

SHM

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What do I mean by SHM?

- System Health Monitoring
- Structural Health Monitoring
- Structural Health Management
- Inspection, condition based maintenance
- Non Destructive Testing / Non Destructive Evaluation

A lot of common methodologies, physics overlaps and differences

→ What is our objective?

→ Which type of objects are considered?



Structural Health Monitoring

- “Structure” = element through which efforts are transmitted



Airbus



Viaduc Millau

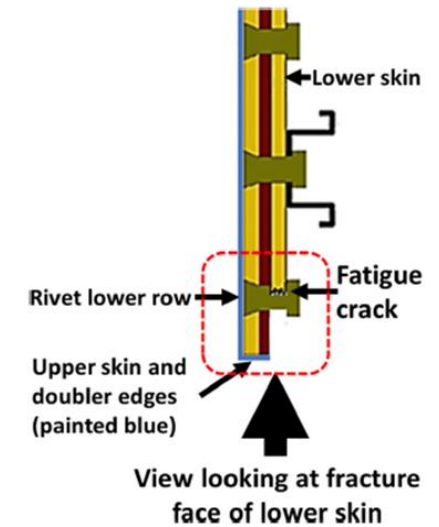


Fig. 4 Viewing the lower fracture face (line of sight)

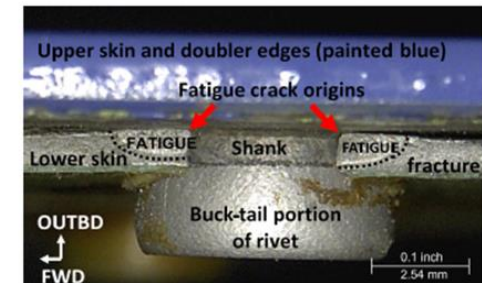


Fig. 5 Lower skin fracture face showing fatigue cracks (outlined by dashed lines) that emanated from the rivet hole

Zakar, F. Multiple-site Fatigue Cracking of Fuselage Structure Due to Improper Rivet Installation. *J Fail. Anal. and Preven.* 24, 24–31 (2024).
<https://doi.org/10.1007/s11668-023-01801-w>

Structural Health Monitoring

Structural Health Monitoring: “The process of acquiring and analyzing data from on-board sensors to evaluate the health of a **structure”**

From: “Guidelines for Implementation of Structural Health Monitoring on Fixed Wing Aircraft”, standard n°ARP6461, published by SAE International, 2013



→ **First document of the SHM community to standardize terminology and methodologies (for aerospace)**

Document elaborated by the working group *Aircraft Industry Steering Committee on SHM* (AISC-SHM) which brings together:

- aircraft manufacturers – such as Airbus, Boeing, Embraer
- companies – such as Delta Airlines
- technology providers – such as Accellent Technologies, Metis Design
- maintenance service providers – such as Testia
- authorities – such as FAA, EASA
- and research centers / university – such as Stanford University



