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IMPLEMENTING AGREEMENT

ON

"“PHASED ARRAY ULTRASONIC INSPECTION OF THICK AUSTENITIC STAINLESS STEEL WELDS”

BY AND BETWEEN

THE INDIRA GANDHI CENTRE FOR ATOMIC RESEARCH of the Department of Atomic Energy, Government of India located at Kalpakkam – Tamil Nadu – India, duly represented by its Director, Dr. Arun Kumar Bhaduri, Indira Gandhi Centre for Atomic Research,

Hereinafter called as “**IGCAR**”

AND

THE COMMISSARIAT À L’ÉNERGIE ATOMIQUE ET AUX ÉNERGIES ALTERNATIVES, a French state-owned research entity with a scientific, technical or industrial activity duly organised under the laws of France and having its registered office located at Bâtiment Le Ponant D - 25, rue Leblanc - Paris 15ème (France) - and declared at the Paris, Register of Commerce and Trade (“Registre du Commerce et des Sociétés de Paris”) under the following registration number: R.C.S. PARIS B 775 685 019, duly represented by Mr. Philippe STOHR acting as Director of the Nuclear Energy Division and duly authorised for the purpose hereof,

Hereinafter referred to as "**CEA**",

Hereinafter also referred to as individually as a “Party” or collectively as the “Parties”

WHEREAS the Government of the French Republic and the Government of the Republic of India signed on September 30, 2008 an Agreement on the Development of Peaceful Uses of Nuclear Energy (hereinafter "the Framework Agreement");

WHEREAS the Government of the French Republic and the Government of the Republic of India signed on December 6, 2010 an Agreement concerning intellectual property rights on the development of the peaceful uses of nuclear energy(hereinafter "the Intellectual Property Agreement");

WHEREAS CEA and DAE signed on December 6, 2010 an agreement in the field of nuclear science and technology for peaceful uses of nuclear energy with the aim to establish a general framework for their cooperation (hereinafter "Cooperation Agreement"),

WHEREAS CEA and IGCAR endorsed in November, 2005 a cooperation agreement in the field of Liquid Metal Fast Reactor Safety, which expired on November 2010;

WHEREAS CEA and IGCARhave common interest to co-operate in the field of Liquid Metal Fast Reactor Safety, and especially in the control of weldings which is an important safety topic,

WHEREAS CEA and IGCAR have decided, pursuant to articles 4 and 5 of the Cooperation Agreement, to establish an Implementing Agreement to cooperate on a joint research project titled "phased array ultrasonic inspection of thick austenitic stainless steel welds", hereinafter called the "Joint Research Project",

WHEREAS the Parties consider that no nuclear incident can occur from the cooperation between the Parties subject to the Implementing Agreement within the meaning of the Civil Liability for Nuclear Damage Act, 2010 in force in India or the Paris Convention on Third Party Liability in the Field of Nuclear Energy of July 29th, 1960 as implemented by legislation in force in France, and that, as a consequence, the Implementing Agreement is not subject to nuclear civil liability.

Now therefore, in consideration of the foregoing and mutual covenants contained herein, the Parties agree as follows:

ARTICLE 1 - DEFINITIONS

The words defined in Article 1, have the same meaning in this Implementing Agreement.

(i)**"Implementing Agreement"** means the present agreement, its annexes and its prospective amendments.

(ii) "**Own Information and Technology**" means without limitation any know-how, data, studies, software, specifications or any information whether patented or not, in any and all medium belonging to one Party prior to the effective date of this Implementing Agreement or acquired or developed thereafter independently of this Joint Research Project of this Implementing Agreement,

(iii) "**Joint Results**" means any and all document and information whether in written form or not including but not limited to manuals, drawing, know-how, trade secrets, trademarks, copyrights, manufacturing process data, studies, software, designs, specifications, technical description and data whether patentable or not generated during the Joint Research Project.

ARTICLE 2 - OBJECTIVES OF THE IMPLEMENTING AGREEMENT

The objective of this Implementing Agreement is to define the terms and conditions under which the Parties shall co-operate on a balanced basis on the following Joint research Project

"Phased array ultrasonic inspection of thick austenitic stainless steelwelds".

The Parties agree to cooperate pursuant to the terms of this Implementing Agreement according to the provisions of the Cooperation Agreement unless otherwise specified herein.The present implementing agreement could be later amended or completed by other implementing agreement(s) or to update the planning of actions of this Implementing Agreement.

ARTICLE 3 – SCOPE OF THE COOPERATIVE ACTIVITY

According to the joint statement attached as Appendix, this Implementing Agreement essentially deals with the goal of comparing different advanced ultrasonic phased array techniques for detection and sizing of defects (i.e. flaws) in thick 316LN weld joints.

