Radiological laboratory commissioning of the VTT Centre for Nuclear Safety

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SAFIR2018 Interim Seminar
23-24.3.2017
VTT nuclear energy R&D competencies
Materials research and testing for safe operation

- VTT has been hosting the national hot laboratory infrastructure since it was first constructed and equipped in the 1970’s.
- Principle use has been for handling, testing and examining RPV materials for surveillance testing.
- Many critical plant life management issues for operating nuclear power plants are related to materials.
- Lifetime extension, power upgrading, and construction of new plants require investigating and solving problems related to components and structural integrity.

- Aging degradation of structures and components is an important aspect of power plant safety.
- Ageing management requires activities related to the utilization, inspection, surveillance, testing, examination, and degradation mitigation of materials.
VTT nuclear energy R&D competencies
Safety of radioactive waste disposal solutions

- Characterization of radioactive waste
- Operating waste and decommissioning
- Design of disposal concept (KBS-3)
- Operating waste and decommissioning
- Bedrock and groundwater characterization
- Long-term safety of materials, disposal facilities and safety case
- Engineering barrier system component manufacturing and quality control
- Operational safety of disposal facilities, incl. PRA
- New and alternative waste management technologies
- Licensing support
- Low and Intermediate waste storage.
VTT Rad Materials Service Ecosystem: R&D in support of safe nuclear power

- Basic Research & Numerical Simulation
- Single Effect Experiments
- Post-Irradiation Examinations
- Experimental Data Expertise
- Codes Validation
- Qualification Documents
- Design
- Hot Specimen Characterization & Refabrication
- Hot Laboratories for PIE
- Behaviour Under Irradiation
- Material Test Reactor
- Hot Laboratory
- EBW
- EDM
Renewal of radiological research infrastructure
The VTT Centre for Nuclear Safety
Renewal of radiological research infrastructure
The VTT Centre for Nuclear Safety

- 3,300 m² office wing includes a ground-level conference centre, and three floors of modern, flexible office space for 150 people.
- Office wing is intended to serve nuclear sector employees in:
  - computerized fluid dynamics
  - process modelling (APROS)
  - fusion plasma computations
  - severe accidents
  - core-computations
  - waste-management
  - safety assessments
  - staff working in the laboratory wing.
Renewal of radiological research infrastructure
The VTT Centre for Nuclear Safety

- 2,360 m² laboratory wing: a basement level and two floors of laboratory space.
- Basement mainly for storage and handling of radioactive materials and waste.
- Laboratory space arranged around a main high-bay, which houses the hot-cells proper:
  - mechanical and microstructural characterisation of materials
  - Radiochemistry & dosimetry
  - HR-ICP-MS
  - iodine filter testing
  - nuclear waste management
  - failure analysis
Renewal of radiological research infrastructure
Commissioning of the VTT Centre for Nuclear Safety

- Common decommissioning/commissioning kick-off meeting was held at STUK in February 2016.
- Included STUK departments involved in the commissioning of the CNS, as well as the decommissioning of the research reactor and the old laboratory facilities.
- Second meeting was held at VTT focused only on the CNS commissioning practicalities.
- A phased approach is being taken:
  - Application for B- and C- laboratories first, in 2016.
  - Expansion to A-laboratories with the hot cells after hot cell installation is completed in 2017.
Renewal of radiological research infrastructure
Commissioning of the VTT Centre for Nuclear Safety

- VTT took delivery of the laboratory wing of the new Center for Nuclear Safety in May of 2016.
- Moving of laboratory equipment into the new facilities is mostly complete.
- The existing devices from the old radiochemistry laboratory have mostly all been moved into the new facilities.
- Tests on non-active specimens have resumed as each device has come on-line in their new setting.

✓ Nuclear safeguards permit and facility operating license for B- and C-class facilities were granted by STUK.
✓ ES iodine handling permit was also granted by STUK, and first shots of radioactive iodine have been prepared in the new labs for field tests.
Renewal of radiological research infrastructure
Commissioning of the VTT Centre for Nuclear Safety

✓ New, top-of-the line FEI Talos transmission electron microscope has been successfully installed in the new laboratory.
✓ The first operator training on the microscope has been held.
✓ The new Zeiss Cross-beam scanning electron microscope was moved in, and gotten up and running in its new location in record time.

