NUCOBAM

Innovation Action (IA)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 945313

Start date : 2020-10-01 Duration : 48 Months

EUG lessons learnt

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NUCOBAM - Contract Number: 945313

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Document title	EUG lessons learnt
Author(s)	Mrs. Nawel BOUDEBZA
Number of pages	16
Document type	Deliverable
Work Package	WP6
Document number	D6.5
Issued by	EDF
Date of completion	2025-01-17 11:56:34
Dissemination level	Public

Summary

This report presents shared experiences, codification routes and expectations of different partners (industry, research centers, regulators?) from different countries.

Approval

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Disclaimer

Preface

This project named NUCOBAM NUclear COmponent Based on Additive Manufacturing has received funding from the EURATOM research and training programme 2014-2018 under grant agreement No 945313.

The partners are:

- CEA: Commissariat à l'énergie atomique et aux Energies Alternatives,
- EDF: Electricité de France,
- LABORELEC: Belgisch Laboratorium van de Elektriciteitsindustrie Laborelec cvba,
- TRACTEBEL: Tractebel engineering,
- NAVAL: Naval group,
- FRAMATOME: Framatome SAS,
- CIEMAT: Centro de investigaciones energeticas, medioambientales y tecnologicas-ciemat,
- UDSD: The university of Sheffield, VTT: Technical Research Centre of Finland Ltd,
- SCK.CEN: Centre d'étude de l'énergie nucléaire fondation d'utilité publique,
- JRC: Joint Research Centre- European commission,
- RAMEN VALVES: Ramen valves ab,
- IRSN: Institut de radioprotection et de sureté nucléaire.

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History

Date	Version	Submitted by	Reviewed by	Comments
31/05/2024	1	Nawel BOUDEBZA	Gaëlle LEOPOLD	First version
18/12/2024	Final Version			

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Executive Summary

This deliverable describes the way in which the End User group was set up and the various meetings proposed to them in order to exchange on the content of our work. All exchanges are traced and all data that was transmitted to the End User group is collected here. Thus, all the data presented here have been submitted to their expertise and questions. Their feedback on our work is very important and we thank them for agreeing to be part of our End User Group.

Keywords

Nuclear, additive manufacturing, qualification, nuclear code, nuclear standard

Abbreviations and Acronyms

Acronym	Description
NUCOBAM	NUclear COmponents Based on Additive Manufacturing
WP	Work Package
AM	Additive Manufacturing
EUG	End User Group

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1. Objective of the project NUCOBAM

The main objective of NUCOBAM (NUclear COmponents Based on Additive Manufacturing) is to develop the qualification process allowing the use of a metal Additively Manufactured (AM) components in a nuclear installation.

The 6 objectives of the project are:

1. Establish a qualification methodology for AM nuclear components to be proposed for standardization and to be communicated to nuclear design code committees
2. Develop a laser powder bed fusion manufacturing plan to manufacture 316L laboratory specimens and two components that ensures and demonstrates process stability, repeatability and reproducibility that meet nuclear quality standards
3. Demonstrate that laser powder bed fused material performance meets qualification requirements (laboratory tests)
4. Demonstrate that laser powder bed fused in-core use (debris filter component) case meets its safety-related function and operational requirements
5. Assess the operational performance of ex-core AM components (valve body) regarding safety related function and operational requirements
6. Disseminate and prepare the exploitation of results with nuclear industries and regulatory bodies in support to codification and industrialization of AM.

