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French Alternative Energies And Atomic Energy Commission (CEA)
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Under the scope of:
French Presidency

FISA 2022

CONFERENCE PROCEEDINGS
Volume 2

10th European Commission Conferences
on EURATOM Research and Training in Safety of
Reactor Systems & Radioactive Waste Management

30 May – 3 June

Lyon, France

In cooperation with

With the support of

FISA 2022 – Conference Proceedings

European Commission
Directorate-General for Research and Innovation
Directorate C — Clean Planet
Unit C.4 — Euratom Research

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EUROPEAN COMMISSION

FISA 2022

Conference Proceedings
Volume 2

2024

Directorate-General for Research and Innovation
Euratom Research and Training Programme

EN

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FISA 2022
EURADWASTE'22

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JOINT INTRODUCTION

Co-chair: Bernard SALHA (FR, SNETP)
Co-chair: Rosalinde VAN DER VLIES (EC, DG RTD)
Rapporteur: Henri PAILLERE (FR, Expert)

Connecting Nuclear Youth!

Vision, collaboration, innovation - YGN perspective

Jadwiga Najder, Chair
European Nuclear Society
Young Generation Network

FISA - EURADWASTE 31/05/2022

Challenges and opportunities of nuclear

positioning of nuclear in a climate-aware world

6g
of CO2eq. per kWh of electricity

Source: UNECE, 2021

competitivity on job market and workforce replaceability

36%
of global nuclear workforce is 55+

Source: GETI 2021

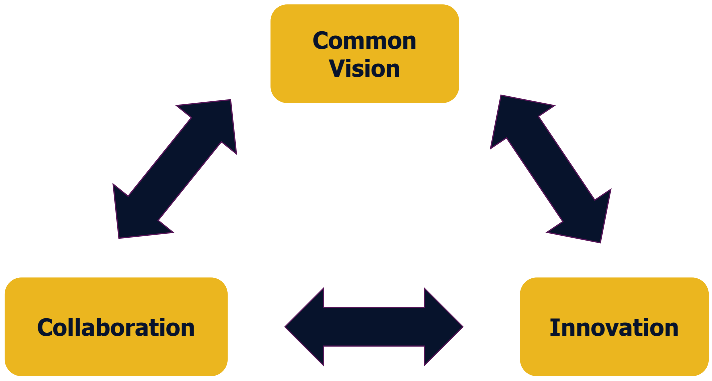
internal challenges of nuclear industry to be addressed for future

32
reactors planned or constructed in Europe

Source: PRIS, FORATOM

2

Vision, Collaboration, Innovation



„ ensure safe, accessible, affordable energy and essential services for the development and well-being of the low-carbon world „

3

ENS YGN - who are we?

YGNs are youth sections of the national nuclear societies

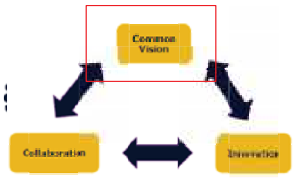
ENS-YGN is a network of Nuclear Young Generation groups (YGNs) all over Europe, since 1995 connecting a widespread community of young professionals in nuclear field

4

ENS YGN member countries

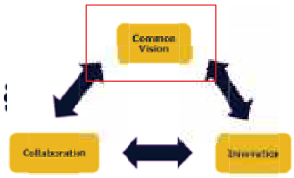
5

Translating and sharing the vision



Nuclear closer to the youth and general public

Promoting nuclear among current and future employees



Translating and sharing the vision

Shaping the image of nuclear outside our bubble


Nuclear for CLIMATE

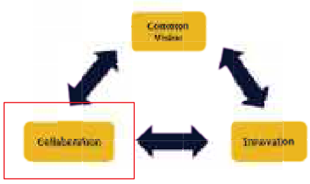
COP26 Position Paper

Net Zero Needs Nuclear

Nuclear for Climate is an initiative gathering nuclear professionals and scientists from over 150 societies and associations, with the goal of opening a dialogue with policymakers and the public about the necessity of including nuclear energy among the carbon-free solutions to climate change.

We have a vision of a clean, sustainable and abundant low-carbon future for all. Our mission is to accelerate the ability of the world to achieve Net Zero by 2050, by driving collaboration between nuclear and renewable technology. We believe that Net Zero Needs Nuclear and these are the reasons why:

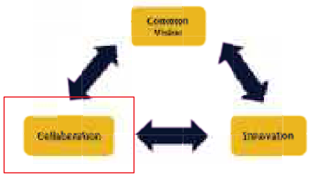
150+ organisations since 2015



Foster collaboration

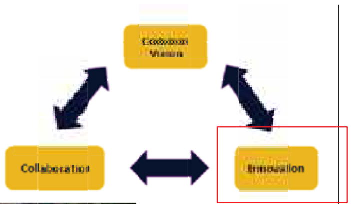
Cooperation between YGNs

Bridging the generation gap



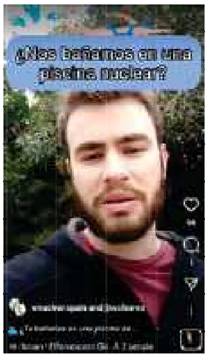
Foster collaboration

Relations between young professionals, exchanging opportunities



Shape innovative thinking

Innovative ways of communication



Activities promoting innovation and business creation

What do we need?

➔ modern, flexible workplace

➔ learning and development opportunities

➔ clever management

➔ satisfactory remuneration

➔ …

11

Conclusions

➔ YGNs educate, inspire, empower young people
- to know and own the vision of nuclear sector
- to collaborate to gain network and skills to create nuclear future
- to think innovatively and learn about the entrepreneurship

➔ Action is needed to support development of future leaders

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Thank You!

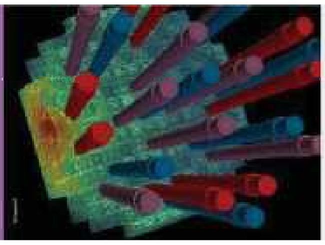

FISA 2022
EURADWASTE'22

SESSION 1: SAFETY OF NUCLEAR INSTALLATIONS

Co-chair: Myriam CALACICCO (FR, NUCLEAR VALLEY)

Co-chair: Stefano MONTI (IAEA)

Rapporteur: Ferry ROELOFS (NL, Expert)



FISA 2022

30 May - 3 June 2022
Lyon, France

Reactor Performance, system reliability: Long-Term Operation

Marta Serrano CIEMAT, Sebastian Lindqvist VTT, Madalina Rabung, Fraunhofer ZFP, Akos Horvath, EK-CER, Murthy Kolluri, NRG

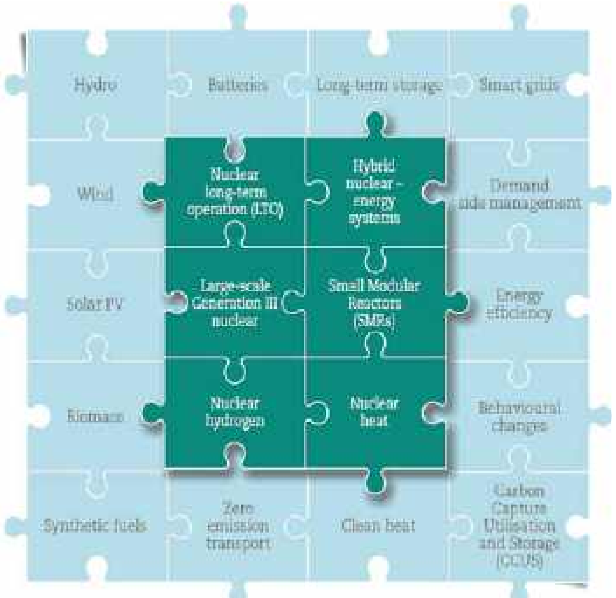
ENTENTE – ATLASplus – NOMAD – STRUMAT-LTO

20min

Contents

- Introduction
- Reactor pressure vessel
- Primary circuit
- Non destructive diagnosis

Introduction



Nuclear technologies and applications in future low-carbon energy systems
[*Meeting Climate Change Targets: The Role of Nuclear Energy OECD 2022 NEA No. 7628*]

- The nuclear sector can support climate change mitigation efforts in a variety of ways
  - **Long term operation**
  - Large-scale Generation III nuclear new builds
  - Generation IV and small modular reactors (SMRs)
  - nuclear hybrid energy systems,
  - Nuclear hydrogen
  - Nuclear heat

Introduction

- Long term operation
  - The operating time frame for a nuclear power plant is ultimately governed by the ageing of critical structures, systems and components (SSCs)

the following SSCs may become life-limiting

- Reactor pressure vessel (LWR)
- Reactor coolant system piping, welds and core internals (LWRs, PHWRs);
- large, civil and concrete structures, such as the containment building (LWRs, PHWRs)
- large sections of the plant’s electrical cable system (LWRs, PHWR).

ENTENTE — European Database for Multiscale Modelling of Radiation Damage

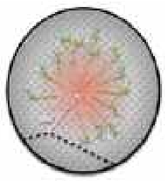
STRUMAT-LTO — Structural Materials for Nuclear Safety and Longevity

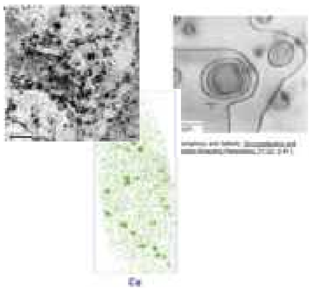
NOMAD — Nondestructive Evaluation (NDE) System for the Inspection of Operation-Induced Material Degradation in NPP

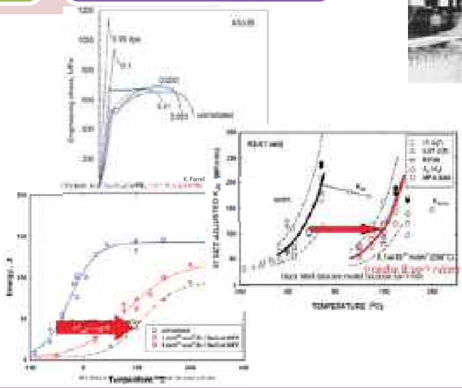
Introduction

- The Reactor Pressure Vessel (RPV)
  - **The problem** -> Neutron embrittlement

Neutron irradiation → Microstructural damage → Mechanical properties



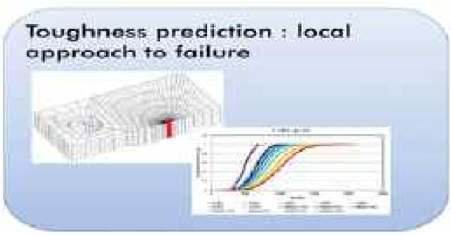


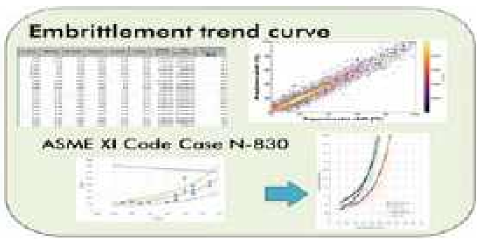


Large and not (economically) replaceable component

ENTENTE - Objectives

- ENTENTE "European Database for Multiscale Modelling of Radiation Damage" aims to design a **new European experimental/modelling materials database** to collect and store highly-relevant data on **radiation damage of Reactor Pressure Vessel** (RPV) steels
- Specific objectives
  - Design and maintain a unique experimental/modelling database for model validation and calibration
  - Collect previous data and enrich the database with microstructural and mechanical data on neutron irradiated RPV materials to fill gaps
  - Development of advanced models based on data analytics/mining and previous knowledge
- Exploitation objectives
  - Improve the SOTERIA Platform
  - Encourage the dissemination of results
  - Foster International collaboration





http://rdgroups.ciemat.es/web/materiales/entente

ENTENTE - Consortium

- 27 partners, (Coordinator CIEMAT)
  - Industrial partners (EDF, CRIEPI, FRA-G, UJV, NNL);
  - R&D centres (CIEMAT, BZN, CEA, HZDR, IMDEA, SCK•CEN, CCFE); Universities (CNRS, CHALM, KTH, UC, UBRIS, UWAR, UMAN, UA, UPC, UPM)
  - SME (SINTEC, PHIMECA), as well as TSO (VTT, SSTC NRS, IRSN).
- 12 countries: Spain, France, UK, Germany, Finland, Sweden, Belgium, Italy, Hungary, Czech Republic, Ukraine and Japan.

ENTENTE
Grant agreement ID: 900018

DOI
10.3030/900018

Start date 1 September 2020
End date 31 August 2024

Funded under
Euratom

Total cost
€ 4 938 147,94

EU contribution
€ 4 000 000

Coordinated by
CENTRO DE INVESTIGACIONES ENERGETICAS, MEDIOAMBIENTALES Y TECNOLOGICAS-CIEMAT
Spain

ENTENTE - Implementation

Implementation

WP1 (CIEMAT) - Management

WP5 (CIEMAT) - Dissemination, exploitation and training

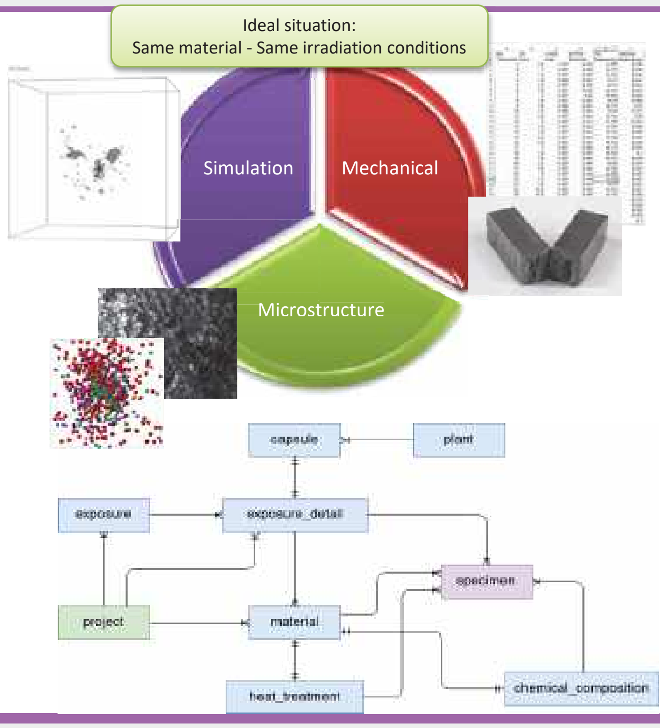
WP2 (EDF) - Model/experiment database
Database design
Data collection
SOTERIA PLATFORM

WP3 (CEA) - Generation of experiment/modelling data
Dedicated experiments and models
Atomistic -> Fracture

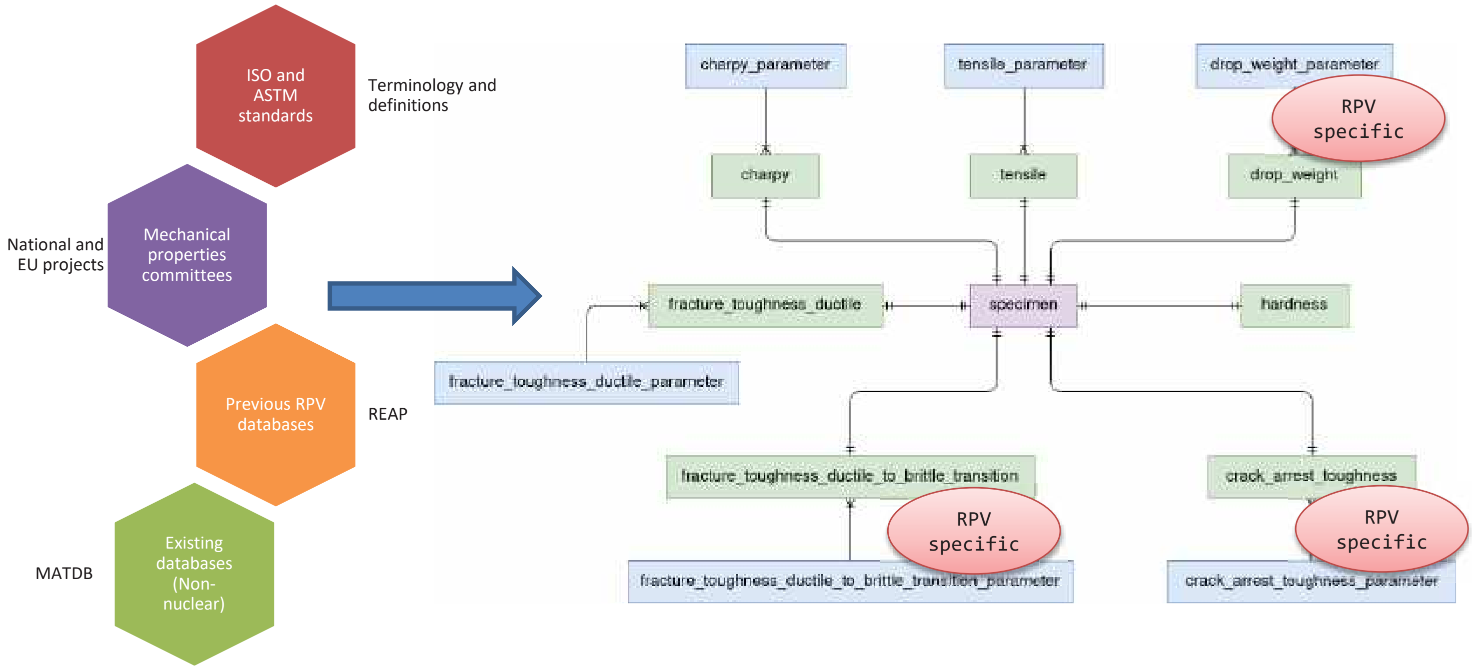
WP4 (VTT) - Accelerated model and analysis approaches
ICME approaches
Artificial networks and Machine learning.
Hybrid atomistic

ENTENTE – Relevant Results

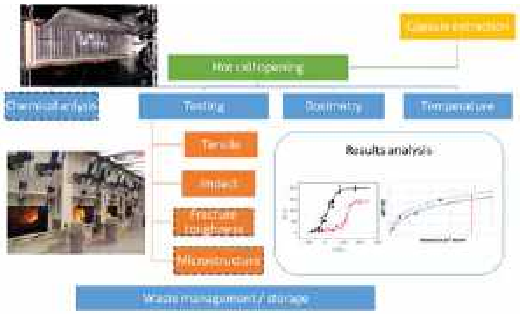
- ENTENTE Database
  - The ENTENTE database is composed of a high-level part, which acts as the core that connects to other modules.
  - These modules refer to specific techniques (e.g., mechanical properties, SEM or APT).
  - This modular structure facilitates data ingestion, and its later exploitation, as different techniques can be treated independently, but they all share a common high-level layer.

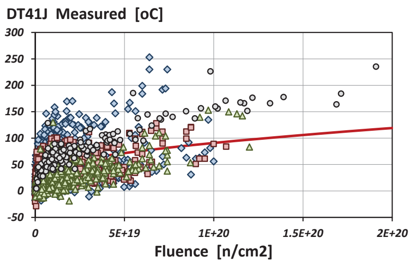


ENTENTE – Relevant Results



ENTENTE – Relevant Results

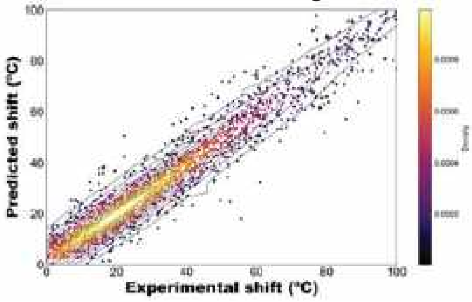




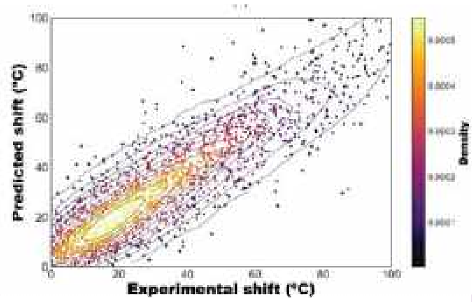
Prediction of the Transition-Temperature Shift Using Machine Learning Algorithms

Available surveillance data from nuclear power plants.
Collected to support ASTM's E900 effort -> ASTM PLOTTER excelfile
4438 transition temperature shifts

Gradient Boosting



ASTM E900-15



Ferreño, D.; Serrano, M.; Kirk, M.; Sainz-Aja, J.A. Prediction of the Transition-Temperature Shift Using Machine Learning Algorithms and the Plotter Database. Metals **2022**, 12, 186. https://doi.org/10.3390/met12020186

STRUMAT-LTO Objectives

High level objectives	Specific objectives (SO)	WP
Address remaining scientific gaps and open issues in RPV embrittlement to support safe long term operation of European NPPs including the scenario of LTO > 60 years	**SO1:** Quantitative characterization of RPV embrittlement and recovery in PWR and VVER-1000 steels at high fluences resembling 60 – 80 years of reactor operation	WP1, WP2
	SO2: Perform exclusive investigation of synergetic effects of Ni, Mn and Si on RPV materials embrittlement at high fluences	WP1, WP2, WP3
Assess and improve prediction tools (ETEs) and surveillance test methods in improving the RPV embrittlement assessment for increased safety for LTO of NPPs	**SO3:** Validation of existing ETEs for LTO above 60 years and a proposal for modifications when needed	WP4
	SO4: Assessment of Master curve (MC) approaches for fracture toughness characterization at high fluences	WP5
	SO5: Assessment and application of small specimen testing methods, i.e., fracture tests with mini 0.16 CT specimens, and small punch test (SPT), to investigate high fluence materials	WP2
Bridging the gap by knowledge transfer from experts retiring in this field to the next generation of young nuclear scientists	**SO6:** Education and training of young researchers in the field, especially PhDs, Post-docs and young researchers, to bridge gaps in knowledge transfer between retiring and new generations	WP6
Dissemination and outreach activities to maximise impact of the project results	**SO7:** Dissemination of the projects results to all stake holders in LTO business, including academic and R&D institutes, Utilities, SMEs, TSOs and regulators, to maximise the overall impact and to pave way for safe LTO of European NPPs.	WP6

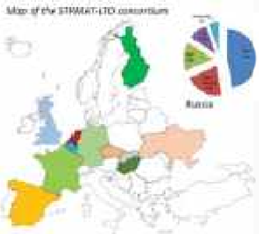
https://strumat-lto.eu/

STRUMAT-LTO Consortium

18 partners, (Coordinator EK-CER, Scientific coordinator NRG)

- R&D institutes: EK-CER, NRG, HZDR, CIEMAT, UJV, BZN, VTT, JRC, UKAEA, VUJE, CNRS, KINR, FhG-IZFP
- TSO: SSTC-NRS
- SMEs: LGI, ARB-NPPS, IPP Centre LLC
- University: STUBA

11 countries: Hungary, The Netherlands, France, Germany, Spain, Czech Republic, Finland, Belgium, United Kingdom, Slovakia, Ukraine



