31.7	~29.7
Output, MWe	440 to 473	570 to 638	800 to 875
In-/outlet temp	270/286 °C	270/286 °C	289/323 °C

TASK 2 - REACTOR PRESSURE VESSEL STEELS

Access to harvested irradiated RPV steels from Oskarshamn 2 and Ringhals 2 enables investigation of the reliability of currently used irradiation embrittlement models for RPV LAS to be evaluated without restraint on suitable irradiated materials

Subtask 2.1 – Irradiation Embrittlement

- Study mechanical properties, particularly fracture toughness, of harvested BWR and PWR RPV steels (Beltline and Nozzle Shell Course)
- Study the metallurgical reasons for irradiation embrittlement in order to contribute to the development/validation of predictive models

EXTRACTED REACTOR PRESSURE VESSEL STEELS

- RPV forgings and weld are planned to be harvested to cover the largest range in dose possible
  - Maximize the range in dose from the same shell course
  - In addition, archive material is available
  - Comparison to surveillance program testing results

Component section	PWR fluence x10^{19} n/cm^2	BWR fluence x10^{19} n/cm^2
Max. dose	~4-0.4	0.3-0.1
Medium dose	~0.7-0.07	-
Min. dose	~0,1-0.001	0.05-0.01
Inlet/outlet nozzles	<0.0001	<0.0001
BMI	<0.0001	-

- R2 Inlet nozzle - lowest temperature and highest flux

TASK 3 -SS CORE SUPPORT STRUCTURES AND INTERNALS

RPV internals are intended to remain in place for the entire design life of the plant

- Doses up to 80 to 100 dpa can be reached in PWRs, and in BWR the maximum doses are ~10X lower
- Neutron irradiation results in increased susceptibility to IASCC and reduction in fracture toughness
- Void swelling can be a problem for locations at high dose and elevated temperature caused by γ heating
- Testing of materials from the internals of O2 and R2 will among other address current gaps regarding neutron embrittlement of internals, susceptibility to IASCC and void swelling

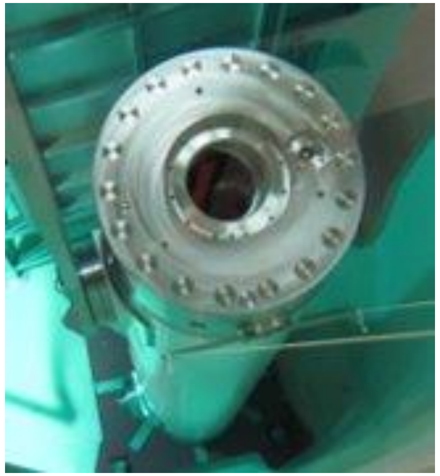
EXTRACTED MATERIALS

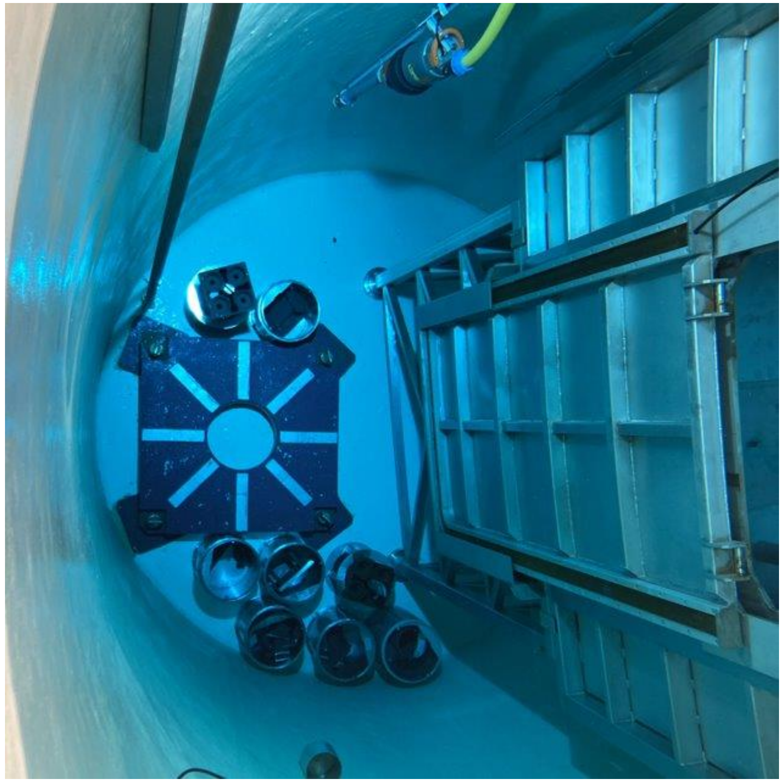
- Materials harvested in a range from the lowest to the highest dose possible