The major steps of the cooperation project include:

- Initial review of conventional and advanced ultrasonic phased array techniques for detection and sizing of defects,

- Raising specifications for welds to be controlled (material, shape, welding procedure, solder…) and defects to be detected (type, size, location…),
- Calculations for simulation of Non Destructive Examination operations, with available softwares,
- Manufacturing of welding join mock-ups, with defects, along RCC-MRx specifications, and associated characterization (material micrography).
- Non Destructive Examination of welding join mock-ups, for comparison with simulation results, with ultrasonic phased array techniques,
- Analysis of results, for comparison of Non Destructive Examination techniques and of influence of weld join characteristics,
- Writing a common paper for publication in International Journal.

ARTICLE 4 – MILESTONES - DELIVERABLES

Milestones and deliverables	Date
D1. Review of conventional and advanced ultrasonic phased array techniques for detection and sizing of defects.	T0 + 3 months
D2. Specifications for welds to be controlled and defects to be detected, and associated characterization.	T0+24 months
D3. Calculations for simulation of Non Destructive Examination operations.	T0+27 months
D4. Manufacturing of welding join mock-ups with artificial defects, and associated destructive examination.	T0+30 months
D5. Non Destructive Examination of welding join mock-ups with defects.	T0+33 months
D6. Analysis of results, for comparison of Non Destructive Examination techniques and influence of weld join characteristics.	T0+48 months
D7 Common paper for publication.	T0+54 months

** T0: date of entry into force of this Implementing Agreement*

ARTICLE 5 – NOMINATED CORRESPONDENTS:

IGCAR	CEA
Dr. Anish KUMAR MMG/NDED Address: Indira Gandhi Centre for Atomic Research Kalpakkam - 603102 (Tamil Nadu), India Tel: +91 44 27480107 Fax: +91 44 27480075 e-mail: anish@igcar.gov.in	Francois BAQUE Senior expert for instrumentation Address: C.E.A. Cadarache F-13108 Saint Paul les Durance, France Tel: +33 4 42 25 38 30 Fax: +33 4 42 25 49 17 e-mail: francois.baque@cea.fr

The technical correspondents have to report the cooperation activities tothe Joint Research Project to the Franco-Indian Joint Committee as stated in article 6 the Cooperation Agreement.

ARTICLE 6 –FINANCIAL PROVISIONS

Both Parties agree that all activities done in the framework of this Implementing Agreement are to be done on a self-financing basis and equally reciprocating manner.

CEA will bear the cost of internal travel, allowance and accommodation of one IGCAR scientific officer for up to one month in France (according to the description of activities defined in Appendix). IGCAR will bear the cost of internal travel, allowance and accommodation of one CEA scientific officer for up to one month in India.

Visits or meetings may be organised if necessary according to provisions of article 8.1 of Cooperation Agreement.

ARTICLE 7 – CONFIDENTIALITY

7.1. "Confidential Information" means:

i. Own Information and Technology and/or any type of written information and in whatever form or medium that one Party discloses, whether directly or indirectly, to the other Party and relating to the Implementing Agreement.

ii. The Results arising from the Joint Research Project.

7.2. Each Party undertakes

i. to disclose only Confidential Information it has the right to dispose of, according to the following;
ii. to keep strictly confidential and not to disclose nor to communicate to any third party, by any means whatsoever, any Confidential Information received from the other Party, unless the communicating Party has explicitly notified to the receiving Party that such proprietary information was not subject to secrecy, and
iii. to use such Confidential Information solely for the purpose of the Implementing Agreement.

7.3. Each Party shall use at least the same degree of care in protecting Confidential Information against disclosure to any third party as it exercises in protecting its own Confidential Information.

7.4. Each Party undertakes to disseminate Confidential Information only to its employees on "a need to know" basis to use it within the scope of the performance of the Implementing Agreement, and the receiving Party shall take appropriate measures with such employees to ensure that the latter should be bound by equivalent confidentiality provisions as those stipulated herein.

Notwithstanding the above provisions, each of the Parties has the right to communicate Confidential Information received from the other Party to its government authorities and its national safety authorities subject to appropriate protection of the Confidential Information by the receiving government authorities.

7.5. However, the provisions of this article shall not apply to Confidential Information for which the receiving Party can prove in writing that:

- Such Confidential Information is or has become publicly known through no wrongful act on its part;
- Such Confidential Information is available to the public and already known, at the time of disclosure by the disclosing Party;
- Such Confidential Information was rightfully received by the receiving Party from a third party without breach of any confidentiality obligation;
- Such Confidential Information was independently developed or discovered by the receiving Party without use of any Information received under the Implementing Agreement;
- Such Confidential Information is disclosed pursuant to a judicial order, a lawful requirement of government agency; or by operation of law, but then only to the extent so

ordered; in such case the receiving Party will make its best efforts to timely advise the disclosing Party prior to disclosure.

7.6. The provisions of this article shall remain in force during the term of this Implementing Agreement, and for ten (10) years after the expiration or termination of the Implementing Agreement.