STRUMAT-LTO
Grant agreement ID: 945272

DOI
10.3030/945272

Start date 1 September 2020 | **End date** 31 August 2024

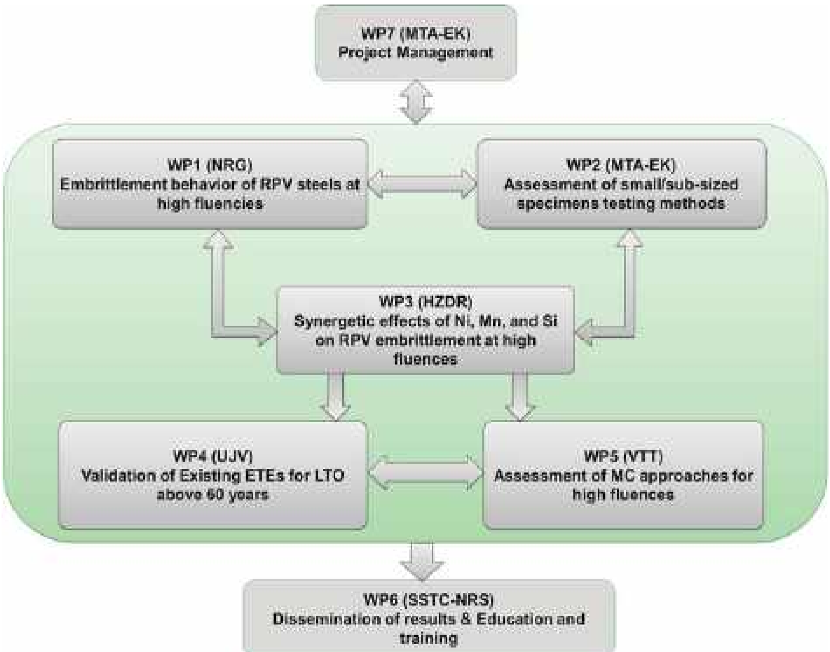
Funded under
Euratom

Total cost
€ 4 466 997,50

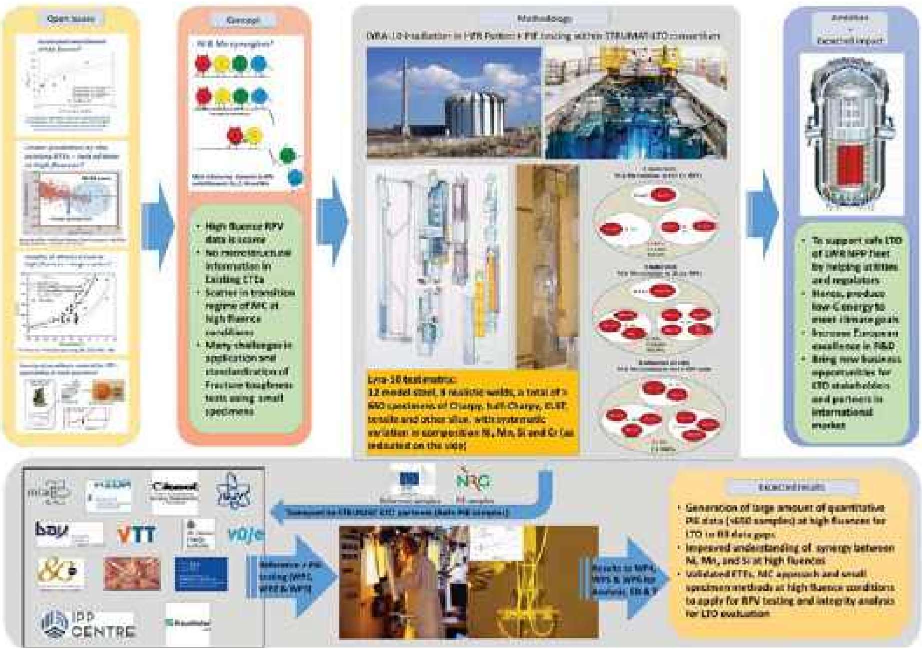
EU contribution
€ 3 965 029,25

Coordinated by
ENERGIATUDOMANYI KUTATOKOZPONT
Hungary

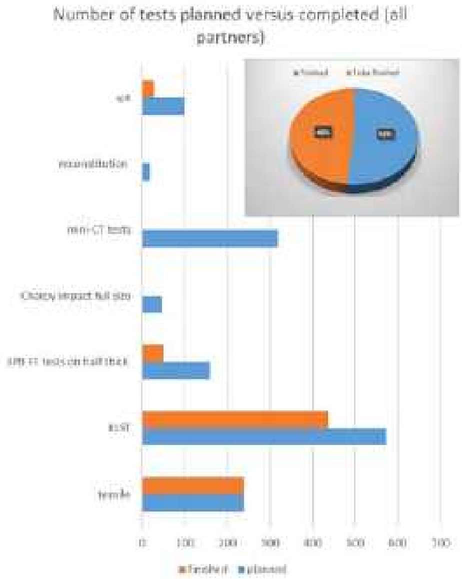
STRUMAT-LTO Implementation



STRUMAT-LTO concept and methodology



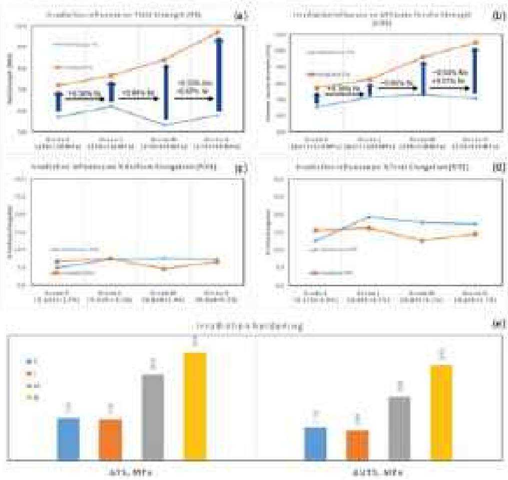
Achievement Sep 2020- Mar 2022: Large part of PIE campaign finishend

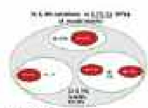


STRUMAT-LTO Relevant results

- A total of 118 samples (12 TENSILE + 106 KLST). The results of this research showed that:
  - No big change in irradiation induced hardening was observed with increase of Ni from ~0.6% to 1.0 %.
  - A large increase in irradiation induced hardening was observed in both model steels (M & N) containing high Ni content.
  - No significant change in %UE and a slight decrease in %TE was observed in all model steels after irradiation

Tensile testing results of PWR model steels





Test type	Steel grade	Number of specimens tested and testing laboratory			
		Unirradiated		Irradiated	
Tensile	K	1	NRG	2	NRG
	L	1		2	
	M	1		2	
	N	1		2	
KLST	K	0	JRC	8	
	L	0		15	
	M	11-15	JRC + NRG	15	
	N	0	JRC	15	

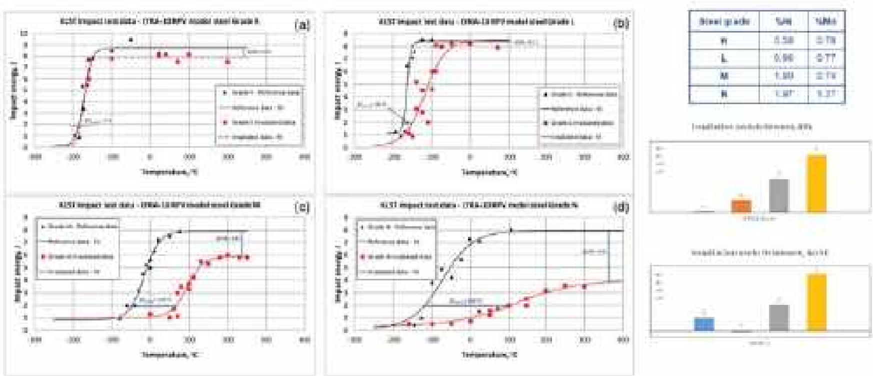
Steel grade	Nominal fast fluence ($x 10^{19}$ n.cm^{-2})	
	Tensile	KLST
K	1.18	1.19
L	1.05	1.10
M	1.06	1.15
N	1.09	1.17

Model steel	C	Si	Mn	Cr	Ni	Mo	V	Cu	S	P
K	0.17	0.35	0.78	0.30	0.58	0.64	-	0.07	0.005	0.009
L	0.18	0.35	0.77	0.08	0.96	0.63	-	0.05	0.005	0.010
M	0.16	0.37	0.74	0.09	1.30	0.61	-	0.05	0.005	0.010
N	0.15	0.33	1.27	0.07	1.57	0.62	-	0.06	0.005	0.010

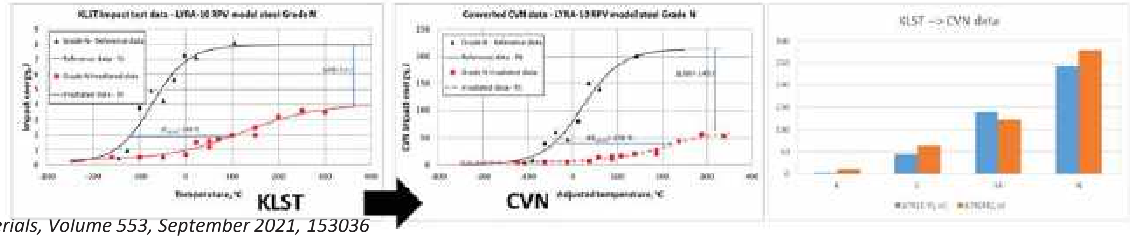
STRUMAT-LTO Relevant results

- The **shift in transition temperature** measured by KLST testing, ΔTk(1.9J) **increased proportionally with Ni** content for the model steels containing a constant Mn of ~0.8% (K, L, M)
- On the other hand a large increase in ΔTk(1.9J) and a decrease in upper shelf energy, ΔUSE was observed for model steel N with an **increase in Mn from ~0.8 to ~1.3** (compared to model steel M) for the same amount of Ni, indicating a **synergetic effect of Ni and Mn on the embrittlement behavior at these high neutron fluences**
- the combined effect of Ni and Mn on the shift in transition temperature follows a similar trend as observed for **Ringhals 3 and 4 RPV welds**

KLST testing results of PWR model steels



Data conversion from small to standard specimens



M. Kolluri et. al., Journal of Nuclear Materials, Volume 553, September 2021, 153036

NOMAD Objectives

- NOMAD **Nondestructive Evaluation (NDE) System for the Inspection of Operation-Induced Material Degradation in Nuclear Power Plants**
- The objective of NOMAD is the development, demonstration and validation of a non-destructive evaluation (NDE) tool for the local and volumetric characterisation of the embrittlement in operational reactor pressure vessels (RPVs). In order to address these objectives, the following steps will be taken:
  - Development and demonstration of an NDE tool for the characterisation of RPV embrittlement, especially accounting for material heterogeneities and exceeding the existing information from surveillance programmes
  - Extension of the existing database of RPV material degradation by adding correlations of mechanical, microstructural and NDE parameters as well as including quantification of reliability and uncertainty.
  - Application of the developed tool to cladded material resembling the actual RPV inspection scenario

https://www.nomad-horizon2020.eu/

NOMAD Consortium

- 10 partners (Coordinator Fraunhofer)
  - Industrial partners (Tecnatom, SVTI);
  - R&D centres (Fraunhofer, SCK CEN, CER, PSI);
  - Universities (Coventry Univ.);
  - SME (HEPENIX), as well as TSO (VTT).
- 7 countries: Germany, Belgium, Finland, Spain, UK, Swiss, Hungary.

NOMAD Implementation

WP5: Management, Dissemination, Exploitation
(Eurice & All)

WP1: Description and delivery of the sample sets and irradiation conditions, sample provision, microstructure characterization and determination of the mechanical properties
(SCK CEN)

WP2: Nondestructive materials characterization and evaluation of the progression of the material properties
(Fraunhofer)

WP3: Advanced non-destructive evaluation tool for materials characterization
(VTT)

WP4
Application & Validation (SVTI)

NOMAD Relevant results

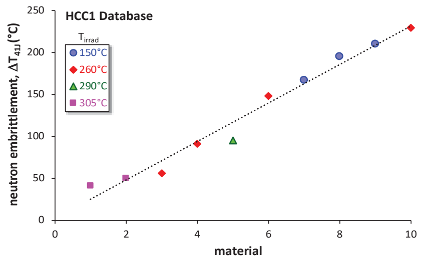
Materials / Irradiation

- Materials of Western and Eastern RPV design, weld and base materials

Neutron irradiation
- high neutron flux
- different fluences / temperatures
- Different sample geometries

Charpy

Large non-cladded and cladded blocks

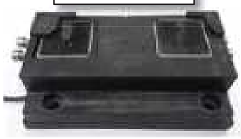


Application of six NDE methods to irradiated non-cladded and cladded samples

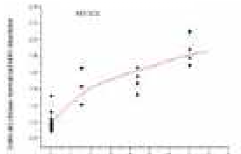
Micromagnetic techniques

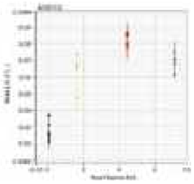
Electrical techniques

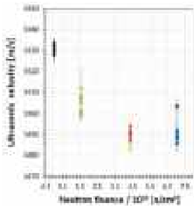
Ultrasonic technique



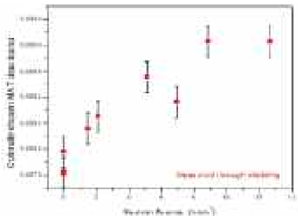
Charpy

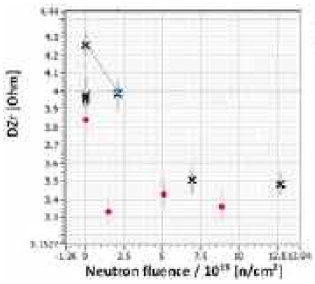






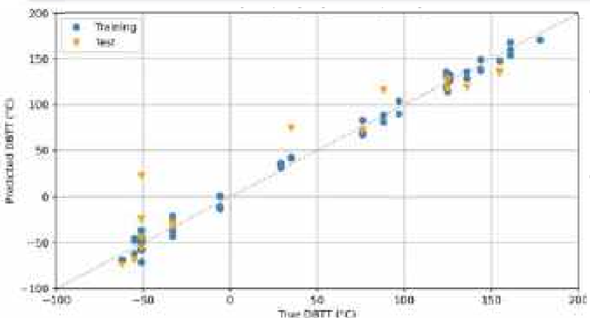
Blocks





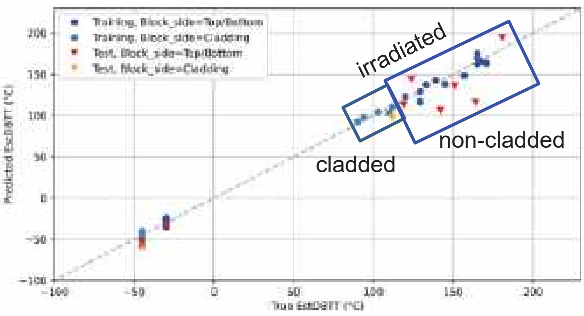
NOMAD Relevant results

Prediction of DBTT by AI-driven NDE tool



Charpy's

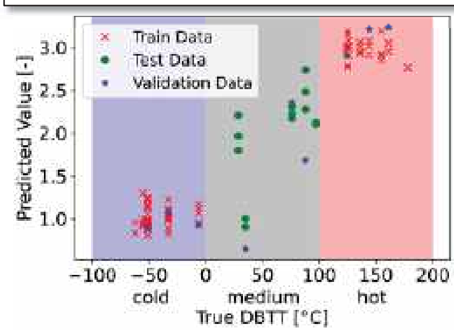
Training
(MAE = 6,59°C
R^2 = 0,99)
Test
(MAE = 15,95
R^2 = 0,92)



Blocks

Training
(MAE = 4,06°C
R^2 = 1)
Test
(MAE = 17,8°C
R^2 = 0,93)

Validation of the NOMAD tool for Charpy samples



Linear regression model **trained on classes "cold" and "hot"**, and **tested on class "medium"**

Additional data on irradiated cladded blocks (class "medium") needed for the validation of the NOMAD tool for cladded material

Introduction

- Long term operation
  - The operating time frame for a nuclear power plant is ultimately governed by the ageing of critical structures, systems and components (SSCs)

the following SSCs may become life-limiting

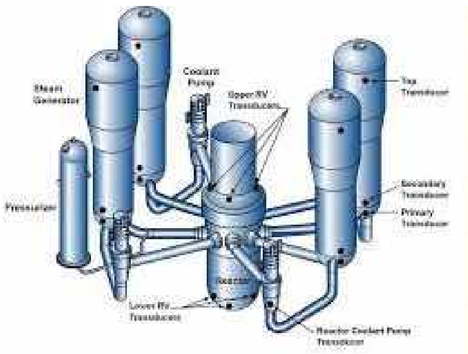
- Reactor pressure vessel (LWR)
- Reactor coolant system piping, welds and core internals (LWRs, PHWRs);
- large, civil and concrete structures, such as the containment building (LWRs, PHWRs)
- large sections of the plant's electrical cable system (LWRs, PHWR).

ATLAS+

Advanced Structural Integrity Assessment Tools for Safe Long Term Operation

Introduction

- Reactor coolant system piping & welds
  - **The problem** **->safety assessment of acceptable degradation and defects in piping components for LTO.**
- The PWR primary system piping constitutes a barrier to the release of fission products and activated species to the containment during normal, off-normal, accident and test conditions.
- The large diameter primary system piping (main coolant piping) carries the hot coolant from the reactor pressure vessel to the steam generators and then provides cold coolant back to the vessel.
- The other piping facilitates plant operation and plays a role in mitigating any off-normal or accident conditions.
- Therefore, maintaining the structural integrity of this piping is essential to the safe operation of a PWR plant.



ATLAS+ Objectives

- ATLAS+ **Advanced Structural Integrity Assessment Tools for Safe Long Term Operation**
- Specifically this project will focus on developing:
  - innovative quantitative methodologies to transfer laboratory material properties to assess the structural integrity of large piping components,
  - an enhanced treatment of weld residual stresses when subjected to long term operation,
  - advanced simulation tools based on fracture mechanics methods using physically based mechanistic models,
  - improved engineering methods to assess components under long term operation taking into account specific operational demands,
  - integrated probabilistic assessment methods to reveal uncertainties and justify safety margins.

ATLAS+ Consortium

In-kind contributions are provided by
Oakridge Consulting International Incorporated (OCI, Inc.),
Mitsubishi Heavy Industries, Ltd (MHI) and University of Soul.

ATLASplus
Grant agreement ID: 754589

DOI
10.3030/754589

Closed project

Start date
1 June 2017

End date
30 November 2021

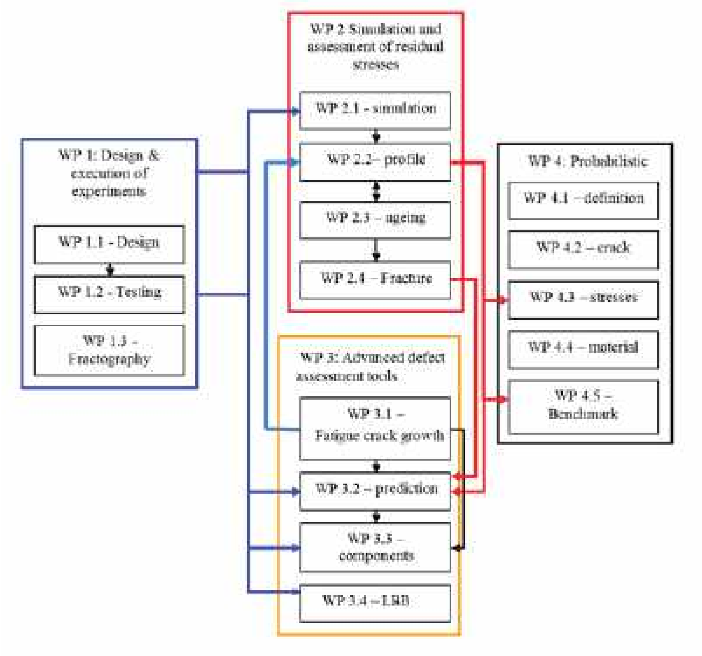
Funded under
Euratom

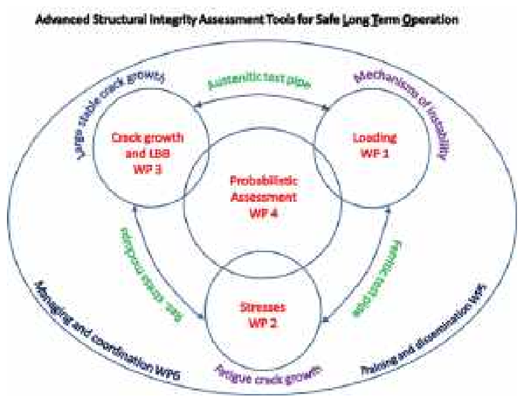
Total cost
€ 7 195 162,59

EU contribution
€ 3 930 863,92

Coordinated by
TEKNOLOGIAN TUTKIMUSKESKUS VTT OY
Finland

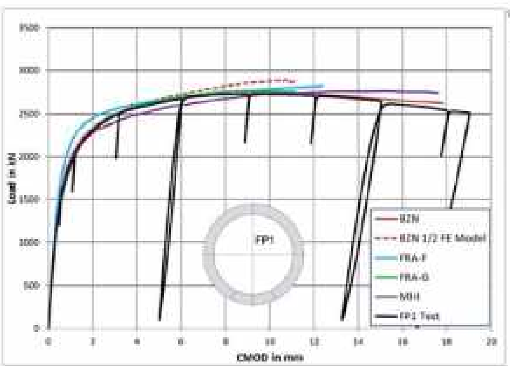
ATLAS+ Implementation

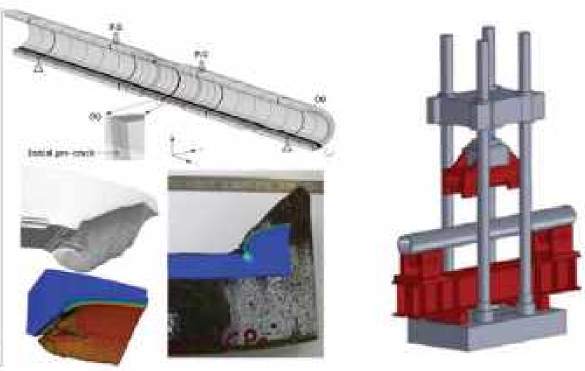


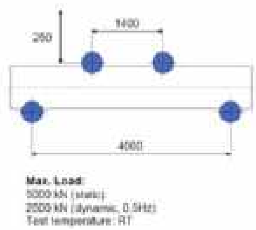


ATLAS+ Relevant results

- Most of the participating organizations were able to develop a reasonable approach for prediction of ductile fracture in large and mid-scale mock-ups that are representative of real nuclear components. Performed benchmarks revealed a robust implementation of GTN type LA models in different FE codes and their capability to take into account both the constraint and transferability effects.
- The models were calibrated based on small scale specimen data (C(T) and SE(T)) and validated based on the large scale experimental data.







ATLAS+ Relevant results

- WP2 primarily focuses on modelling and measuring residual stresses. Thick and thin-walled (manufactured with low and high heat-input) narrow-gap gas tungsten arc-welds (GTAW) (AISI 316L), fully circumferential and 120° patch overlay welds, and thick walled thermally aged NGGTAW were manufactured, and the residual stress profiles were measured with different techniques vital to minimize uncertainty.
- The FEM 2D and 3D residual stress predictions agreed with the experimental results determined with several techniques and the results were repeatable.

Figure 42. Hoop residual stresses on the longitudinal-normal plane of a low HI thin-walled AISI 316L pipe girth weld measured using the contour method.

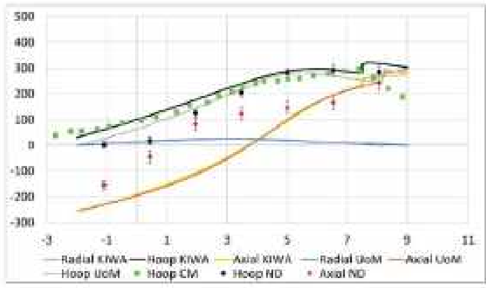


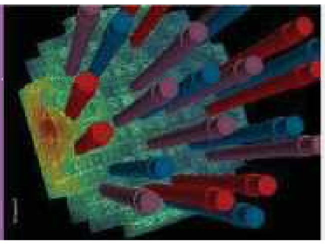
Figure 46. Line plots of the axial, radial, and hoop stresses on a through-wall line at the weld centreline of a high HI 3-pass weld in an AISI 316L pipe, showing both measured stresses (contour method and neutron diffraction) and predicted stresses.

ATLAS+ Relevant results

- Final report available at: https://cris.vtt.fi/en/publications/final-project-report-atlas-advanced-structural-integrity-assessme
- Honorable mention: A best practice guidance document on LBB. The best practice guidance document takes into account and highlights LBB methodologies from various codes and assessment procedures developed and utilised in different countries. This enables the user to be well informed when performing a LBB assessment and effectively provides a template for carrying out LBB assessments. The guidance contains two types of LBB methodologies. The two types of methodologies and the strong emphasis on undertaking sensitivity studies are considered to be an enhancement on some of the current LBB methodologies and practices.
- WP1, WP2 and WP3 → New best-practice simulation models for assessing ductile tearing and residual stresses in industrial components were validated based on high-quality experimental data.
- The probabilistic round robin analyses had initially large differences, but after refining of the parameters acceptable agreement between the partners was achieved despite the different fracture assessment methodologies applied and differences in the limit states. The results have made it possible to better understand how different assumptions and parameters influence a probabilistic assessment.

Summary

- This presentation show the main results of 4 EURATOM-funded projects aligned with the SNETP-NUGENIA Technical area 4 – System and component integrity
  - Three projects devoted to the ageing management of the reactor pressure vessel from different perspectives:
    - Data management and modelling approaches
    - Irradiation embrittlement and hardening evaluation of highly irradiated materials
    - Non destructive diagnosis of irradiation embrittlement
  - One project dealing with the best practice guidance document on LBB (leak before break) and probabilistic assessment of primary piping
- Relevant results are already available
- Well-consolidated consortiums



FISA 2022

30 May - 3 June 2022
Lyon, France

Increase of Nuclear Installations Safety by Better Understanding of Materials Performance and New Testing Techniques Development

MEACTOS, INCEFA-SCALE AND FRACTESUS H2020 Projects

Tomasz Brynk, *SCK CEN, Belgium*
Francisco Javier Perosanz Lopez, *CIEMAT, Spain*
Alec Mclennan, *Jacobs, UK*

Project has received funding from the Euratom research and training programme 2014-2018 under grant agreement no. 755151.

