



Partitioning And Transmuter Research Initiative in a Collaborative Innovation Action

PATRICIA

Grant Agreement Number 945077

Research and Innovation Action

Activity: NFRP-2019-2020

Topic: NFRP-2019-2020-07 Safety Research and Innovation for Partitioning and/or Transmutation

Start date: 01/09/2020 – Duration: 48 months

D14.1 Project Presentation

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This project has received funding from the Euratom Research and Training Programme 2019-2020 under grant agreement No 945077.

DOCUMENT CONTROL SHEET

DOCUMENT INFORMATION

Document title	Project presentation
Document type	Deliverable
Document ID	D14.1
Work package n°	WP14 (Domain: MECT)
Work package title	WP14 Knowledge management, education and training
Lead beneficiary	SCK CEN
Dissemination level	Public
Date of issue	24/02/2022
Archive reference	SCK CEN/39396479

DOCUMENT SUMMARY

This document presents PATRICIA's objectives and activities, the expected results and societal impact.

DOCUMENT HISTORY

Version	Date
v0	29/06/2021
v1	24/02/2022 Correction on the front page and in Chapter 6, page 10 referring to EU funding, for which the correct sentence is: <i>"This project has received funding from the Euratom Research and Training Programme 2019-2020 under grant agreement No 945077"</i> .

DOCUMENT APPROVAL

The author, WP Leader and Coordinator acknowledge and accept delivery of the work completed for this deliverable.

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24/02/2022	Philippe Planquart (WP Leader)	IVKDF
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DISTRIBUTION LIST

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Project Officer Renata Bachorczyk-Nagy	EC	Copy on PATRICIA SharePoint
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1. Introduction

PATRICIA, the **P**artitioning **A**nd **T**ransmuter **R**esearch **I**nitiative in a **C**ollaborative **I**nnovation **A**ction, is established in NFRP-07 ‘Safety Research and Innovation for Partitioning and Transmutation’ of the EURATOM work programme 2019-2020. PATRICIA focusses on four technical domains: [partitioning](#), [transmutation](#), [driver fuel & fuel assembly safety](#) and [ADS system safety](#). A fifth domain outlines the project management and dissemination.

The project focusses on a combination of experiments, theoretical studies and numerical simulations, calling upon each partner’s skills and expertise.

2. Project objectives

The SET-Plan¹ (Strategic Energy Technology plan) is the technology pillar of the EU’s energy and climate policy. For 2020, the specific goal is ‘*to maintain the competitiveness of current reactors (Generation II and III) combined with the implementation of solutions for waste management*’. For 2050, the objective is ‘*to demonstrate the long-term sustainability of fission Generation IV technologies with closed fuel cycle*’.

To address these two issues, the European nuclear research, development and deployment community has defined a Strategic Research and Innovation Agenda (2013) and a Deployment Strategy (2015) within the frame of the Sustainable Nuclear Energy Technology Platform (SNETP). In addition, one of the main objectives of the European Sustainable Nuclear Industrial Initiative² (ESNII) is to demonstrate Gen-IV fast reactor technologies with closed fuel cycle, to harness European research and industrial capabilities to build advanced fast reactor prototypes and develop supporting infrastructure.

In Europe, four prototypes/demonstrators are studied: ASTRID for Sodium-cooled Fast Reactor (SFR), MYRRHA³ for Accelerator Driven System/Lead-cooled Fast Reactor (ADS/LFR) pilot plant, ALFRED (demonstrator) for LFR and ALLEGRO for Gas-cooled Fast Reactor (GFR).

PATRICIA is divided in four technical domains: Partitioning, Transmutation, Driver fuel & core safety and ADS system safety. A fifth domain deals with management, education and training.

Partitioning

- ✓ Focus on separation of Am and
- ✓ Conversion of Am solution to usable fuel material

Transmutation

- ✓ Focus on reaction of Am under irradiation and
- ✓ Model development and implementation of the model development in fuel performance codes

Driver fuel and fuel assembly safety

- ✓ Focus on safety research related to driver fuel and MYRRHA core and
- ✓ R&D input for MYRRHA PSAR (Preliminary Safety Assessment Report)

ADS system safety

- ✓ Focus on Safety of the ADS system and
- ✓ Research that will serve as input for the MYRRHA PSAR

¹ <https://ec.europa.eu/energy/en/topics/technology-and-innovation/strategic-energy-technology-plan>

² <http://www.snetp.eu/esnii/>

³ Multi-purpose hYbrid Research Reactor for High-tech Applications

Education and training

- ✓ Education will focus on 2 schools (HLM technology and P&T)
- ✓ International workshop in combination with the conference IEMPT-TCADS
- ✓ Booklet for high school students.