7.7 Any scientific publication, presentation or release paper relating to all or part of the Confidential Information, all or part of the work carried out under the Implementing Agreement shall be submitted to the prior approval of the other party as the case may be through the Joint Committee. The other Party shall examine it promptly and notify the submitting Party of (i) its consent to the content of the paper or (ii) its request to amend and/or remove certain parts of the paper or (iii) to delay the paper publication, presentation or release as long as necessary to ensure adequate industrial and intellectual protection, provided that such period shall not exceed eighteen (18) months from the date of the receipt of the paper by the notified Party.

Any failure of the notified Party to communicate its decision to the submitting Party within thirty (30) calendar days shall be deemed as its consent and a waiver of any objection to the contents thereof.

Unless otherwise agreed between the Parties, any scientific publication, presentation or release paper by the submitting Party shall clearly mention the collaboration with the other Party.

ARTICLE 8 – CLAIMS RESULTING FROM INFORMATION TRANSFERRED

8.1. While the information (including Confidential Information as defined in article 7.1) given by one Party to the other under this Implementing Agreement is accurate, in the opinion and to the best of the communicating Party's knowledge, the communicating Party does not warranty the pertinence of such information to any use which may be made by the receiving Party or by a third party. The use of such information by the receiving Party (including the communication to a third party) shall be entirely at the receiving Party's risk.

8.2.No claim shall be made against a Party for any direct or consequential damages to its property, its personnel or to third parties, which might result from the use of information given to the other Party.

ARTICLE 9 – INDUSTRIAL PROPERTY AND RIGHTS OF USE

9.1 Ownership

9.1.1 Ownership of Own Information and Technology

Each Party shall remain the exclusive owner of its Own Information and Technology. As such, each Party shall be free to transfer to a third party its Own Information and Technology.

9.1.2 Ownership of Results

9.1.2.1 General principles

The Parties shall ensure adequate and effective protection of the Joint Results.

The Parties shall inform each other of any Joint Result which is likely to be protected and shall engage in a timely manner on ensuring protection for the Joint Results.

To this end, the Parties undertake not to oppose the seeking, by a Party, of protection of Results in countries authorising such protection.

Each Party shall on the basis of its respective domestic legislation grant the other Party non-discriminatory treatment regarding the property, allocation and exploitation of Joint Results.

9.1.2.2 Co-ownership instrument

Before any exploitation for industrial and/or commercial purposes by one Party, the Parties shall draw up a co-ownership instrument determining the rights of use of the said Joint Results, according to the following principles:

- The co-ownership instrument shall take into account the respective material, human, financial and intellectual contributions to the acquisition of the Intellectual Property of each Party, the benefits of exclusive and non-exclusive licences in each territory or field of use, the conditions required by the respective national legislation of the Parties or other factors deemed appropriate.
- If the Parties cannot reach agreement on instrument of co-ownership within a maximum of six (6) months from the date of expiry of the Implementing Agreement, each Party may directly or indirectly exploit Joint Results throughout the world subject to remuneration for the other co-owner. Each Party should notify the other Party of its intention to invoke this clause before beginning exploitation with industrial and commercial purposes with prior notice of at least two (2) months.

9.2 Rights of use

9.2.1 Rights of use of Own Information and Technology

Each Party undertakes to grant to the other Party a non-exclusive licence without the right to sublicense on its Own Information and Technology within the scope of this Implementing Agreement for the Joint Research Project. This licence shall be granted royalty-free.

Each Party undertakes to grant to the other Party a non-exclusive licence without the right to sublicense on its Own Information and Technology if needed for industrial and/or commercial exploitation of its Joint Results. This licence shall be granted with fair and reasonable conditions as agreed by the Parties in a specific agreement.

9.2.2 Rights of use of Results

Each Party shall have the right of free use of the Joint Results for research and development purposes.

The Parties shall facilitate the effective exploitation of the Joint Results. To this end, the Parties agree to conclude a co-ownership instrument before any industrial and/or commercial exploitation of Joint Results, as mentioned above in article 9.1.2.2.

ARTICLE 10 – LIABILITY

10.1. Personal damages to the staff of each Party

Each Party on its own account, is fully liable for the damages to its own staff, e.g. for the insurance coverage of its own staff for workmen's compensation and professional diseases, in accordance with the appropriate local regulatory and legal requirements. Consequently, each Party proceeds to the appropriate formalities, and sustains if any, all the costs associated to the insurances underwritten in order to cover its own staff against the risks.

Each Party shall inform the other Party of any claim or damage that has occurred during or consequent to any work, by the staff of other Party, employed by it, in order to proceed to the various regulatory and legal requirements.

Notwithstanding the above provisions, each Party is liable in compliance with the applicable law to damages caused by its staff to the staff of the other Party in case such damages were caused by or contributed to by the gross negligence or wilful misconduct of that staff.

10.2. Damages to the other Party's properties

Each Party keeps on its own account, without any right of recoveries against the other Party, the damages caused to its own property by the staff of the other Party when the staff thereof put to its disposal, unless such damages were caused by or contributed to by the gross negligence or wilful misconduct of that staff.