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Objective and motivations

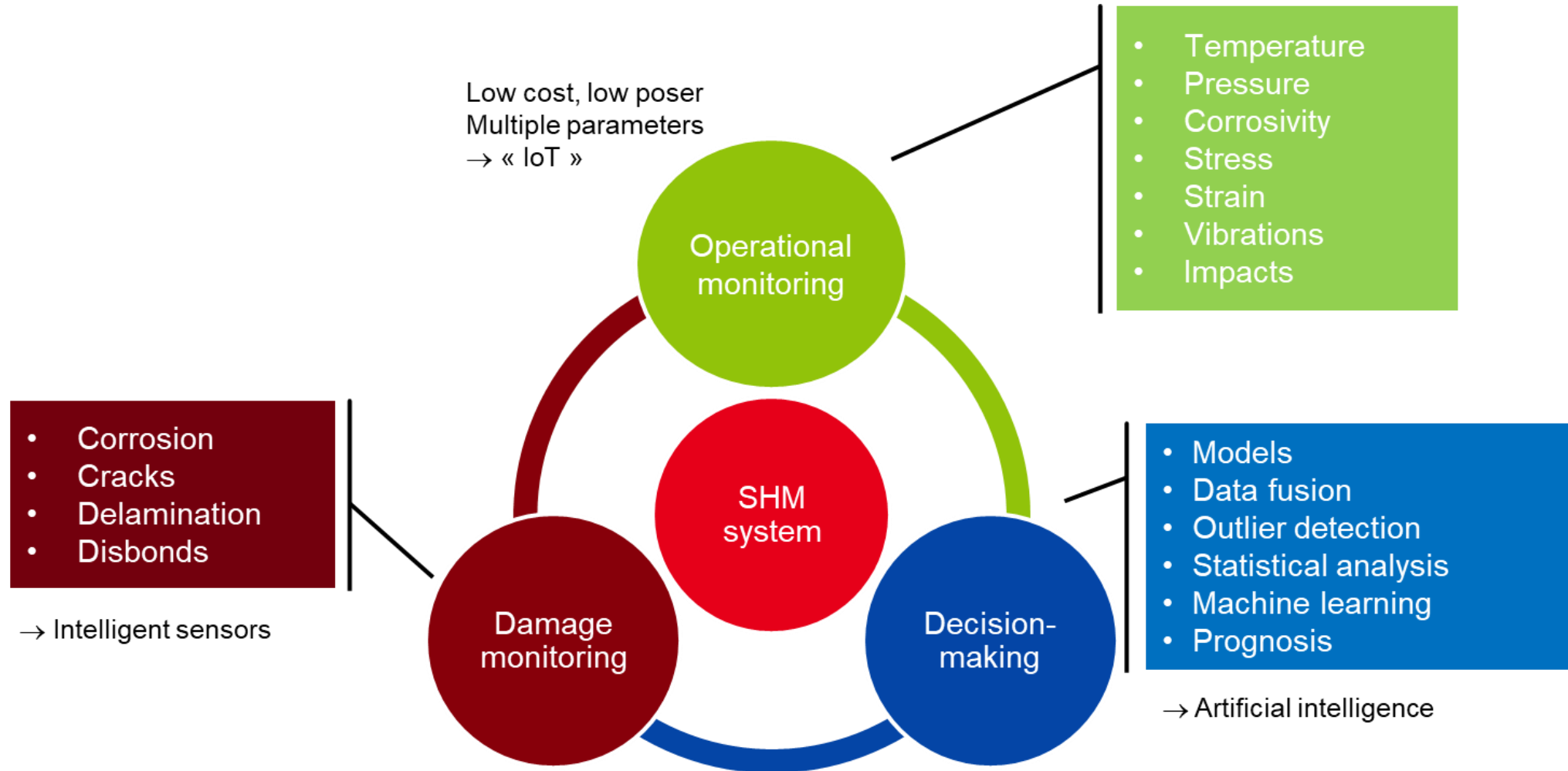
The SHM system must certify the health of the structure until next maintenance operation

Motivations:

- Safety
 - Thanks to continuous and automated inspections (less human factor)
 - Better design by reduction of design security coefficients (long term)
- Simplified or anticipated maintenance
 - Increase inspection intervals
 - Condition based monitoring to avoid unanticipated downtimes
 - Monitoring of inaccessible areas
- Structural life extension
 - Remaining Useful Life estimation



Types of SHM



Example: monitoring of corrosion

- Monitoring of atmosphere corrosivity (Operational Monitoring)
 - Temperature
 - Salinity
 - ...

