French developments for improving In Service Inspection of SFRs

F. Baqué, R. Raillon-Picot, K. Vulliez, B. Chassignole, G. Corneloup

French developments for improving In Service Inspection of SFRs

F. Baque[1*], R. Raillon[2], K. Vulliez[3], B. Chassignole[4], G. Corneloup[5]

[1] CEA, DEN, DTN, CEA Cadarache, 13108 Saint-Paul-lez-Durance Cedex, France
[2] CEA, DRT, LIST, DISC, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France
[3] CEA, DEN, DE2D, SEAD, Laboratoire d'Etanchéité, 30207 Bagnols-sur-Cèze, France
[4] EDF R&D, Avenue des Renardières – Ecuelles, 77818 Moret-sur-Loing, France
[5] LMA, CNRS, 13625 Aix-en-Provence, France

Abstract

In Service Inspection (ISI) is a major issue to be taken into account for future Sodium Fast Reactors safety, thus, a large R&D work is performed since 2010 in France for the future SFRs.

ISI requirements have been taken into account since the early pre-conceptual design phase (specific rules for design have been merged into RCC-MRx design rules until 2012), then consolidated through the basic design phase with more detailed specifications leading to increase the ISI tools ability for immersed sodium structures of SFRs, at about 200℃ (shut down conditions). Inspection within the main vessel are planned with transducers immersed in sodium and also with transducers located out of sodium medium.

Finally, the qualification of ISI ultrasonic transducers (for Non Destructive Examination, Telemetry and Imaging) is being performed with experimental water and sodium testing, to be compared to simulation with CIVA software platform results. A pluri-annual R&D program mainly deals with the reactor block structures, the primary components and circuit, and the Power Conversion System.

Specific developments have been performed for NDE of thick austenitic steel welds, NDE using guided Lamb waves, telemetry from the outside of reactor vessel, imaging of immersed structures and components within the large primary vessel (in a pool type reactor concept) and associated in sodium robotics (with in-sodium tightness).

Some results of testing and simulation are given for some ASTRID project applications.

KEYWORDS: *SFR, ASTRID, Inspection, Non-Destructive-Examination, Viewing, Robotics*

Introduction

Within the framework of the future Generation IV reactors, Sodium-cooled Fast Reactor have been considered by France as the most mature concept in 2008 and an extensive R&D programme was launched in 2010[1]. In that frame, In-Service Inspection has been identified as a difficult task to be performed (as sodium coolant is opaque, hot and highly chemically reactive) based on experience feedback (French Phenix and Superphenix SFRs, as well as foreign power plants). Ultrasonic techniques have been extensively studied as they are well adapted to Non-Destructive Examination and telemetry measurement in this harsh environment[2].

Improving the inspection tool deals with developing ultrasonic transducers to be immersed in sodium at about 200℃ in the reactor block (ISI operations ar e performed at shutdown conditions). This is being done based on consolidated specifications and a pre-qualification process involving increasingly more realistic experiments using acoustic techniques and simulations performed with the patented CIVA code.

ISI items (inspection: ultrasonic sensors, telemetry, vision and volumetric control, associated robotics) are being developed and qualified for the inspection of reactor block systems, structures and components, and for the power conversion system[3]. This program is ensuring the strong ties needed between the reactor designers and inspection specialists since the aim is to optimize inspectability. This already induced specific rules for design in order to shorten and facilitate the ISI operations: new rules have been merged into the RCC-MRx design code (2012 edition).

R&D effort depends on what is required for each component and structure, using the risk-informed method, which take into account potential damage and the consequences in case of a break of the considered structure or component.

This paper presents some up to date developments for the inspection of SFRs; other items are simply described with a brief abstract and associated main references. NDE of innovative Compact Heat Exchange Modules design is not included.

Extended SFR Design Rules

CEA initiated a study in 2008 to improve the design rules of fast reactors with French utilities (EDF), French designers (AREVA NP) and non-destructive examination (NDE) specialists (Aix Marseille University), focusing on the specific issue of in-service inspection (ISI). Thus, at the end of 2012, the RCC-MRx specifications for NDEs was enlarged, orienting design and manufacturing choices and rules to account for future in service inspection. Due to the complexity of the links between design, materials, access for inspection, inspection techniques and tools, these rules cannot be considered as strict instructions, but rather as leading to fruitful dialogue between designers and inspectors. The links between in-service inspection and manufacturing processes and specifications are now being explored in further detail. This initiative should lead to better connections and compromise between design work, material specifications and in-service inspection: design rules taking into account NDE requirements)[4].

Ultrasonic transducers for in-sodium inspection

Several ultrasonic transducers have been developed and tested[5]: among them, the TUSHT model by the CEA, the TUCSS model by FRAMATOME/INTERCONTROLE (both using piezoelectric materials), and electromagnetic acoustic transducers (EMAT) by the CEA. Each type of transducer has several advantages and disadvantages regarding the ultrasonic applications considered for ASTRID: transducer location, ultrasonic techniques (“contact” or “immersion”, bulk or guide waves, etc.), temperature, and the type of measurement (telemetry/vision or defect detection). Their development and qualification programmes are currently underway which aim at ultimately selecting the most appropriate transducer for each ASTRID ultrasonic application. This involves tests on both simple and elaborate targets (with defects to be detected or specific shapes to be measured/seen), together with tests in water at room temperature and in sodium at 200℃. Simulation tool s have also been improved by developing the CIVA software platform for volumetric and guided wave techniques[6].