10.3. Third party liability

In accordance with the appropriate local regulations, each Party remains liable for damages to third parties caused by its own staff, except if this staff is under the management and/or the control of the other Party, unless such damages were caused by or contributed to by the gross negligence or wilful misconduct of that staff.

ARTICLE 11 – DURATION AND TERMINATION

11.1 Subject to the entry into force of the Cooperation Agreement according to article 16.1 of the said Cooperation Agreement, this Implementing Agreement shall come into force upon signature by both Parties and shall remain valid up to 5th Dec 2020.

11.2 Three months before the date of termination, the Parties shall consult each other in order to decide whether this Implementing Agreement shall be extended or not.

11.3 Termination of this Implementing Agreement for any reason whatsoever shall be without prejudice to the rights which may have occurred under this Implementing Agreement to either Party up to the date of termination.

11.4 This Agreement shall remain in force up to 5th Dec 2020. Thereafter it shall be extended for further periods (as indicated in Article 4) after mutual written consent of the parties unless terminated by the either party by giving a 3 (three) months written notice in advance to the other party of its intention to terminate this agreement through diplomatic channels. Extension of this Implementing Agreement after 5th Dec 2020 is automatic after mutual consent subject to renewal of the said Cooperation Agreement beyond 5th Dec 2020. (Mutual consent will be in the form of one letter mentioning all the relevant Implementing Agreements).

ARTICLE 12 - SETTLEMENT OF DISPUTES

The Parties agree that any dispute arising out of this Implementing Agreement will be settled amicably if possible with assistance of one or more independent experts.

All disputes which cannot be settled between the Parties will be finally settled under the Rules of conciliation and arbitration of the International Chamber of Commerce by one or more arbitrators appointed in accordance with the said Rules. Procedures of arbitration shall be conducted in English. The place of arbitration shall be in Geneva (Switzerland).

ARTICLE 13 - AMENDMENT

The Implementing Agreement may be amended by mutual consent in writing of the Parties.

ARTICLE 14 – LANGUAGE

This Agreement is drawn up and executed in two copies each in the English and Hindi languages.

Done at on day of 2019 in two originals each in Hindi and English languages, all texts being equally authentic. In case of divergence in the interpretation, the English text shall prevail.

For the Indira Gandhi Centre for Atomic Research

Full Name: Dr. Arun Kumar Bhaduri

Title: Director, Indira Gandhi Centre for Atomic Research

Place and date: KALPAKKAM, 08/04/2019

(Signature)

For the Commissariat à l'Energie Atomique et aux Energies Alternatives:

Full Name: Mr Philippe STOHR

Title :Director of the Nuclear Energy Division

Place and date: May 21. 2019

(Signature)

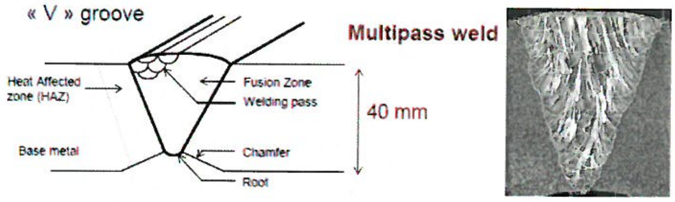
APPENDIX

Phased array ultrasonic inspection of thick austenitic stainless steel welds

Improvement of in-service inspection (ISI) is a major transverse issue to insure the safety of Sodium cooled nuclear reactors. ISI is strongly linked to safety analysis (the three defence lines: checking the state of material and equipment during the reactor lifespan, detection of premature failures, and in-operation detection of significant failures) and economic reliability (implementation delays).

One of the major difficulties for SFR ISI deployment is the sodium environment.

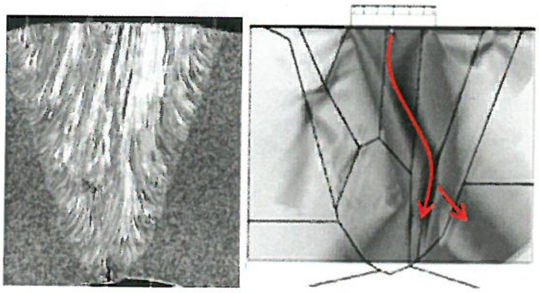
Mandatory inspection of various structures and components inside the main vessel will be periodically performed with acoustic sensors for Non Destructive Examination (NDE), well adapted to sodium environment: it is focused on welds as they are considered as the weakest parts.



Type of multipass weld designs and associated microstructure (as examples)

The development of ultrasonic methods for detection, localization and characterization of potential defects is a complex issue. Indeed, due to 20 to 40mm thickness range, heterogeneous and anisotropic nature of multi-pass austenitic stainless steel welds (AISI 316LN) induces strong perturbations in the propagation of the acoustic beam (skewing, division, attenuation, noise) that distort the diagnosis.