3. International context and relation to other EU projects

The consortium of PATRICIA project is composed of 25 partners; European partners from Belgium, France, Sweden, Spain, Germany, UK, Italy, Czech Republic, the Netherlands, Finland and Romania together with partners from non-EU countries, Switzerland, the Russian Federation and one international partner from the US.

As shown in the figure below, PATRICIA is building on the knowledge generated in previous projects. In particular the section on partitioning builds on SACSESS and the still active projects GENIORS and INSPYRE. On the other hand, the part supporting the development of MYRRHA as a transmuter expands the actions performed previously in MYRTE, SESAME and MAXISIMA. In the present call, the PASCAL project that is supporting the safety of lead and lead alloy systems is closely related to PATRICIA and a close collaboration is established.

The project also has connections with global organisations with IAEA and OECD/NEA via representation of project members in different working parties and task forces.

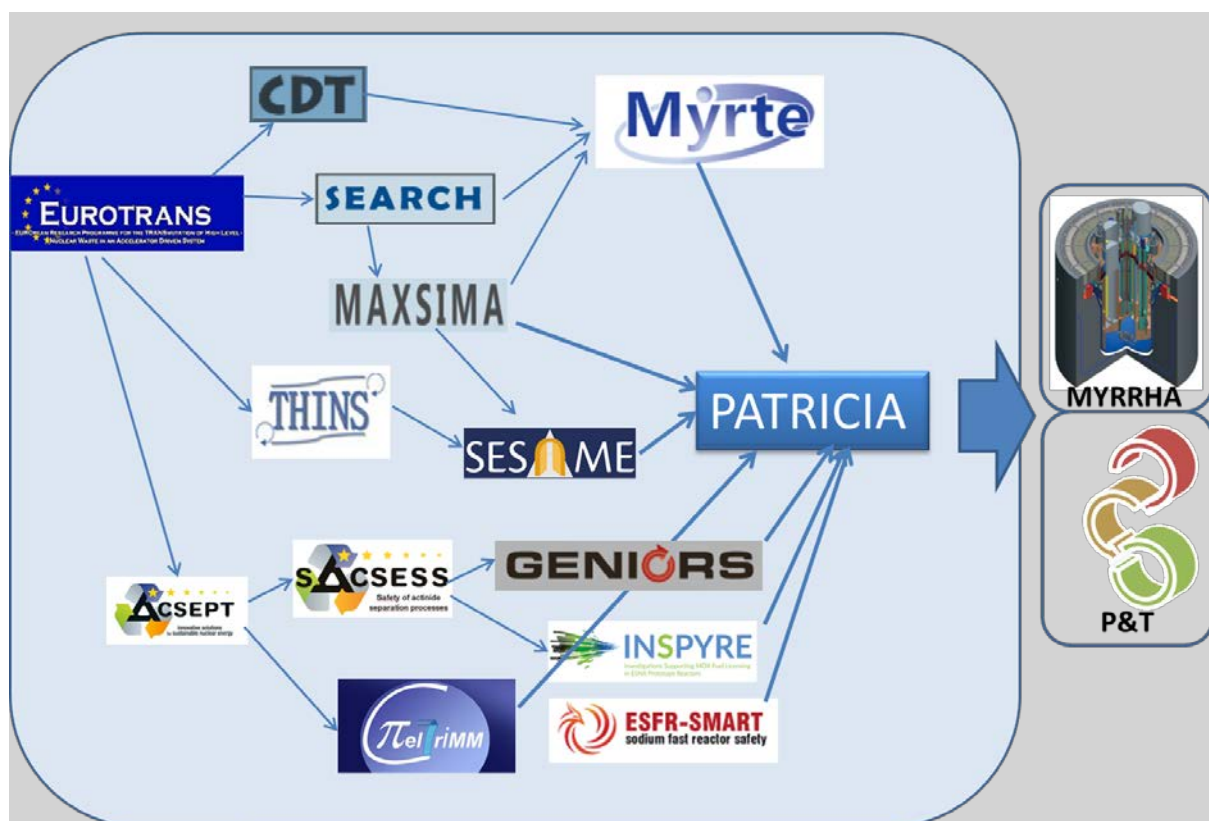


Figure 1: PATRICIA in relation to previous EU projects

4. Expected results

The core objective of the project is to contribute to the closure of the nuclear fuel cycle by advanced partitioning and transmutation. The problem tackled here is the treatment of the minor actinide (MA) component in spent fuel. By doing this, in addition to the multi-recycling of Pu that can be done with existing technology, we can decrease the waste burden, optimize disposal and improve public acceptance. It will pave the way toward a sustainable carbon-free energy source.

MA transmutation requires four steps to be completed. Firstly, the spent fuel is partitioned where the Pu is separated for recycling and the minor actinides are separated individually for transmutation. The fission products are the nuclear “ashes” and need to go to geological disposal. Secondly, the MA fuel is converted into fuel that can be used in a transmutation device. Thirdly, we need to irradiate the MA fuel with fast neutrons so that fission can occur. In order to realize this in a safe way, a thorough understanding of behaviour of MA bearing fuel under irradiation is needed and a nuclear system with an intense fast spectrum neutron needs to be available. Finally, we need partitioning of MA bearing fuel after irradiation since several irradiation cycles will be needed. In our project we focused on the first three steps since the final one is needed to come to an industrial scale transmutation, it comes later in time. Moreover, it is expected to be similar to partitioning MOX fuel.

A second consideration in the programme is the development of the MYRRHA ADS system. MYRRHA is a key part of the third step in Europe, in particular since it is the only fast spectrum system, explicitly dedicated to transmutation that has concrete plans for construction following decision of the Belgian government in 2018. With the above in mind, the project was set up with four technical domains on partitioning, transmutation, driver fuel and fuel assembly safety and finally ADS system safety.