In sodium telemetry: ultrasound wave propagation in a heterogeneous fluid medium

Inside a sodium cooling system, the environment is heterogeneous because of the complex flow states, particularly during operation. Even if they are lower in shutdown conditions, the effects of this heterogeneous environment cannot be disregarded with respect to acoustic propagation. It is thus necessary to carry out experiments with the objective of investigating developments for component technologies, though such experiments using liquid sodium tend to be relatively large-scale. This is why numerical simulation methods are essential prior to carrying out real experiments or filling up the limited number of experimental results. Though various numerical methods have been applied to wave propagation in liquid sodium, there is still no method for verifying heterogeneities on a three-dimensional scale. Moreover, it has also proved difficult to simulate such issues with conventional methods because a reactor core represents a complex acousto-elastic region. Thus, a study was launched to solve these two issues by applying a three-dimensional spectral element method[7]. Initial results of a three-dimensional simulation study on heterogeneous media (the first point) was discussed. In order to take into account the heterogeneity of liquid sodium, four-dimensional temperature fields were used (three spatial and one temporal dimension) which were calculated by computational fluid dynamics (CFD) with large eddy simulation (LES), instead of using a conventional method (i.e. Gaussian Random field). This three-dimensional numerical experiment demonstrated that it is possible to check the effects of heterogeneous propagation media on waves in liquid sodium.

Non Destructive Examination using guided waves

Ultrasonic guided wave techniques are considered as suitable candidates for the inspection of welded structures within SFRs, as the long-range propagation of guided waves without amplitude attenuation can overcome the accessibility problem due to the liquid sodium.

Guided wave technique for defects detection within core supporting shell

Guided wave NDT methods can be applied to control the integrity of welds located in a junction-type structure welded to the main vessel. The method is based on the analysis of scattering matrices related to each expected defect, and takes advantage of the multi-modal and dispersive characteristics of guided wave generation. Simulations studies have shown the effectiveness of the method on a simplified junction-type structure immersed in air, but experiments were limited to the performance verification of the mode selection procedure on a structure without any defect.

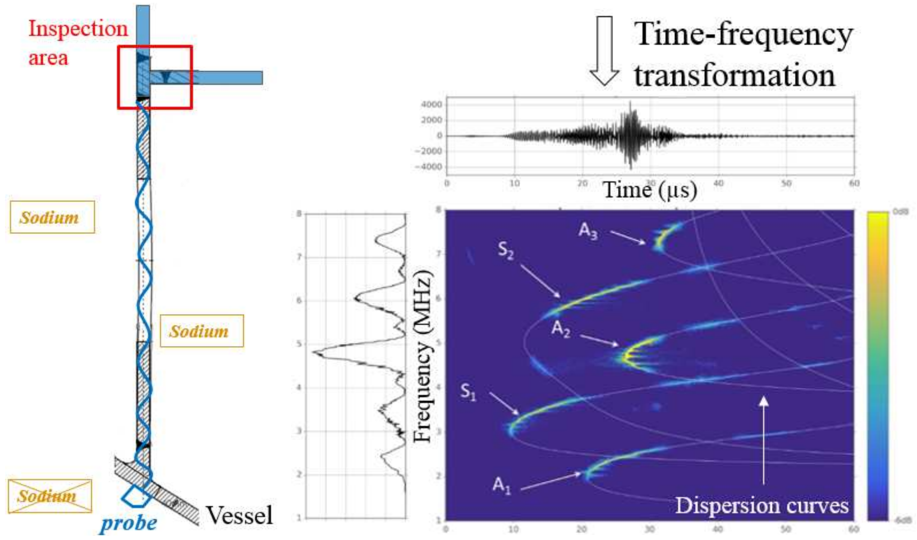

Figure **: Inspection configuration (left) and modal identification (right)

The validity of this NDT method to characterize calibrated defects embedded in a junction-type structure has been investigated in detail[8]. The detection capabilities of the method was evaluated through simulations and experimental campaigns, with the junction immersed in air then in water. In order to limit the displacement of the probes, time-frequency analysis using reassigned spectrograms was used to identify the modal content of guided wave signals from a single measurement point. The results show good agreement between experience and simulation as well as the detection of several defects in the junction. Finally, a simulation study of the modal propagation within a structure immersed in liquid sodium was conducted, in order to evaluate the attenuation caused by the fluid..

Study of Leaky Lamb Waves for Non-Destructive Testing of Structures behind Screen

The purpose is to evaluate the possibility of propagating Lamb waves to the inside of the reactor vessel while generating them from the outside, and to study their Non Destructive Testing (NDT) capability to detect and locate potential defects within immersed structures. The propagation of Lamb wave in a immersed plate (called Leaky Lamb Wave, or LLW) is first characterized and measured, with a focus on the attenuation due to the re-emission of energy into the surrounding fluid[9].

The 2D Fourier transform and a time-frequency processing are used to measure velocity and attenuation while taking into account the dispersive and multimodal nature of propagation. The re-emitted acoustic field during multimodal propagation is analysed in detail, and the interferences occuring are explained. Then the propagation in a second plate is modelled by taking into account the energy supply re-emitted along the first plate. Due to this supply, the apparent attenuation in the second plate differs from the attenuation in the first plate and becomes lower. This behaviour is predicted and measured. Bulk wave paths in the fluid between plates are analyzed, and the interference they can cause on the Lamb waves in the plates is theorized and experimentally observed. Finally, the Energy Based Model (EBM) is successfully used to predict the return echo from a plane defect located in the second and third plates.