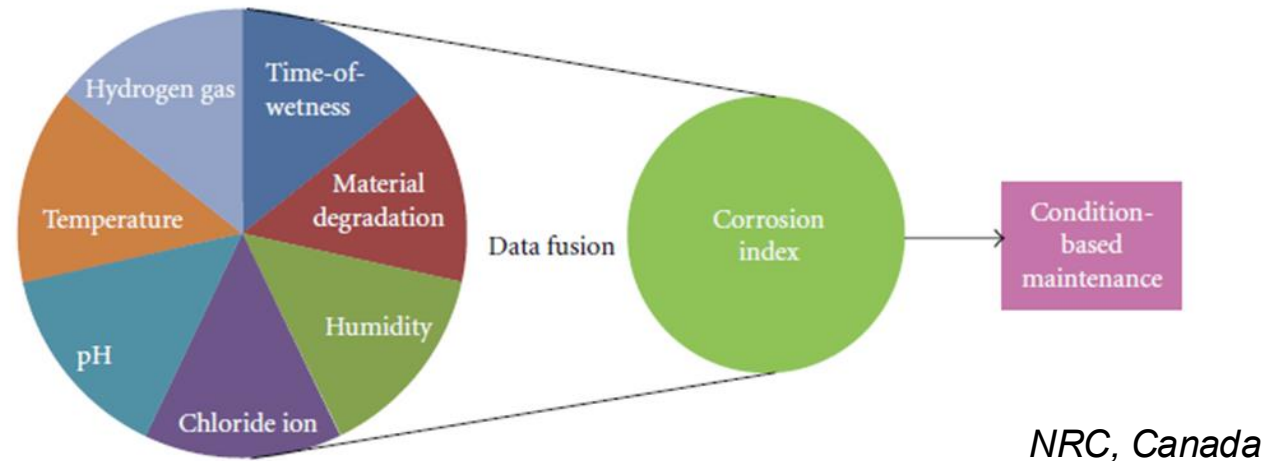
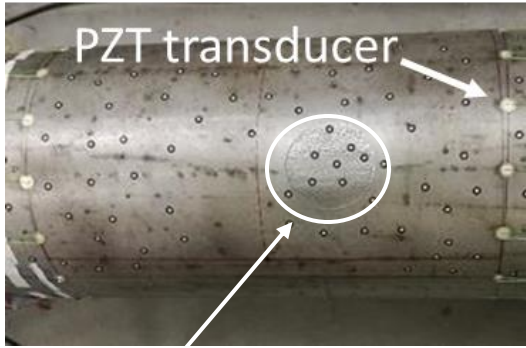


FIGURE 2: An overview of the proposed sensor nodes.

Measurement of 7 parameters to define a **corrosion index**
from which the **likelihood** of corrosion is established

→ **Indirect** monitoring of corrosion

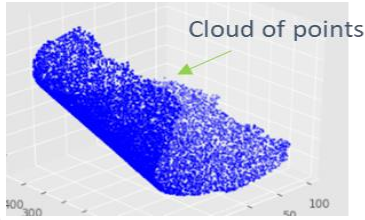
Example: monitoring of corrosion



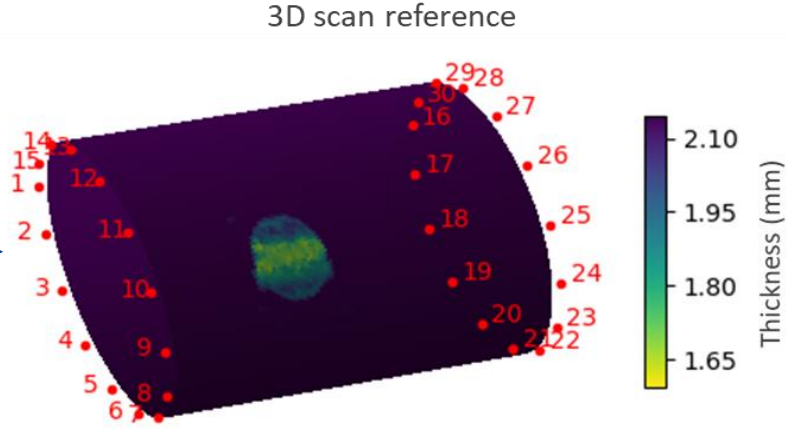
Corrosion by electrolysis



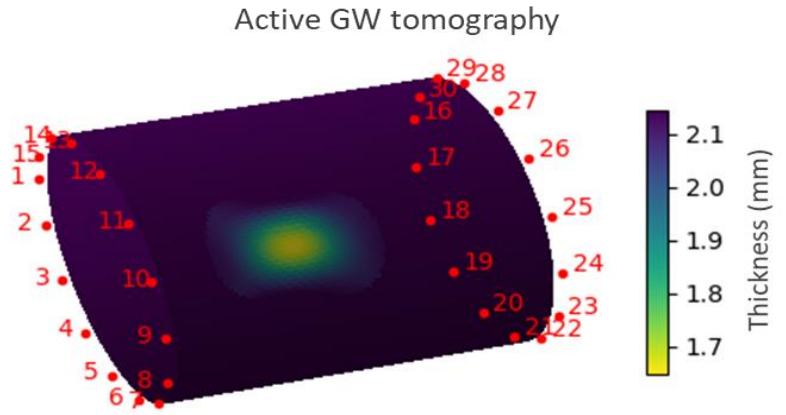
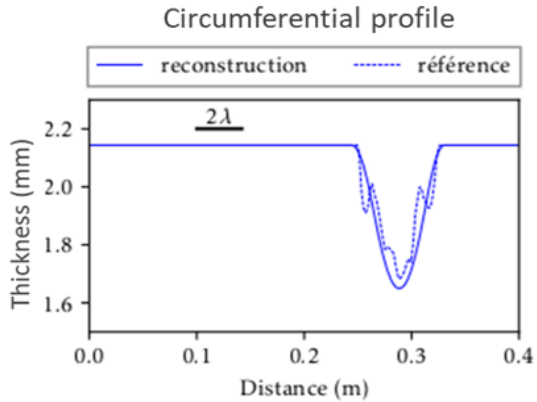
3D scanner



