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In Service Inspection and Repair Developments for SFRs and Extension to Other Gen4 Systems

Summary / Objectives:

In Service Inspection is a major challenge to consider for future Generation IV Reactors safety. Therefore, a large focus of R&D work has been performed since 2010 in France for the Sodium Fast Reactor systems (SFR), mainly dedicated to the inspection of reactor block structures, primary components and circuits, and Power Conversion System main components (Heat Exchangers). In Service Inspection requirements have to be **taken into account since the early pre-conceptual design phase**, then consolidated through the basic design phase with more detailed specifications leading to increase the inspection tools **ability for immersed sodium structures of SFRs, at about 200℃ (shut down conditions).** Inspection within the main vessel should be performed either with transducers immersed in sodium (with associated in sodium robotics) and with transducers located out of sodium medium. **Nondestructive Examination, Telemetry and Imaging** are qualified with experimental **in-water and then in-sodium testing**, using ultrasonic transducers. Experimental results are then compared to simulations using French CIVA software platform results. Repair was also part of this program, with laser system development. This webinar provides a technical overview of this ISI&R program that involves specific international collaborations done through GENIV mainly. Of course, it also benefits to other Gen4 systems.

Meet the Presenter:

Dr. François Baqué works as a Senior Expert on inspection for **fast reactors at CEA Cadarache IRESNE** in the Nuclear Technology Department.
Previously, he was the Manager of R&D activities associated **with In Service Inspection and Repair for ASTRID Project** at CEA (2010-2019). During this period, he led CEA organizations engaged in **the development and qualification of ultrasonic and electromagnetic sensors and related inspection methods**. He supervises PhD works on ultrasonic methods in the French University and National Centre for Scientific Research. He is an active participant to the Gen4/SFR-CD&BOP (Component Design and Balance of Plant) group for inspection systems and methods.

1. Developments of Examination and Inspection Techniques for SFRs

Liquid sodium is opaque, and not easy to drain. However if we use ultrasonic metrology, we can inspect in the liquid sodium.

In France, 3 R&D program for NDE, 1) **Telemetry** of specific targets in the reactor block, 2) **Imaging** of lost parts/ opened cracks, identification of **fuel elements**, **positioning** for robotics, 3) **Volumetric control** of immersed structure **welded** joints.

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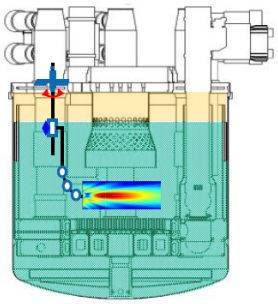
Developments of Examination and Inspection Techniques for SFRs

Inspection mainly with ultrasonic means:

- Liquid sodium is opaque, not easy to drain.
- Ultrasonic metrology chosen as key technology to render feedback for in sodium inspection: *Propagation, Damping, Reflection and Diffraction of Ultrasonic Waves*



Acoustic techniques:
- Low attenuation by the sodium medium
- High velocity of US wave (≈ 2400 m.s^{-1} at 200°C)

French R&D Program for ASTRID Non Destructive Examination:

- *Telemetry* of specific targets in the reactor block
- *Imaging* of local and general areas, of lost parts, of opened cracks, identification of fuel elements, positionning for robotics
- *Volumetric control* of immersed structure welded joints

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10

2. Developments of Examination and Inspection Techniques for SFRs
-Principle for ultrasonic measurement-

Ultrasonic measurement using emitted wave and reflected wave from target is applicable to opaque environment.