The first technical domain focusses on minor actinide partitioning. The starting point here is the PUREX raffinate that contains minor actinides and fission products after removal of uranium and plutonium from spent fuel. The first step in any transmutation scenario is the sole recovery of Americium from this raffinate since it avoids the difficult partitioning of curium. Moreover, americium is the main contributor to the long-term radiotoxicity and heat-load of the remaining waste. As such, the main goal is to deliver americium containing material with mastered properties that are in accordance with the requirements for fuel production. For that, we will study both the separation process and the conversion step. The expected results can be summarized in three items. The first is the selection and assessment of a suitable chemical system fit for the selective recovery of the americium alone with the best possible understanding of the actinides and fission product chemistry in it. The second expected result is the development and validation of an efficient americium separation process, using the selected chemical system that provides a significant improvement compared to the existing reference EXAM process developed in the previous decade. For that, we will use modelling, simulation and active tests using spikes samples (Figure 2). The third expected result is the production of fully characterized americium containing base material that can be used to produce americium bearing fuel or targets.

In the second technical domain, the main topic is the safety evaluation of minor actinide bearing fuels. For this purpose, we intend to improve the robustness, accuracy and predictability of fuel performance codes that are the cornerstone of fuel behaviour evaluation and safety analyses. The specific idea is to investigate safety-related behaviour of americium bearing fuel.

A first expected research outcome in this domain is the extension of the validation database of models and simulation codes. This is done by studying irradiated samples produced in the latest European irradiation campaigns using a combination of state-of-the-art modelling methods and experimental techniques. We expect to generate data on the thermo-chemical properties of fuels containing Am

under irradiation and on the production and behaviour under irradiation of helium, fission gases and fission products.



Figure 2 Centrifugal contractor cascade for spiked tests of flowsheets at Forschungszentrum Jülich research centre, Germany

Secondly, we expect to improve the prediction capabilities of fuel performance codes using the knowledge gained from the experimental and modelling activities. On the one hand by developing and implementing more reliable mechanistic models, and on the other hand by moving towards coupling of fuel performance codes with neutronics and/or thermal-hydraulics codes. The steps to be taken here are a benchmark of the fuel performance codes on the evolution of physical properties of minor actinide-bearing fuels in normal conditions, where we compare the results obtained from the various codes with each other, but also with post-irradiation examination data. This leads an extension of the validation domain. Additionally, we expect to make significant progress towards multiphysics coupling of fuel performance codes with neutronics / thermal-hydraulics codes for off-normal conditions. The third expected result is an identification of experimental needs for code validation in off-normal situations. This includes a pre-design of a simulation-based transient irradiation experiment.