reference



Guided wave tomography using permanently installed PZT transducers



Druet, Thomas, Recoquillay and Chapuis, Passive Guided Wave Tomography for Erosion Monitoring in an Air/Sand Test Loop, e-Journal of Nondestructive Testing, COFREND Marseille 2023



More on SHM...



Toulouse: world capital of aeronautics

Globally renowned for its aeronautics and space industries, its universities and state-of-the-art research laboratories in the fields of health, biotechnologies, nanotechnologies, robotics...

- Airbus: the world's leading manufacturer, more than 750 planes per year and 27,000 jobs
- Space ecosystem: 12,000 jobs (25% of European jobs)
- but also a gentle way of life and undeniable architectural and cultural qualities

Highlights of EWSHM 2026



STUDENTS CHALLENGE

A specific event for students



SITES VISITS

Discover exceptional facilities for SHM on July 10th



GALA DINNER

Welcome to Aeroscopia, aeronautical museum on July 9th



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FIND

Future Instrumentation and coNtrol based on innovative methods and Disruptive technologies for higher safety level

17/04/2025 - FIND - SNETP webinar



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01 | Project introduction

Increasing safety thanks to online monitoring system

- ❑ **Early detection / anticipation of damages**
 - Long-term operation requires improved ageing monitoring programs
 - Reinforce the 1st level of defence-in-depth
- ❑ **Instrumentation supporting incident and accident management**
 - Not the focus of today
- ❑ **High acceptability**
 - Deployment with limited impact on existing systems & cost
 - Reduction in dosimetry
 - Improves industrial performance
- ❑ **Screening many technologies and giving momentum to SHM in the nuclear industry**



Consortium organisation

- ❑ NRT 01-01: Safety of existing reactors (long term operation) + crosscutting with new builds
- ❑ 5.8 M€ including 5 M€ Euratom subsidy
 - Significant experimental budget: 900 k€ for equipment and facilities
- ❑ Partners:
 - ASNR (coordinator), CEA, Framatome, SSTC NRS, VTT, IPP, EDF, KTU, Vuez, Tractebel, LGI (management)
 - Possibility to join the end-user group of the project or to participate without funding
- ❑ Contact:
 - Bastien Poubeau (bastien.poubeau@asnr.fr)



WP1: Coordination

WP2: Specifications

- Early detection / anticipation of damages in normal operation
- Improved management of incidents/accidents
- Roadmap for future developments

WP3: Innovative technology development

- Defect detection with SHM
- Advanced simulation with real plant data: the Digital Twin
- Accidental instrumentation

WP4: Testing in experimental and industrial conditions

- Performance assessment in controlled conditions
- Robustness tests (irradiation, humidity, temperature, vibration)
- Tests in industrial conditions

WP5: Evaluating the acceptability of technologies

- Human, social and organisational impacts of the new technologies
- Qualification of the technology
- Recommendations for the adoption of the technology

WP6: Communication, dissemination, preparation of exploitation

02 | Project construction

Selection of use-cases

❑ Selection criteria during the project preparation

- Added value for safety
- Generalisation to other systems
- Feasibility

❑ Focus on metallic pipes

❑ Systems considered

- Progressive difficulty: tertiary, secondary and primary circuits
- Partially buried raw service water pipes: crevice corrosion, leakage, soil movement
- Fatigue on the pressurizer surge line
- Stress corrosion cracking (SCC) on the safety injection line
- Flow-accelerated corrosion (FAC) on the high-pressure turbine extraction line