As a perspective, a new PhD work was launched by end 2018 in order to study the contribution of time reversal technique for ultrasounds nondestructive testing for generation and propagation of Lamb waves within multi-plate structures.

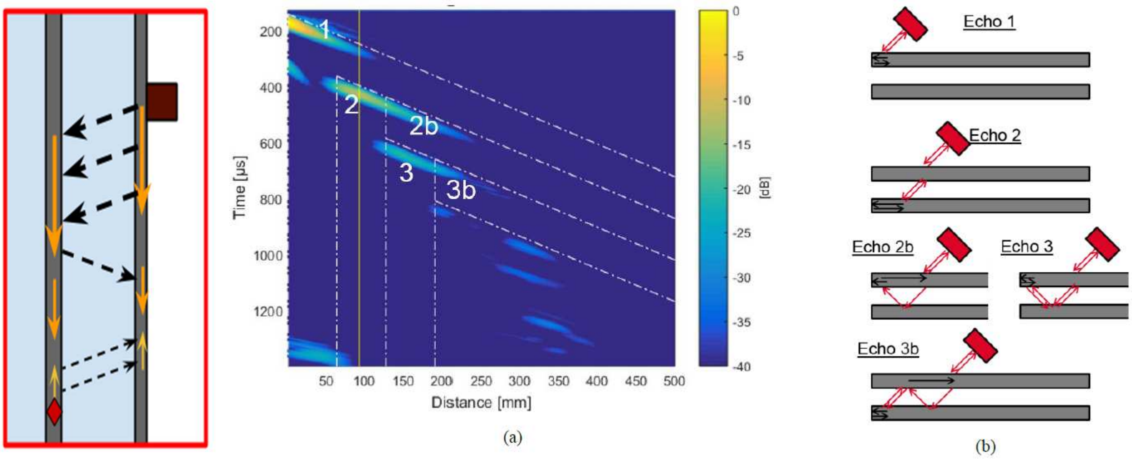

Figure **: Inspection configuration (left) and under water results with two 8mm thick plates (right)

Non Destructive Examination of thick austenitic welds

Ultrasonic testing of austenitic stainless-steel multi-pass welds is very challenging. Because of the welded structure, both anisotropic and heterogeneous, the propagation of the ultrasonic beam is disrupted (attenuation, deviation, division), making diagnosis difficult.

This diagnosis can be improved by using modelling codes in order to simulate the beam propagation and the beam to defect interaction in a weld[10]. For this purpose, a realistic description of the microstructure is required[11]. This can be obtained by macrography, but this involves a destructive cutting of the weld, or a weld sample. In the latter case, the sample must have been made and stored, and it must be representative of the weld. This weld description is then coupled to the ATHENA ultrasonic simulation code, developed by EDF R&D, to simulate the impact of welding on propagation and therefore control.

As an alternative, since 2000, EDF French Utilities and the Acoustics and Mechanics Lab (LMA) have been studying a numerical model (called MINA) for predicting the microstructure of SMAW multi-pass welds, which only takes into account information from welding conditions[12]. The order of the passes, in particular, and its consequences on the solidification of the molten bath, have shown that the growth of the grains has a predictable direction. The MINA model developed estimates this texture. The application to SFR components of this methodology developed for PWR welds is discussed in this section.

The testing configuration is presented on next figure. The welds to be inspected connect two horizontal and one vertical plates made in 316L(N) steel and with a 40 mm thickness. This study focuses on the detection of two plane defect (notch type), referenced E3 and E4.The grain orientation mapping in the weld was determined on the weld macrography given on Figure 1b. The elastic properties and attenuation coefficients have been drawn from previous studies on 316L austenitic welds[13].

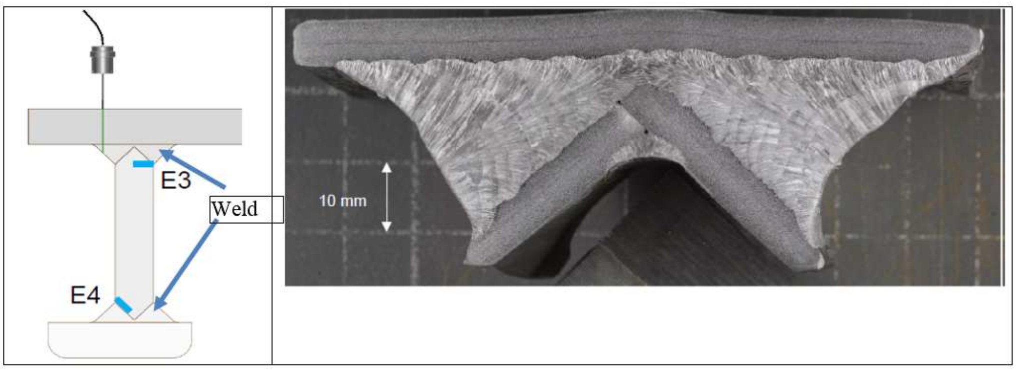

Figure **: Inspection configurations (left) and weld microstructure (right)

Longitudinal waves at 0° incidence are used to dete ct E3 notch. The ATHENA2D result obtained for an underwelding defect is compared to the isotropic configuration (propagation in the base metal). The simulation concludes that, despite a 6 dB attenuation of the notch echo due to the weld microstructure (see next figure), this defect can be detected by L0 waves. This conclusion was confirmed by a experimental test on a representative mock-up.