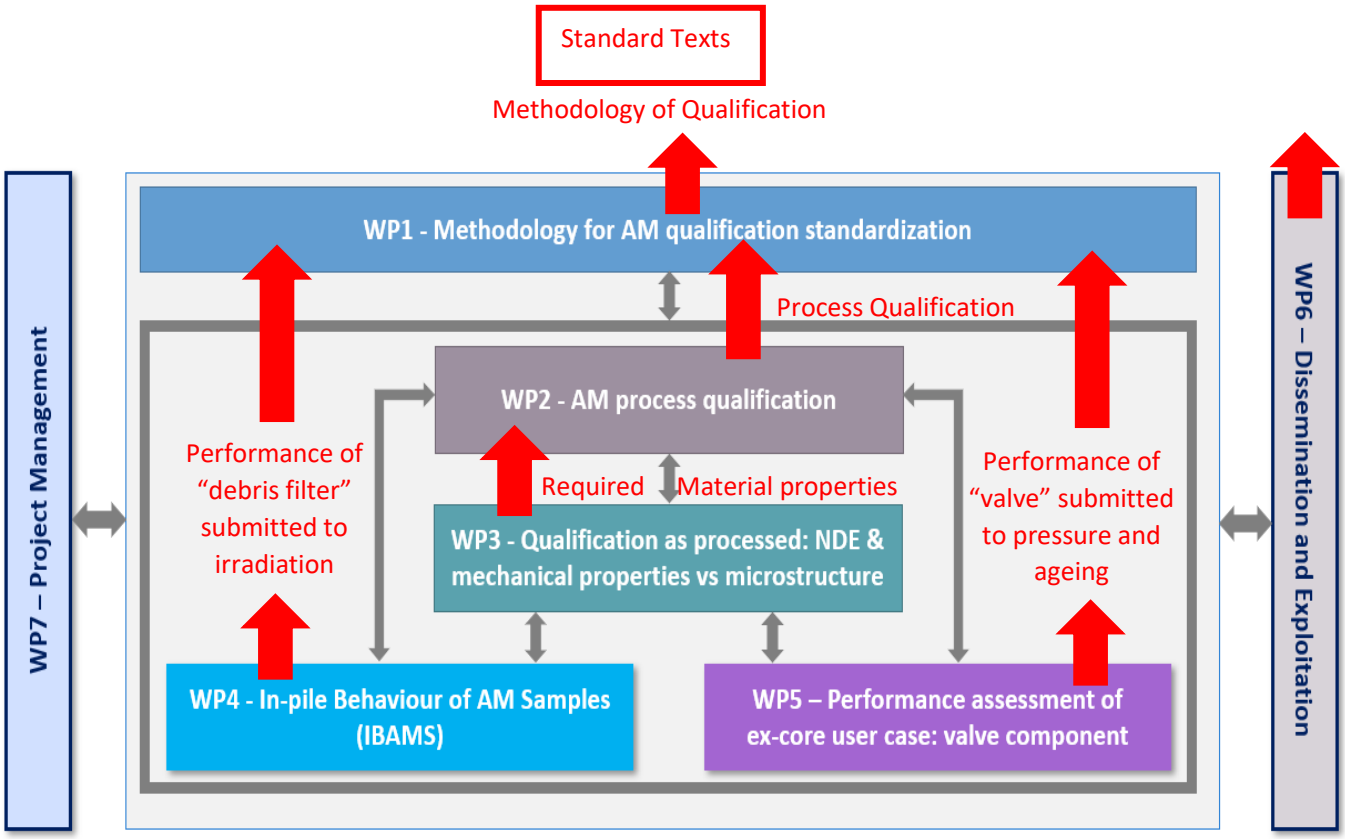

Figure 1: Graphical representation of the NUCOBAM workplan.

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NUCOBAM project has set itself five technical objectives and one dissemination related objective, which are strongly correlated to the project methodology and the structure of the work packages. The implementation of the project was divided in 6 main Work Packages directly linked to these 6 objectives.

The members of the NUCOBAM consortium have the complementary expertise necessary to achieve the goal of the project. It gathers electricity utilities, operating nuclear assets, component manufacturers, and design owners, public service experts in nuclear and radiation risks as well as research and competence centers involved in mechanical assessment, metal powder qualification, metallurgical characterization, materials irradiation capabilities and nuclear power research.

The main deliverable – "Nucobam Methodology of AM qualification" reflects all the work performed during the 48 months of the project. All other Work Packages contributed to the demonstration that the new L-PBF 316L material meets all the nuclear properties requirements (better or equal to those existing in codification for a conventional 316L), and that both demonstrators "debris filter" and "body valve" passed in service requirements respectively -irradiation & geometrical conformability- and -thermomechanical loadings ageing & corrosion-, provided that the manufacturing of the new L-PBF 316L follows the procedure of qualification that has been established here in the Methodology and used for the production of all specimens and components of the project.