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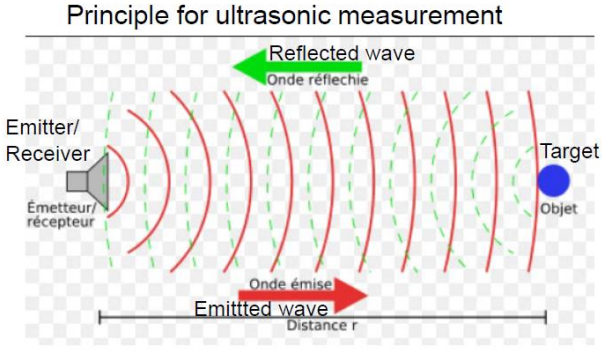
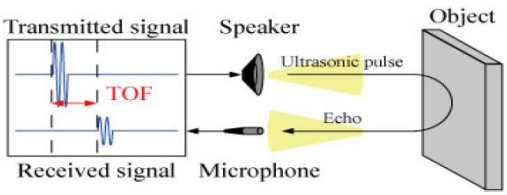
Developments of Examination and Inspection Techniques for SFRs

Principle for ultrasonic measurement





Distance =

Wave speed in the media (m/s)
x
Time of flight (s)
/ 2
(outward & return)

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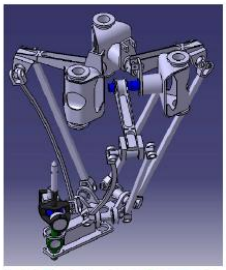
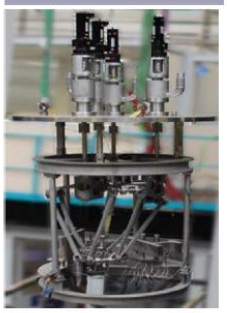
12

3. Under Sodium Near Distance Imaging

The result of imaging test using ultrasonic is shown whose experimental condition is under sodium with temperature of 200℃. (Near distance implies distance less than 20cm)

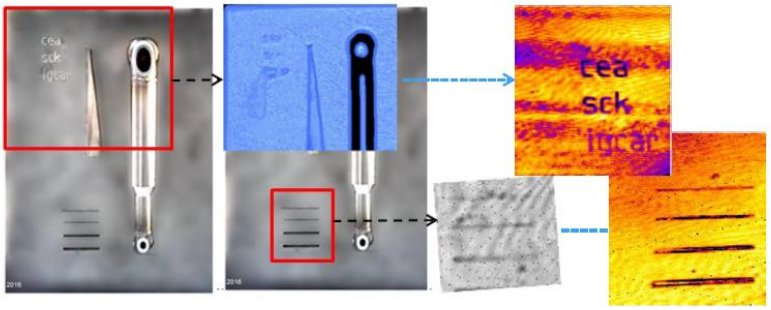
Under Sodium Near Distance Imaging

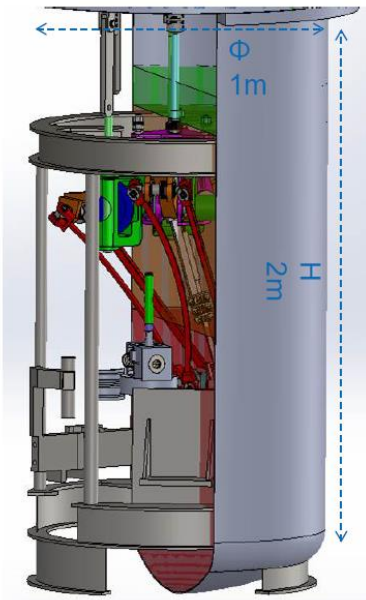




Qualification in 200°C sodium with VENUS facility at 200°C:

- With 3D robot
- With TUSHT^{CEA} sensor (flat and focused front face)





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4. Under Sodium Imaging for Non Destructive Examination (effective for welds)

A. Extracting acoustic field due to the perturbation.
B. Focusing on defect location using time-reversal techniques.
C. Imaging while computing the time-gated topological energy.