Detection of the E4 notch requires 45° wave propaga tion and multiple reflections on the vertical plate. Shear waves are given first consideration as they do not lead to mode conservation echoes in this particular configuration. However, an experimental result concludes to the failure in detecting the E4 notch with this propagation mode. This result was explained by ATHENA calculation. Indeed, the weld microstructure is too disrupting for shear waves (significant beam deviation and division) to detect this in-depth defect. The beam disruption is illustrated on next figure).

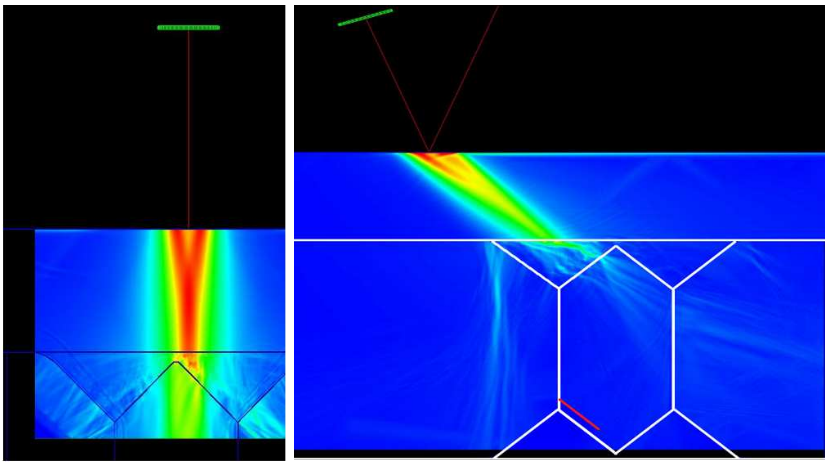

Figure **: Examples of beam visualization in the weld from ATHENA2D calculation for L0 wave (left) and SW45 (right)

First calculations were performed with 45° Longitud inal waves (LW45). Compared to the no defect configuration, the notch generates numerous echoes at various times of flight. But the diagnosis in terms of defect characterization will be difficult because of these multiple echoes. Moreover, echo amplitudes estimated by simulation are very low and the Signal-to-noise ratios have to be accurately determined by experimental approach to confirm the potential of LW45.

In conclusion, those examples well illustrate the usefulness of numerical approach to explain the propation phenomena in complex polycristalline materials, and also to help in the design to an ultrasonic technic by taking into account the set of the influential parameters (material, geometry,…).

In the same way, a collaborative work between LMA and CEA, develop a similar model to MINA for GTAW[14] (or TIG, so MINA TIG). The consideration of this specific metallurgical aspects has led to the introduction of new parameters. So, in contrast of SMAW where fluid flows (Marangoni, Lorentz, …) in the weld pool are constant or negligible, whereas, in case of GTAW welding process, these effects are not negligible and not constant. They depend strongly of welding conditions (voltage, current, speed, electrode tip angle, composition and flow of shielding gas) and also the chemical composition of steel and shielding gas (surface active elements).

Near distance under-sodium viewing

The aim is to develop and qualify inspection tools for viewing of sodium-immersed structures and components, imaging of small defects (e.g. open flaws in a weld) and looking for lost parts (if any), at short distance (less than 200mm). Sodium tests were performed at 200℃ in the DOLMEN sodium CEA circuit, with the VENUS robot, which can move sensors with a high level of accuracy, despite the environmental constraints due to the sodium medium and high temperature level[15].

Images were reconstructed and demonstrate the operational visualization capacity (for near distance imaging i.e. less than 200mm distance) of such techniques through the reconstruction of 3D images obtained from the ultrasonic tests performed in static sodium at 200℃. As the distance between acoust ic sensor and target to be imaged is rather small, a specific robotic system (so called VENUS robot) was designed, manufactured and used in 200℃ static bul k sodium. VENUS instrumentation & control (I&C) system was combined with two high-temperature ultrasonic transducers (TUSHT) and a suitable processing method for the signals. These sensors are used to emit ultrasounds and receive the resulting echoes reflected by targets immersed in liquid sodium. The high-temperature ultrasonic transducers (TUSHT) used can be described as single-element piezoelectric sensors, with one being flat and the other being equipped with a focusing lens.