The "ultimate Deliverables are the two standard texts", from the Deliverable of NUCOBAM Methodology are:

- a proposal intended for RCC-M code (AFCEN) and
- a proposal intended for ASME-III code.

It should be noted here that submitting these proposals to the corresponding nuclear code's committees is not included in the NUCOABM work plan. However, this work was initiated for the RCC-M by members of AFCEN, who were also experts in the "codification" task of this project and other French project.

2. Role of the End User Group

AM introduces new solutions that consider various aspects of a product's lifecycle, from its initial requirements to its use and maintenance. Safety is of paramount importance in the nuclear industry, which imposes stringent constraints on equipment. Component qualification must meet strict standards. However, the adoption of such processes depends on demonstrating the equivalence in terms of the quality and safety of AM components compared to materials and processes conventionally used in the industry. This applies to components both within the reactor core (in-core) and situated outside of it (ex-core). To address this challenge, the European project NUCOBAM has been initiated.

Additive manufacturing technology is already incorporated in the supply chain of aerospace, automotive, industries, among others. However, commercialization of AM components by commercial vendors and supplier are not as successful, mainly due to the lack of clear qualification standards. In order to ease a rapid industrialization of AM in nuclear industry, one of the most "non-technical" objectives of NUCOBAM was to establish dialogue with nuclear industries and regulators to define the regulatory pathway for using AM in the nuclear industry.

To ensure in Nuclear Industry the applicability of models and tools developed in NUCOBAM, an end-user group (EUG) have been set up at the beginning of the project, with the aim of assessing NUCOBAM models, tool and

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results all along the project. The EUG was composed of experts from the partner's organizations as well as experts external to the project.

The dissemination and exploitation of results with nuclear industries and regulatory bodies are the last main objective of the project. And the EUG set up was key to prepare the exploitation of results with nuclear industries and regulatory bodies in support to codification and industrialization of AM.

The NUCOBAM objective is to provide and demonstrate high confidence level scientifically and technical results in the project and to bring and share these results with nuclear industry and regulator for future operation of AM components in NPPs.

EDF lead the WP6 activities and specifically the set up and management plan of the EUG. Its aim is to organise the assessment of models and tools.

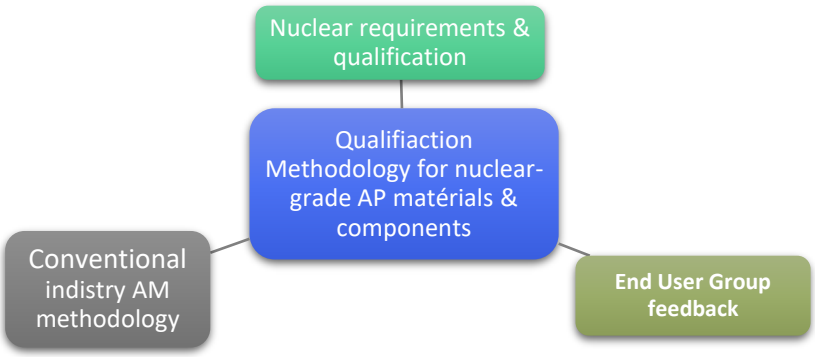

Figure 2 : Relation and conversion of the methodology into a standardized text

The EUG had no decision-making authority but it provided advice and made proposals.

3. Set-up and monitoring of the End-Users group

To ensure the industrial applicability of models and tools developed in NUCOBAM, an end-user group (EUG) has been set up. Due to organizational and pandemic issues, the first meeting with EUG took place only on *May 2, 2022*. The sign up of the Non-Disclosure Agreements (NDA) was delayed too due coordination issue (and was only completed after this meeting. The objective of the first meeting was the review of theobjectives and implementation of the project (no confidential data at this point).