Accurate prediction of the propagation of ultrasonic waves strongly depends on detailed knowledge of the crystalline orientation, specific to each welding method and associated notebooks.



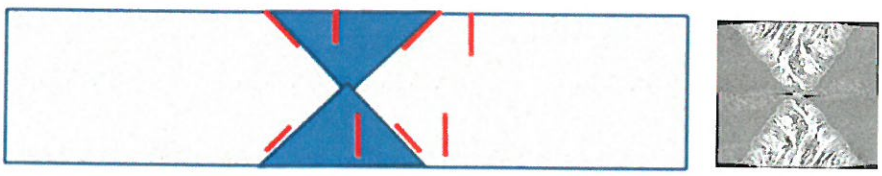
Example of skewing *and splitting of the ultrasonic wavefront*

Recent work on the subject has led to advances in the provision of a multi-pass welded structure made by Shielded Metal Arc Welding (SMAW). Thus, the aim is to analyse the crystalline orientation in order to understand the effect of welding parameters provided by the information contained in the welding notebook (sequencing order of the passes, intensity, ...), based on physical phenomena (thermal gradient, grain competition, pass shape ...). The local orientation is then provided at a lower scale than that of the welding pass. The forecast ultrasound propagation is then obtained using this orientation map and a set of elasticity constants specific to the weld metal.

In this context, the aim of this Implementing Agreement is to perform a study on the examination of thick TIG-welded joints (TIG or GTAW welding process being anticipated for future SFRs), with ultrasonic phased array techniques, in order to compare their efficiency. Chamfer shape will be determined latter but should be X or V or narrow shape.

Experimental work will be performed with dedicated weld mock-ups where some artificial defects will be looked at (detection and sizing), using conventional and advanced ultrasonic Non Destructive Examination techniques.

Ultrasonic control solutions will then be considered using available propagation models (COMSOL, CIVA, ABAQUS ...), conventional or advanced, to assess these solutions for detecting and sizing the defects in such thick welds.



Location and size of defects to be detected in welds (as example, not exhaustive)

Six main goals have been identified:

- Initial review of conventional and advanced ultrasonic phased array techniques for detection and sizing of defects,
- Raising specifications for welds to be controlled (material, shape, welding procedure, solder…) and for defects to be detected (type, size, location…),
- Calculations for simulation of Non Destructive Examination operations, with available softwares,
- Manufacturing of welding join mock-ups, with artificial defects, along RCC-MRx specifications, and associated characterization (material micrography).
- Non Destructive Examination of welding join mock-ups, for comparison with simulation results, with ultrasonic phased array techniques,
- Analysis of results, for comparison of Non Destructive Examination techniques and of for determining the influence of weld join characteristics on NDE efficiency.

OBJECTIVE

The objective of the collaboration is to check the ability of defect detection in thick stainless steel austenitic welds, with ultrasonic phased array techniques, for periodical inspection of sodium immersed components and structures: evaluation of such techniques will be done, depending on many parameters (welding process, weld join geometry and material, ultrasonic phased array sensors, access, ultrasonic scanning, signal treatment…) for finding the most efficient and also for evaluating the welding process influence on NDE results.

Indeed, heterogeneous and anisotropic nature of multi-pass austenitic stainless steel welds induces strong perturbations in the propagation of the acoustic beam (skewing, division, attenuation, noise) that distort the diagnosis. Accurate prediction of the propagation of ultrasonic waves strongly depends on detailed knowledge of the crystalline orientation, specific to each weld characteristics.

IGCAR and CEA aims at evaluating the effect of the specific crystalline weld orientation on the ability and performance of ultrasonic phased array techniques.

On the basis of PFBR and ASTRID design, CEA and IGCAR will specify the welding join characteristics, along an experience plan covering most of the possible welding process parameters (welding notebook with sequencing order of the passes, energy...). Some mock-ups will be manufactured, with some artificial defects, and then examined with different conventional or advanced NDE techniques and tools.

Destructive examination of each weld mock-up will also be performed in order to be able to link specific crystalline weld orientation and NDE results. Discrepancy of crystalline weld orientation (along the weld length) will also be looked at.

Simulation of these NDE operations will be performed with available softwares and techniques, for comparison to experimental results, to be validated and qualified.

Finally, IGCAR and CEA aim at evaluating the effect of these welding parameters on the defect detection efficiency: using different ultrasonic phased array transducers, scanning processes and signal treatments, the ability to detect defects in such thick welds will be evaluated.

MAIN STEPS

This collaboration will be done in six main steps:

- Initial review of conventional and advanced ultrasonic phased array techniques for detection and sizing of defects.
- Raising specifications for welds to be controlled (material, shape, welding notebook, solder…) and for defects to be detected (type, size, location…).
- Calculations for simulation of Non Destructive Examination operations, with available softwares.
- Manufacturing of welding join mock-ups, with defects, along RCC-MRx specifications, and associated material characterization (material micrography).
- Non Destructive Examination of welding join mock-ups, for comparison with simulation results, with available ultrasonic phased array techniques.
- Analysis of results, for comparison of Non Destructive Examination techniques and of influence of weld join characteristics.