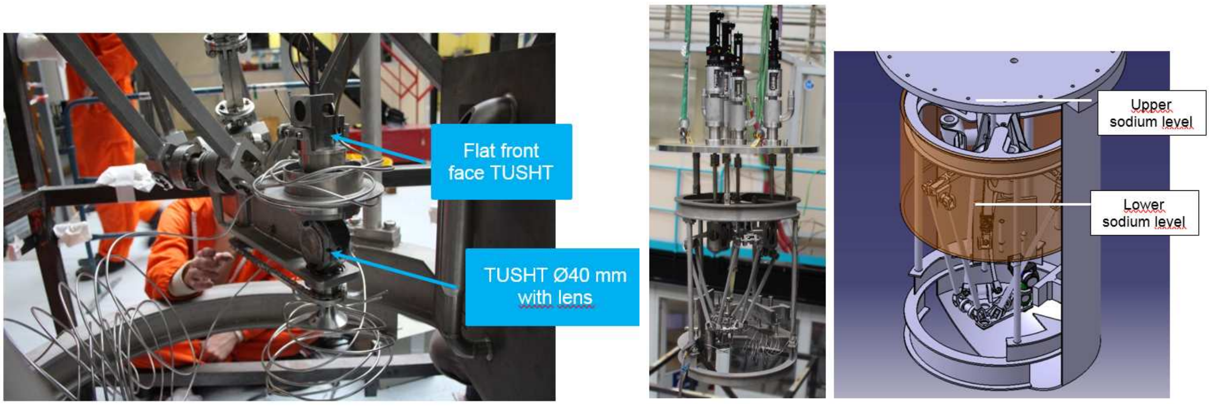

Figure *: TUSHT sensor located on the VENUS device (view before sodium tests)

By processing the resulting signals, the data can be used to reconstruct images that indicate the position, size and shape of the different parts of the targets. The VISION mock-up was used to visualize and detect defects at the liquid-solid interface: it was equipped with 4 grooves and series of letters ("CEA") engraved on the plate, as well as a triangular inset with sharp edges and a pipe with an elbow.

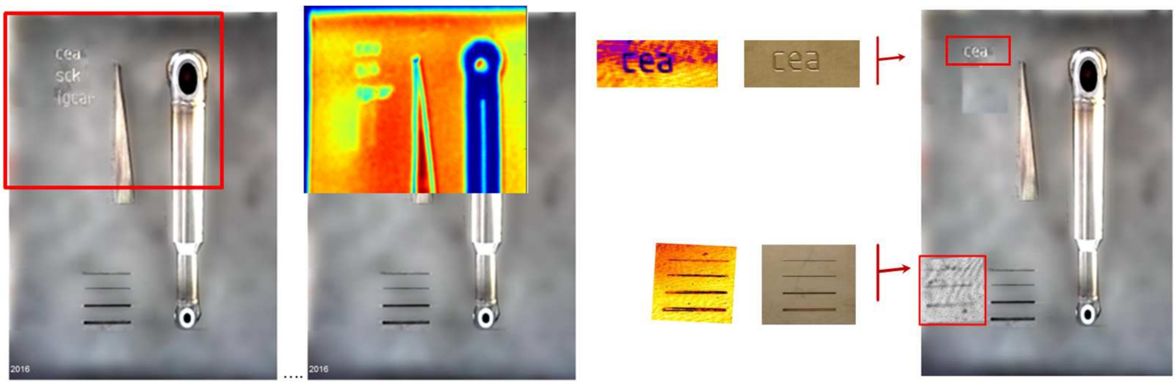

Figure *: Ultrasound images of the VISION mock-up: triangle, pipe, grooves and letters, with flat front face TUSHT Ø40 mm coupled with focusing lens (at 6.5 ± 0.4 MHz)

The scanning was carried out using the VENUS robot with four degrees of freedom: this made it possible to demonstrate the ability for close visualization (between 150 and 200mm distance) of objects in sodium under operational conditions. This was done by reconstructing a 3D image based on the ultrasonic echoes, as well as by providing a representation of the grooves simulating open cracks and barre-coding. The grooves, including the thinnest one which was 500 µm wide, were detected by the TUSHT Ø 40 with a focusing lens.

Long distance under-sodium viewing

Sub-marine techniques

The aim is to develop and qualify inspection tools for viewing of global scenery sodium-immersed structures and components (with possible displacements and deformations), imaging of specific targets and looking for lost parts (if any), at long distance (from 200mm to some meters).

This work was partially performed with the Marine Physical Laboratory (san Diego USA) in order to take advantage of available submarine acoustic processes[16]: indeed, passive structural monitoring can be performed using Matched Field Processing technique. The source localization method is based on the comparison between measured data $\mathrm{D}(f, \mathbf{x_r})$ and forward field $\mathrm{G}(f, \mathbf{x}|\mathbf{x_r})$ derived by a propagation model at a given frequency.

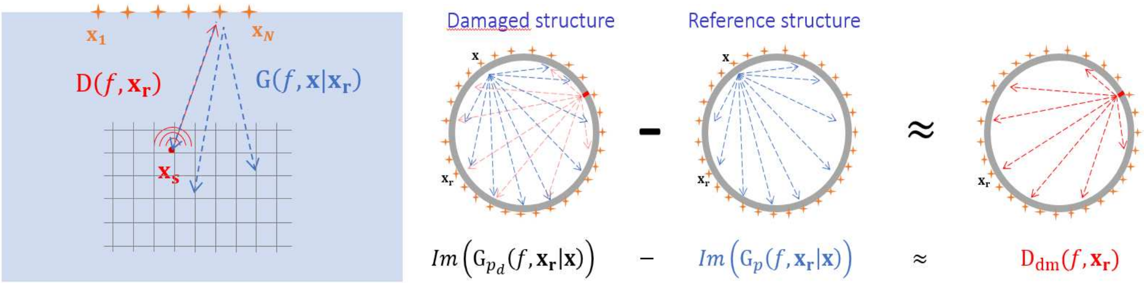

Figure *: Match Field Process principle (left). Measured and forward acoustic fields. Subtracting operation between reference and damage states (right)

Taking into account the main conditions of SFR operation, some submarine acoustic techniques based on acoustic source localization, such as Matched Field Processing, seem likely to detect and localize local defects in a given structure: it should be possible to detect abnormal structure and component evolution within the primary sodium loop, using the defect's acoustical signature. As one has no propagation model, but do have sensors all around the structure, a model can be built based on measured and forward acoustic fields data. Furthermore, using lower frequency range, a passive approach could use the ambient noise (within the main vessel) for a global imaging.