Project has received funding from the Euratom research and training program 2014-2018 under grant agreement No 945300.

Project has received funding from the Euratom research and training programme 2020-2024 under grant agreement No 900014.

Motivation

Research to better understand the phenomena influencing materials and components performance is important for **increasing the safety of Generation II and III nuclear plant**.

Main research path of **MEACTOS** (2017-2022), **INCEFA-SCALE** (2020-2025) and **FRACTESUS** (2020-2024) H2020 projects:

- Better understating of phenomena related with **fracture** and **fatigue** of materials used to build reactor components (**environmental effect, surface effect, scaling effect**)
- Development of **new testing techniques** that allow to precisely determine mechanical properties with relatively small amount of material needed (**optimization of material usage** in surveillance programs, **scaling from laboratory to real size components**, **new specimen designs**)

Increase of nuclear installations safety (Generation II and III reactors)

Better understanding of phenomena influencing materials and components performance

Development/validation of material testing techniques

Environmental and surface effect

New testing techniques

MEACTOS (2017-2022)

Mitigating Environmentally-Assisted Cracking Through Optimisation of Surface Condition

Main aim: Improvement the safety and reliability of Generation II and III nuclear power plants by improving the resistance of critical locations, including welds, to **environmentally-assisted cracking (EAC)** through the application of optimized surface machining and improved surface treatment

Database of testing results

INCEFA-SCALE (2020-2025)

INcreasing safety in NPPs by Covering gaps in Environmental Fatigue Assessment – focusing on gaps between laboratory data and component SCALE

Main aim: Advance the ability to predict lifetimes of Nuclear Plant components when subjected to **Environmental Assisted Fatigue** loading

Scale effect

FRACTESUS (2020-2024)

Fracture mechanics testing of irradiated RPV steels by means of sub-sized specimens

Main aim: To demonstrate the **applicability of miniaturized compact tension specimens (MCT) in fracture toughness testing** (master curve determination) of the reactor pressure vessel steels in hot cell conditions

MEACTOS

Project has received funding from the Euratom research and training programme 2014-2018 under grant agreement no. 755151.

General information

Mitigating Environmentally-Assisted Cracking Through Optimisation of Surface Condition

This project receives funding from the Euratom research and training programme 2014-2018 in the topic NFRP-01: Continually improving safety and reliability of Generation II and III reactors; Grant Agreement Nº. 755151.

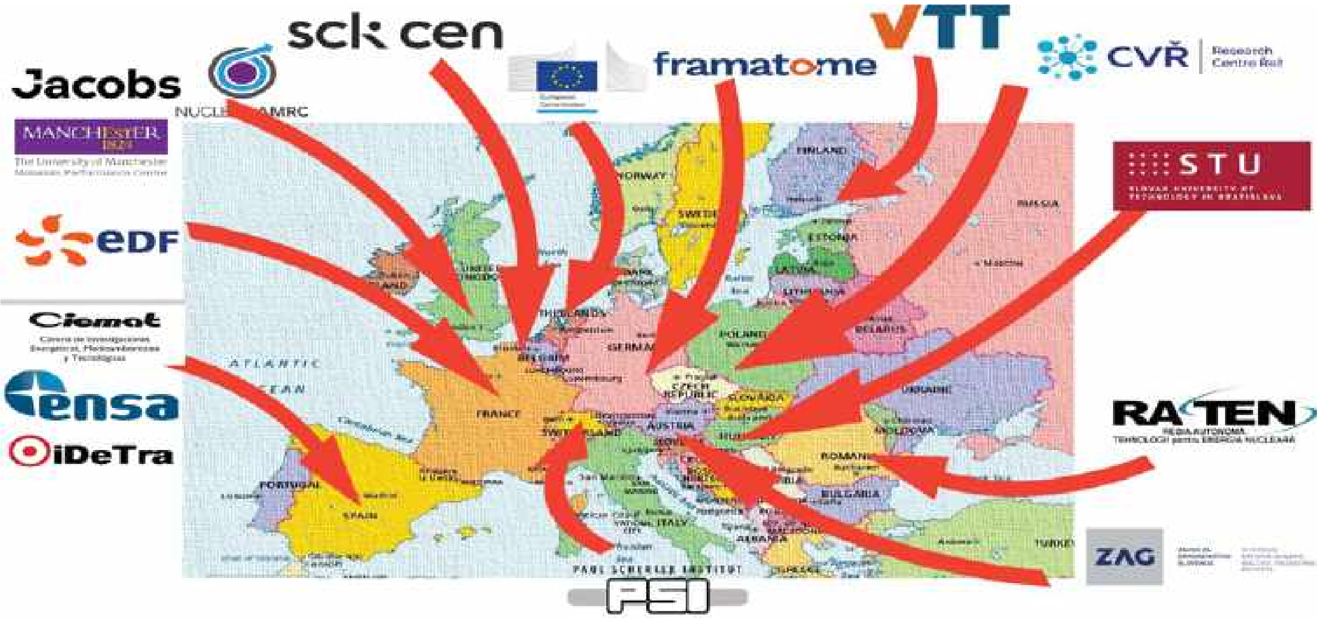
- Start date: 01/09/2017
- End date: 27/02/2022
- 16 partners

The goal of the MEACTOS project is to improve the safety and reliability of Generation II and III nuclear power plants (NPPs) by improving the resistance of critical locations, including welds, to environmentally-assisted cracking (EAC) through the application of optimized surface machining and improved surface treatments.

Project website: https://meactos.eu/

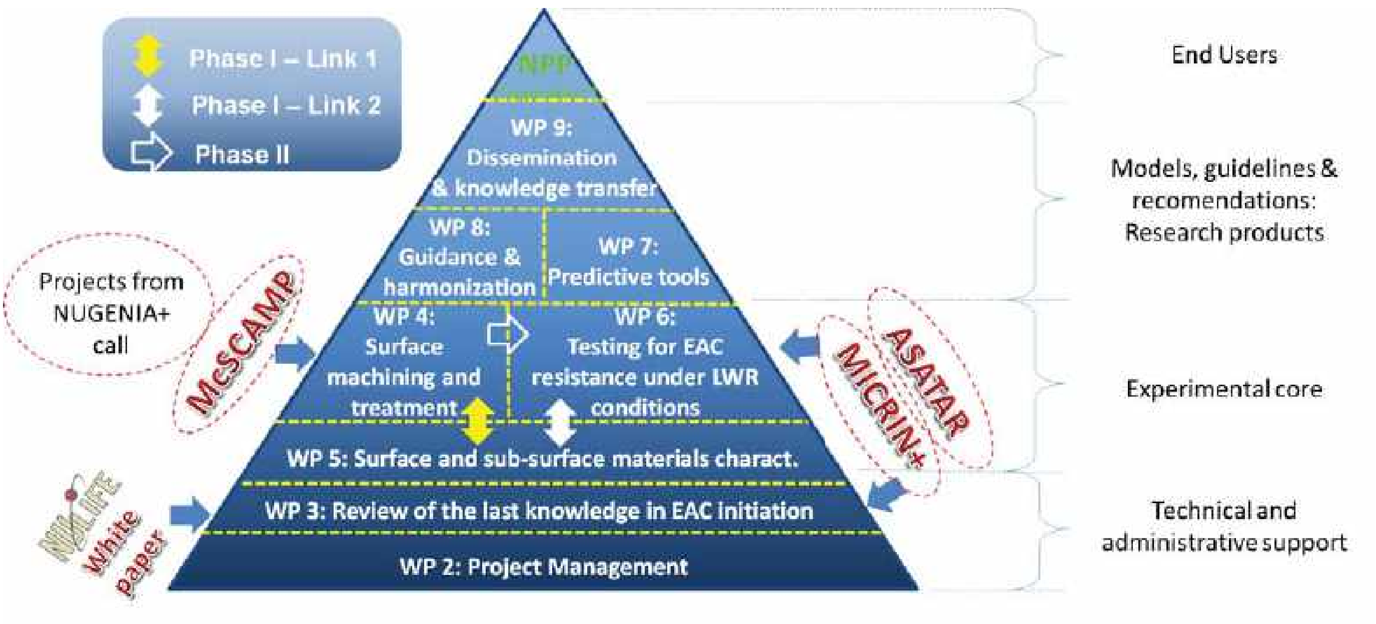
Partners

15 laboratories from different European countries



MEACTOS

Work package structure



Workflow

SOTA Workshop → Fabrication of coupons → Machining specimens → Test campaign → Results collection → Fit models → Final Workshop

SOTA Workshop

Choice of materials and conditions to be tested during the project

Fabrication of coupons

- A182 by weld overlay on carbon steel plate
- 316L Cold Worked Up to a 15% of thickness reduction by rolling

Machining specimens

- Flat tapered specimens for task 6.1
- Flat tapered and other geometries for task 6.2

Side A: Machined
Side B: Manually Polished

Test campaign

- Task 6.1
  - 3 strain rates
- Task 6.2
  - Constant load

Environments

- **PWR**
- **BWR**
- **SCWR**

Results collection

Task 6.1
- Stress threshold for crack initiation

Task 6.2
- Time to initiation

Fit models

3 models
- EngInit (SCK-CEN)
- ACETMA (CVR)
- Local (EDF) parametrized with tests results

Final Workshop

Harmonization guidelines

Main results

- Despite the scatter, **the trend** of the observed results seems to indicate that for the **A 182** advanced machining slightly improves the resistance to the initiation of cracks , compared to traditional machining and to the reference surface (manually polished).
  - **Resistance of surface to EAC: Advanced machining > Traditional machining > Polished**
- For **316L** and for the applied cold work level (around 14%) there is no clear benefit in the applied surface treatments. However, this material is itself very resistant, so the initial degree of cold work applied may not have been sufficient to increase the susceptibility to EAC.
- **All machining processes** used have produced **ultrafine-grained layers (UFG)** or different thickness in both materials. At least for A 182 this UFG layer seems to correlate with the enhanced EAC resistance.
- Since critical stress data from standard and advanced surfaces show only little difference it can be further concluded, that **advanced surface machining methods have nearly the same impact on EAC initiation behaviour than standard methods, i.e. they are not inferior**. In combination with benefits like higher cutting speed and less pollution by lubricants, **advanced surface machining methods are therefore a promising alternative to standard procedures**.
- **Advanced surface machining methods** can be used for future applications or if standard methods cannot be used **(e.g. repair robots for pipes)**.
- The resistance to EAC of **the layer treated by peening techniques** strongly depends on the quality of the resulting surface.

INCEFAscale
Horizon 2020

Project has received funding from the Euratom research and training program 2014-2018 under grant agreement No 945300.

General information

INcreasing safety in NPPs by Covering gaps in Environmental Fatigue Assessment – focusing on gaps between laboratory data and component

- Start date: 01/10/2020
- End date: 30/09/2025
- 18 partners (2 associate partners being engaged through non-disclosure agreements)

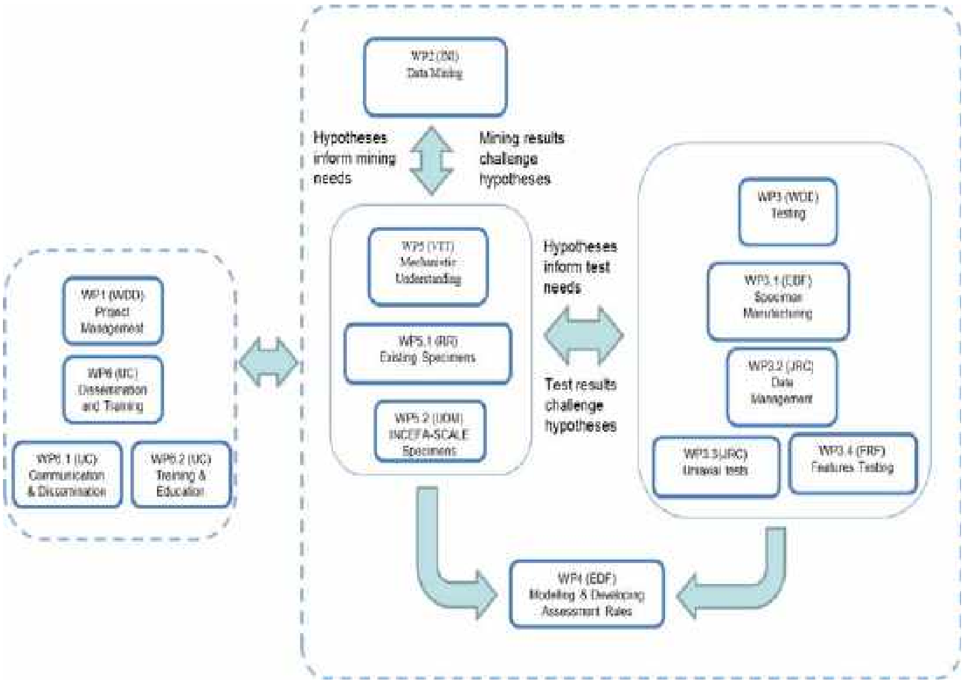
Primary focus: developing mechanistic understanding of EAF to permit extrapolation of lab data up to component scale

Project website: https://incefascale.unican.es/

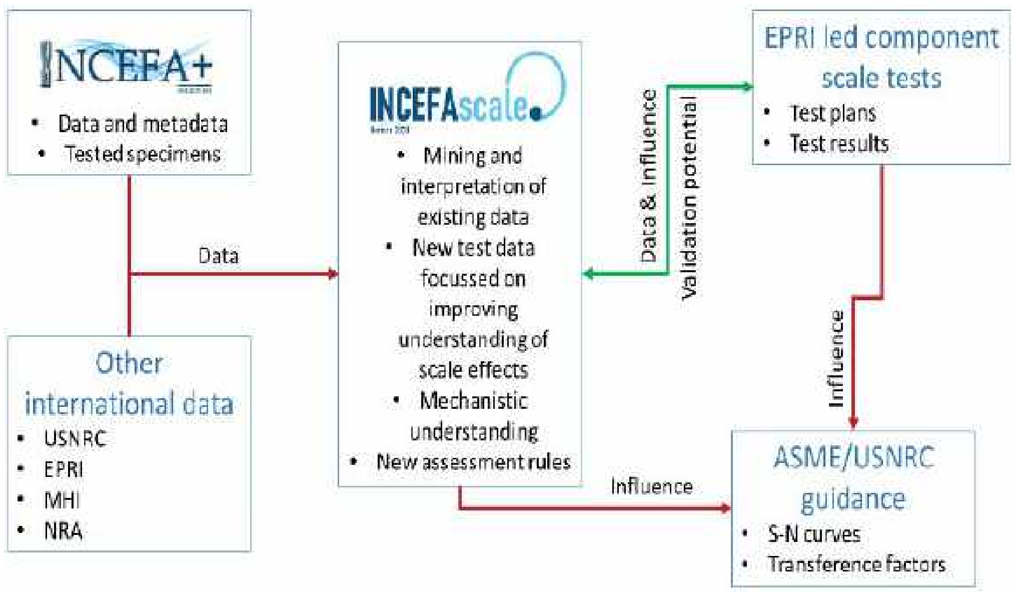
Partners

UK NED KOR FRA ESP SWI FIN CZ LIT GER USA

Work Package structure



Workflow/external relationship



Highlights

- A collaboration with EPRI, through a non-disclosure agreement (NDA) (under development), has been agreed.
- WP2 has completed the development of a software application that will facilitate datamining activities using the information stored in MatDB.
- An upcoming International Fatigue Database Agreement will make significant additional data available for examination from external collaborators.
- INCEFA-SCALE will target conservatisms in the treatment of Variable Amplitude loading of current design codes.
- Three working hypotheses were identified for the first year of testing to be expanded on as the project progresses:
  - The negative effects of mean stress on fatigue life are relatively less damaging at higher temperatures and are conservatively accounted for in current design codes.
  - In PWR environments, the effects of hardening on fatigue life should not be treated as additional to effects of environment.
  - In PWR environments, negative effects from hardening, environment and surface roughness are not multiplicative.
- WP3 uniaxial testing has commenced and features testing defined with support from the recently established Expert Panel and Data Management Committee.
- WP4 modelling and assessment has kicked off and defined the aims and scope for the work package.
- WP5 characterisation continues to progress and support the INCEFA-SCALE aims.
  - A round robin for striation counting has reached completion and issued a common method for calculating striation spacing.
  - The WP team is now in the process of engaging with the consortium on analysing pre-test specimens.
- The project dissemination channels have been set up consists of a public website (https://incefascale.unican.es), ResearchGate, Twitter and LinkedIn presences.

FRACTESUS

Project has received funding from the Euratom research and training programme 2020-2024 under grant agreement No 900014.

General information

FRACTure mechanics TEsting of irradiated RPV steels by means of SUb-sized Specimens (FRACTESUS)

Project within EURATOM Work Programme 2019-2020 in the section NFRP-04: Innovation for Generation II and III reactors:

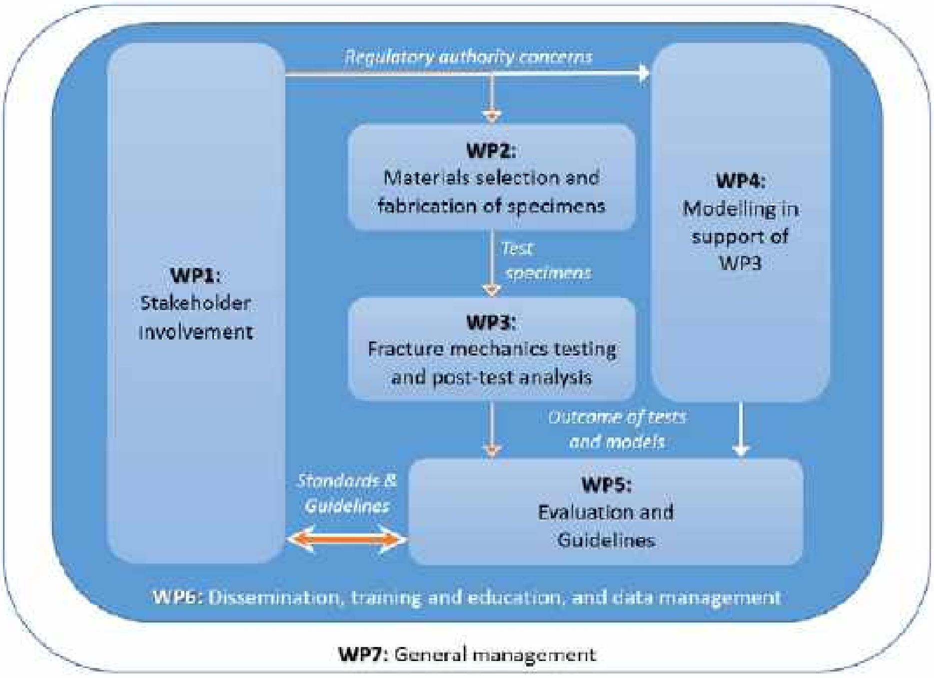
- Start date: 01/10/2020
- End date: 30/09/2024
- 21 partners from Europe, Japan and Canada

Main aim: to demonstrate the applicability of miniaturized compact tension specimens in fracture toughness testing (master curve determination) of the reactor pressure vessel steels under hot cell conditions.

Project website: https://fractesus-h2020.eu/

Partners

Work package structure



With support of:

- Scientific Advisory Committee
- End User Group
- Standardization Committee

General workflow

Analyze of current standards and selection of **RPV materials** with various T, T_{41J},…

- Database of results available
- Materials are available in sufficient amount

FT testing

Comparison to large specimens (FEM supported)

The same results

Guidelines and dissemination

<u>Validation of MC(T) approach</u>

Approval by the Authorities

Usage by NPP Operators

<u>Different results</u>

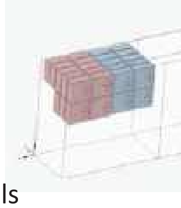
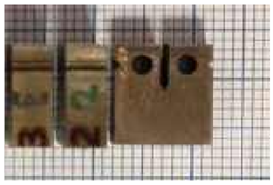
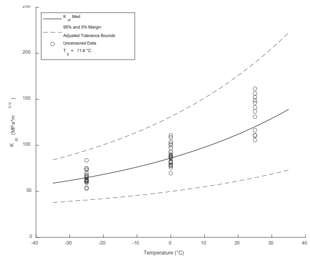
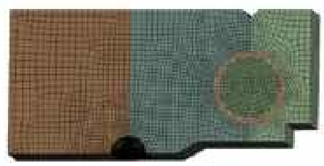
- Discrepancy of results
- Validity problems

Investigation on the reason/importance/trend… (FEM supported)

Correction method (including changes in standard if needed)

Current status

- Current standards overview was done
- Material selection process is finalized
  - Main requirements
    - Wide spectrum of properties typical for rector pressure vessel materials
    - Results from larger specimen testing available
    - Availability for testing by multiple partner (round robin)
- Selected unirradiated materials were distributed to partners to be tested in round robins
- Preparation of irradiated material is started
- First fracture toughness tests on unirradiated materials are done
- First results from round robin on numerical modelling are available

Summary

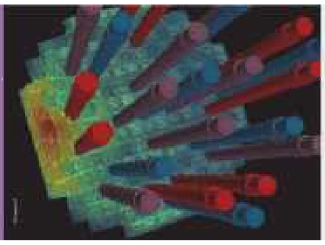
- Three presented here H2020 projects aim to increase the safety of nuclear reactors
- The output of multidirectional research activities is important to assure a longer and more reliable service of currently operated nuclear power plants, and will be also taken into account during new facilities design
- The results delivered in all three projects will have influence on providing electric power in safe and sustainable way that will meet still growing demand of modern European and worldwide societies

THANK YOU FOR YOUR ATTENTION

Project has received funding from the Euratom research and training programme 2014-2018 under grant agreement no. 755151.

Project has received funding from the Euratom research and training program 2014-2018 under grant agreement No 945300.

Project has received funding from the Euratom research and training programme 2020-2024 under grant agreement No 900014.