- **Step 1: Initial review of conventional and advanced ultrasonic phased array techniques for detection and sizing of defects**

First, IGCAR and CEA will select the ultrasonic phased array techniques, adapted to such defect detection in thick austenitic welds. Of course, as this task has many connections with the next one (step 2 bellow on specifications for welds and defects), step 1 and 2 will start together.

The present status of the state of the art shall be reviewed.

A table will be drawn, giving transducer behaviours (number, size and pitch of elements, frequency spectrum, relative bandwidth (RBW) and signal to noise ratio (SNR) on planar reflector, possible deflection of the beam…), with also corresponding access for acoustic transducer to the mock-ups to be controlled (anticipating the global shape of mock-ups with a strait weld join between 2 plates: see Step 2 bellow), surrounding medium (water or air), "immersion" or "contact" NDE technique…

Types of waves	Piezo-electrical pellet diameter (mm)	Frequency (MHz)	Focalization depth (mm)	Controlled depth	Focusing zone at -6dB (mm)*	
					Dx**	Dr***

L0°						
L45°						
T45°						
*measurement at the focusing depth ** along translation axis *** along radial axis						

Characteristics of ultrasonic transducers (as example, not exhaustive)

Excitation pulse will be detailed (amplitude, duration, repetition…).

Associated signal processing implementation and scanning strategies will have also to be determined. In principle, ultrasonic transducer displacement can be raster scan. They could be as follows (not exhaustive):

- Straightforward C-scan with a single mono-element transducer using DSP-implementation.
- Synthetic Aperture reception scanning using a single mono-element transducer.
- Synthetic Aperture Focusing Technique transmission (beam forming) and Synthetic Aperture reception using an array.
- Ultrasonic Tomography.

The application of TOFD shall also be reviewed.

Two reports (D1C & D1I, see description in §IV below) will be written, summarizing the ultrasonic phase array sensors (with all associated conditions and data) which will be used by both companies.

- **Step 2: Raising specifications for welds to be controlled (material, shape, welding procedure, solder…) and defects to be detected (type, size, location…)**

Weld join specifications are very important for the next NDE analysis capabilities. Material will be only AISI 316LN ($X_2CrNiMo17\text{-}12\text{-}2$ with controlled nitrogen).

<u>It is assumed that both CEA and IGCAR will use the same welding notebookfor weld mock-up manufacturing.</u>

It is anticipated that automatic TIG process, with flat position of the mock-ups to be welded, will be studied. Welding voltage will be monitored in order to be as constant as possible during the whole welding operation (AVC Automatic Voltage Control).

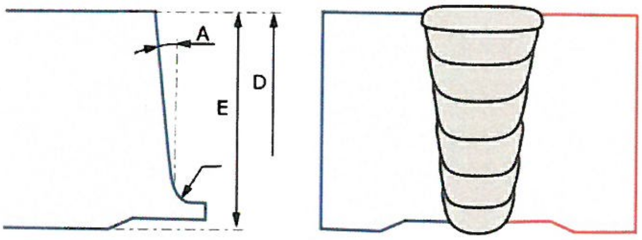
In a general manner, the up-to-date state of the welding art will be used.

A number of welding parameters will be determined, such as:

- Filler material:
  - CEA proposesThermanit 19-15filler material.
  - IGCAR proposes another Filler material 16-8-2 filler material.

  Selection of Filler material(s) will be discussed later.
  Filler wire speed will be in a range to be determined.
- Welding energy will be in a range to be determined.
- Welding torch lateral sweeping and speed will have to be determined.
- Number and size of passes will also have to be determined
- In case of any refusing operation, it will be written in the notebook as it is of great importance for next analysis.
- Size of the mock-ups: thickness should be in the range [25 – 40mm], length and width will be determined for optimizing the material stocks and allowing further destructive and non-destructive operations.
- Shape of the edge-to-edge welds (see next figure as an example): Chamfer shape will be selected among X or K or V or narrow shape.
- Basic material (plates) will be RCC-MRx proven and the original material casting direction will be taken into account for welding.
- Stiffeners (clamping) will have to be used for avoiding any strong bending of the mock-ups, during welding operations.
- Recording of welding temperature (fusion area) could be interesting for next understanding of solidification.

An experience plan will be fixed in order to cover the effects of the main welding parameters for next analysis. Thus, the number of weld mock-ups will depend on this experience plan but should be at least of some dozens for takin into account the effect of the main parameters (due to welding process and defect characteristics).