Unfortunately, during the Christmas holiday period, an accident happened leading to water damage in several rooms of the microscope island. Repairs are expected to last through March.
Renewal of radiological research infrastructure
Commissioning of the VTT Centre for Nuclear Safety

- Official inauguration event on September 20\textsuperscript{th}, 2016.
- VTT-Fortum stand at the 2016 World Nuclear Expo, with CNS offerings.
- A nuclear research display has been prepared for the CNS lobby, profiling Finnish nuclear competencies over the decades.
- New nuclear services marketing video featuring the CNS was unveiled at the inauguration event.
- New marketing materials developed to profile the nuclear offerings of CNS.
- VTT’s nuclear pages have been updated with new marketing materials.
Hot Cell laboratory
A-class hot cell facilities on main floor- HC1

Cell 1.1 EDM
Cell 1.2 EBW
Cell 1.3 Metallog.
Cell 1.4 Mech.test
Cell 1.5 Mech.test
Cell 1.6 Measuring
horizontal transfer
Facility cask port
Access to secondary airspace
A-class hot cell facilities relationship b/n floors

- External transport cask reception in the basement HC
- Specimen elevator between basement and main hall HCs
Active material handling

- All foreseen work is carried out within shielded HCs
- Transportation casks, docking stations, specimen elevator, horizontal rail, pass-through ports, facility casks, in-cell hoists, manipulators
Active material handling in HC

- Docking station, cask max 10 tn
  - Vertical port, dia. 400 mm
  - Horizontal port, dia 200. mm
- Stationary hoist, ca. 500 kg
- In-cell hoist, ca. 500 kg
- Specimen elevator, ca. 20 kg
- Manipulators
  - 2x A201, ca. 10kg
  - 2x A100, ca. 60 kg

- Docking station, facility cask
  - Vertical port, dia. 235 mm
  - Pass through port
  - Horizontal rail from elevator
  - In-cell hoist, ca. 100 kg
  - Manipulators
    - 4 x A201, ca. 10 kg
Basic HC design features

- **Space limiting liner**
  - Provides containment
    - Contamination space
    - Manipulator reach area
    - Enables under-pressure
    - Gloved maintenance ports

- **Biological shielding**
  - Provides $\gamma$-radiation protection
    - Design source term 3700 – 370 - 1,85GBq Co$^{60}$ (HC3-HC1-HC2)
    - Front wall lead thickness 250 – 200 - 100 mm (HC3-HC1-HC2)
    - Lead windows with equivalent thickness
    - Maintenance doors, rear

- **Steel frame**
  - Support structure for liner, shielding and cover plates
General HC design features

- **Ventilation**
  - Supply air from service area
  - HC air exchange rate 10 times / hour
  - Inlet/outlet filters HEPA H13
  - HC underpressure 200 Pa
  - Several PLC controlled operation modes
    - Normal, Service, Fire, Seal-off mode
- **Fire suppression system**
  - Temperature sensor gives warning
  - Manual alarm, operator controlled
  - Inert gas
- **Radiation monitoring**
  - ALMO system, 1 x probe/reading unit/HC
  - Measurement stations in suite
    - 2 x dose rate, 1 x spectra
- **Pneumatic sealing system**
  - Pass-through ports, docking stations, maintenance doors
- **Cameras**
  - Overall and detail cameras,
  - 4 x sockets and 1 x LCD display
- **Hoists**
  - In-cell hoists
  - Stationary hoists
- **Electricity**
  - Normal and UPS supply
  - 4-6 x sockets, switchable
  - UPS power
    - Inflable seals, rad. monitoring,
      2 x lights per HC, PLC transformer
- **Lighting**
  - Fluorescent 3 x tube, switchable
- **Alarms**
  - Temperature, fire (manual)
  - Pressure
Metallography, elevator, measuring HC1.3-1.7-1.6