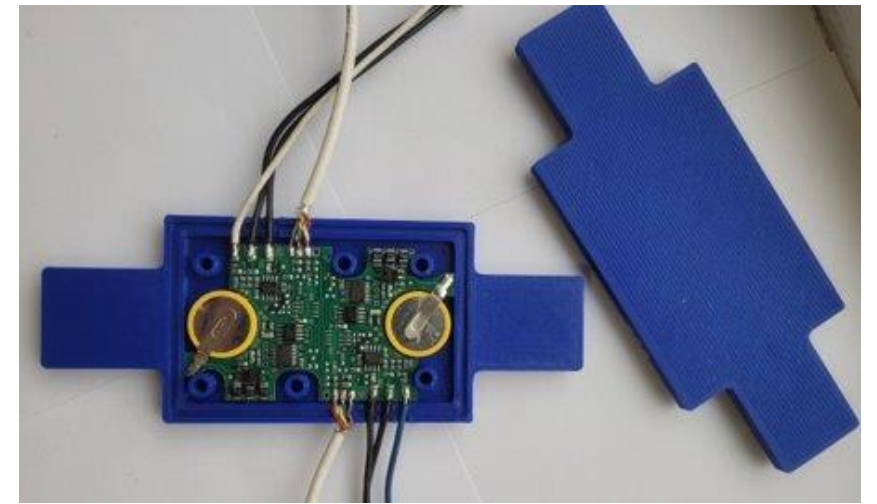
❑ Accident monitoring systems: not detailed here.



Raw feedwater line of Gravelines plant with leak due to crevice corrosion

Interdisciplinary team

- ❑ **Many technology providers were contacted**
 - Academics, nuclear and conventional industry...
 - Many technologies are available or under development in other sectors
- ❑ **Operational constraints are key:**
 - Performing controls during plant operation instead of doing it during outages.
 - The operating environment must be characterised: irradiation, accessibility...
- ❑ **Complex signal treatment**
 - Continuous data acquisition and analysis: large datasets.
 - Compatibility with operational constraints: embedded, low-power systems...
- ❑ **Degradation phenomena must be known**
 - Each technology is looking for a specific type of defect.
- ❑ **Adapted experimental test facilities are rare:**
 - E.g., equipping thermal-hydraulic loops with pipes including artificial defects.



Data treatment module
for the intelligent pipe
system

Technology screening

❑ Optical methods

- 2D laser scanning, infrared thermography...
- Impossible for buried and thermally-insulated pipes

❑ Robotic controls

- Various probes mounted on flying, swimming or crawling robots
- Problems: Thermal insulation, heat and compartmentation...
- Too long distances for swimming robots

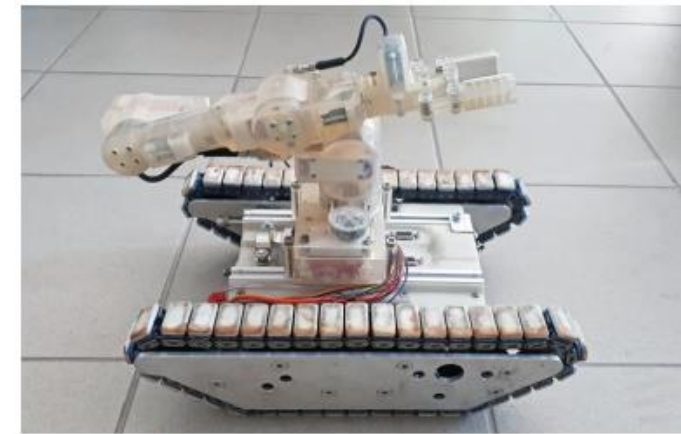
❑ Ultrasonic methods

- Low-intrusive delocalised measurement
- Heat- and rad-hard technologies under development

❑ Digital twins

- No direct defect detection
- Combination of sensors and models to reconstruct the stress field in a specific component.