FISA 2022

30 May - 3 June 2022
Lyon, France

CODES AND METHODS IMPROVEMENTS FOR SAFETY ASSESSMENT AND LTO: VARIED APPROACHES

APAL PROJECT

APAL - Advanced PTS Analysis for LTO

Objectives of APAL project

- **Development of advanced probabilistic pressurised thermal shock (PTS) assessment methods**
- **Quantification of safety margins for LTO improvements**
- **Development of best-practice guidance.**

APAL – basic information

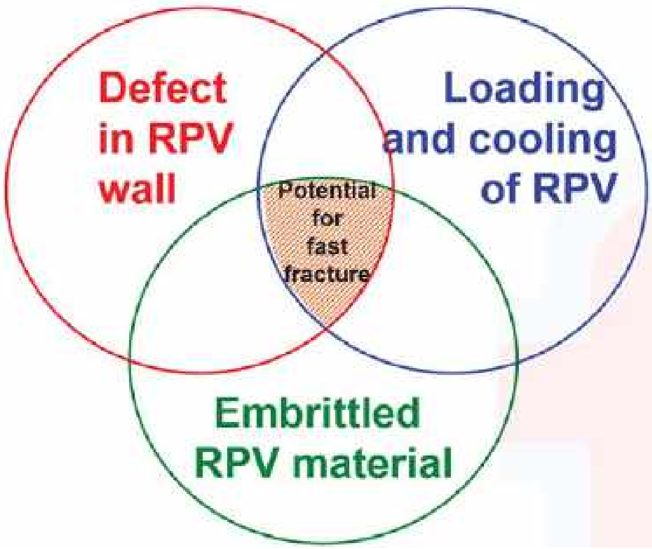
- **EU funded project – Horizon 2020 research and innovation programme**
- **Duration 10/2020 – 9/2024**
- **Budget 4 mil. Euro**
- **14 EU partners + 2 international partners**

APAL – partners

Participant No		Participant organisation name	Country
1	UJV	ÚJV Řež, a. s.	**CZ**
2	FRA-G	Framatome GmbH	**DE**
3	PSI	Paul Scherrer Institut	**CH**
4	IPP	IPP Centre LLC	**UA**
5	KIWA	Kiwa Inspecta Technology AB	**SE**
6	TECNATOM	Tecnatom S.A.	**ES**
7	GRS	Gesellschaft für Anlagen- und Reaktorsicherheit (GRS)	**DE**
8	BZN	Bay Zoltán Nonprofit Ltd. for Applied Research	**HU**
9	EURICE	European Research and Project Office GmbH	**DE**
10	JSI	Jožef Stefan Institute	**SL**
11	IRSN	Institut de radioprotection et de sûreté nucléaire	**FA**
12	LUT	Lappeenranta University of Technology	**FN**
13	WUT	Warsaw University of Technology	**PL**
14	SSTC	State Scientific and Technical Center for Nuclear and Radiation Safety	**UA**
I1	OCI	Oakridge Consulting International	**US**
I2	JAEA	Japan Atomic Energy Agency	**JA**

Characterisation of pressurised thermal shock (PTS)

- Rapid cooldown of the primary circuit
- (Usually) non-uniform cooldown
  - due to ECCS injection
  - due to asymmetric cooling down by steam generators
- (Usually) high inner pressure

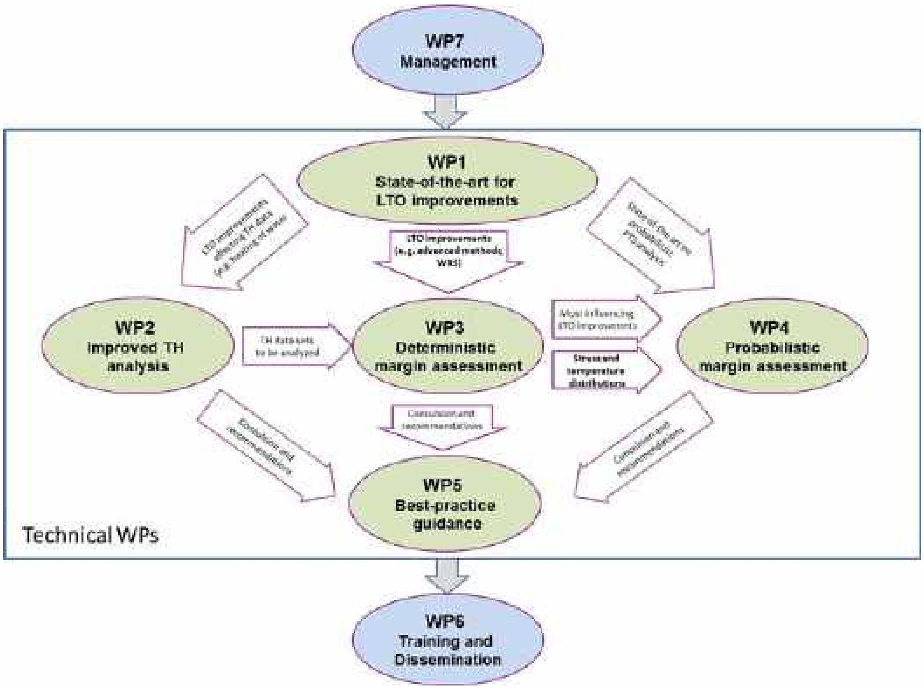


Under which circumstances fast fracture in RPV could occur?

Main parts of PTS analyses

- Thermal-hydraulic analyses
  - system
  - mixing
- Structural analyses
  - temperature fields
  - stress fields
  - fracture mechanics

APAL - Project Structure



APAL – overview of the technical work packages (WP1 – WP5)

- **WP1 State-of-the-art of Long-Term Operation Improvements.** Extensive literature review and collection of experience (based of questionnaires filled by the partners) to identify the state-of-the-art of LTO improvements that may have an impact on the results of PTS analysis. WP1 finished 2/2022. Public summary report of WP1 can be downloaded from APAL public web page **https://apal-project.eu/**
- **WP2 Improved TH analysis.** System and mixing thermal-hydraulic (TH) calculations are performed, including uncertainty quantification relevant to the PTS assessment. The impact of both LTO improvements and human factor on the results of TH analysis are quantified.
- **WP3 Deterministic margin assessment.** Deterministic structural and fracture-mechanics analyses will be performer to quantify the safety margins related to both LTO improvements and uncertainties in TH analyses. At first they will be tested on a common deterministic benchmark.
- **WP4 Probabilistic margin assessment.** Probabilistic fracture-mechanics analyses will be performed. They will enable the quantification of safety margins in terms of risk of RPV failure. An appropriate benchmark for the probabilistic fracture-mechanics analysis will be performer first.
- **WP5 Best-practice guidance.** Recommendations and conclusions will be gathered from the work to define the best practices for advanced PTS analysis for LTO.

Numerical Codes used in APAL

- Several codes and software are used in APAL project, in order to reach the objectives of the project. These tools can be categorized following the different approaches studied in the PTS analyses.
- **System thermal-hydraulic analysis.** It's the analysis of behaviour of the whole NPP system (primary and secondary circuits, emergency core-cooling systems, auxiliary systems, etc…) from the thermal-hydraulic point of view. The resulting parameters include, among others, temperatures, pressures, flow rates, velocities, and heat transfer coefficients.
- **Mixing thermal-hydraulic analysis.** It's the detailed analysis of coolant mixing inside the reactor, namely in the reactor downcomer.

Numerical Codes used in APAL

- **Structural and fracture-mechanics analyses.** The structural and fracture-mechanics analyses can be performed using either a **deterministic or a probabilistic approach**. The software tools for both approaches significantly differ.

– **Deterministic approach:**

- **For structural analysis, commercial "general" finite-element method (FEM) software** tools are used. Among many capabilities of general FEM codes, the solutions of heat-transfer problem and mechanical problem (either linear-elastic or elastic-plastic) are used for PTS analysis. The **fracture-mechanics analysis** is generally performed in two different methods. The first method is based on the formulae from standards. The second method is based on the FEM model of the RPV with the assessed crack included in the FEM mesh. Fracture-mechanics parameters are calculated directly in the post processor of the commercial FEM software.
- **Probabilistic approach:**
- Because the commercial software is not suitable for this type of analyses, a **specific software** especially for the fracture-mechanics assessment, frequently created in-house, is used. The main task of the probabilistic software for fracture-mechanics analysis is sampling some of the input data, which are treated as statistically distributed, and to **calculate the conditional probability of crack initiation** or RPV failure. Usually, a Monte Carlo method or FORM/SORM method is used.

CAMIVVER PROJECT

CAMIVVER

- **CAMIVVER Project Context**
  - VVER type constitutes a dynamic and growing part of the European fleet. Several VVER reactor units are planned for construction – or are currently under construction – inside the EU (Slovakia, Hungary and Finland) and in the neighboring countries (Ukraine, Turkey, Belarus, Russia)
  - VVER fleet is highly dependent on Russia for fuel supply. The Euratom Supply Agency (ESA) underlined as a matter of concern the reliance on a single Russian supplier, which constitutes a significant risk. Consequently the EU is strongly supporting the development of alternative supply chains, preferably within Europe
  - **Considering the growing influence of international export controls the same statement can be drawn regarding scientific softwares used by the nuclear industry for designing reactors. The availability of european state-of-the-art computer codes became a priority for preserving EU sovereignty and nuclear operators independence**

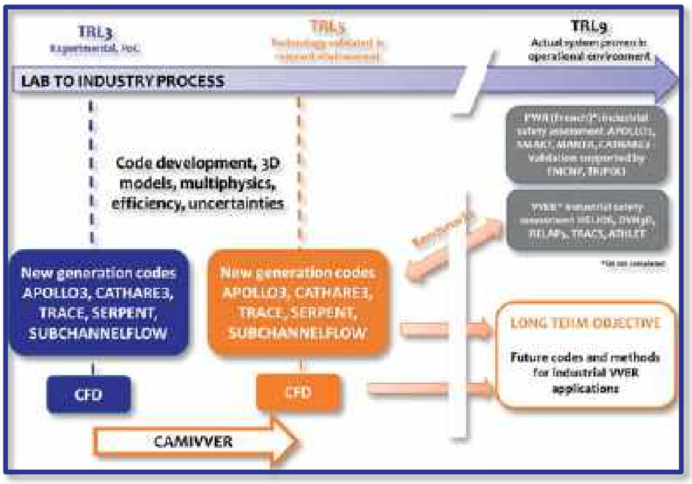
www.camivver-h2020.eu

camivver-h2020-european-project

CAMIVVER Project Ambitions

- Pushing new generation codes and methods towards an industrial use for VVER and PWR safety assssments
- Performing code development of a neutrons library generator prototype based on APOLLO3® code and of a proof of concept of an innovative coupling based on APOLLO3®/CATHARE3 codes.
- Benchmarking those new generation codes against codes currently used for VVER and PWR safety assessment and high-fidelity calculations based on Monte Carlo codes (TRIPOLI-4 and SERPENT, coupled with subchannel codes (SUBCHANNELFLOW)) for steady state and transient calculations.
- Performing methods development based on 3D-modelling to improve system thermal-hydraulics modelling of VVER plant, especially by challenging the robustness and validation of CATHARE3 against reference RELAP5 and TRACE models.
- Performing methods development based on 3D-modelling and uncertainty propagation in CFD analyses, using partners codes (STARCCM+, CFX, FLUENT, TRIO-CFD).

CAMIVVER Roadmap

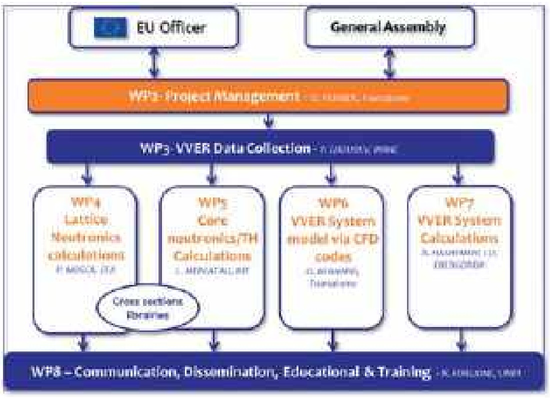


CAMIVVER Project Overview

- *Consortium is 7 partners from 5 countries*:
  - Framatome, EDF and CEA from France,
  - LLC Energorisk from Ukraine,
  - INRNE from Bulgaria,
  - KIT from Germany, and
  - UNIPI from Italy
- *The Project*
  - Budget of **4 M€** funded by the European Commission, in the framework of the Horizon 2020 research program
  - Started on September 1st 2020, for a duration of 3 years
  - Framatome is the project coordinator

CAMIVVER Project Organization

- CAMIVVER relies on lead Industries in the nuclear sector, Research Centers and Universities
- CAMIVVER relies on a strong safety culture established on Gen. II and Gen. III reactors, a consolidated experience of VVER and PWR safety analyses, and on a strong expertise of codes and methods development and validation



Focus on some CAMIVVER works (not exhaustive)

- **WP4 Lattice Code**

– **Task 4.1** dedicated to the status and characterization of the APOLLO3® lattice code and to the set up of first steps toward its industrialization (common work done with EDF and CEA) – ***1st prototype expected in 2022***

D4.1 - Representative use cases and specification requirements for the prototype multi-parameter library generator

– **Task 4.2** dedicated to APOLLO3® calculations V&V for PWR and VVER-1000 assemblies

D4.3 – Definitions of tests cases for the verification phases of the multi-parametric library generator
http://camivver-h2020.eu/src/assets/doc/D4-3.pdf

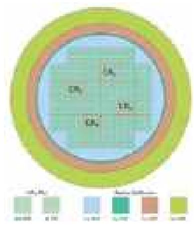
– **Task 4.3** dedicated to VVER lattice calculation scheme optimization – ***1st calculation scheme expected in 2022 - Development and validation of the double-level scheme in 2023***

– **Task 4.4** dedicated to APOLLO3® advanced application (e.g. 3D MOC modeling)

- **WP5 Core physics**

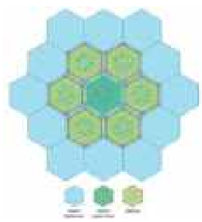
– **Task 5.1** dedicated to the definition of the **mini core reference test cases** and boundary conditions

D5.1 - Description of the core reference test cases – Part 1
http://camivver-h2020.eu/src/assets/doc/D5-1.pdf



– **Task 5.2** dedicated to APOLLO3®/THEDI core calculations of the VVER mini core case and benchmark against SERPENT/SCF

– **Task 5.3** dedicated to the :
  - development of a proof of concept of APOLLO3®/CATHARE3 advanced coupling dedicated to rod ejection and loss of flow transients on the PWR mini core case
  - extension to an hexagonal VVER geometry
  - Tests of multiparametric data libraries provided by WP4
  - Benchmarking with SERPENT/SCF



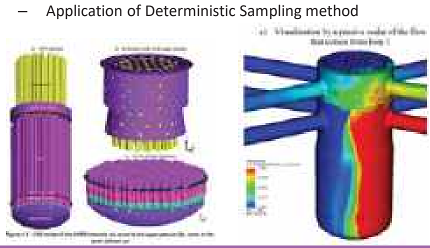
Focus on some CAMIVVER works (not exhaustive)

- **WP6 CFD of primary vessel**

– **First Task in 2021** consisted in the development of CFD models
  - CAD construction
  - 100% NP steady state calculations
  - Code-to-code comparison on core outlet distribution

D6.1 – Description of CFD models from partners
Results of outlet flow distribution benchmark
http://camivver-h2020.eu/src/assets/doc/D6-1.pdf

– **Coming activities**:
  - Mixing experiment (Kozloduy-6 Start-Up test) : CFD validation regarding the evaluation of mixing matrices for VVER primary vessel
  - Uncertainties propagation:
    – Demonstration of inlet-parameters uncertainty propagation through CFD models
    – Application of Deterministic Sampling method



- **WP7 System Analysis**

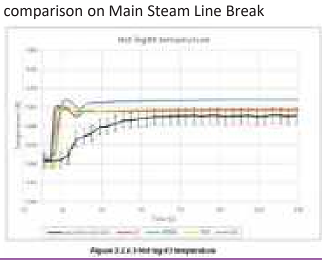
– **First Task in 2021** consisted in the development of the CATHARE3 model

D7.1 –Description of thermal-hydraulics models. Results of steady-state benchmark
http://camivver-h2020.eu/src/assets/doc/D7-1.pdf

– **Beginning of 2022** results of Kozloduy-6 Main Coolant Pump start-up test have been established

D7.2 - Results of Kozloduy-6 MCP start-up transient benchmark
http://camivver-h2020.eu/src/assets/doc/D7-2.pdf

– **Coming activities**:
  - Code-to-code comparisons on Small-Break LOCA due to SG failure
  - Code-to-code comparison on Main Steam Line Break



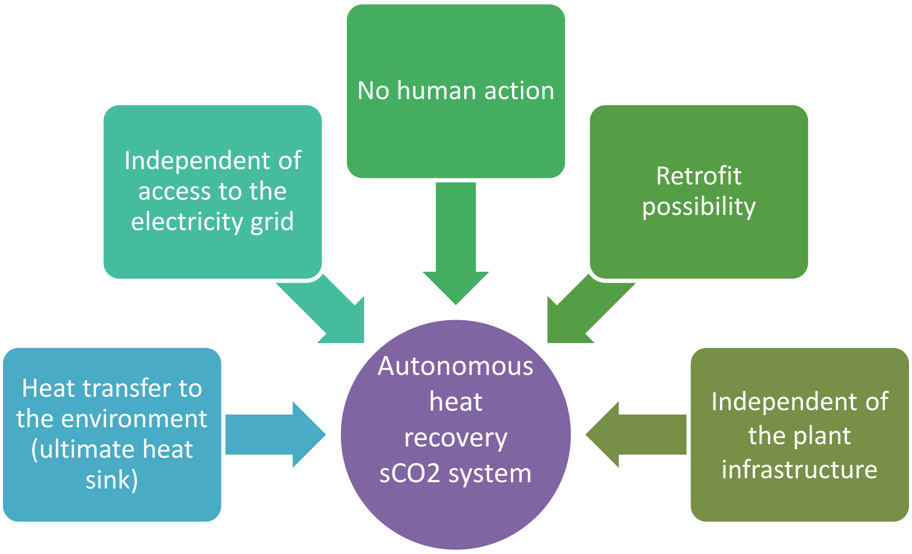
SCO2-4-NPP PROJECT

Motivation - Fukushima Follow-Up

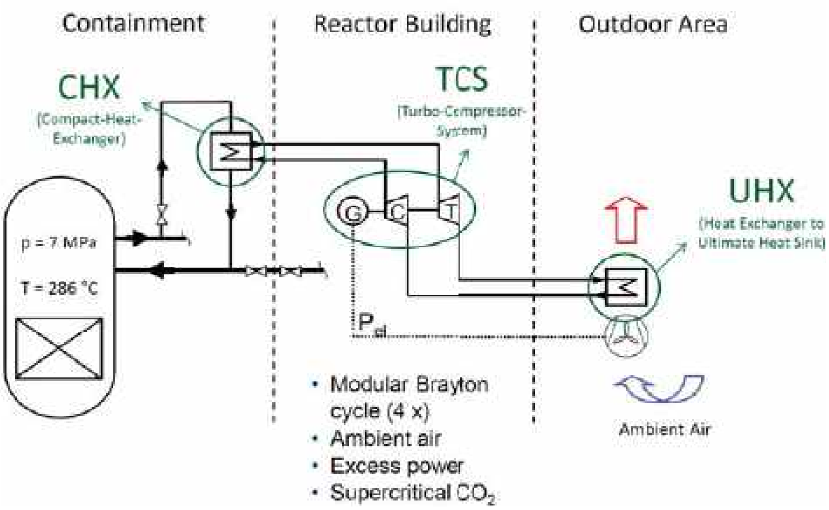
- Loss of ultimate heat sink
- Loss of main, auxiliary, and emergency power supply
- Loss of infrastructure
- Difficulties of rapid access and rehabilitation of the plant

Scientific Trend: **Passive safety systems**, but small driving forces, requirement of large space, difficult for retrofitting, performance under off-design conditions unknown, …

Motivation - New approach



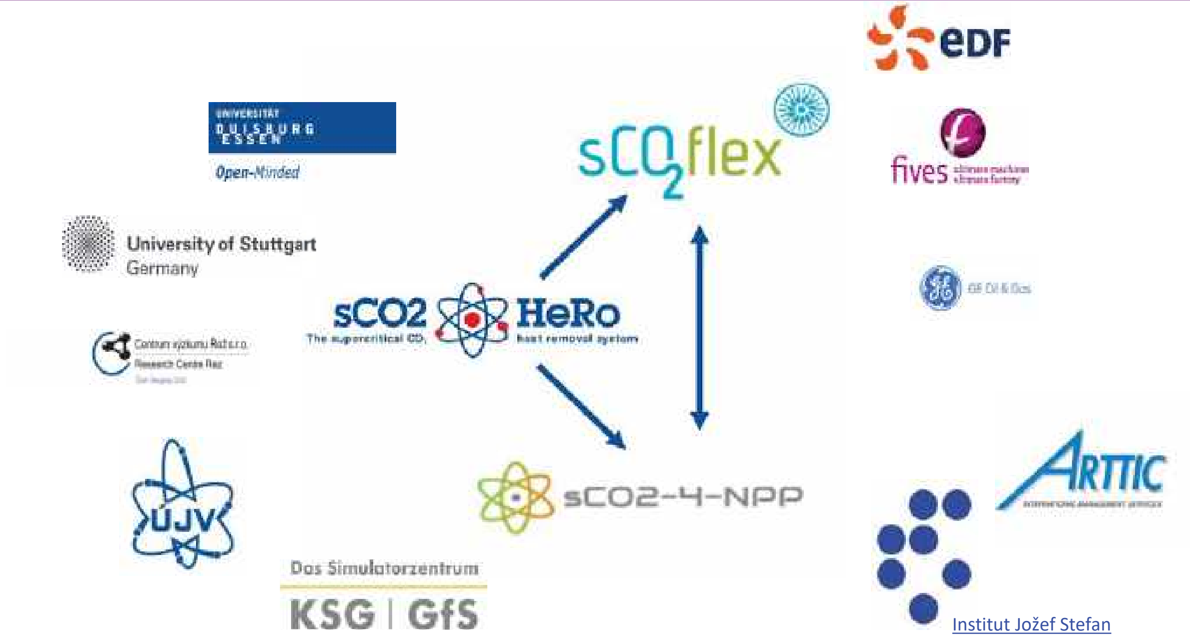
Background : A look back at the work of the sCO2-Hero team



© sCO2-HeRo project

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May - 3 June 2022 | Lyon, France
17-18 September 2019

Consortium

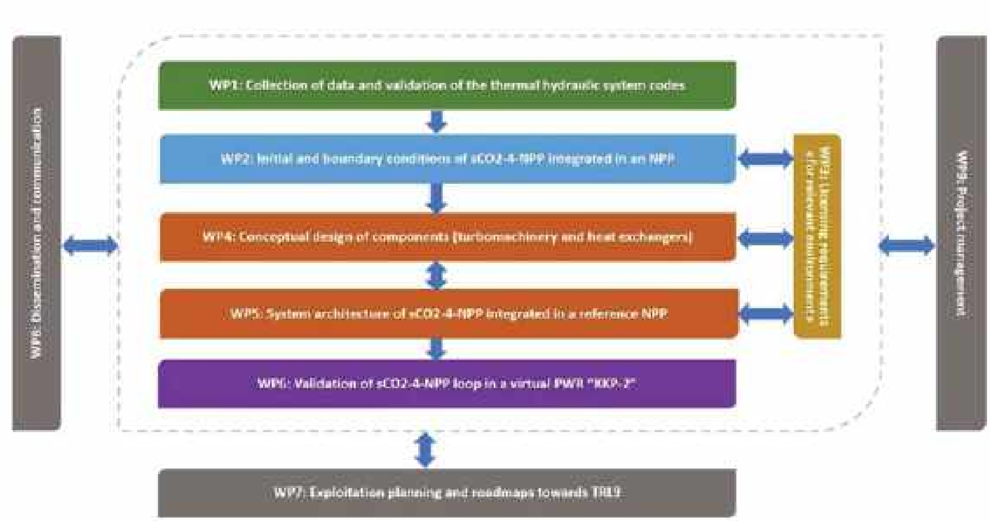


General objectives

- Enhanced sCO2 Heat Removal system validation
  - Validation of the sCO2 models with 2 codes : ATHLET and CATHARE (french code)
  - Validation on PWR reactors like western reactors with the 2 codes
  - Operation of the system integrated into PWR simulator

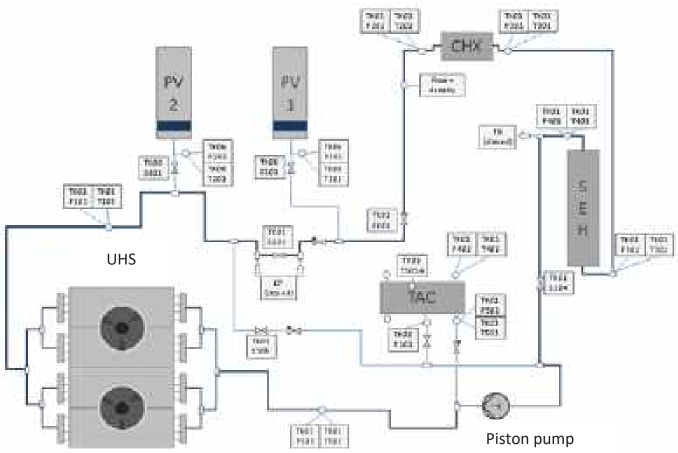
- Preparation of the industrial scaling up
  - Specification of upscaled components for implementation in a full-scale NPP
  - Final design of the system architecture integrated to a real design of PWR reactor
  - Licensing roadmaps and licensing requirements for the upscaled components and the overall system

SCO2-4-NPP Work Plan structure



sCO_2 loop modelling

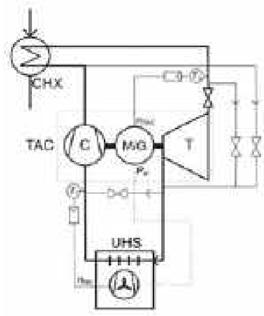
- Loop modelling in 3 thermohydraulic codes

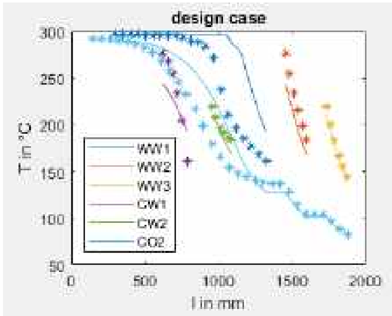


- Results: Comparison between tests data and models in ATHLET, CATHARE, MODELICA

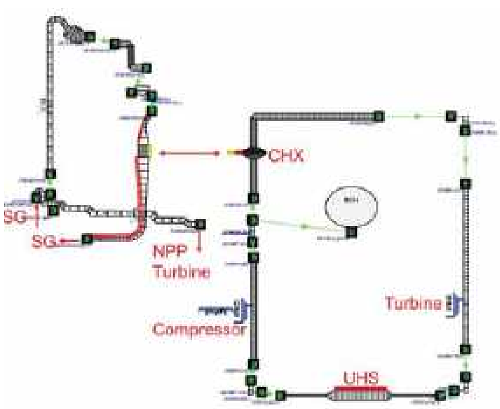
Integration in Thermohydraulic codes

- Challenges :
  - Use of different codes, with SBO type accident scenario, 3 different reactors
  - Testing of different hypotheses (start-up, regulations,...)
  - Modelling of sCO2 cycles in the CATHARE code (new version, new fluid, no components already modelled)

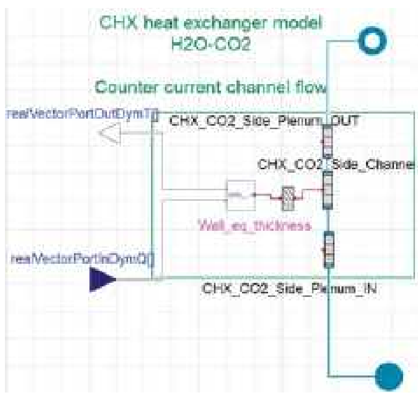




Integration in Thermohydraulic codes



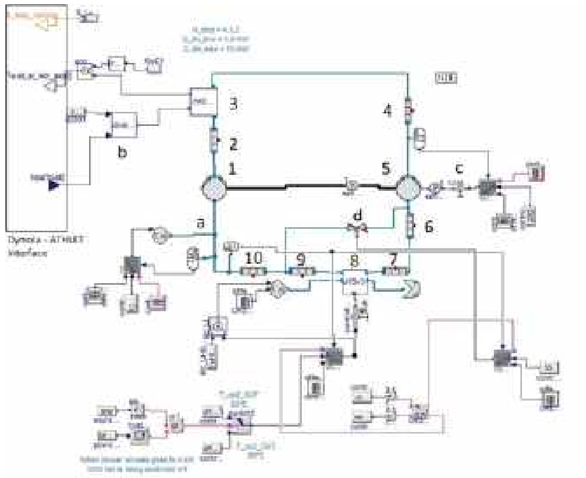
EPR : sCO2 loop allows to cool down the primary circuit but the power dissipated is too low and several sCO2 loops are needed (at least 4)



VVER : 3 starting sCO2 loops can remove the decay heat after the SBO while the fuel-cladding temperature is kept within the safety limits

Thermodynamic modelisation

- Highlights :
  - Evaluation in ATHLET/Dymola for VVER NPP



- Control strategy in Dymola model based on changing the loop filling and UHS bypassing
- Alternative approach without changing the loop filling and without UHS bypassing studied

Start procedures :
- push-up starting procedure (current choice)
- operational readiness state starting procedure

Real-time simulations for implementation in PWR simulator

- Challenges
  - Use of MODELICA to build the real-time simulator of the sCO2 heat removal system to prepared for coupling to the existing FORTRAN based simulator of the NPP (KONVOI).
  - General model will be validated by data obtained at the sCO2-HeRo loop (WP1).