- **Equipment HC1.3 and HC1.6**
  - *Diamond saw*
    - Struers Minitom
  - *Hot/cold moulding*
    - Struers CitoPress
    - Struers CitoVac
  - **Dimensions**
    - Video measuring system (tbd)
  - **Fracture surface**
    - Optical / digital microscope (tbd)
    - Crack extension
  - **Hardness**
    - DuraScan80
    - Test load 0.098 – 98.1 N
  - **Marking device (tbd)**

- **Equipment HC1.7**
  - *Elevator, capacity 20 kg*
  - *Dose rate measuring station*
  - *Horizontal rail*
Specimen preparation HC1.1 and HC1.2

- **Equipment**
  - Electron beam welder
    - CVE 2010, 4 kW
    - Chamber 300x300x300 mm
    - X-Y table, rotary axis
  - Marking device (tbd)

- **Equipment**
  - Electric discharge machine
    - Agie Charmilles CUT200 mS
    - Axial travel x-y-z, 350-220-220 mm
Mechanical testing HC1.4 and HC1.5

- **Equipment**
  - Small instrumented impact hammer
  - Static testing machine
  - Low and intermediate temperatures

- **Equipment**
  - Dynamic universal testing machine
  - Fatigue pre-cracking device
  - Ambient and high temperatures
Mechanical testing HC1.4

**Pendulum impact tester**
- Zwick HIT50

**Temperature range**
- Tempering unit -180 – 600°C
- Semiautom. feeding unit RoboTest I
- Liquid Nitrogen

**Instrumentation**
- Zwick TestXpert II software
- Instrumented pendelums
  - ISO179-2, ASTM E23, 50J

**Test types**
- Instrumented impact test
  - 5x5x27 mm, 3x4x27 mm

**Electro-mechanical univ. testing machine**
- Zwick Z250SW, max 250 kN
- XforceK 50, 100 kN load cell

**Temperature range**
- Environmental chamber -150 – 400°C
- Liquid Nitrogen

**Instrumentation**
- Zwick TestXpert II software
- Instrumented pendelums
- LaserXtens Compact HP,
- Extensometers, COD clips

**Test types**
- Tensile test
- Fracture toughness test
  - 10x10x55 mm SE(B), ½”C(T)
Mechanical testing HC1.5

Servohydraulic univ. testing machine
- MTS 370.10, max 100 kN
- 50, 100 kN load cell

- Temperature range
  - Ambient (option for HT furnace)

- Instrumentation
  - MTS Test software
  - Extensometers, COD clips,

- Test types
  - Tensile test
  - Fracture toughness test
    - 10x10x55 mm SE(B), ½”C(T)
  - Low cycle fatigue test
  - Fatigue precracking

Fatigue precracking device
- SCK-CEN hot-cell ready
- 10pc magazine, automatic

- Temperature range
  - Ambient

- Test types
  - Fatigue precracking
    - 10x10x55 mm SE(B)
    - ½”C(T)
Material reception HC3.1

- **Docking ports**
  - Transportation casks, max 10 tn
    - Vertical port, dia. 400 mm
    - Horizontal port, dia 200 mm
- **In-cell hoist**, max. 500 kg
- **Stationary hoist**, max. 500 kg
- **Elevator**, max 20 kg
- **Vacuum cleaner**

- **Equipment**
  - **Machining**
    - Milling machine (tbd)
    - Saw (tbd)
    - Marking device (tbd)
  - **Radiation measurement station**
    - Dose rate (tbd)
    - Spectra (tbd)

- **Cask handling equipment**
  - **Electric low-lift truck**
    - Genkinger ESU 100-So, load 10 tn
  - **Main hall grane, load 10 tn**
    - Operated through floor hatch
CNS commissioning process

- In August the Factory Acceptance Test of the first of five hot cell modules took place at the Isotope Technologies Dresden manufacturing site in Germany.
- Final FAT took place in March, so all units are manufactured.
- The first 10 truckloads of components arrived to VTT in November ’16, including 160 tonnes of lead shielding bricks.
- Site installation of the hot cell modules is now underway.
HC installation work initiated 2\textsuperscript{nd} Jan 2017
HC installation work initiated 2\textsuperscript{nd} Jan 2017