Retained for the project

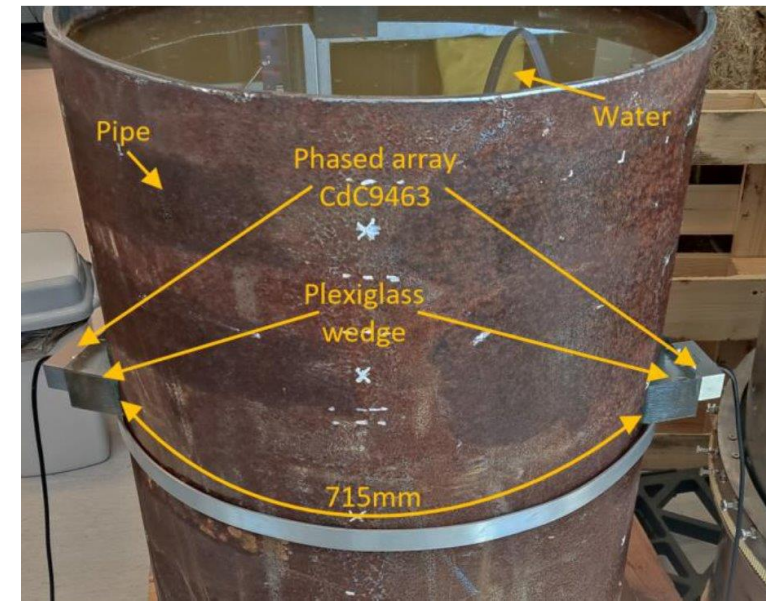


CVR multi-purpose crawler with magnetic caterpillars

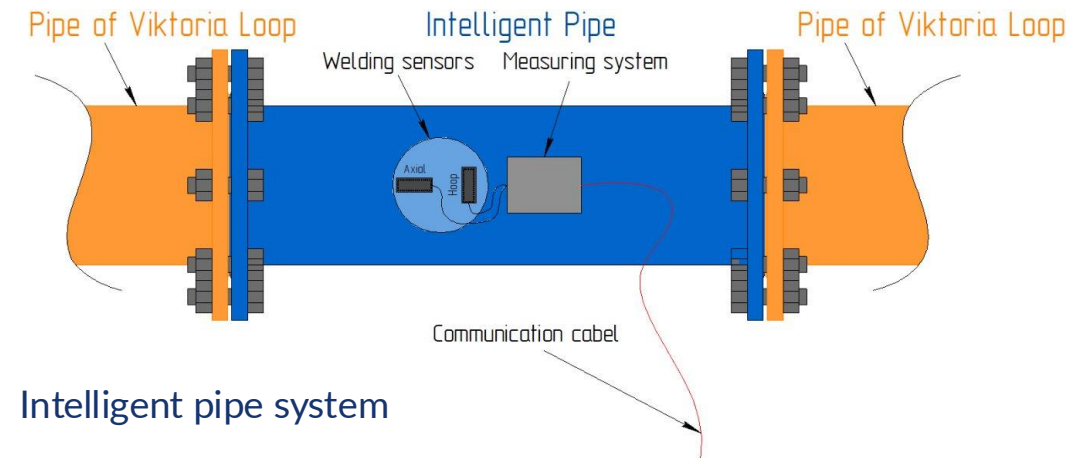
03 | Project workplan

Essential service water pipes

- ❑ **Active guided-wave for crevice corrosion (KTU)**
 - Transportable phased-array piezoelectric (PZT) transducers
 - Monitoring concealed pipe sections: wall penetrations, under support structures...
- ❑ **Acoustic monitoring of leakages (SSTC-NRS)**
 - Technology derived from urban water systems
 - Localisation of underground leakages with acoustic noise correlation
- ❑ **Intelligent pipe system (IPP Center LLC)**
 - Strain measurement feeding a mechanical model.
 - Identifying stress concentration zones.



Experimental test with phased-array probe



Intelligent pipe system

Primary and secondary circuits

□ Passive guided-waves for FAC on the secondary circuit (CEA)

- Robust Fibre Bragg Grating (FBG) sensors on optical fibres
- Exploitation of the elastic noise of the structure
- 2D reconstruction of the wall-thickness map

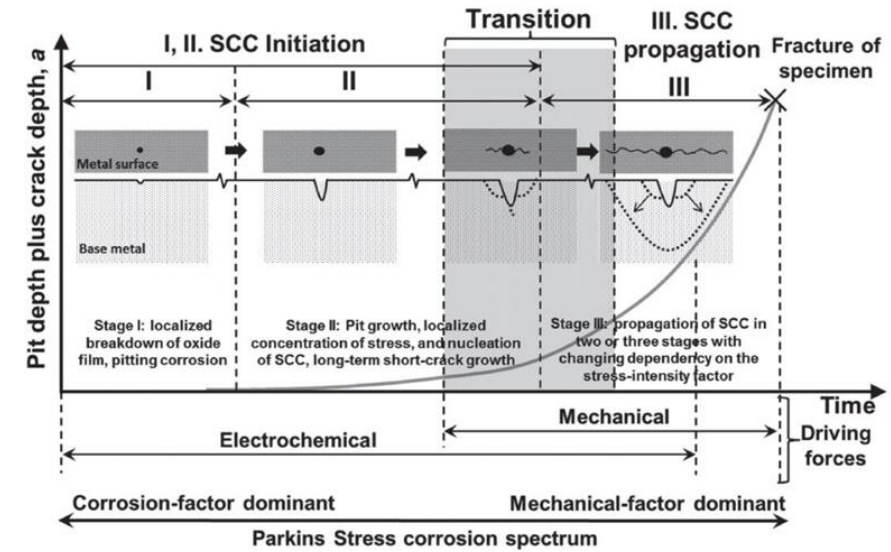
□ Acoustic emission to monitor stress corrosion cracking