- First results
  - FMU version of the Dymola model runs in version FMU Co-simulation ver 1.0. Need to be running in ver 2.0
  - Zero iteration sCO2 loop Dymola model for evaluation of the Dymola model real time capabilites.
  - First iteration Dymola model prepared with input and output connectors – Needs for behavior assessment (controls…)

Lessons learned

- Continue the necessary comparisons and harmonizations of the different codes
  - Ensure that the results obtained for these different codes will be of acceptable quality for the different nuclear studies in cases where keeping different codes is necessary.
- Share new developments related to innovations.
  - New developments of libraries or models in a code.
  - Improve the dissemination of these innovations
- Moving towards common digital tools.
  - Sharing and common developments can also lead the different actors towards the choice of a common tool, and not the multiplication of codes.

Thank You

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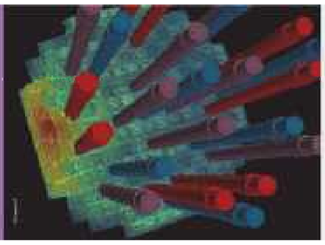

FISA 2022

30 May - 3 June 2022
Lyon, France

Methodologies for efficient and reliable NPP polymer ageing management

TeaM Cables – Morgane BROUDIN (EDF R&D)
El-Peacetolero – Mohamed BEN CHOUIKHA (Sorbonne Université Paris)

HORIZON 2020 TeaM CABLES El-Peacetolero

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May - 3 June 2022 | Lyon, France

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Methodologies for efficient and reliable NPP polymer ageing management

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May - 3 June 2022 | Lyon, France 2

Why do we care about polymer ageing?

- Since 1960, the use of polymer materials has increased dramatically
    - From **10Mt** to **359Mt** in 2018, *i.e*. 3,600% growth in less than **60 years**

- In the French nuclear sector, polymers occupy a share of **16%** by mass compared to **6% 25 years ago**

Polymer needs are real…

1500 km of cables per NPP including 50 km in reactor building

5 Tons of polymers in reactor building ~ football field

Polymer needs consist in providing…

- Key solutions
    - Cheaper (faster) repair techniques with the same security level
    - Specific materials (much more than ever): gamma stabilization, super hydrophobic

- Justifications "**durability**": obsolescence, duration life extension and set-up non-destructive exams
    - **To schedule preventive and corrective maintenance operations**

Reactor building dom repair Bruce Nuclear Generating Station (Ontario – Canada)

Cable jacket and insulation layer

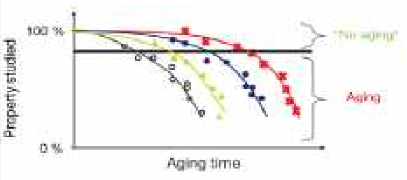
HDPE Pipes EDF NPP SIZEWELL B, UK

How to schedule maintenance operations?

Experimental methodologies

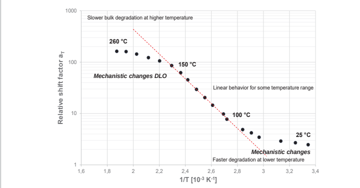
Numerical methodologies

Sampling



Do Lab tests to chase no ageing indicator

Empirical

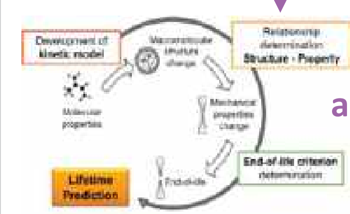


Apply Arrhenius law

Kinetic modelling to simulate long term P

Non-destructive exams

Multi-scale approach



How to schedule maintenance operations?

Experimental methodologies

Numerical methodologies

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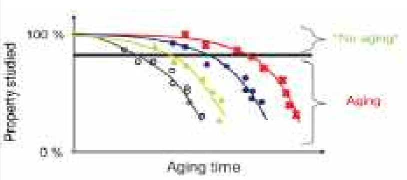

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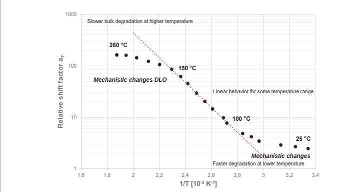

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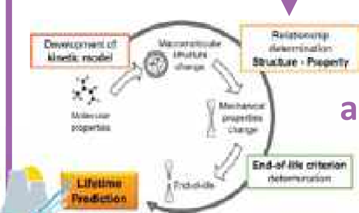


El-Peacetolero

TeaM CABLES

TeaM Cables in a nutshell

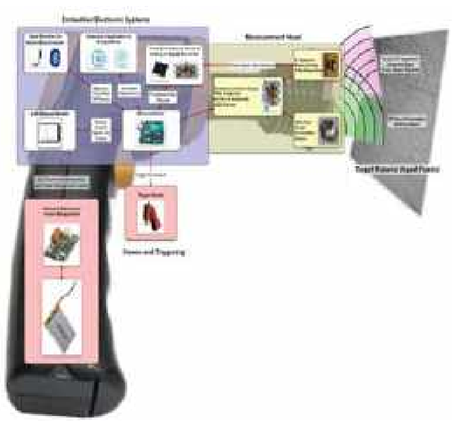
European tools and methodologies for an efficient ageing management of nuclear power plant cables

- H2020 Framework: "Continually improving safety and reliability of Generation II and III reactors"
  - 2017 – 2022
  - 5,5M€ including 4,2M€ financed by EU
  - 13 partners : from cable manufacturers to utilities through academic labs
  - Lead: EDF
  - XLPE insulations, NPP Cables
  - 3 PhD students (thesis presented) + 1 post-doc student
- A dedicated end-user's group
  - EDF, Tecnatom, Engie LaborElec, Airbus, Forsmark, Paks II, NEXANS
- Work plan combines
  - Experimental work packages to obtain data throughout accelerated ageing
  - Highly scientific work packages for the polymer ageing kinetics models

El-Peacetolero in a nutshell

Embedded Electronic solutions for Polymer Innovative Scanning Methods using Light Emitting devices for diagnostic Routines

- H2020 Framework: "Innovation for generation II and III reactors"
  - 2020 – 2023
  - 3,65M€ including 3M€ financed by EU
  - 9 Partners with a large spectrum of skills (materials, optoelectronic, artificial intelligence and robotics fields)
  - Lead: Sorbonne Université Paris
  - HDPE/Neoprene Pipes
  - 3 PhD students
- Work plan divided into two distinct large blocks of work:
  - Material's ageing and characterization, data generation, AI and algorithms
  - Device itself: LED set up, laser heads and the optoelectronics needed



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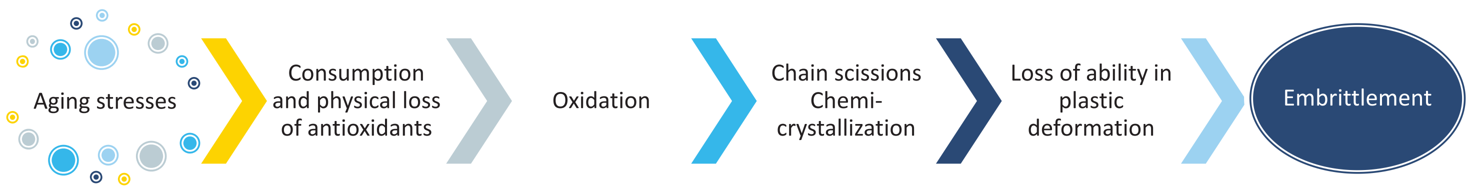
Methodologies for efficient and reliable NPP polymer ageing management

Main scientific challenges?

- Deeper **understanding** of operation-induced **degradation mechanisms**

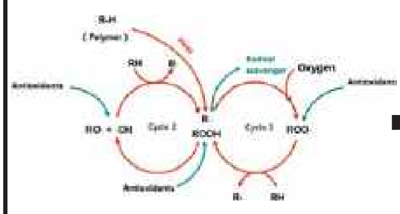


A. Xu, et al., "Physico-chemical characterization of the blooming of Irganox 1076® antioxidant onto the surface of a silane-crosslinked polyethylene", PDST, 2020.
A. Xu, et al., "Thermal ageing of a silane-crosslinked polyethylene stabilised with a thiodipropionate antioxidant" , PDST, 2020.
A. Xu, et al., "Physico-chemical analysis of a silane-grafted polyethylene stabilised with an excess of Irganox 1076®. Proposal of a microstructural model", PDST, 2021.
A. Xu, et al., "Thermal ageing of a silane-crosslinked polyethylene stabilised with an excess of Irganox 1076®", PDST, 2021.

Main scientific challenges?

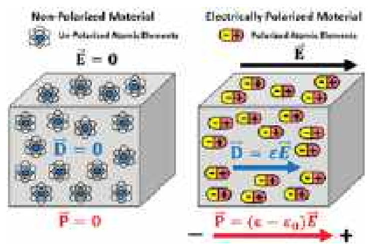
- Deeper **understanding** of operation-induced **degradation mechanisms**
- Using **multi-scale approach** to predict reliable **lifetime**

1 Matrix & degradation species



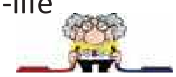
Through kinetic modelling

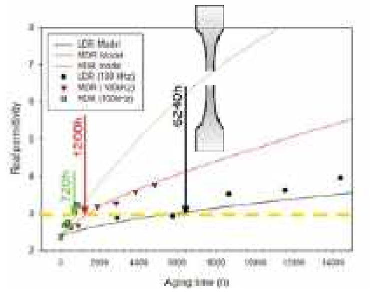
2 Dielectric permittivity, ε



Refers to the ability of the substance to store energy

3 Define end-of-life criterion





Predict duration life

S. Hettal, et al., "A new analytical model for predicting the radio-thermal oxidation kinetics and the lifetime of electric cable insulation in nuclear power plants. application to silane cross-linked polyethylene", Polymer Deg. and Stab., 2021.
S. V. Suraci, et al., "Multi scale aging assessment of low-voltage cables subjected to radio-chemical aging: Towards an electrical diagnostic technique", Polymer Testing, 2021.
S. Hettal, et al., "Towards a Kinetic Modeling of the Changes in the Electrical Properties of Cable Insulation during Radio-Thermal Ageing in Nuclear Power Plants. Application to Silane-Crosslinked Polyethylene", Polymers, 2021.
S. Hettal, et al., "A kinetic modeling approach for predicting the lifetime of ATH filled silane cross-linked polyethylene in a nuclear environment (under review)", Polymer, 2022.
S.V.Suraci, et al., "Multiscale modelling of permittivity of polymers with aging: how molecular scale properties modify the electrical permittivity" (under review)", Transaction on Dielectrics and Electrical Insulation, 2022.

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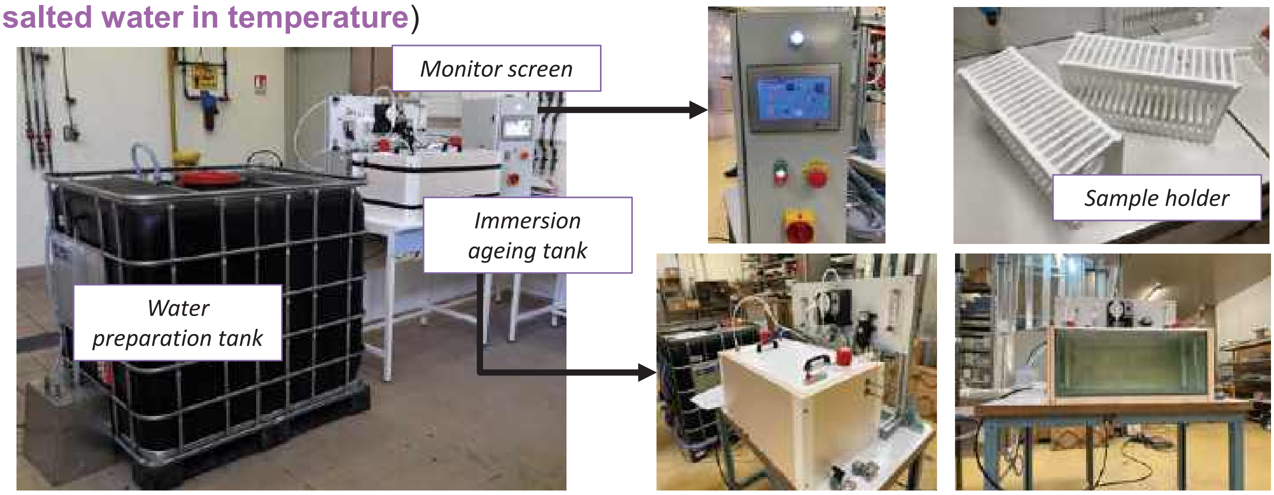
Methodologies for efficient and reliable NPP polymer ageing management

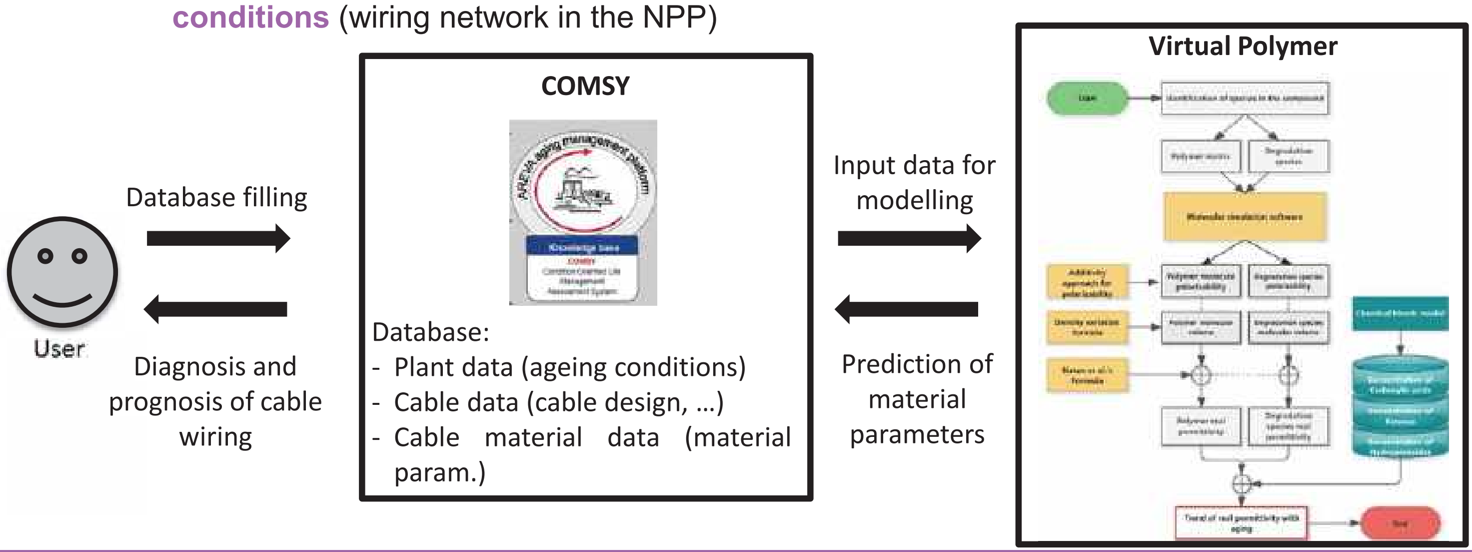
Lessons learnt and follow-up issues

- **Accelerate** YES but **keep** the **representativeness** of the **degradation mechanisms** observed in **NPPs conditions**
  - Setting up a dedicated accelerating aging loop within the framework of El-Peacetolero project considering numerous environmental factor (**immersion in chlorinated and salted water in temperature**)



Lessons learnt and follow-up issues

- **Capitalization**!
  - A novel "**TeaM Cables tool**" has been developed integrating the **multiscale model** and providing the **residual lifetime of cables** knowing **material** data and the **exposure conditions** (wiring network in the NPP)



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Methodologies for efficient and reliable NPP polymer ageing management

Introduction

Main scientific challenges

Lessons learnt and follow-up issues

Conclusions

Conclusions – to be continued…

- The combination of these 2 projects allows to **provide non-destructive and predictive tools**, that can help assessing the reliability and functionality of the **polymer's-based components such as cables or pipes**

- Predictive tool
  - TeaM Cables highlights the importance of **ageing models' choice** (**multi-scale approach** *vs*. empirical approach), but also the need to **crosscheck** the results with **data from in service inspections**, which allows for **predictive maintenance** (as opposed to scheduled maintenance)

- NDTs
  - El-Peacetolero tool will be an **innovative TRL7 product** that will **have demonstrated a real use in a safety critical industry**
  - Within TeaM Cables EU H2020 project, **dielectric spectroscopy** already shown **promising results** to evaluate the **degradation rate** for portions of the **cable**

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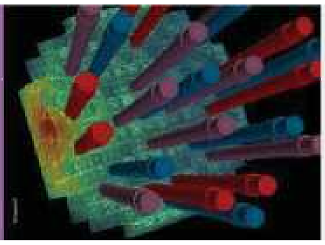
Lyon, France

Methodologies for efficient and reliable NPP polymer ageing management

TeaM Cables – Morgane BROUDIN (EDF R&D)
El-Peacetolero – Mohamed BEN CHOUIKHA (Sorbonne Université Paris)

HORIZON 2020 TeaM CABLES El-Peacetolero

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May - 3 June 2022 | Lyon, France



FISA 2022

30 May - 3 June 2022
Lyon, France

ADVANCED NUMERICAL SIMULATION AND MODELLING FOR REACTOR SAFETY – CONTRIBUTIONS FROM THE CORTEX, McSAFER AND METIS PROJECTS

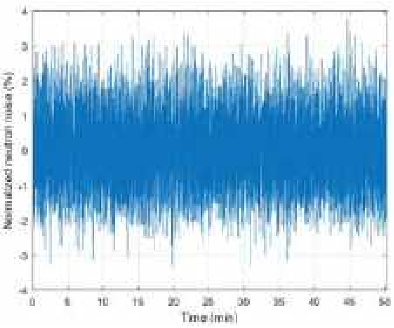
C. DEMAZIÈRE (Chalmers University of Technology, Sweden)
V.H. SANCHEZ-ESPINOZA (KIT, Germany)
I. ZENTNER (EDF R&D, France)

Introduction

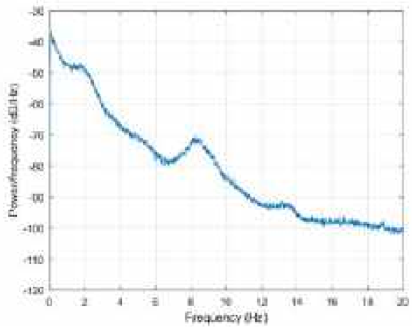
- Numerical simulations = one of the pillars of nuclear reactor safety
- New situations and/or new conditions require new modelling capabilities
- Any new modelling development also require:
  - Verification of the tools
  - Validation of the tools
- Presentation giving an overview of the CORTEX, McSAFER and METIS projects in this respect

Short description of the projects

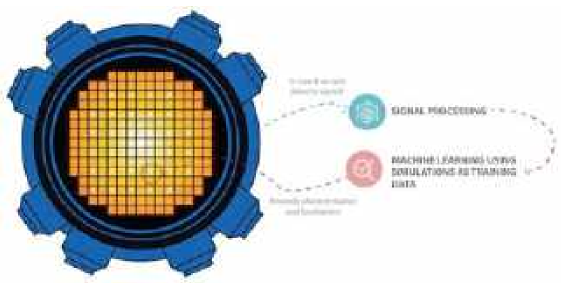
- CORTEX project overview:
  - Project running between September 1st, 2017, and August 31st, 2021
  - 18 European organizations and more than 70 researchers involved + Japan + USA
  - Main objective: develop a neutron noise-based core monitoring technique



Example of an in-core neutron detector time signal



Corresponding power spectrum of the in-core neutron detector signal

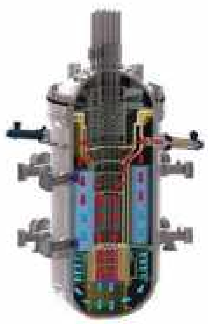


More info at:
cortex-h2020.eu

Short description of the projects

- McSAFER project overview:
  - Perform key experiments relevant for SMR-safety (core, helical HX) at EU-facilities (COSMOS-H, MOTEL, HWAT)
  - Develop, improve, validate simulation tools for safety evaluations of SMRs
  - Demonstrate advantages of advanced (multiphysics/multiscale) tools compared to legacy ones
- Consortium of 13 partners (6 R&D, 4 universities, 3 industry partners)
- Project running between September 1st, 2020, and August 31st, 2023
- Apply simulation tools to four SMR-designs (F-SMR, CAREM, NuScale, SMART)

CAREM (Argentina)



SMART (Korea)

NuScale (USA)

F-SMR (France)

More info at:
mcsafer-h2020.eu

Short description of the projects

- METIS project overview:
  - Project running between September 1st, 2020, and August 31st, 2024
  - 12 European organizations + 1 Japan + 2 USA
  - Main objective: innovation in methodologies and tools for seismic risk assessment

METIS
Seismic Risk Assessment for Nuclear Safety
http://metis-h2020.eu

- METIS high level objectives:
  - Improve the predictability of (non-linear, best-estimate) beyond design analyses
  - Testing model performance by comparison to data and model updating
  - Uncertainty quantification and propagation
  - Develop, improve, disseminate open-source tools for seismic risk analysis

Key objectives in modelling needs

- In CORTEX, development of a set of complementary modelling tools:
  - Time-domain vs. frequency-domain
  - Deterministic methods vs. probabilistic methods (i.e., Monte Carlo)
  - Several levels of refinements/discretization:
    - For the angular variable, from coarse (i.e., diffusion) to fine (i.e., transport) discretization
    - For the spatial variable, from coarse (i.e., fuel assembly) to fine (i.e., fuel pin) discretization
    - For the energy variable, from coarse (i.e., two energy groups) to fine (i.e., several tens of energy groups)
    - ➢ Objective: determine the areas of validity of “low-order” approaches
  - Noise source specification via “expert opinion” or using more physical approaches (i.e., using structural mechanics models)