Design of nNarrow gap shape of edge-to-edge welds

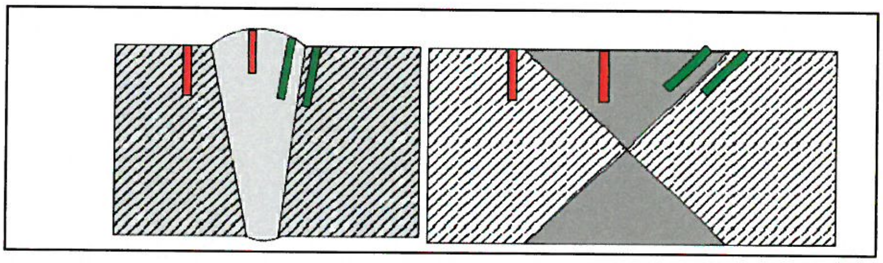
Artificial defects to be detected in the weld joints will also be specified for further evaluation of NDE techniques (see next figure):

- Shape (hole, flaw…)
- Size (compared to structure thickness, length, and orientation; width should be as small as possible)

- Location in the distance to transducer
- Location in the weld seam (in the molten bath or in the heat affected zone)

Defects characteristics will cover the range of potential defects for ASTRID and PFBR welds: they could be due to welding operation (sticking, lack of penetration, blow hole) or due to further nuclear reactor operation (open cracks due to thermal cracking).

Techniques for defects machining will be discussed.



Potential longitudinal cracking location, size and direction in welds (as example)

Two reports will be written as a common action (D2 & D3, see description in §IV below), one on specifications for welds to be controlled, and the other on specifications for defects to be detected.

- **Step 3: Calculations for simulation of Non Destructive Examination operations, with available softwares**

After having specified weld join mock-ups with artificial defects and manufactured them, both IGCAR and CEA will perform calculations for demonstrating the ability of available sofwares for simulating acoustic behaviour in such heterogeneous medium with defects.

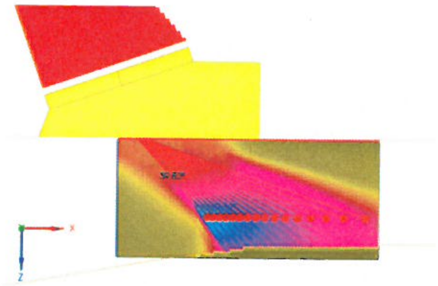
NDE of each weld join mock-up will be simulated, in order to check the influence of the different parameters (welding process and defects). Conditions of these NDE operations will be shared and selected, for a common approach (sensor characteristics – see step 1 above -, distance from sensor to mock-up, acoustic beam incidence…).

Same material data will be shared then used for the simulation (density, sound speed, soundattenuation).

CIVA software platform could be a common tool for this task. Furthermore, CEA is able to specify accurate acoustic characteristics of the weld sub-areas while describing them thanks to destructive examination results.

CIVA calculations are performed in two steps: first, acoustic field propagation in the medium, then calculation of the interactions of the acoustic field with defects, producing resulting echoes. CIVA takes into account the acoustic reflexion (with specular echoes) and the diffraction on edges (sharp defects).

COMSOL or ABAQUS could also be used (with finite elements).



Phased array acoustic beam in thick weld (as example)

IGCAR and CEA will define accurately the calculation conditions (2D/3D, longitudinal or shear waves…) and the way to present simulation results (A-Scan, B-Scan, C-Scan…), in order to be able to compare the results of the different mock-ups and also with simulation results.

A report will be written by each company (D4C and D4I: Technical note on simulation results of weld NDE, see description in §IV below).

- **Step 4: Manufacturing of welding join mock-ups, with defects, along RCC-MRx specifications, and associated characterization (material micrography)**

Based on former step 2 results, CEA and IGCAR will manufacture a certain number (to be determined) of weld join mock-ups. The same welding notebooks will be used by qualified welders at CEA and IGCAR.

Weld join mock-ups will be mainly manufactured at IGCAR, CEA anticipating to manufacture 6 of them. Some of IGCAR samples could be sent to CEA for next examinations and NDE operations in France.

Destructive examination of weld join mock-ups will be performed after cutting them with available means (saw or laser or else).

Some samples could be treated for relaxing residual stresses, using heating.

Then chemical treatment will be performed in two steps:

- Aqua regia or oxalic acid, for showing the welding passes,
- Iron perchlorate or sodium hydroxide, for showing the weld join macrostructure.

Other examination could also be envisaged, such as Scanning Electron Microscope, Electron Backscatter Diffraction or even Xrays…

A report will be written by each company (D5C and D5I: Technical note on welding join mock-up manufacturing, and associated destructive examination, see description in §IV below).

A visit will be organized so that one researcher of each institute will come and participate to the welding manufacturing carried out in the other institute during one week.

- **Step 5: Non Destructive Examination of welding join mock-ups, for comparison with simulation results, with ultrasonic phased array techniques.**

Non Destructive Examination of all welding join mock-ups will be performed at CEA and at IGCAR, using selected ultrasonic phased array transducers (see former step 1).

They will be performed at room temperature, in air and in water.