We have encountered legal difficulties with organizations from the United States. Their law obliges them to cite the law of their state while Nucobam being a European project obliges us to cite the Public Courts of Brussels. Unfortunately there is no solution for this situation. It was impossible for them to sign an NDA and to have this important members in our EUG.

Due to Covid restrictions, the Kick Off Meeting was held remotely. Then the first plenary in person meetings took place at La Cristallera near Madrid 18 months after the beginning of the project. It was decided to organize the meeting without external participants. It was not possible to invite the EUG members, because not all of them have signed the NDA document. That is why the WORKSHOP with EUG did not take place during the first plenary meeting (26-28 Sept 2022) but the NUCOBAM results were presented in a dedicated meeting for EUG on *November 9, 2022*, just one month after the first Nucobam internal plenary session.

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3.1. First results meeting, November 9, 2022

Presentations were focused on results: WP1, WP2 and part of WP3:

- 9h30 – 10h00 - WP6: Round table, Informations, Introduction (Romain VERLET)
- 10h00 – 10h30 - WP1: CEA or Tractebel
- 10h30 – 11h15 - WP2: Laborelec and USFD
- 11h15 – 12h00 – WP3:
    - Naval Group tests
    - CIEMAT tests
    - Fatigue tests : Framatome
- 12h00 – 12h15: general feedback from end users group (Romain VERLET and End Users Group)
- 12h15: closure

The project have planned several plenary meetings listed here with the participation of the EUG.

Heading 1	Main audience	Special session	Objective
Kick-off meeting 12 Dec 2020 On-line	Consortium members	Remote meeting	Introduction of project Presentation of each WP Discussion on EUG
Mid-term: internal meetings only 26-28 Sept 2022 La Cristallera, Spain	Consortium members	First in person meeting for Nucobam consortium members	WPs Progress meeting Review meeting with PO General assembly
Second period: internal & external meetings Fab lab event **19-21 Sept 2023** host LABORELEC Brussels, Belgium	Consortium members **End User Group** Other actors from nuclear field or regulators	External session **Main Nucobam Results** **Workshop** **Fab lab event**	WPs Progress meeting Review meeting with PO General assembly Feedback of EUG and Nuclear field
Final period Internal & external **17-19 Sept 2024** host CIEMAT Madrid, Spain	Consortium members **End User Group** Other actors from nuclear field or regulators	Final External session **Nucobam results and assessment**	WPs Final meeting General assembly consortium Feedback + Feedback of EUG and Nuclear field

Table 1 – NUCOBAM project events and End User Group

The WORKSHOP with the EUG took place in 2023 with a lot of results presented to EUG to get their feedback. It was decided not to have another WORKSHOP during the last plenary Meeting, but to have more presentations focused on relevant discussions on NUCOBAM results and perspectives.

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3.2. September 20, 2023

The Mid term workshop and a *Fab Lab event* were held in Brussels hosted by LABORELEC on *September 20-21, 2023*. The agenda was:

DAY 2: *September, 20 2023*

- 13h00 – 16h00 -External SESSION: Welcome End Users & Nuclear sector
  High Level presentations:
  - WP1-Methodologies (CEA, Tractebel)
  - WP2- Manufacturing (VTT)
  - WP3-1 Introduction-Metallography intergranular corrosion (Naval Group)
  - WP3-2 Slow Strain Rate Tests Results (EDF)
  - WP3-3 Stress Corrosion Cracking (EDF)
  - WP3-4 Tensile & Charpy-Tests Results (CIEMAT)
  - WP3-5 Fatigue Tests Results (IRSN)
  - WP3-6 Fracture Toughness Tests Results (JRC)
  - WP5- Valve Body component (Tractebel)
- 16h00 – 16h30: Coffee Break
- 20h00: Dinner

DAY 3: *September, 21 2023*

- 9h30 – 10h00 - Introduction
- 10h00 – 12h00 – LAB TOUR 1 (4 groups)
- 12h00 – 13h00 – Lunch (Finger Food)
- 13h00 – 15h00 – WORKSHOP (4 groups)
- 15h00 – 15h30 – Coffee Break
- 15h30 – 16h00 – Conclusion of the Workshop
- 15h00 – 15h30 – Coffee Break
- 15h30– 17h30 – LAB TOUR 2

LAB TOUR: visit of AM Laboratory, presentation of printed valve & filters, 3D scanning, non-destructive testing demonstrations, tour of LBE qualification installation

WORKSHOP: Small workshop in 4 groups to collect feedback from participants on different topics: Codification, material performance (properties, irradiation…), qualification strategy ….