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Under Sodium Imaging for Non Destructive Examination

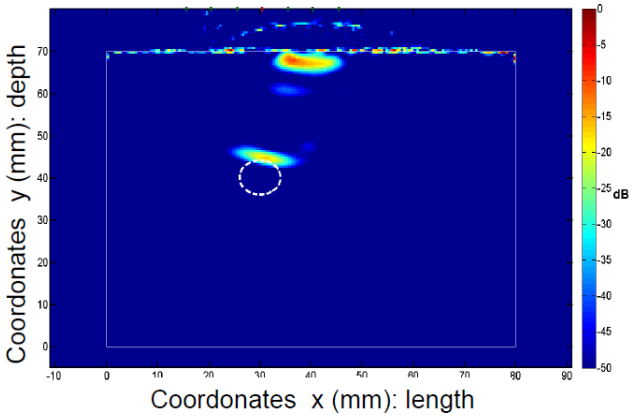
Heterogeneous medium: differential method

Aix*Marseille université
2014 - 2016

A 3 step-process:

1. Extracting acoustic field due to the perturbation. This step consists in making the difference between a reference medium and the inspected one.
2. Focusing on defect location using time-reversal techniques.
3. Imaging while computing the time-gated topological energy.

Topological energy mapping



$$ET(x) = \int_{\frac{d(x)}{c}-\frac{\Delta t}{2}}^{\frac{d(x)}{c}+\frac{\Delta t}{2}} \|u_0(\boldsymbol{x},t)\|^2 \|v_{rt}(\boldsymbol{x},T-t)\|^2 dt$$

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5. In-sodium Robotics

The robotics which is important tool for inspection are summarized and example typical developments such as **robot mockup with 2 degree of freedom** are shown.

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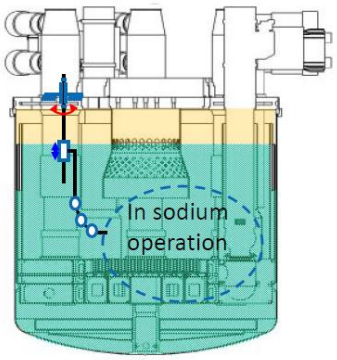
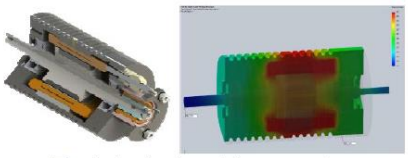
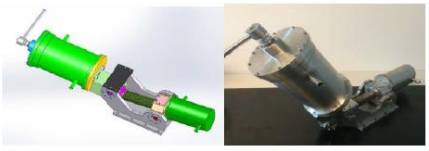
In-sodium Robotics

- Generic studies on robotics (in sodium or not);
- Associated means for testing (air/water/sodium);
- Case 1: main vessel inspection with robot in the gap between main and safety vessels (out of sodium);
- Case 2: sensor for steam generator tubes;
- Case 3: in sodium pushed chain type robot;
- Case 4: in sodium pole and cable type robot;
- Case 5: on-wheels robot for large in-gaz equipments;
- Case 6: robot for repair tools;





Prototypic brushless motor working at 200°C



Specific tight robot mockup with 2 degrees of freedom

39

6. Conclusions and Perspectives

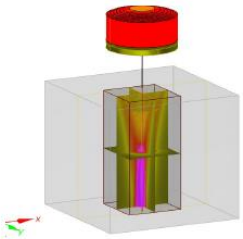
Ultrasonic transducers, qualification of non destructive examination and robotics which are key technologies for in service inspection and repair development for SFRs and other Gen4 systems.

Conclusions and Perspectives

The R&D program launched by France for Inspection & Repair of Sodium Fast Reactors is on the way for technical demonstration capabilities in this harsh environment.
It has been strongly linked to ASTRID prototype design, from 2010 to 2019.

Development of ultrasonic transducers for telemetry, imaging, Non Destructive Examination: piezoelectric and electromagnetic concepts for operation at about 200°C in liquid sodium

Development and qualification of Non Destructive Examination techniques: extensive simulation with CIVA software platform and experimental testing (under water and under sodium)



Development of robotics for large reactor vessel: generic studies for associated materials and specific concepts

46