Key objectives in modelling needs

- McSAFER
  - Thermal hydraulics: Cross flow in the core, Helical HX, Transition from forced to natural convection, CHF, 3D flow inside the RPV, effectiveness of PRHRS, stability of natural convection flow
    - ➢ Key thermal hydraulic experiments at three EU facilities: COSMOS-H (KIT), HWAT (KTH), MOTEL (LUT)
  - Core physics: Small size (H, D), heterogeneity, harder spectrum, increased role of reflector design, increased leakage from core, etc.
    - ➢ Multiphysics deterministic and MC-based coupled codes for improve core analysis
  - 3D phenomena in integrated Reactor Pressure Vessel: Many components located inside the RPV, e.g., pumps, helical HX, PZR, structures to enhance mixing inside RPV, etc.
    - ➢ Multiscale/multiphysics safety analysis tools combining CFD, system TH and subchannel TH codes based on a modular and flexible coupling approach (ICoCo)
  - Improve safety analysis tools needed due to increase the prediction of complex phenomena in the core and inside the RPV (perturbed 3D TH phenomena) during accidents, e.g., ATWS, boron dilution, steam line break

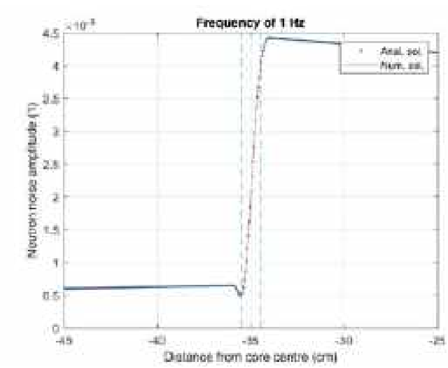
Key objectives in modelling needs

- METIS integrated approach from source to site:
  - For simulation of wave propagation from seismic source to the structure and equipment response to avoid conservatism at interface
  - For uncertainty propagation to avoid “double counting”
  - Open-source tools

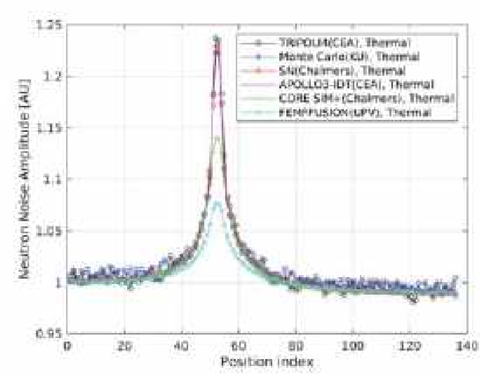
OPENQUAKE calculate share explore	code_aster	salome_meca	OpenSees	SCRAM
PSHA code	General purpose FEM code available with salome_meca platform	Simulation platform including pre and post processing (geometry, mesh, analyses, visualization)	FEM tool dedicated to earthquake engineering	PSA code

Key achievements

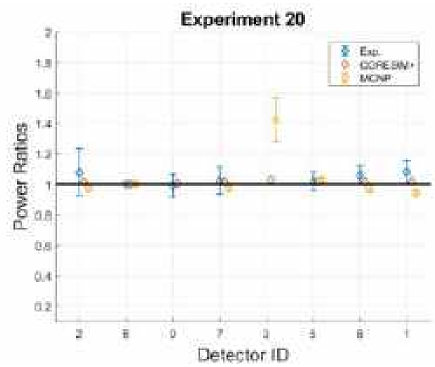
- In CORTEX, extensive program of verification and validation of the tools:



Comparison between CORE SIM and the analytical solution obtained for the case of a vibrating region



Benchmark of the various tools for a vibrating fuel pin in an infinite fuel assembly lattice

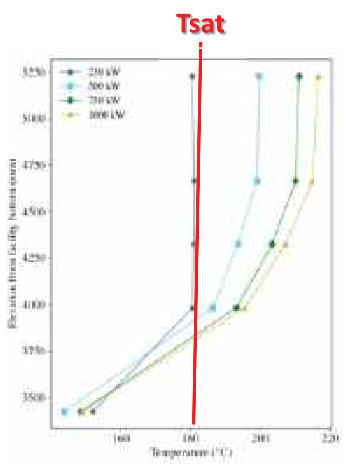


Comparisons between calculations and experiments at AKR-2, TU Dresden, Germany

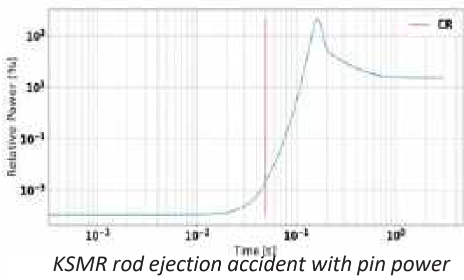
Key achievements

- McSAFER

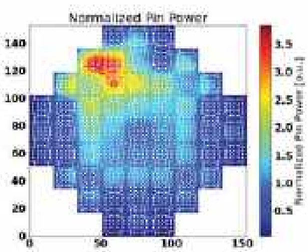
MOTEL test to study the TH of helical HX



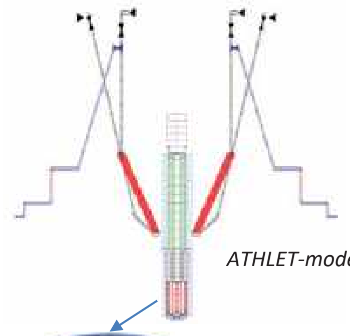
Averaged axial temperature profiles of all steam generator tubes with different core power levels



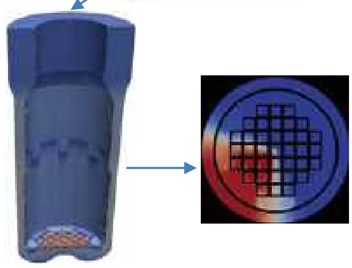
KSMR rod ejection accident with pin power reconstruction at power peak



KSMR REA analysis: relative power [%] predicted by PARCS/SCF



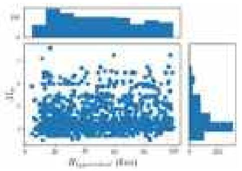
ATHLET-model



Multiscale TH: NuScale analysis with ATHLET/TrioCFD

Key achievements

- METIS

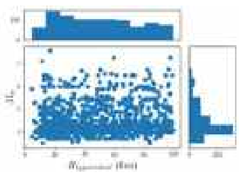


Seismic source and ground motion

- Efficient sampling plans for uncertainty propagation
- Stochastic ground motion simulation model
- Aftershock seismicity models
- V&V procedure (« PSHA Testing »)

Key achievements

- METIS



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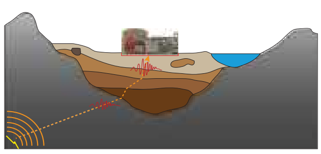
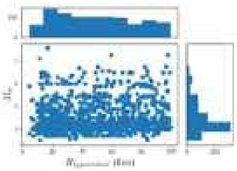
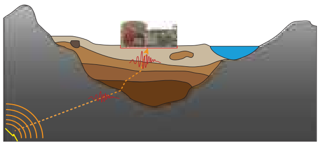


Site response

- Numerical simulation of wave propagation including geometry and spatial variability of soil properties

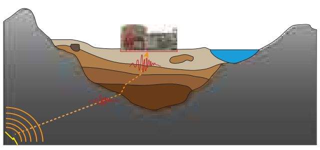
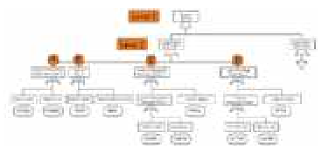
Key achievements

- METIS

		
Seismic source and ground motion	**Site response**	**SSCs response and fragility**
• Efficient sampling plans for uncertainty propagation • Stochastic ground motion simulation model • Aftershock seismicity models • V&V procedure (« PSHA Testing »)	• Numerical simulation of wave propagation including geometry and spatial variability of soil properties	• V&V procedure including Bayesian model updating by comparison to observations

Key achievements

- METIS

			
Seismic source and ground motion	**Site response**	**SSCs response and fragility**	**Risk quantification**
• Efficient sampling plans for uncertainty propagation • Stochastic ground motion simulation model • Aftershock seismicity models • V&V procedure (« PSHA Testing »)	• Numerical simulation of wave propagation including geometry and spatial variability of soil properties	• V&V procedure including Bayesian model updating by comparison to observations	• New open-source tool for seismic risk assessment (SCRAM coupled to Andromeda) and data management tool to facilitate uncertainty propagation and parametric analysis

Training, education and dissemination activities

- All projects are based on:
  - The organization of short courses/workshops/summer schools
  - The organization of training sessions on tools/codes
  - The involvement of young scientists
  - The publication of many reports (deliverables), journal papers and conference proceedings – most of them being open access
  - The participation to and presentation at conferences and technical meetings
  - The use of various communication channels (website, social media channels, newsletters, popular science videos, posters, flyers)
  - The establishment of contacts with other projects and international organizations

Utilization and cross-fertilization

- Industrial applications and usefulness at the core of the projects
- Development of new modelling capabilities not (yet) part of the industrial tools
- ➢ Some of the tools are open source/freely available
- Cross-disciplinary projects involving many areas profiting from each other
- Projects having ramifications beyond Europe
- Heavy “end-user’s” involvement to always remain align with the needs of the industry
- ➢ Projects resulting in better understanding of the physics, safer plants, higher operational flexibility and enhanced economics

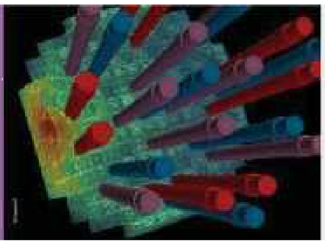
Conclusions and future recommendations

- CORTEX/METIS: Methods, if to be used by the industry, should be made:
  - Directly applicable to industrial contexts
  - Easier to use
  - More robust
  - More transparent
  - Available with validated software
- McSAFER:
  - New data from safety-related thermal hydraulic test under SMR-conditions will be available for code validation
  - Promising capabilities of multi-physics and scale methods for safety evaluations and their complementarity with industry-like tools
  - Potentials of modular and flexible ICoCo-approach for code coupling (multi-scale and physics)

Acknowledgements

- All contributors to the projects are deeply acknowledged for their efforts and dedication
- Financial support:

  - The CORTEX project was funded from the Euratom Research and Training Programme 2014-2018 under the grant agreement number 754316
  - The McSAFER project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement number 945063
  - The METIS project has received funding from the Horizon 2020 programme under grant agreement number 945121



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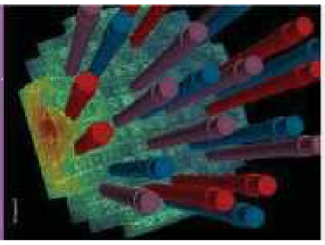

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Ensuring safety of innovative solutions ELSMOR, PASTELS, and NUCOBAM projects

Ville TULKKI, Michaël MONTOUT, Myriam BOURGEOIS

Novel solutions, novel reactors

- In order to renew safe and sustainable nuclear energy production, new solutions must be innovated
  - Technologies are being developed that can be utilized in the nuclear field, such as advanced manufacturing technologies
  - Improved understanding of physical behaviour allows for robust safety functions such as those based on natural convection of water
  - Simpler systems enable even whole new breed of designs, such as small modular reactors
- Safety of new systems must be ensured when they're taken into use
  - NUCOBAM, investigating advanced manufacturing technologies
  - PASTELS, modelling and experiments on passive safety systems
  - ELSMOR, safety of light water small modular reactors

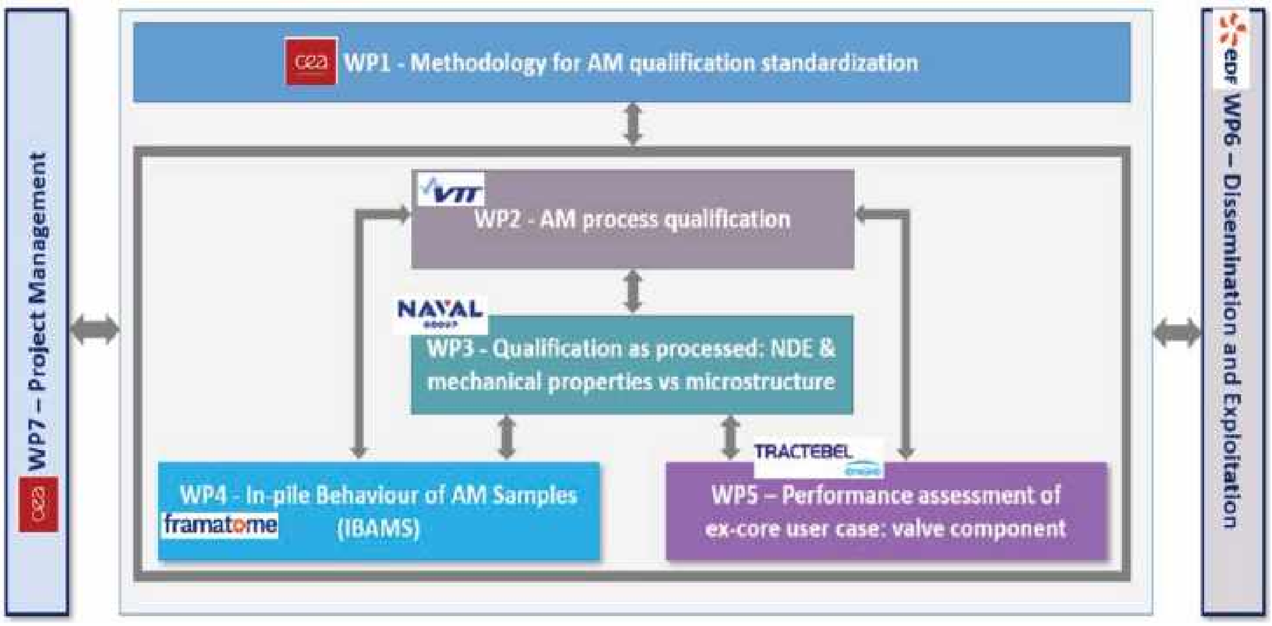
NUCOBAM

NUclear COmponents Based on Additive Manufacturing aims at:

- developing the qualification process
- provide the evaluation of the in-service behaviour allowing the use of additively manufactured components for nuclear installations

- Two types of demonstrators in 316L stainless steel will be manufactured:
- debris filter
- valve block body

NUCOBAM



NUCOBAM manufactured components

VALVE BODY

Assembled valve body with internals (Ramén Valves)

DEBRIS FILTER

Debris filter (Framatome)

NUCOBAM

Current status of NUCOBAM

- Draft methodology available and will be refined based on test results.
- First test coupons shipped to consortium members, test programme to start soon.
- Final methodology towards end of project (mid 2024).
- Mid-term workshop (end of September 2022), fab-lab event (March 2023) and final project workshop (September 2024) planned.

FIRST DRAFT OF AM QUALIFICATION PROCESS FOR NUCLEAR INDUSTRY

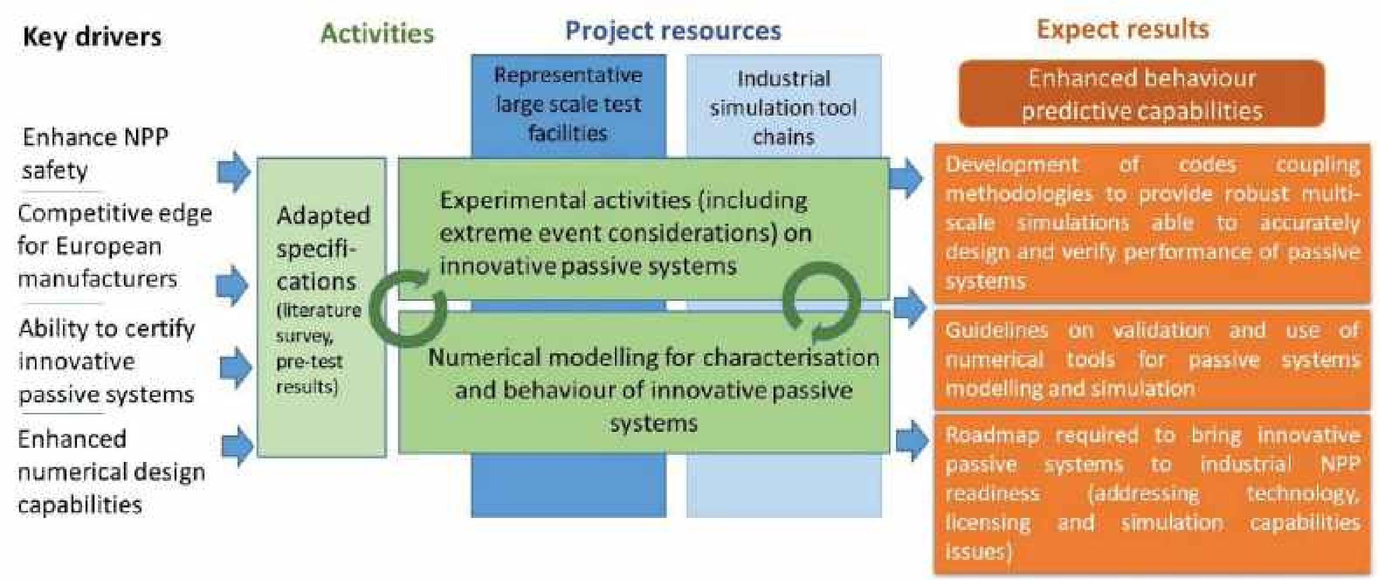
OUTLINE OF REPORT
General:
Terminology:
Documentation:
Powder Procurement
Qualification of the AM Process
Manufacturing of Component & Test Specimens
Heat Treatment
Inspections & Tests
Finishing of AM component
Examination

PASTELS - PAssive Systems: Simulating the Thermalhydraulics with ExperimentaL Studies

In order to ensure their safe and reliable functioning, the study of innovative passive systems encompasses several important aspects:

- The identification and understanding of the main physical phenomena governing the behaviour of these systems.
- The efficient numerical modelling of these physical phenomena, and their validated implementation in dedicated computational codes, to use these numerical tools for the system design and safety demonstration.
- The adaptation of the safety demonstration methodology in order to consider the specificity of passive systems (scaling, reliability, performance level, etc.).

PASTELS

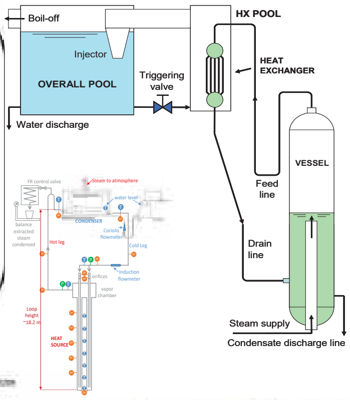


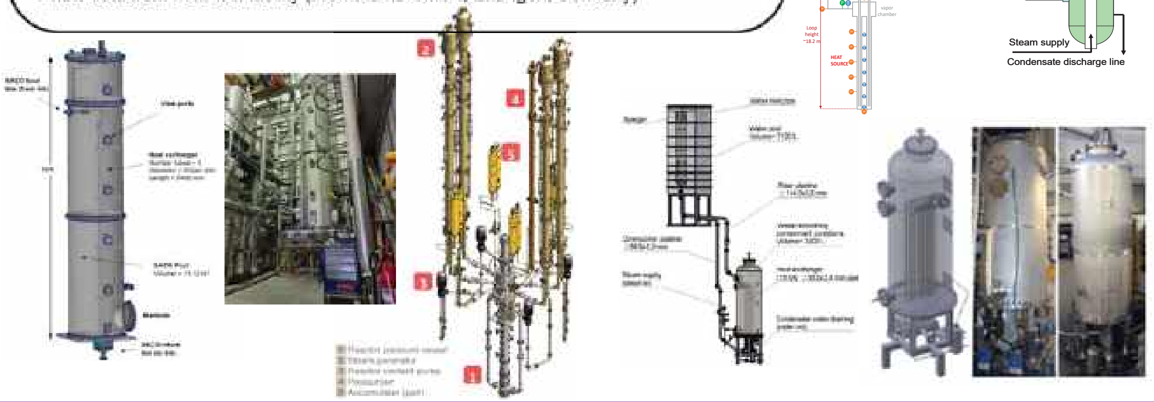
The PASTELS project focuses on two specific passive safety system designs: SAfety COndenser (**SACO**) and Passive Containment Cooling System (**PCCS**)

PASTELS experimental devices and numerical tools

Experimental means at different scales

- Separated effect tests for studying of closed two-phase flow thermosiphon loop
  → existing data from **HERO-2** test facility (SIET, Piacenza, Italy)
- Combined effect tests for studying of passive heat exchanger system in-pool
  → existing data from **PERSEO** test facility (SIET, Piacenza, Italy)
- Integral tests for studying of an open two-phase flow thermosiphon loop design of **PCCS**
  → new data from **PASI** test facility (LUT University, Lappeenranta, Finland)
- Integral tests for studying of an innovative design of **SACO**
  → new data from **PKL** test facility (Framatome GmbH, Erlangen, Germany)





Benchmarking of various numerical tools acting at different scales

- **system codes:** AC², CATHARE, RELAP5, TRACE
- **CFD codes:** CFX, Fluent, neptune_cfd
- **severe accident codes:** ASTEC, MELCOR

PASTELS

- PASTELS project will contribute to increase the reliability of safety demonstration for nuclear power plants and to enhance industrial design capabilities of European actors.
- Thanks to improved simulation tools and experimental support, the technologies relying on passive cooling will be better understood to help their qualification for future implementation in NPPs.
  - The PASTELS project will also increase academic and scientific knowledge in Europe concerning the understanding of passive systems.
- A synthesis of achievements and deficiencies of code capabilities for simulating passive systems will be established with suggestion for future work, new developments and additional experimental support.
- The expected outcome of numerical activities is to ensure that thermal-hydraulic numerical simulation tools capture the key physical phenomena observed during the experiments.
  - These activities will also contribute identifying the optimal range of conditions within which the passive cooling systems can operate.