For this, Green functions reconstruction have been performed with ambient noise data measurement. Then, signal treatment for defect localization is undertaken with numerical data for a two-dimension example. When an acoustic wave hits the defect, it acts as a point source. The residuals computed at the receivers isolate the defect's signature. The subtractive operation removes the contribution of the sources. When a wave hits the defect, it acts as a point source. By a subtractive operation at the receivers between data from the reference and damaged structures, one can isolate the defect's signature.

Conventional Matched Field Processing has been used for the case of a local defect in a cylindrical structure, using 13 acoustic frequency ranges from 7 kHz to 10 kHz. Using incoherent ambient noise, the defect is detected and located by a 5 dB peak above highest side-lobes.

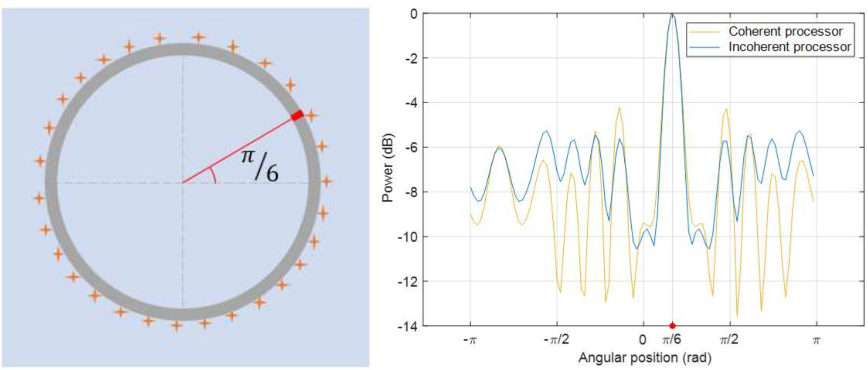

Figure *: Detection of a local defect with Matched Field Processing

Next step is an experimental program for the qualification phase, with water-immersed mockup at small scale.

Phased-array sensor for long distance under-sodium viewing

An ultrasound imaging system made up of 2 orthogonal antennas was developed for long distance vision in liquid sodium[17]. Recently, a simulation study was performed with CIVA that allow understanding the phenomena involved in the antenna radiated beamforming and echo response, as well as the effect of important parameters on its imaging capabilities. This study allows to determine the suitable values of the antennas parameters for the targeted practical applications

At the same time, 2 antennas with 128 elements each, built in 1999 at CEA Cadarache, were used for under water experimental trials. The results obtained for different targets and different types of acquisitions (mechanical C-scans, Full Matrix Capture and Total Focusing Method reconstruction) allowed to confirm the good performances of the system in terms of sensitivity and spatial resolution and to validate the predictions of CIVA.

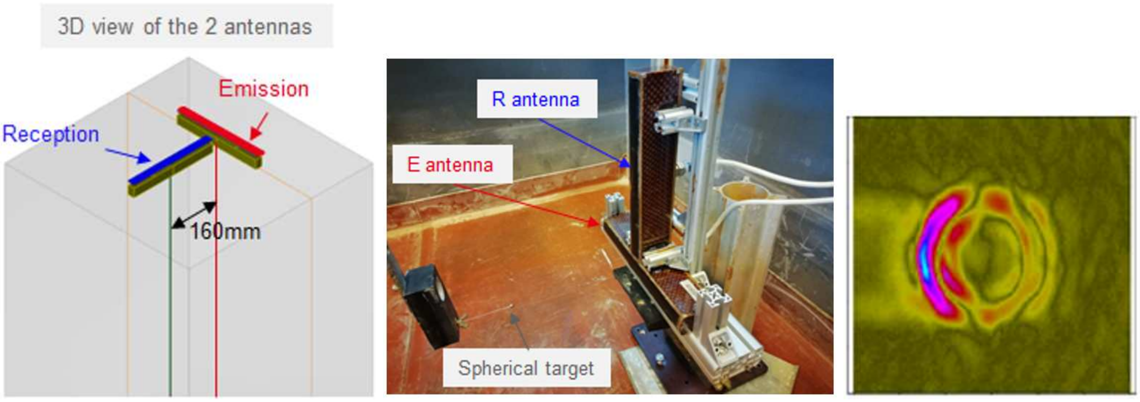

Figure *: 2 antenna concept and under water imaging of a 30mm nut at 500mm distance

A first prototype of 2 antennas with 64 elements each will be available by end 2019.

In-sodium Robotics

Technological bricks for Under Sodium Robotics

The maintenance of SFRs (inspection, repair) will be performed during shut down periods with some robotic carriers which have to be introduced within the main vessel, in primary 200℃ sodium coolant with argon gas coverture. Inspection campaigns should be less than one month.