Each workshop was chaired by the corresponding NUCOBAM WP leader and co-chaired by a Laborelec facilitator. The klaxoon (virtual whiteboard sotfware) has been used to facilitate discussions with remote people.

3.3. September 17-19, 2024

The Last Term internal and external Sessions took place *on September 17-19, 2024* in Madrid, hosted by CIEMAT. This event was organized by CIEMAT, EDF and CEA.

The external *agenda was focused on synthesis and feedback of NUCOBAM project and future works or others following projects.* New projects “De Facto”, “EASI-SMR”, “CONNECT-NM” were presented respectively by the project managers from EDF and by two research managers from CIEMAT. Research actives in AM frame were

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presented by two experts from CEA and industrial activities on AM components were presented by a speaker from Framatome (presentation are confidential).

DAY 3: *September, 19 2024*

- 9h00 – 9h30–Welcome, Round table, presentation of the agenda
- 9h30 – 9h50 – Overview of NUCOBAM Results
- 9h50 – 10h30 – WP leaders & Partners Overview – open discussion on results
- 10h30 – 10h50 – Feedback from End Users, stakeholders and nuclear community members
- 10h50 – 11h10 – New EURATOM project: EASI-SMR, WP dedicated to AM), CIEMAT
- 11h10 – 11h40 – Coffee Break
- 11h40 – 12h00 – De FACTO New French project, Direction of Industrial Qualification, EDF
- 12h00– 12h20 – FRAMATOME Overview of the AM Activities and Roadmap
- 12h20– 12h40 – PhD Results on fracture behaviour on L-PBF & WAAM on 316L alloy, CEA
- 12h40– 13h00 – AM for Nuclear Application : Ongoing R&D Work, Challenges and Perspectives, CEA
- 13h00– 13h20 –Open Discussions, Conclusions, Perspectives

Participants of the EUG are presented below, and they come from **7 countries**: Belgium, Czech Republic, Finland, France, Germany, Sweden, and United Kingdom. The EUG is composed of **14 members** coming from **13 organizations**. Their implication at the four events during this project show their great interest for our project.

	Member	***First Meeting***	***2022***	***2023***	***2024***	***EUG***	***Country***
1	ENGIE Electrabel	x	x	x	x	Yes	Belgium
2	Vattenfall	x	x			Yes	Sweden
3	Ringhals	x	x	x		Yes	Sweden
4	Volum-E	x	x	x	x	Yes	France
5	TVO	x				Yes	Finland
6	Add'Up	x	x	x		Yes	France
7	ORANO	x	x	x		Yes	France
8	Czech Technical University	x	x	x	x	Yes	Czech Republic
9	ISO/TC 261	x				Yes	Germany
10	Direction Générale de l'Armement	x	x			Yes	France
11	Lloyd's Register EMEA	x	x	x	x	Yes	UK
12	VELAN	x	x	x		Yes	France
13	AFCEN	x	x	x		Yes	France
14	SULZER	**	x			Yes	France

Table 2: composition of the End-Users Group and attendance to Nucobam meetings,

** Sulzer integrated later the EUG

3.4. Exchanges during meetings

3.4.1. Answers and questions

Main questions & Answers are given as examples in this paragraph and extract from the fisrt results on-line meeting on *November 9, 2022.*

<u>Presentations by VTT on WP2: manufacturing plan for AM</u>

Question by one EUG member:

"One comment on the minimum density limit of >99,0%. For information, the minimum limit stated in ISO/ASTM DIS 52908 is >99.8% (which is also specific to LPBF)."