- Detect crack growth events from the background noise
- Monitor the acceleration of crack propagation
- Comparison of PZT sensors and FBG sensors

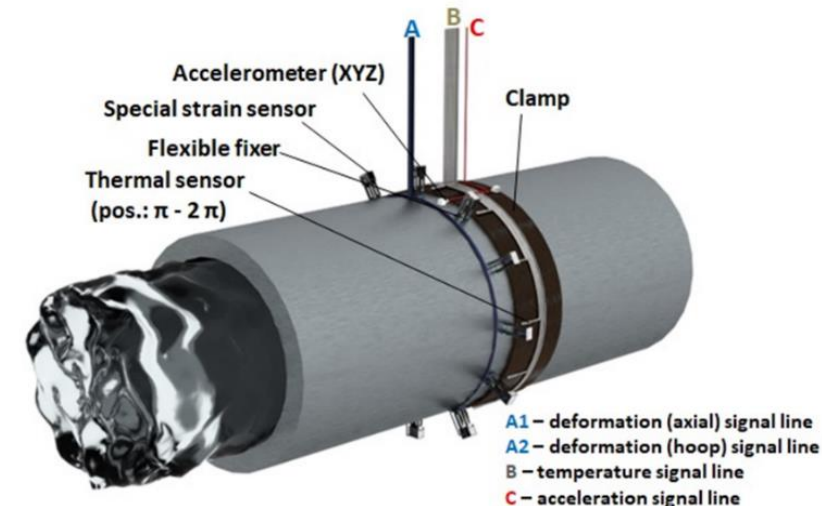
□ Fatigue on the pressurizer surge line (IPP & Framatome)

- Thermal sensors, strain gauges, accelerometers
- Process data (CADIS software)
- Semi-detailed fluid & solid mechanical models

Conceptual view of the Digital Twin for high-energy pipes



Schematic diagram of a three-stage model for SCC progression



Experimental tests

❑ Main experimental loops:

- VIKTORIA loop for concealed pipes and leakage detection
- Thermal stratification loop at IPP
- Corrosion loop at VTT (primary circuit conditions)

❑ Robustness tests in the IRMA irradiator

VIKTORIA facility (Vuez)



IRMA irradiator (ASNR)

Industrial tests

- ❑ Dryer / superheater extraction line of the Tihange NPP subject to flow accelerated corrosion
- ❑ Raw service water pipes for seaside plants
- ❑ Preheater siphon extracted from Tricastin and shipped to KTU
- ❑ Representative pipes in conventional industries:
 - urban water supply
 - oil & gas industry



Turbine extraction line



Oil & gas transport pipe



Preheater siphon

Evaluating the acceptability of the technology

- ❑ **Human, Social and Organisational impact of the technology**
 - Automation reduces human errors, but also error recovery by operators.
 - Role in ageing management programs, in combination with NDE
- ❑ **Review of applicable standards**
 - Cross-roads between NDE and I&C
- ❑ **Qualification supported by simulation**
 - The operation of the systems depend on its environment: too many different conditions to be qualified solely by tests.
 - Position paper in collaboration with ENIQ?
- ❑ **Recommendations summarised in a report issued at the end of the project.**

Expected outcomes of the project

- ❑ Several proofs-of-concepts adapted to nuclear environment
- ❑ Recommendations to put technologies to the market
- ❑ A roadmap for future developments:
 - Extending the approach to new systems and technologies
- ❑ **Objective: Generalise the strategy to many other relevant cases**
 - Support safety in the context of long-term operation
 - Power reactors and fuel cycle facilities



Thank you!



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