These robots (or carriers) will allow bringing inspection and repairing tools up to concerned components and structures. The needed degrees of freedom associated to these operations will be assumed either directly by the carrier itself or by specifics lower end carrier device for accurate local positioning. Several carriers will be designed, well adapted to specific needs: type of maintenance operation and location of inspection and repair sites.

Feedback experience was gained during Superphenix SFR operation with the MIR robot which allowed to successfully make the Non Destructive Examination of main vessel welding joints, the carrier being outside bulk sodium. Operating conditions for SFR robots will be harder from those of the MIR robot: about 200℃ temperature, radiation dose ranging from 105 to 106 Gy, and especially mainly direct immersion within liquid sodium coolant.

At the design phase of these robots, three main configurations have been considered, depending on the adopted solution for robot component seclusion: zone 1 with tight surrounding shell cooled by argon gas flow (constraints: irradiation and 70℃ t emperature), zone 2 with not cooled tight surrounding shell (constraints: irradiation and 180℃-200℃ temperature), zone 3 with no tight surrounding shell (constraints: irradiation, 180℃-200℃ temper ature and immersion within liquid sodium).

It appears that some technical solutions do exist for future in sodium carriers, using available trade components. Nevertheless, qualification tests will be necessary in order to confirm some specific components (such as polymers, greases, sensors, reducers, motors, bearings). For bearings, specific test program are performed in order to check their capability for static and dynamic loadings during in sodium operation (without lubricant). Electrical motor development for 200℃ operation was performed and first under sodium tests are on the way in 2019[18].

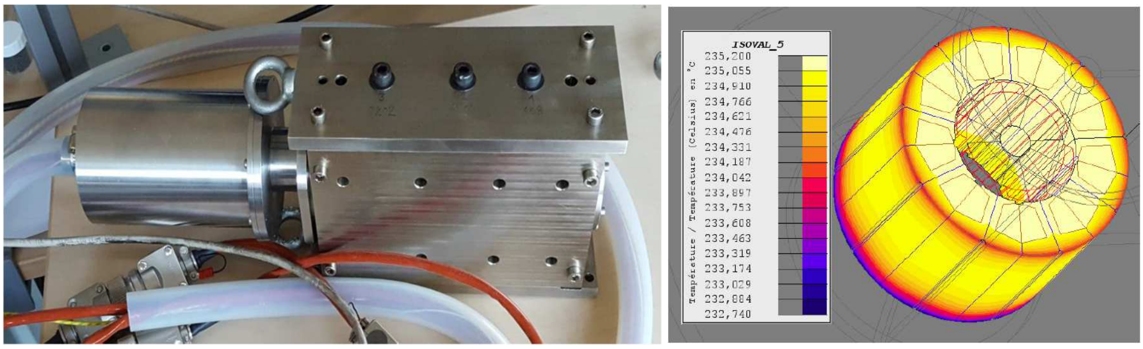

Figure *: Under sodium rotation mockup (left) and calculated motor temperature map (right)

Sealing issues for the SFRs

A dedicated R&D program is conducted to design and qualify a sodium-tight diving bell to board the inspection and tools[19]. This bell will be attached to a Remote Handling arm and will be moved inside the nuclear vessel then docked on its inners surface. The docking of the bell compresses a seal against the surface to explore/repair, once the inner volume of the seal drained a shutter opens a window to allow the deployment of the ISI tools. The development of the system focuses on the conception of a reliable mechanical system (a rocking shutter that can be opened and closed by two double-acting pneumatic actuators) and on sealing related issues.

If the mechanical part was challenging, the development of elastomer based seals compatible with a use under high temperature liquid sodium remains the most critical point. Safe for some reserve concerning the drop of the sealing performance of the seal of the docking flange due to the chemical degradation of the elastomer with the liquid sodium, the system successfully passed through series of qualification tests. More details regarding the R&D program can be found in this conference.

Conclusions and perspectives

For the future SFR Generation IV reactors, France launched an extensive R&D programme in 2010[1]. In-Service Inspection has been identified as a key point and ultrasonic techniques have been extensively studied for Non-Destructive Examination and telemetry/imaging.

After specifying the links between SFR design, structure materials, access for inspection, inspection techniques and tools, accurate connection between ultrasonic propagation and stainless steel material microstructure is looked at.

Dedicated ultrasonic transducers, well adapted to the specific Non Destructive Examination applications (flaw detection and sizing, imaging…), are developed for each application, in connexion with simulation made with CIVA software platform. A three-dimensional numerical experiment demonstrated that it is possible to check the effects of heterogeneous propagation media on acoustic waves in liquid sodium.

Guided wave NDT methods are applied to control the integrity of welds: time-frequency analysis using reassigned spectrograms is used to identify the modal content of guided wave signals from a single measurement point. It was also demonstrated that it is possible to propagate Lamb waves to the inside of the reactor vessel while generating them from the outside, and to study their Non Destructive Testing capability to detect and locate potential defects within immersed structures.

Near distance under sodium imaging (less than 20cm) was performed using a robot with four degrees of freedom: 3D images, based on the ultrasonic echoes of TUSHT sensor with a focusing lens, were reconstructed with 500 µm wide grooves, letters and barre-coding.

Longer distance under sodium imaging (more than 20cm) is studied using Matched Field Processing and associated techniques from submarine area, for global viewing and large defect detection. An ultrasound imaging system made up of 2 orthogonal antennas is developed: a first prototype will be available by end 2019 for qualification under sodium tests.