PASTELS

Current status of PASTELS

- 6 technical reports submitted to date, learn more on:

→ *PASTELS official website: https://ww.pastels-h2020.eu*

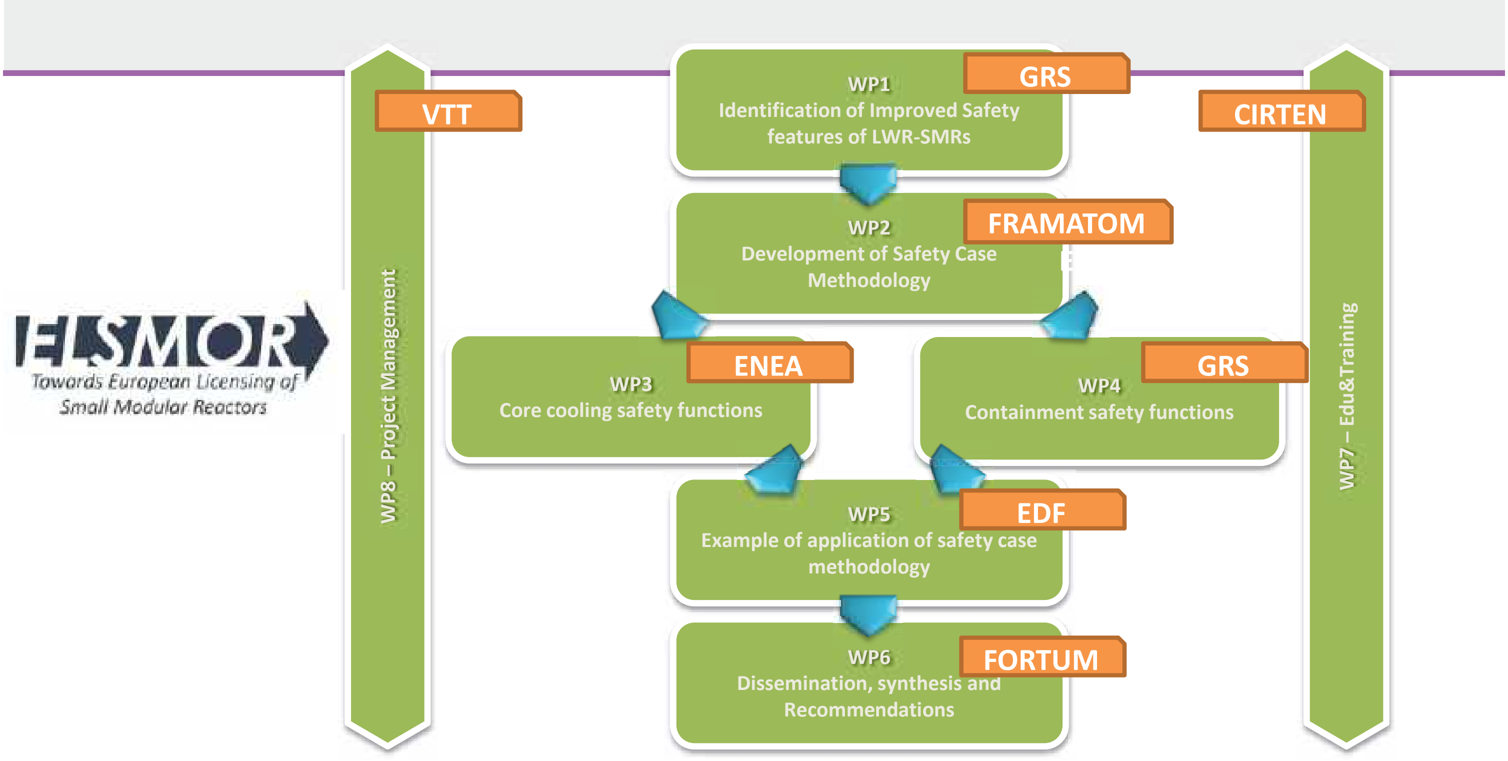
→ *https://www.linkedin.com/company/pastels-h2020*

PASTELS technical deliverables (May 22)	Statut
D2.1 Bibliographic research on the phenomena related to the natural circulation in closed loop	Public
D2.2 Description of HERO-2 facility and simulations	Public
D3.1 Technical description and design review of the PKL facility and the SACO component	Public
D4.1 PASI test specification	Public
D4.2 PASI facility description for PASTELS	Public
D4.3 PASI pre-test analysis results	Public

- Bibliographic studies on the phenomena related to the natural circulation in closed loop performed at the beginning of the project
- PKL/SACO test programme started in January 2022 – phase P1 dedicated to sensitivity analysis on boundary conditions is completed
- PASI/CWC test programme underway - initial testing started in spring 2022
- Hero-2 simulation activities terminated in early 2022
- Pre and post-tests calculations on PASI/CWC and PKL/SACO have begun

ELSMOR

- ELSMOR ais investigate selected safety features of LW-SMRs
  - Prevention of early release
    - Core cooling functions
    - Containment
- Research on methods for robust safety assesments
  - Several prior proposals / methodologies developed for both currently operating plants as well as non-conventional, e.g. for GenIV, fusion…
- Demonstration of the applicability of developed tools and methods
  - Test case ”E-SMR” (”European SMR”)
- Dissemination to stakeholders



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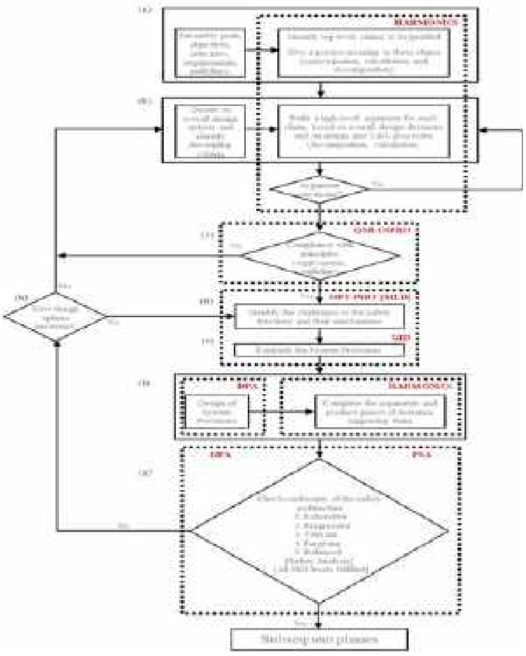
Safety Methodology for innovative reactor design – Main results

Proposed ELSMOR safety methodology for innovative reactors:

- mainly derived from the insights provided by the SARGEN_IV project that, in turn, is based on the GIF ISAM and IAEA INPRO methodologies.
- complemented with the HARMONICS method to develop high-level safety goals into more concrete requirements in a systematic and hierarchical manner

→ provide a framework for defining requirements of different level of detail and for documenting the results of different types of safety assessments.



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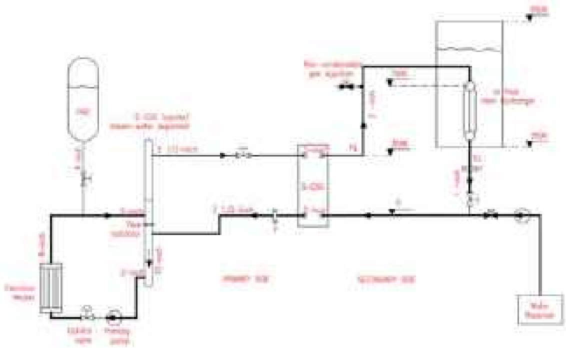
Other ELSMOR work

- Investigation of passive core cooling
  - Phenomena identification and ranking, code benchmarks, experimental work at SIET
- Work on assessing containment
  - Metallic containment in pool, phenomena and code benchmarks
- ”E-SMR” dataset
  - Creation of ”E-SMR” dataset describing an SMR sharing similar safety functions as Nuward but based on publicly available data and expert judgement – aim to provide a common benchmark case that can be used afterwards too

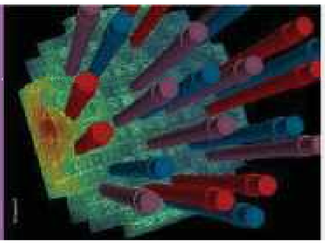


Thank you

- The NUCOBAM project receives funding from the Euratom research and training programme 2019-2020 under the grant agreement no. 945313.
- The PASTELS project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945275.
- The ELSMOR project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847553.

https://www.pastels-h2020.eu/

www.elsmor.eu



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Innovation & Qualification of LEU Research Reactor Fuels & Materials

Jared Wight – SCK CEN
Stéphane Valance – CEA
Stefan Holmström – SCK CEN

Non-proliferation Background

- 1953: **Atoms for Peace** speech of Eisenhower
- Late 1970s: Concerns about nuclear proliferation
- 1978: U.S. DOE initiated the Reduced Enrichment for Research and Test Reactors (**RERTR**), development of high density LEU fuels (e.g. uranium silicide)
- 1990 – 2000 : LEU silicide fuel utilized for LEU conversions where technically feasible
    - 4.8 gU/cc; moderate power/BU (not applicable to HPRRs)
- 1999 - 2013: Europe addresses high density LEU fuel qualification for High Performance Research Reactors: IRIS, LEONIDAS, ALPS
- Since 2013: **The HERACLES group forms as a joint European effort**
- Since 2015: HERACLES-CP
- Since 2017: LEU FOREvER
- Since 2020: EU-QUALIFY

Euratom Projects

HERACLES

Leu FOREvER

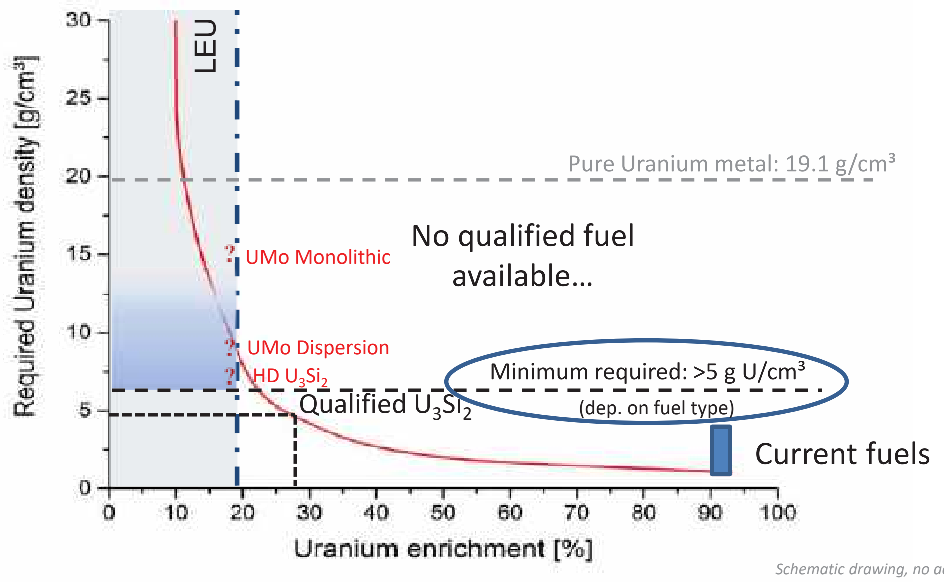
HERACLES Team & Partners

EU's Leading Nuclear
Fuel Developers

www.heracles-consortium.eu

HERACLES Partners

LEU Fuel Challenge



Schematic drawing, no actual data!

EURATOM Projects

- Initial fuel development
  - Fabrication development
  - UMo dispersion
    - Irradiation & PIE
  - UMo monolithic

This project has received funding from the Euratom H2020 research and training work programme 2014-2018 under grant agreement No 661935

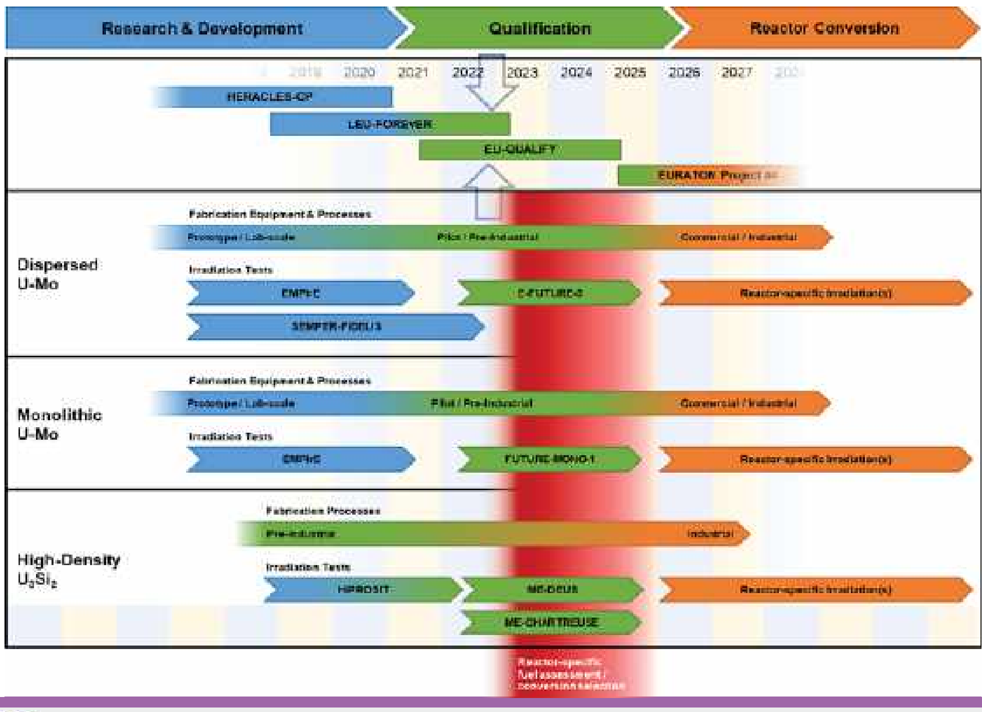
- Further fuel development
  - Fabrication development
  - UMo dispersion
  - UMo monolithic
    - PIE
  - Alternative: U3Si2 dispersion
    - Irradiation & PIE

This project has received funding from the Euratom H2020 research and training work programme 2014-2018 under grant agreement No 754378

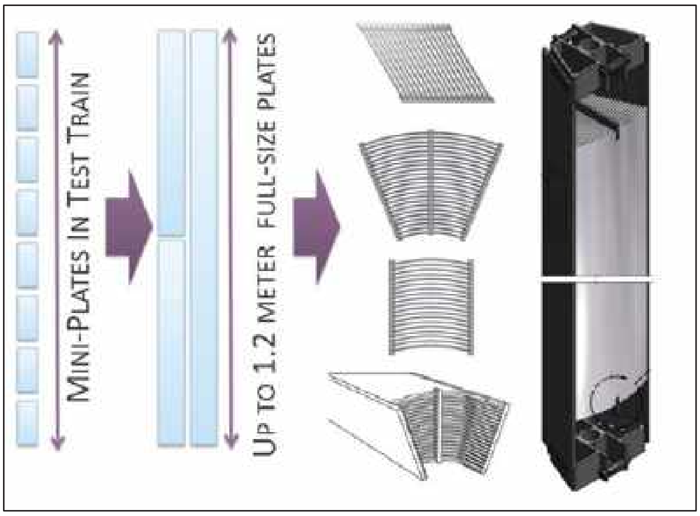
- Initial fuel qualification
  - Fabrication development
  - UMo dispersion
    - Irradiation & PIE
  - UMo monolithic
    - Irradiation & PIE
  - U3Si2 dispersion
    - Irradiation & PIE

This project has received funding from the Euratom H2020 research and training work programme 2018-2019 under grant agreement No 945009

HERACLES Roadmap



Fuel Qualification Strategy

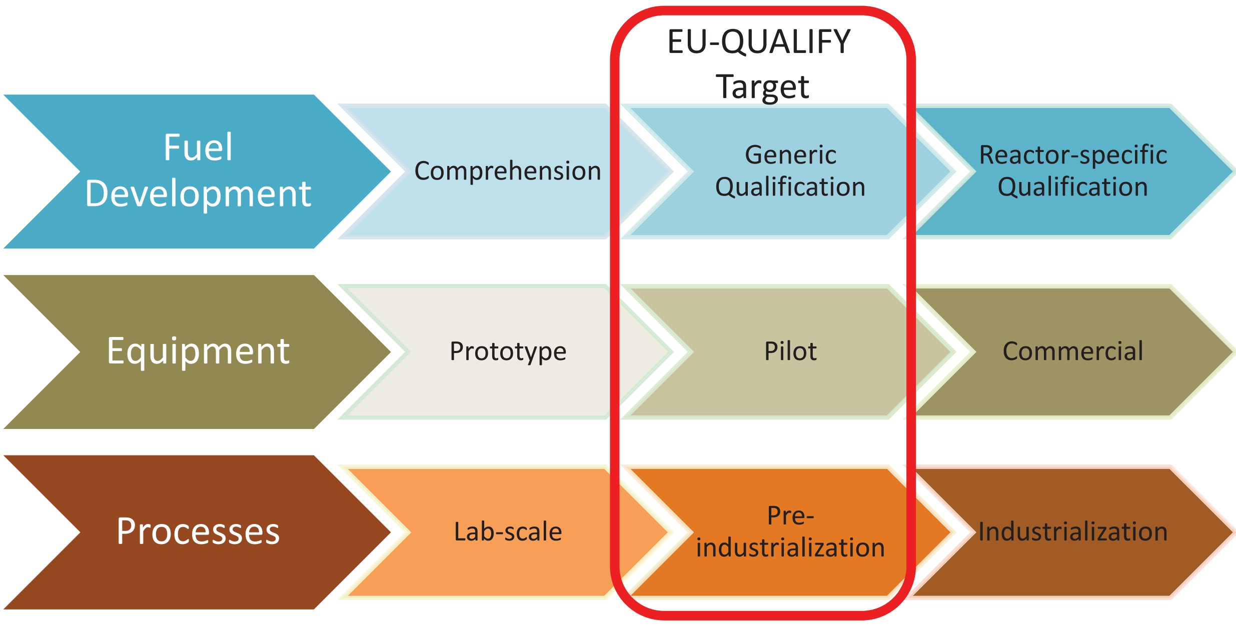


Scale: miniplates -> full-size plates -> assemblies

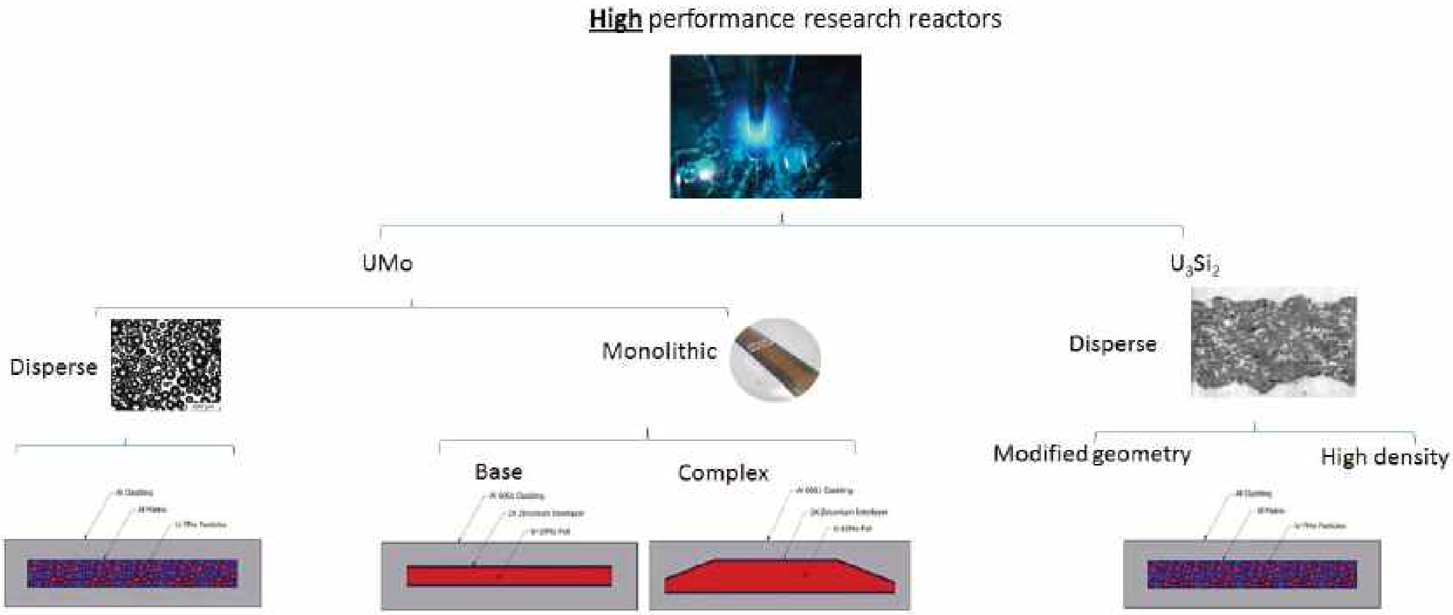
Volume: individual plates to multiple plates in assemblies

Maturity: lab-scale fabrication to commercial-scale manufacturing

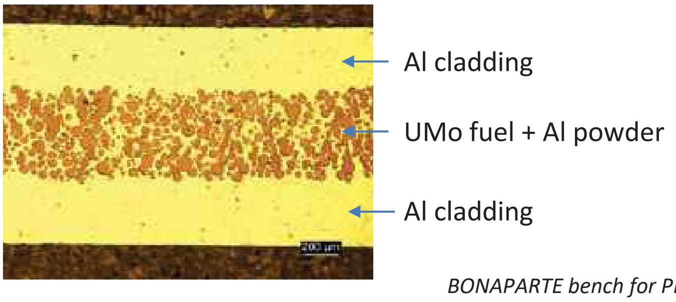
Fuel Qualification Objectives



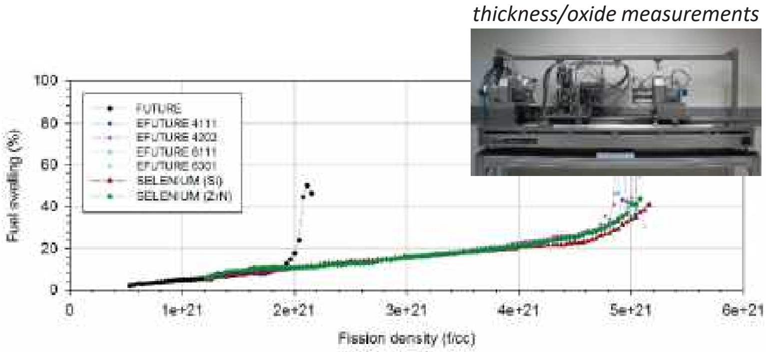
LEU Fuel System Development for HPRRs



UMo Dispersion Fuel – Overview



BONAPARTE bench for PIE thickness/oxide measurements



UMo fuel

- In 2000 UMo alloy was identified as best candidate high density fuel
  - 7-10 wt% Mo added to stabilise high temperature γ-U phase
  - High U density in alloy: >15 gU/cc
- Development pursued in two paths:
  - U-7wt% Mo dispersion
  - U-10wt% Mo monolithic
- Challenge: U-Al interdiffusion leading to unacceptable swelling behavior

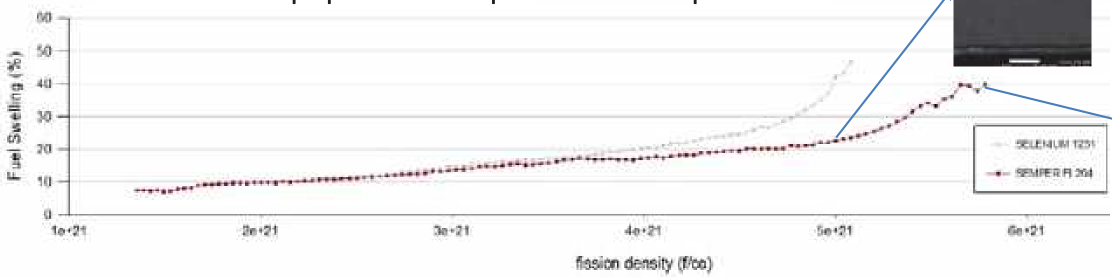
UMo dispersion fuel

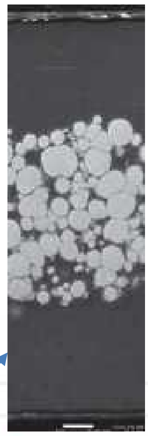
- Dispersion of 50 vol% fuel/Al matrix results in 8-8.5g U/cm³
- Various initial tests identified the unacceptable swelling behavior
- Various modifications tried in SEMPER-FIDELIS experiment

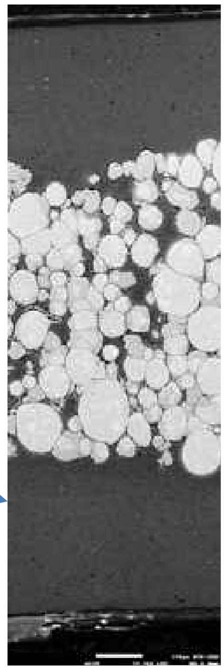
UMo Dispersion Fuel – Status

Results of LEU-FOREvER

- PIE/comprehension of SEMPER-FIDELIS experiment results
  - HERACLES identified optimizations for acceptable fuel performance at high power and high burnup
    - Heat treatment of the atomized powder
    - ZrN coating of the powder
    - Addition of 5% Si to the matrix
  - Optimizations demonstrated with commercial-scale fabrication equipment and pre-industrial processes







UMo Dispersion Fuel - Objectives

Objectives of EU-QUALIFY

- E-FUTURE-III test
  - Fabricate 4 UMo dispersion fuel plates
  - Irradiate flat plates in FUTURE-5 basket
  - Perform NDE PIE

FUTURE-5 basket loaded with fuel plates

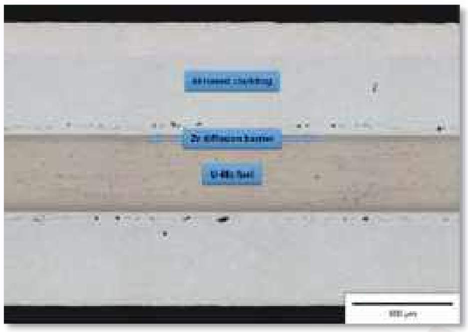
FUTURE-5 fuel plates

EU-QUALIFY Objectives	
Fuel Development	• Establish fuel performance database • Increase data set with E-FUTURE-III test
Equipment	• Establish/implement pilot scale equipment: atomizer, heat treatment, and powder coater
Processes	• Demonstrate all processes at pre-industrial with E-FUTURE-III test