The third and fourth domain of the project support the preliminary safety assessment report (PSAR) of MYRRHA as one of the inputs for the licensing process. The particular actions in DM3 focus on the safety of the driver fuel and fuel assembly of MYRRHA. We follow a systematic approach since in the first work package of the domain, the fuel-clad material is further investigated, the second work package deals with the safety of the fuel itself while in the third, fuel assembly safety is addressed.

The specific expected research outcomes are firstly, the study of the long-term behaviour of clad material under representative flow and coolant chemistry conditions of the MYRRHA fuel assembly (FA) by an integrated experiment using a FA simulator with heated fuel pins. The work will yield data

on clad corrosion in representative conditions, deposition rates of corrosion products and accumulation of dispersed particles and data on the effects of corrosion on mechanical properties of clad material.

In the second work package addresses the behaviour of MYRRHA driver fuel in off-normal conditions. This consists of a detailed post irradiation examination of fuel segments that have undergone transient tests in the TRIGA reactor at ICN-RATEN in the MAXSIMA project from which the failure limit of the driver fuel is assessed. Furthermore, we will study fuel-coolant interactions studies at pin-centre temperatures (1650°C) with both irradiated and unirradiated fuel.

The fuel assembly safety related work is a study of the heat transfer in the driver fuel bundle in off-normal conditions: blockage and fuel assembly deformation. The focus is on identifying the maximum clad temperature in the core (hot spot). For this, a set of experiments and numerical CFD simulations are planned for each scenario. The particular expected research results on this topic is the generation of new experimental data on fuel assembly thermal-hydraulics in the two scenarios mentioned above, the validation of numerical tools (CFD) using these data and investigation of scenarios which cannot be practically tested in an experiment with the validated numerical tools.

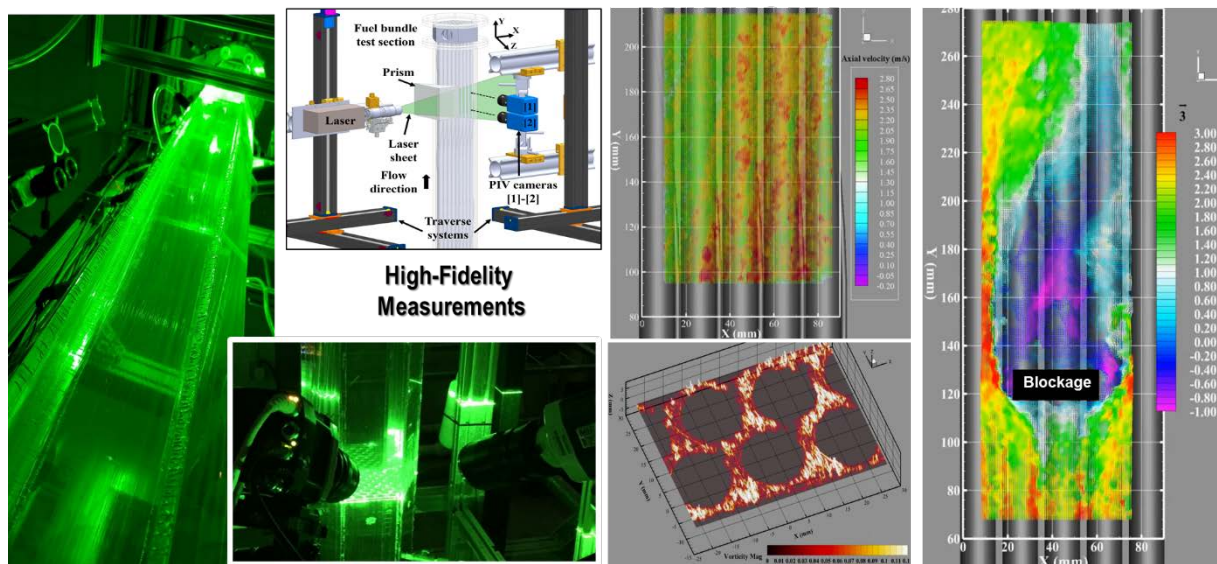


Figure 3 The 61-pin wire wrapped hexagonal bundle at Texas A&M University

The fourth technical domain of the project has a similar approach, also supporting the PSAR of MYRRHA, as Domain 3 albeit that here, the focus is put on the safety and reliability of the heavy liquid metal (HLM) cooled accelerator system. In particular, topics are addressed that occur only because of the accelerator system or because of the nature of the HLM coolant.