Reactor	Material and origin
Oskarshamn 2	Type 308 Core shroud weld, max. dose 1.5 dpa Type 308 Core shroud weld, min. dose 0.3 dpa
Oskarshamn 1	XM-19 core spray bracket
Ringhals 2	Type 304 Baffle plate and bolts max. dose, 70 dpa Core barrel plate and weld, max dose, 7 dpa

STATUS - EXTRACTED MATERIALS

- Material from Oskarshamn (BWR) has arrived to Studsvik
  - Three pieces from the core shroud (including welds), and pieces from the core spray
  - NDT (VI, ET, UT) has been performed on the materials from the core shroud
  - Coarse cutting performed, and pieces for specimen machining have been sent to the active mechanical lab





NCS-45
Type B
Ø = 220 mm
L ~ 4,5 m

29-tons
Type A
Ø = 450 mm
L ~ 4 m

TESTING MOTIVES

Materials extracted will enable testing/examination of the full range of doses

Baffle plate and bolts testing of

- Structural materials at higher dose than has previously been available
- In situ PWR irradiation
- Thick section materials to properly assess materials behavior
- Sufficient volume of material at full range of dose allows development of systematic testing approach

Core barrel and testing of irradiated welds testing

Weld metal and HAZ at higher dose than has previously been available

Weld metal and HAZ at doses where no or very little data exist

Testing of BWR material will add data for a different weld/HAZ in the lower range of dose

Thick section materials

Sufficient volume of material for systematic testing approach

TASK 4 – AUSTENITIC PRESSURE BOUNDARY ALLOYS WITHOUT SIGNIFICANT IRRADIATION EFFECTS

Task 4 concerns long term integrity and SCC resistance of Ni-base DMWs and MSIP treated welds in primary system components outside the zone where irradiation induced degradation is dominant

Nickel base alloys are used as steam generator-tubes and in critical locations, often when safety or operational impact is high

- Complex component geometries cause
  - Manufacturing flaws
  - Complex stress states
  - NDT limitations

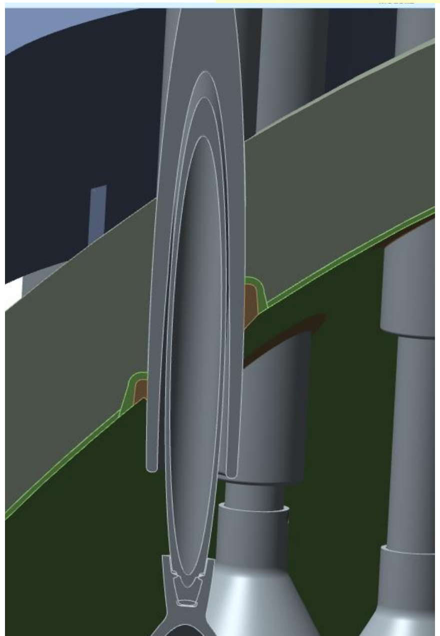
Reactor	Origin	Test environment
O2	Core shroud support	BWR
	Bottom nozzle	BWR
	Weld subjected to MSIP	BWR
R2	RPV BMI Nozzle	PWR
R2/R4	Pressurizer Heater Penetration, or RPV Head Penetration	PWR

- Where IGSCC mitigation techniques have been utilized, is the long-term effectiveness adequate?
- Testing addresses gaps in long term stability (LRO), stress relaxation and resistance to SCC of Nickel base and Stainless steels.

NEAR TERM TESTING OF COMPONENTS

- MSIP[1]-treated 304 SS-weld from Oskarshamn 2
  - Cracking detected 1986 and weld treated in 1988
  - Treated and untreated welds on each side of a pipe elbow are extracted
- SG tubes of Alloy 690 and CRDM penetrations with Alloy 690/52 will be harvested from Ringhals 2
  - SG tubes of various heats/lots from hot and cold legs
  - Central and peripheral CRDM penetrations, including surrounding pressure vessel steel

12 INCH WELDMENT IN SWEDISH NUCLEAR PLANT TREATED WITH MSIP TO ARREST PRE-EXISTING CRACK



1. Mechanical Stress Improvement Process

SMILE SUMMARY

- Studsvik/OECD/NEA five year project started in January 2021
- Supports LWR operators and authorities worldwide in plant ageing management
  - The main objective is to provide critical data and mechanistic understanding of materials ageing mechanisms in support of plant ageing management, life extension programmes and operating licence renewals
- Materials from three Swedish decommissioned reactors after 40+ years of operation will be harvested and examinated
- SMILE includes examination and testing of e.g.:
  - Highly irradiated wrought stainless steel and weld metal after 40+ years in service
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