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Answer by VTT:
"99.8% is to be achieved with optical image analysis? Or Archimedes relative density? We had a lot of internal discussion about this topic and representativeness of the area to be analysed is also of interest."
Answer by one EUG member:
"Yes, this particular limit seems to be a moving target. A few years ago when ISO/TC 261 was launched I remember the limit was 98%, then 99%, then 99.5% and most recently 99.8%. Regarding the methods used to determine relative density: "Density can be tested by Archimedean methods, by gas pycnometry (see ISO 12154) or optically by quantitative analysis of metallographic specimen images. Non-destructive testing methods can also be used for density evaluation via image processing of 2D or 3D images. I predict your next question will be about the accuracy of Archimedes method vs the required limit."
Question by EUG:
"According to Heat Treatment at 650°C is one of the temperature of structural and corrosion sensitization of 316L? Is it a criteria taken into account."
Answer by EDF:
"For Stainless steel with low carbon (L) is supposed to don't have sensitization because we can have precipitation of chromium carbide in grain boundaries to decrease the concentration of chromium in the grain boundaries and increase sensitivity of grain boundaries to corrosion. This heat treatment is proposed to check if is sufficient to have good behaviour of the material, and the corrosion in PWR environment and inter-granular corrosion with standard method will be check of course."
Answer by EUG:
"But depending on the initial C distribution (as built) and time of Heat Treatment temperature which is in direct relation of the size/thickness of the making parts."
Answer by EDF:
"Yes of course, and for additively manufacturing material, it can be more complicated. Is the reason why we will test 4 Heat Treatments. Maybe only stress relieve is OK."
Answer by EUG:
"Annealing seems always a good solution but for geometrical and dimensional considerations, it could be a real issue!"

<u>Presentations by CEA on WP1: Methodology of AM qualification</u>
Question by EUG:
"Do you confirm that the objective is to have at the end of the project a list of essential parameters that could be codified?"
Answer by CEA:
The objective is to have a list of parameters as exhaustive as possible.
Question by EUG:
Is welding of component make by additive manufacturing taken into account in the project?
Answer by CEA:
This part will be written in the methodology but will not be tested in NUCOBAM project (not part of the project).
Question by EUG:
"Are there any requirements related to grain size for process qualification?"
Answer by CEA:
A part is dedicated to this parameter, based on the existing criteria

3.4.1. Workshop with white board tool

For the external session that took place in Brussels at Laborelec, the Klaxoon software and a questionnaire was used to facilitate exchanges during the **workshop** *September 20, 2023*. Example of virtual board is given bellow.