The first expected research outcome of the domain is an improvement of the safety and reliability of the coupling of the high-power proton beam to the MYRRHA. On the one hand, we will improve the reliability of the proton beam by enhanced fault tolerance and failure detection. To do this we will elaborate a reliability model of the ADS driver linac, including its fault tolerance characteristics and capabilities. On the other hand, we will investigate the release of Po in a vacuum tube and study the subsequent migration behaviour of the Po atoms that would occur in case of a beam window failure. Indeed, it is very important to know if the Po can migrate outside the confinement of the first section of the beam line inside the reactor (that will be replaced on a regular basis) or if, and to what extent, contamination of the rest of the accelerator line can be expected.

A second important expected result is an improved reliability of thermal hydraulic modelling in a pool configuration since the safety analyses of the MYRRHA reactor requires a reliable thermal hydraulic

analyses for which modern simulation tools used that must be validated and possibly improved. Because of its importance in the safety analyses, we will concentrate on natural circulation transients in liquid metal-cooled pool-type reactor configurations. Specifically, the work will provide experimental reference data, develop models and validate stand-alone CFD, system thermal hydraulics (STH) and coupled CFD + STH codes. Furthermore, we analyse the possibilities and performance of hybrid turbulence modelling approaches and finally develop an engineering turbulent heat transfer model for CFD to simulate heat transport in liquid metals at the required accuracy

The final expected result of the fourth technical domain is an improvement on the basic knowledge of chemical interactions in the coolant as applied to coolant chemistry modelling and radiological release assessment. For the former we will develop and validate a proper model coupling between the thermal hydraulics of the system and the chemical interactions of species in the coolant. For the latter we expect to generate a better understanding of the retention capacity and release rates of radioactive elements in LBE as a function of temperature and other relevant conditions, e.g. oxygen content (Figure 4) by advancing current models and validating them with new experimental data. The most relevant spallation products and polonium are to be considered.

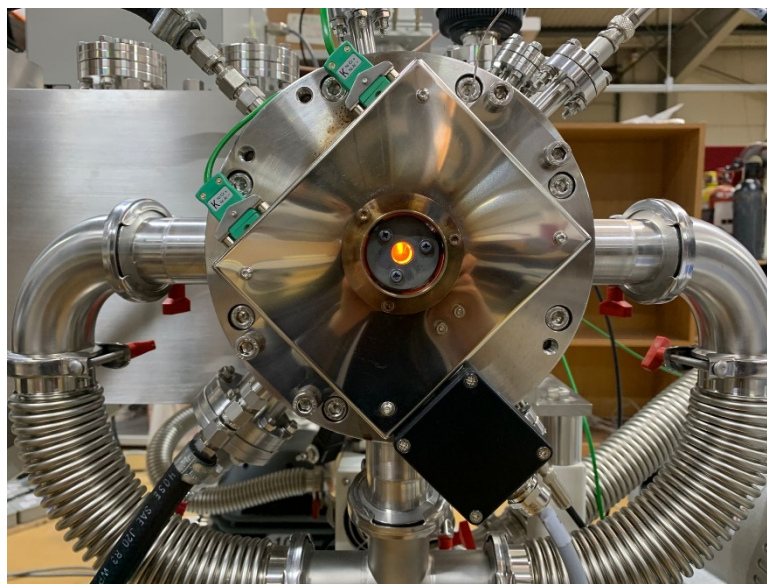


Figure 4 Molecular beam mass spectrometer for analysis of hot vapours (<1000°C) from LBE (SCK CEN)

5. Societal impact

The work in PATRICIA has direct societal impact since it contributes to a solution for high-level radioactive waste and spent fuel via the track of partitioning and transmutation of minor actinides. Indeed, untreated spent fuel requires a storage time in geological depository of several hundred thousand years. Independent of the technical status of this solution, the societal acceptance can be improved and constraints are easier to achieve if the storage time can be significantly reduced and the storage volume is diminished. The main contributor to the long storage time is the plutonium content in the spent fuel and removing it by burning them via MOX fuel using existing technology reduces the storage time to about ten thousand years. The latter is caused by the minor actinide elements that

remain in the spent fuel. In PATRICIA, work will be done on the next step of the solution to separate and burn these, thus reducing the required storage time to a few hundred years.