Robotic systems are developed, based on rotation and elevation movements. Qualification tests are performed for various components (polymers, greases, sensors, reducers, motors, bearings). Electrical motor is available for 200℃ under sodium operation .

A dedicated sodium-tight diving bell has been designed and is being qualified for ISI tools. The development of elastomer based seals compatible with a use under high temperature liquid sodium remains the most critical point.

Acknowledgment

All the presented results have been conducted and funded by Sodium Fast Reactor Project within Generation 4 frame at CEA and EDF. The authors would like to thank their colleagues who take part to this strong effort for improving inspection in this harsh conditions.

References

1) F. Baqué, F. Jadot, R. Marlier, J.-F. Saillant, V. Delalande, *In Service Inspection and Repair of Sodium cooled ASTRID Prototype*. ICAPP 2015, Nice, France, May 3-6, 2015
2) F. Baqué, R. Marlier, J.-Fr. Saillant, M.S. Chenaud, *In Service Inspection and Repair developments for SFRs*, Oral talk at the Training Workshop on Online Monitoring, Non-Destructive Examination and In-Service Inspection of Research Reactors. IAEA's Headquarters in Vienna, Austria, June 18-22, 2018
3) F. Baqué, R. Marlier, J.-Fr. Saillant, M.S. Chenaud, *In Service Inspection and Repair developments for SFRs.* oral talk at the Symposium GIF, Paris, France, October 16-18, 2018
4) F. Baqué, R. Marlier, J.-M. Augem, G. Corneloup, M.-A. Ploix, C. Gueudré, *Inspection specifications leading to extended ASTRID Design rules.* Int. Conf. FR17, Ekaterinburg, Russia, IAEA-CN-245-277
5) F. Baqué, C. Lhuillier, F. le Bourdais, F. Navacchia, J.-F. Saillant, R. Marlier, J.-M. Augem, *R&D status on in-sodium ultrasonic transducers for ASTRID inspection.* Int. Conf. FR17, Ekaterinburg, Russia, IAEA-CN-245-279
6) CIVA software platform, Website: *http://www.extende.com*
7) M. Nagaso, D. Komatitsch, J. Moysan, C. Lhuillier, *Wave propagation simulation .* Int. Conf. ANIMMA 2017, Lièges, Belgium, June 19-23, 2017
8) Q. Elie, F. Le Bourdais, K. Jezzine, V. Baronian, *Study of a guided wave technique for the characterization of defects within a complex junction in sodium cooled reactor.* Int. Conf. ANIMMA 2017, Lièges, Belgium, June 19-23, 2017
9) P. Kauffmann, M.-A. Ploix, J.-F. Chaix, C. Gueudré, G. Corneloup, F. Baqué, *Non-Destructive Testing of Nuclear Structures behind Screen using Leaky Lamb Waves.* QNDE 2018, Burlington, Vermont, USA, July 15-19, 2018
10) B. Chassignole et al., *Application of modelling for enhanced ultrasonic inspection of stainless steel welds. Welding in the World*, 2011.55(7-8): p. 75-82.
11) B. Chassignole et al., *Ultrasonic and structural characterization of anisotropic austenitic stainless steel welds: Towards a higher reliability in ultrasonic non-destructive testing*. NDT & E International, 2010.43(4): p. 273-282.
12) J. Moysan et al., *Modelling the grain orientation of austenitic stainless steel multipass welds to improve ultrasonic assessment of structural integrity*. International Journal of Pressure Vessels and Piping, 2003.80(2): p. 77-85.
13) M.-A. Ploix et al., *Measurement of ultrasonic scattering attenuation in austenitic stainless steel welds: Realistic input data for NDT numerical modeling*. Ultrasonics, 2014. 54(7): p. 1729-1736.
14) Q. Marsac, C. Gueudré, M.-A. Ploix, F. Baqué, G. Corneloup, *MINA-TIG: a model for predicting the microstructure of a multi-pass GTAW weld (TIG) of austenitic stainless steel.* ICWAM 2019, Metz, France, June 5-7, 2019
15) G. Gobillot, E. Sanseigne, F. Baqué, *Under-Sodium Imaging of SFR Internals – Four degrees of freedom with a sodium transducer displacement system.* Int. Conf. ANIMMA 2017, Lièges, Belgium, June 19-23, 2017
16) E. Lubeigt, S. Rakotonarivo, S. Mensah, J.-F. Chaix, W. Kuperman, J. Sarkar, F. Baqué, G. Gobillot, *Passive structural monitoring based on matched processing.* ASA Meeting, Victoria, Canada, November 5, 2018
17) C. Imbert, *Fast Under-Sodium Viewing. Application to Sodium Fast Reactors*, PhD at INSA Lyon, France, 1997
18) T. Jouan, F. Rey, F. Baqué, *Generation IV SFR Nuclear Reactors: under Sodium Robotics for ASTRID*. Int. Conf. ANIMMA 2013, Marseille, France, June 23-27, 2013
19) K. Vulliez, L. Mirabel, F. Rouillard, M. Berger, A. Beziat, F. Baque, F. Dechelette, H. Lorcet, B. Rouchouze, *CEA R&D program on sealing issues for the SFRs.* ICAPP 2019, Juan les Pins, France, May 13-15, 2019