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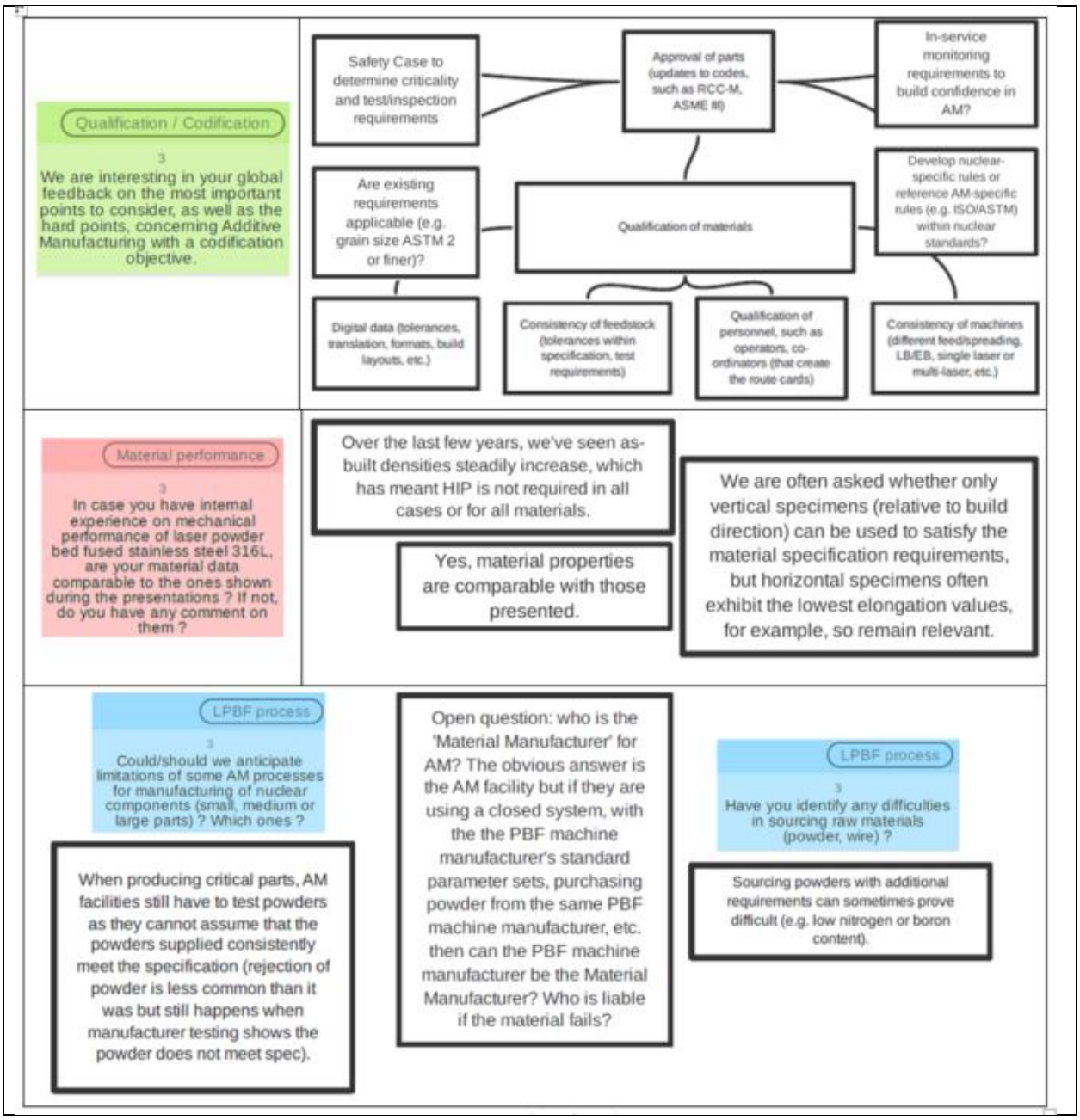

Figure 3 : Results of exchanges

3.4.2. Interactions with others external organizations

September, 2023 in Brussels

During the workshop, the round table was completed by presentations of external people from:

- CAMINA: Canadian Advanced Manufacturing in Nuclear Alliance
  & OCNI: Organization of Canadian Nuclear Industries

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- IAEA: International Atomic Energy Agency

Others external peoples came from others organizations:

- Aubert & Duval, Powder and steel manufacturer, France
- ENSI Swiss Federal Nuclear Safety Inspectorate
- March Consulting Associates Inc,
- NAAREA, start-up in Nuclear on Micro-reactor design, France
- PaB Engineering Ltd, Budapest, Hungary
- Université de Lille, France
- UJV, Czech Republic
- PSI Paul Scherrer Institut, Switzerland
- Nuclear Power Plant Leibstadt AG, Germany
- TA TechicAtome, France
- CETIM, Centre Etudes des Industries Mécaniques, France
- INOVSYS, Additive Manufacturing, Innovative Technologies, France
- CRM Group, Belgium
- BZN, Nuclear frame Laboratory, Hungary
- McMaster University, Canada
- CNSC Canadian Nuclear Safety Commission

September, 2024 in Madrid

- ENSI Swiss Federal Nuclear Safety Inspectorate
- CNSC Canadian Nuclear Safety Commission
- CAMINA
- McMaster University, Canada

The last review meeting took place in Madrid on September 2024, with a dedicated session to present the results to the EUG. Discussions followed the presentations. The presentations have been made available on the NUCOBAM website (public section).