Reference blocks (with calibrated holes) will be used for calibration of the ultrasonic phased array transducers.

Electronic components will be described (at least their main characteristics and references).

Scanning characteristics will be specified: pitch, range and speed of the transducer while performing NDE of each weld join mock-up.

Notation threshold will be fixed along RCC-MRx standard (12dB under the reference reflector echo amplitude). Thus, all upper amplitude echoes will be selected and characterized. Using these data, acoustic images will be made in order to give an accurate view of the defects within the weld join mock-ups.

The way to present the NDE simulation results will be defined in order to be able to compare the simulation results of the different cases (for the different mock-up configurations), and also for comparison with NDE results on the real mock-ups gained in former step 4 (A-Scan, B-Scan, C-Scan…).

A report will be written by each company (D6C and D6I: Technical note on Non Destructive Examination of welding join mock-ups, see description in §IV below).

- **Step 6: Analysis of results, for comparison of Non Destructive Examination techniques and of influence of weld join characteristics.**

The results gained during former steps (NDE results in step 5 and corresponding simulation results in step 3) will be analysed:

- Comparison of ultrasonic phased array transducer efficiency for detecting / sizing / localizing the different defects, along weld join characteristics,
- Comparison of the effect of weld join characteristics on NDE efficiency,
- Comparison of NDE simulation results with NDE results on the real mock-ups, in order to assess the validation level of softwares,

A report will be written by each company (D7C and D7I: Technical note on analysis of results - comparison of Non Destructive Examination techniques and of influence of weld join characteristics - see description in §IV below).

- Step 7: Common papers for publication

Common papers will be written and proposed for publication in an International Journal, in order to conclude this common study on simulation and experimental NDE of thick 316LN weldings (D8, see description in §IV below): two common papers could be issued, one with CEA as main author and the other with IGCAR as main author.

LIST OF DELIVERABLES

- Step 1: Initial review of conventional and advanced ultrasonic phased array techniques for detection and sizing of defects.
    - D1C: Technical note on CEA review of conventional and advanced ultrasonic phased array techniques for NDE.
    - D1I: Technical note on IGCAR review of conventional and advanced ultrasonic phased array techniques for NDE.
- Step 2: Raising specifications for welds to be controlled and defects to be detected.
    - D2: Common technical note on specifications for welds to be controlled.
    - D3: Common Technical note on specifications for defects to be detected.
- Step 3: Calculations for simulation of Non Destructive Examination operations, with available softwares
    - D4C: Technical note on CEA simulation results of weld NDE.
    - D4I: Technical note on IGCAR simulation results of weld NDE.
- Step 4: Manufacturing of welding join mock-ups, with defects and associated characterization (material micrography).
    - D5C: Technical note on CEA welding join mock-up manufacturing report, and associated destructive examination.
    - D5I: Technical note on IGCAR welding join mock-up manufacturing report, and associated destructive examination.
- Step 5: Non Destructive Examination of welding join mock-ups, for comparison with simulation results, with ultrasonic phased array techniques.
    - D6C: Technical note on CEA Non Destructive Examination of welding join mock-ups.

   - D6I: Technical note on IGCAR Non Destructive Examination of welding join mock-ups.
- Step 6: Analysis of results, for comparison of Non Destructive Examination techniques and of influence of weld join characteristics.
   - D7C: Technical note on CEA analysis of results (comparison of Non Destructive Examination techniques and of influence of weld join characteristics).
   - D7I: Technical note on IGCAR analysis of results (comparison of Non Destructive Examination techniques and of influence of weld join characteristics).
- Step 7: Publication in an International Journal, in order to conclude this common study on simulation and experimental NDE of thick 316LN welding.

SCHEDULE

Assumed date of entry into force of this Implementing Agreement (T0) is supposed to be early 2018.

CEA-IGCAR Implementing Agreement PHASED ARRAY ULTRASONIC INSPECTION OF THICK AUSTENITIC STAINLESS STEEL WELDS	2018				2019				2020				2021				2022	
	T0 + 3 months	T0 + 6 months	T0 + 9 months	T0 + 12 months	T0 + 15 months	T0 + 18 months	T0 + 21 months	T0 + 24 months	T0 + 27 months	T0 + 30 months	T0 + 33 months	T0 + 36 months	T0 + 39 months	T0 + 42 months	T0 + 45 months	T0 + 48 months	T0 + 51 months	T0 + 54 months
Assumed date of entry into force of this Implementing Agreement (T0)	▲																	
Review of NDE techniques																		
Spécifications of TIG welds and defects																		
Simulation of ultrasonic examination of welds with defects																		
Manufacturing of weld mock-ups with articificial defects (to be characterized)																		
Destructive examination: macrographic analysis of weld mock-ups																		
NDE operations of weld mock-ups																		
Analysis of results, for comparison of Non Destructive Examination techniques																		
Analysis of results, for comparison of influence of weld join characteristics																		
Common publication																		