02/05/2017
Analytical microscopy
Hot specimen preparation for microscopy

- Several options for specimen preparation in the CNS, $f(\gamma)$
  - Heavily shielded- HC1, 370 GBq Co$^{60}$
  - Shielded glovebox- HC2, 1,85 GBq Co$^{60}$
  - Devices in plexiglass containments
Metallographic sample preparation HC2.1
OM, SEM, TEM

- **Equipment**
  - Optical microscope
  - Digital stereo microscope
    - *Leica DMS300*
  - Grinding / polishing
    - *Struers Tegrapol-15*
    - *Struers TegraForce-1*
    - *Struers TegraDoser5*
    - *Buehler VibroMet-2*
  - Electropolishing / thinning
    - *Struers LectroPol-5*
    - *Struers TenuPol-5*
    - *Lauda Proline RP855*
  - Accessories
    - *ultrasonic bath, magnetic stirrer, hot plate, air dryer, vacuum chamber, punch, etc.*
Analytical Scanning Electron Microscope
Zeiss Crossbeam 540 with EDAX Triade system

- Fracture surface topography
- Microstructure characterisation
- Element distribution mapping
- Compositional analysis of corrosion products
Analytical Scanning/Transmission Electron Microscope
FEI TALOS F200X FEG w/ Gatan Enfinium SE/976 EELS

- Manifestation of neutron irradiation effects
- High resolution microstructural imaging
- Crystallographic information
- Nano-scale elemental distribution mapping
Analytical Scanning/Transmission Electron Microscope
FEI TALOS F200X FEG w/ Gatan Enfinium SE/976 EELS
CNS "hot" autoclave laboratory
CNS hot autoclave research possibilities

- Testing enables proactive and preventive application of countermeasures against the potential ageing degradation by (IA)SCC
- Stress corrosion (and general corrosion/oxide film studies)
- \( t \leq 360^\circ C \), \( p \leq 220 \) bar, BWR or PWR water, modified chemistries, steam (variables: \( t, O_2, H_2, B, Li, K \))
- Specimen loading in SCC tests: electromechanical loading (i.e., stepper motor), load and/or displacement control, self loading
- Test result: crack initiation susceptibility or crack growth rate
- \( f \) (loading, material, chemistry)
- Test duration: 1h to several months (max. 5000 h/\~7 months)
CNS "hot" autoclave lab facilities

1. Lid lift control
2. Venting
3. Temperature sensor
4. Drain
5. Lid lift mechanism
6. Displacement indicator
7. Stepper motor + gears
8. Autoclave
9. Load cell
Research example - SCC susceptibility of a BWR core shroud 304 SS

- Material irradiated for ~80 000 h
  Fluence $1.5 \times 10^{20}$ n/cm$^2$, $E > 1$ MeV
- Weld-HAZ-base metal surveillance specimens

![Diagram of crack growth rate vs. dJ/dt]

Supposed da/dt-loading rate dependency in IGSCC susceptible material

IG 40%  IG 2%  IG 1%

TGSCC in both cases

Supposed da/dt-loading rate dependency in IGSCC resistant material

Irradiated and non-irradiated AISI 304 steel
3 mm x 4 mm x 27 mm
SEN(B) specimens

Simulated BWR water
T 288°C
κ 0.3 μS/cm (outlet)

- Irradiated HAZ
- Base metal and non-irr. HAZ
Research example – crack initiation time of a PWR core baffle 304 SS

- End-of-life fluence 15-30 dpa (depending on the location)
- Design curve established
Radiological laboratory commissioning of the VTT Centre for Nuclear Safety

- 2017 is the climax year of a radiological research infrastructure renewal process begun a decade ago.
- The installation of modern new hot cells will be completed later this year, enabling safe, flexible, testing and characterization of radioactive materials for evaluating structural integrity.
- Top-notch analytical electron microscopes can help identify the manifestation of aging and neutron irradiation effects on power plant materials for their proactive management.
- Hot autoclave facilities enable assessing material performance under simulated primary circuit conditions and its variations.
- Together these research tools offer a comprehensive means for supporting safe operation through confident understanding.
TECHNOLOGY FOR BUSINESS