As previously mentioned, various exchange sessions were organized to exchange with the EUG and also to share the results coming from the studies carried out as part of the project. These face-to-face and video-conference exchanges were rich and constructive.

The final session in Madrid on September 2024 was a special bringing the project to a closure and presenting all the results of the 6 Work Packages, as well as the prospects of AM for each consortium member.

4. Publications and documents

4.1. Conferences & presentations

A special session dedicated to NUCOBAM project took place at the PVP Pressure Vessels & Piping conference, in Bellevue, WA, USA between July 28 and August 2, 2024. Four papers were presented and they are available in the collaborative public platform: https://nucobam.eu.

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During the session, discussions were rich and constructive. Below are 2 examples of questions asked by the audience:

- Is there a correlation between the different fatigue lifetimes depending on orientation (X,Z) and the "static" mechanical properties (Sigma_y, Rm for example) of the material?
- Is this difference in fatigue life depending on orientation problematic for a complete part and not for a machined specimen?

For reasons of confidentiality, the four project manufacturers were anonymised on the slides and in the papers.

Table 3 – PVP 2024: Specific NUCOBAM session in European project session.

	Title / open access link	**PVP2024**	Authors **Speaker**
1	NUCOBAM Project, Nuclear Components Based on Additive Manufacturing	-122057	[CEA] Myriam Bourgeois **[CEA] Jorge Munoz** [EDF] Gaëlle Léopold
2	Some Challenges Regarding Qualification of Additive Manufacturing Components for a Nuclear Use	-123276	[CEA] Cécile Petesch **[TRACTEBEL] Roxane Misler**
3	Fatigue behavior in air of 316L stainless steel obtained by additive manufacturing	- 123296	[IRSN] Thierry Sollier **[IRSN] Jonathan Quibel**
4	Performance Assessment of Additive Manufacturing Components for an Ex-Core Nuclear User : Valve Component	-123236	**[TRACTEBEL] Roxane Misler**

4.2. Peer review articles

Following these exchanges, the NUCOBAM website was updated to include presentations and references to articles published during the project:

- "Non Destructive Inspection of additively manufactured classified components in a nuclear installation" by Alfredo Lamberti, Wouter Van Eesbeeck and Steve Nardone, ***NDT* 2024**, *2*(3), 228-248; **https://doi.org/10.3390/ndt2030014**

Published in NDT journal

- "Mechanical properties of neutron irradiated 316L stainless steel additively manufactured by laser powder bed fusion: effect of post-manufacturing heat treatments", M.J. Konstantinovic, D. Bardel, W. Van Renterghem, S. Van Dycka, G. Badinier, K. Ettaieb, A. Revuelta, T.Riipinen

Preprint version not published yet.

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4.3. Public Deliverables

The public deliverables will be found in the platform: https://nucobam.eu after the validation of the PO of the project (beginning of 2025). The free access deliverables of the project are:

- D1.4 Standard text WP1
- D4.4 Scientific article WP4
- D6.1 Communication plan WP6
- D6.2 NUCOBAM public website WP6
- D6.5 EUG lessons learnt WP6

It should be noted that the first one is the ultimate deliverable of the project intended for codification of AM process and the last Deliverable provides a view of the experimental work performed during this project.

5. Conclusion

To conclude on the feedback from this EUG, this group was interested in both the qualification methodology for manufacturing and the amount of experimental data produced on this material and some of participants were able to promote the results of NUCOBAM project since:

- The qualification standard proposal for RCC-M code will be provided to the AFCEN committee (work not foreseen by the project).
- One of the members proposed the experimental data to be presented to UNM*Union de Normalisation de la Mécanique* (the French sectorial standardization office for mechanical engineering, operating on behalf of AFNOR) in order to develop a dedicated standard on additive manufacturing of 316L by L-PBF. The contact with UNM has been established. It is therefore to be followed and instructed by the CEA coordinator (&Consortium) as regards the most appropriate IP rules.

6. Appendix

All the slides presented at the three meetings for EUG and external people are compiled in this appendix with the date of the event at the bottom of the page:

- EUG_November_2022

- EUG_September_2024

- EUG_September_2023

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