In addition, the work done on the development of the lead-bismuth cooled transmuter will also contribute to the development of the lead-cooled fast reactor, which in its turn is part of an efficient carbon free energy mix.

Furthermore, the PATRICIA project addresses the issues of public perception related to nuclear energy. Although the impact on public understanding of nuclear energy and nuclear waste is not straightforward to realize for a highly scientific and technological project as PATRICIA, specific communication to a layperson audience will be included.

6. Information and exploitation of results

The PATRICIA project will generate relevant results in the area of liquid metal technology and safety for GENIV LFR and heavy metal cooled transmutation systems.

The most direct way of dissemination the project will use is by keeping in close contact with the stakeholders, e.g. the MYRRHA developers by direct networking of the members of the consortium.

Participation to conferences and workshops is a means of expanding scientific knowledge and dissemination the projects' achievements. Next, scientific publications are the basis of a well-established means of dissemination.

The beneficiaries must ensure the visibility of EU funding for any communication related to the project by displaying the EU emblem and the sentence: *"This project has received funding from the Euratom Research and Training Programme 2019-2020 under grant agreement No 945077"*.

The PATRICIA consortium will prepare specific materials such as yearly newsletters, workshops and joint review meetings. The website will address a wider public audience, in particular by providing a general presentation of the project and its objectives, an overview of the Consortium members, information on project events and public deliverables.

7. Project information

Website address: www.patricia-h2020.eu

Work programme: EURATOM

Type of Action: Research and Innovation Action

Project start date: 01/09/2020

Project end date: 31/08/2024

Duration: 48 months

Total budget: EUR 8,489,440.63

EC contribution: EUR 6,499,979.50

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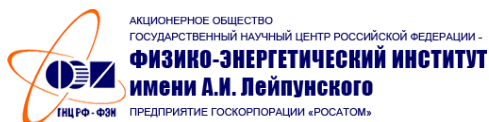
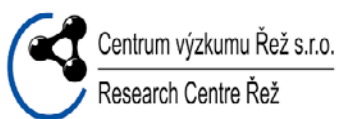
8. Partners

No.	Participant organisation name	Short name	Country code
1	Studiecentrum voor Kernenergie – Centre d’Etude de l’Energie Nucléaire	SCK CEN	BE
	Texas A&M University System (TAMUS), International partner of SCK CEN	TAMUS	US
2	Commissariat à l’énergie atomique et aux énergies alternatives	CEA	FR
3	Chalmers Tekniska Högskola AB	CHALMERS	SE
4	Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas	CIEMAT	ES
5	Forschungszentrum Jülich GmbH	FZJ	DE
6	National Nuclear Laboratory Limited	NNL	UK
7	Politecnico di Milano	POLIMI	IT
8	Ruprecht-Karls-Universität Heidelberg	UHEI	DE
9	University of Leeds	UNIVLEEDS	UK
10	Centrum Vyzkumu Rez Sro	CVR	CZ
11	JRC - Joint Research Centre - European Commission	JRC	BE
12	Karlsruher Institut fuer Technologie	KIT	DE
13	Kungliga Tekniska Högskolan	KTH	SE
14	Nuclear Research and Consultancy Group	NRG	NL
15	Technische Universiteit Delft	TU Delft	NL
16	Teknologian tutkimuskeskus VTT Oy	VTT	FI
17	Agenzia Nazionale per le Nuove Tecnologie, l’Energia e lo Sviluppo Economico Sostenibile	ENEA	IT
18	Regia Autonomă Tehnologii pentru Energia Nucleară - RATEN	RATEN	RO
19	European Organization for Nuclear Research	CERN	CH
20	Centro di Ricerca Sviluppo e Studi Superiori in Sardegna Società a Responsabilità Limitata	CRS4	IT
21	Institut von Karman de Dynamique des Fluides	IVKDF	BE
22	Paul Scherrer Institut	PSI	CH
23	Universiteit Gent	UGENT	BE
25	State Scientific Centre of the Russian Federation - Leypunsky Institute for Physics and Power Engineering, Joint Stock Company	IPPE	RU
27	Università di Pisa	UNIFI	IT

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