UMo Monolithic Fuel – Overview & Status

UMo monolithic fuel

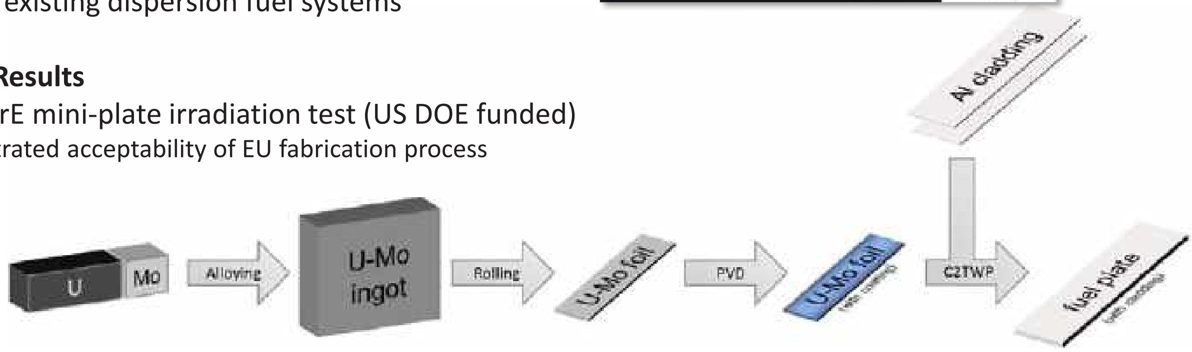
- Highest possible uranium density of all fuel candidates: **up to 15.5 gU/cm³**
- Consists of a metallic U-Mo foil, coated with a Zr diffusion barrier, clad between aluminum
- Acceptable irradiation behavior demonstrated in various irradiation tests performed by US DOE
- Challenge: fabrication equipment/processes considerably different to existing dispersion fuel systems



LEU-FOREvER Results

- PIE of EMPIrE mini-plate irradiation test (US DOE funded)
  - Demonstrated acceptability of EU fabrication process

framatome
TUM



UMo Monolithic Fuel - Objectives

Objectives of EU-QUALIFY

- FUTURE-MONO-1 test
  - Fabricate 2-4 UMo monolithic fuel plates
  - Irradiate flat plates in FUTURE-5 basket
  - Perform NDE PIE

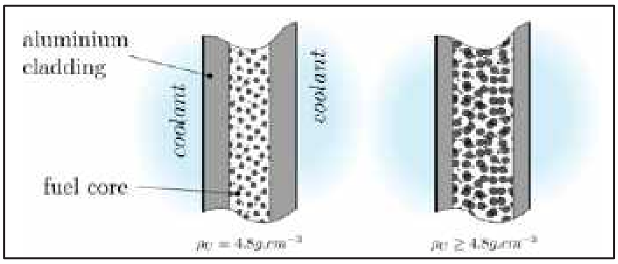
Post-irradiation underwater visual inspection of a FUTURE-5 fuel plate

EU-QUALIFY Objectives	
Fuel Development	• Establish a fuel performance database • Increase data set with FUTURE-MONO-1 test
Equipment	• Establish pilot scale equipment: casting, foil rolling and foil coating
Processes	• Demonstrate all processes at pre-industrial scale with FUTURE-MONO-1 test

High-loaded U_3Si_2 – Overview & Status

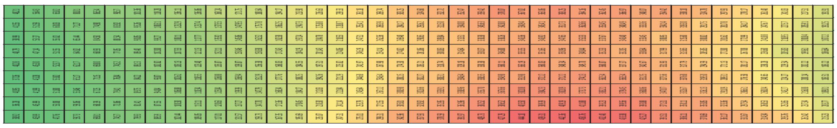
High density/loaded U_3Si_2

- Demonstrated fabrication technology and existing infrastructure at 4.8 gU/cc
- Increase volume of fuel to ~50% in fuel meat
- Change to fuel design may be necessary such as a slightly thicker fuel plate
- Challenge: ensure acceptable fuel performance at higher loading and thinner cladding



LEU-FOREvER Results

- Irradiation & PIE of HiPROSIT test
  - Demonstrated fabrication capability
    - Thicker fuel meat at 4.8 gU/cc
    - Thinner cladding and higher density at 5.3 – 5.6 gU/cc
  - Demonstrated acceptable fuel behavior at high power and high burnup conditions for all candidates

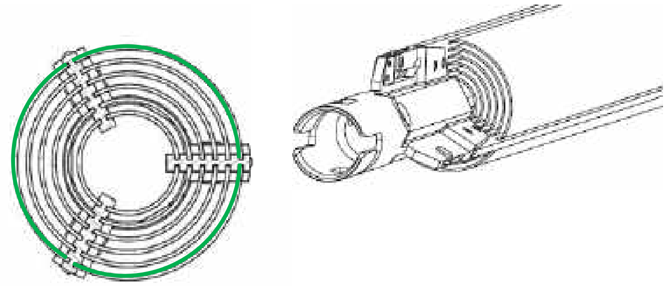


HiPROSIT plate
Post-irradiation neutronics analysis
peak heat fluxes

High-loaded U_3Si_2 – Objectives

Objectives of EU-QUALIFY

- ME-DEUS test
  - Fabricate 3 high density U_3Si_2 (5.3 gU/cc) formed/curved fuel plates
  - Assemble into outer ring of a mixed BR2 fuel element
  - Irradiate at high power and moderate BU
- ME-CHARTREUSE test
  - Fabricate 3 thick meat U_3Si_2 (4.8 gU/cc) formed/curved fuel plates
  - Assemble into outer ring of a mixed BR2 fuel element
  - Irradiate at high power and moderate BU



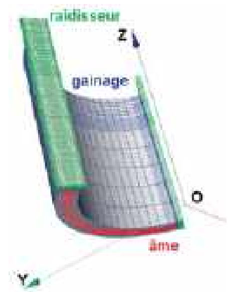
BR2 Mixed Element

LEU silicide plates in green

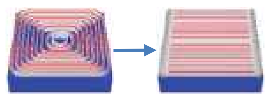
EU-QUALIFY Objectives	
Fuel Development	• Establish a fuel performance database • Increase data set with examination HiPROSIT test • Increase data set with ME-DEUS and ME-CHARTREUSE tests
Equipment	• None necessary All equipment currently at commercial-scale
Processes	• Demonstrate all processes at pre-industrial scale with ME-DEUS and ME-CHARTREUSE tests

Conclusions

- **LEU-FOREvER project was highly successful**
  - Increased comprehension of UMo dispersion fuel system and identified design for qualification through SEMPER-FIDELIS PIE
  - Demonstrated the EU fabrication process for the UMo monolithic fuel system through PIE of EMPIrE
  - Demonstrated high loaded/density U3Si2 fuel system at high power and high burnup enabling an alternative solution for some LEU conversions
  - Demonstrated a new design for LVR-15 fuel assembly (medium-power reactor) to increase EU security of fuel supply through fabrication and irradiation
  - Increased EU fuel performance modeling capabilities through the MAIA code
- **EU-QUALIFY project has high expectations**
  - Demonstrate final design of the UMo dispersion fuel system in multiple FUTURE-5 plates through the irradiation and PIE of EF3 to initiate generic fuel qualification
  - Demonstrate design of the UMo monolithic fuel system in multiple FUTURE-5 plates through the irradiation and PIE of FM1 to initiate generic qualification
  - Demonstrate high loaded/density U_3Si_2 formed/curved plates in MEs for generic qualification



MAIA code mesh for curved MTR fuel plate



LVR-15 current to new FA

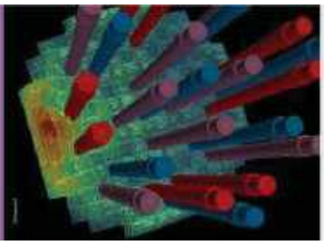
This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 754378

SCK CEN
Studiecentrum voor Kernenergie
Centre d'Etude de l'Energie Nucléaire
Belgian Nuclear Research Centre

Stichting van Openbaar Nut
Fondation d'Utilité Publique
Foundation of Public Utility

Registered Office: Avenue Herrmann-Debrouxlaan 40 – BE-1160 BRUSSELS
Operational Office: Boeretang 200 – BE-2400 MOL

This project has received funding from the Euratom H2020 research and training work programme 2018-2019 under grant agreement No 945009



FISA 2022

30 May - 3 June 2022
Lyon, France

Towards an
Optimized Management of Accidents

Luis E. Herranz (CIEMAT, Spain)

Gonzalo Jiménez (UPM, Spain)

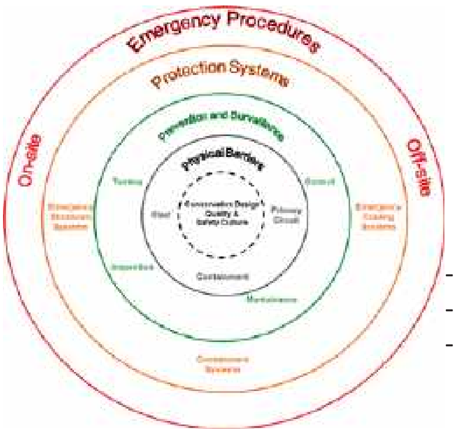
Francesco S. Nitti (ENEA, Italy)

CONTENTS

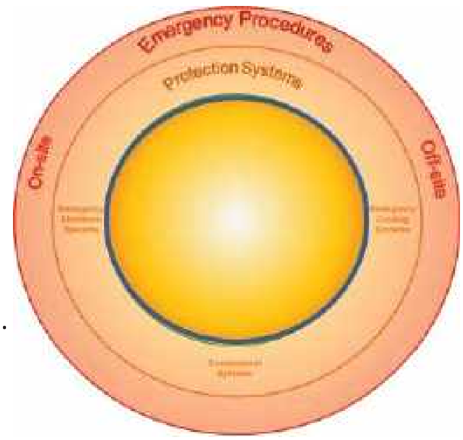
- Motivation
- The PIACE Project
- The MUSA Project
- The AMHYCO Project
- Final Remarks

Motivation

- Research on accidents: Deep-down in the roots of the DiD concept.



- Safety systems – Performance (passive!).
- Analytical tools – From BE to BEPU (AM!).
- Containment – Combustion risk (AM!)



(Herranz, 2021)

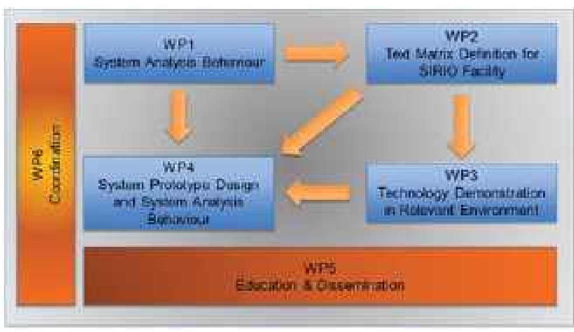
- EURATOM commitment to research on Nuclear Power Plants safety!

The PIACE Project

Overview

- Passive Isolation Condenser (PIACE). H2020 GA nº 847715 (400 p-m).
- **Aim:** To demonstrate the feasibility of a passive innovative Decay Heat Removal (DHR) system.
  - Design assessment
  - Feasibility testing (SIRIO facility)

(LW & LMRs)

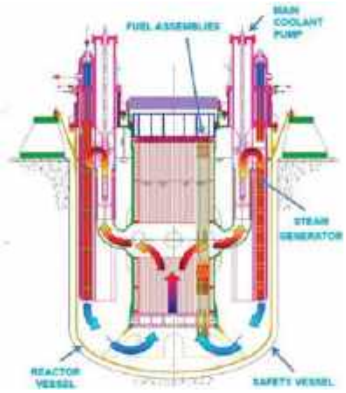


- **Extension:** 2019 – 2022.
- **Partners:** ANN, EAI, ENEA, GEN ENERGIJA, JSI, RATEN, SCK-CEN, SIET, SINTEC, TRACTEBEL, UPM

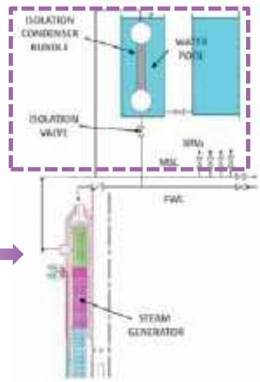
The PIACE Project

Preliminary Results

- **LMRs** (ALFRED, 200 MW_{th}) – A PLOOP (Protected Loss Of Offsite Power)

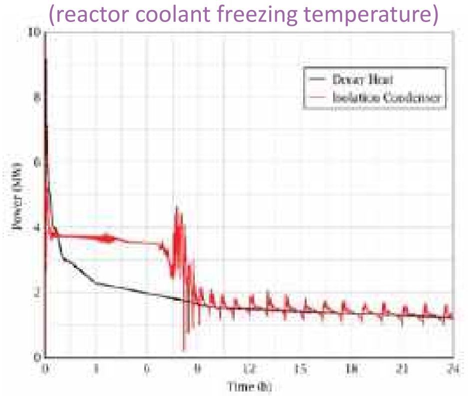


(Alemberti, 2018)



RELAP5-3D

14 h grace-period extension
(reactor coolant freezing temperature)



- Other transients modeled for MHYRRA, PWR (2000 MW_{th}), ESBWR, …

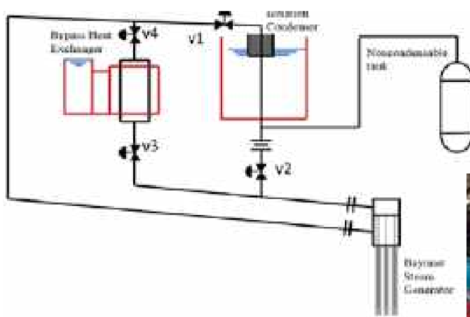
The PIACE Project

Preliminary Results

- **Testing in SIRIO facility**

SIRIO facility upgrading needs and test matrix of each reactor technology

LFR, PWR and BWR are selected for test campaign



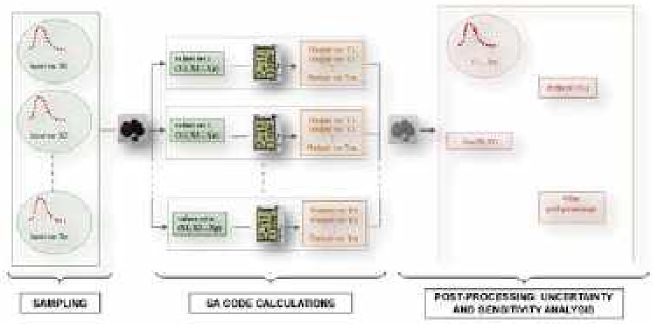
	LFR (SIRIO as it is)	ADS		PWR		BWR		PHWR	
		Proposal 1	Proposal 2	Proposal 1	Proposal 2	Proposal 1	Proposal 2	Proposal 1	Proposal 2
Layout & components modifications required	None	Direct connection of the non condensable tank to the HX upper header		Heat transfer surface of HX increased by a factor 1.82	Heat transfer surface of HX increased by a factor 1.82; Gas Tank volume increased by a factor 1.2	Extra vessel on Steam line. 6" x 5,85 m	None	Modification of the diameters of the most piping of the loop	
Operation parameters									
Power [kW]	55	29.3	1.25	55	55	55	110	30	55
Pressure primary circuit [bar]	180	16.0	16.0	60	60	72.52	72.52	46	46
Pressure gas tank [bar]	110	12	12	50	50	50	69	30	30
Water inventory [kg]	38	38	30.7	38	38	57.1	57.1	38	38

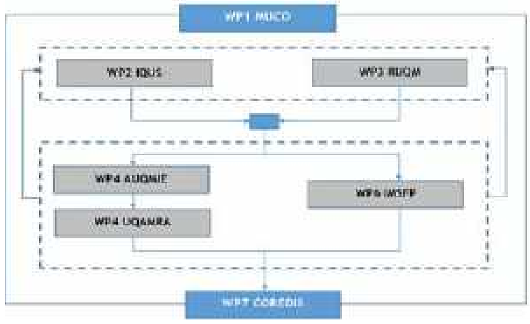
- The test campaign on LFR Technology already ongoing.

The MUSA Project

Overview

- Management and Uncertainties of Severe Accidents). H2020 GA nº 847441 (625 p-m).
- **Aim:** To quantify uncertainties in SA codes' predictions, AM included (FOM: Source Term).





(Gen. II & III; SFPs)

- **Extension:** 2019 – 2023.
- **Partners:** Bel V, CEA, CIEMAT, CNPRI, CNSC, ENEA, Energorisk, EPRI, Framatome, GRS, INRNE, IRSN, JAEA, JACOBS, JRC, KAERI, KIT, LEI, LGI, NINE, PSI, SSTC, Tractebel, TUS, UNIPI, UNIRM1, USNRC, VMU, VTT

The MUSA Project

Preliminary Results

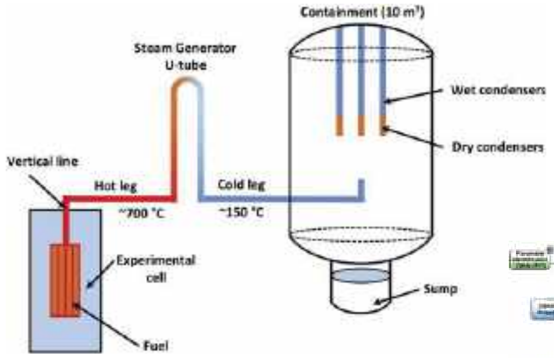
- **On input-deck uncertainties**

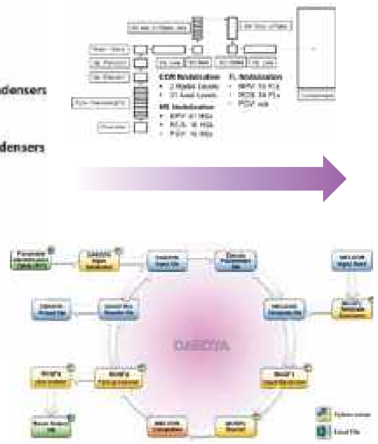
Phenomena	Uncertain Parameter	reference value	lower bound	upper bound	pdf	reference
Sedimentation	Gas viscosity [kg/ms]	1.0 / N/A	-5% / N/A	+5% / N/A	Uniform	Expert Judgment
	Gas temperature [K]	N/A	N/A	N/A	N/A	N/A
	Gas pressure [Pa]	1.55E+07 / N/A	-1.5% / N/A	+1.5% / N/A	Normal	Expert Judgment
	Gas mean free path	N/A	N/A	N/A	N/A	N/A
	Particle diameter Lower Bound [m]	0,000000011	0,00000001	0,0000002	Triangular	1986 Helton et al. "Uncertainty and Sensitivity Analysis of a Model for Multicomponent Aerosol Dynamics"; 2009 NEA/CSNI. "State-of-the-Art Report on Nuclear Aerosols"
	Particle diameter Upper Bound [m]	0,000199	0,000005	0,00002	Triangular	1986 Helton et al. "Uncertainty and Sensitivity Analysis of a Model for Multicomponent Aerosol Dynamics"; 2009 NEA/CSNI. "State-of-the-Art Report on Nuclear Aerosols"
	Slip factor (default = 1.257)	1,257	1,14	1,28	Triangular	1990 D. J. Rader. "Momentum slip correction factor for small particles in nine common gases"; MELCOR Default; Expert judgment (pdf)

The MUSA Project

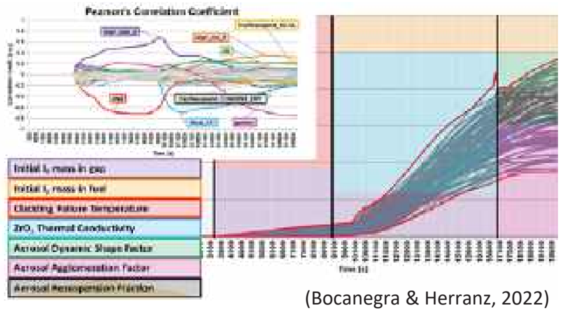
Preliminary Results

- **On PHEBUS-FPT1 modeling**





Iodine Aerosol in Containment

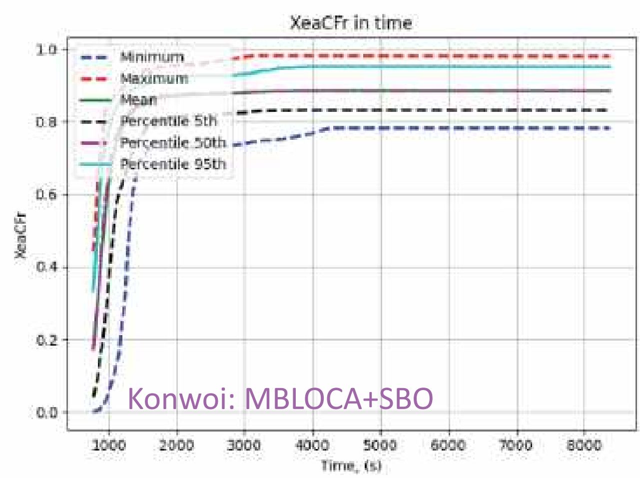


(Bocanegra & Herranz, 2022)

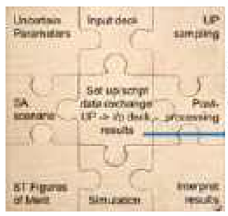
The MUSA Project

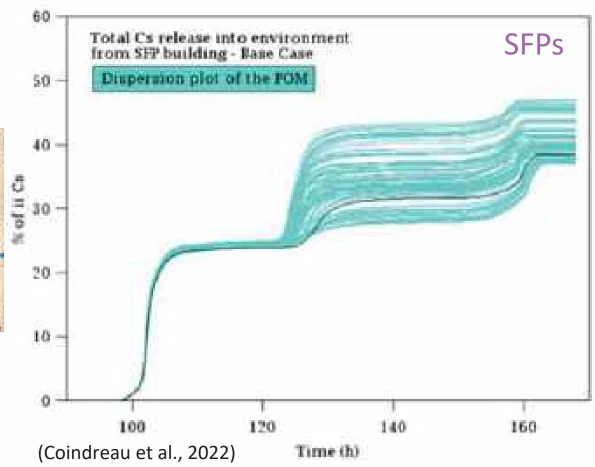
Preliminary Results

- **On Reactor & SFP calculations**



(Brumm et al., 2022)





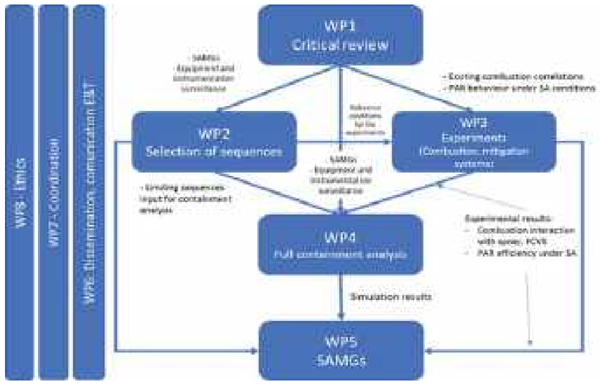
(Coindreau et al., 2022)

The AMHYCO Project

Overview

- Towards an Enhanced AM of the H_2/CO Combustion Risk (AMHYCO). H2020 GA nº 847715 (490 p-m).
- **Aim:** To further minimize the threat posed by combustible gases by SAMGs.
  - Methodologies for containment analyses.
  - Experiments on unexplored domains.

(PWR-W; -K; -V)

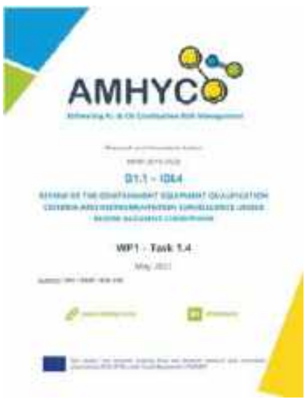


- **Extension:** 2020 – 2024
- **Partners:** CIEMAT, CNL, CNRS, ENERGORISK, FRAMATOME, FZJ, IJS, IRSN, LGI, NRG, RUHR, **UPM.**

The AMHYCO Project

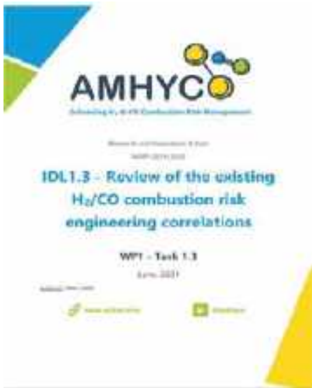
Preliminary Results

- **Critical review of the current status (completed & embedded in D1.1)**

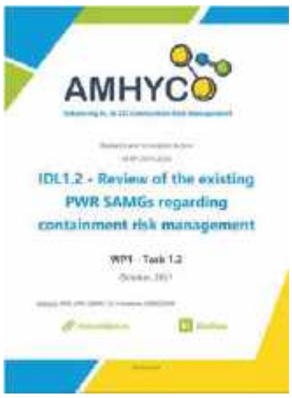


- Efforts in survivability under SA

- Unclear transition H2-CO recomb. regimes.
- CO poissoning; T,P; Pt vs. Pd; deactivation



- P_o to be investigated.
- H_2O y CO_2 effect (P>1 bar)

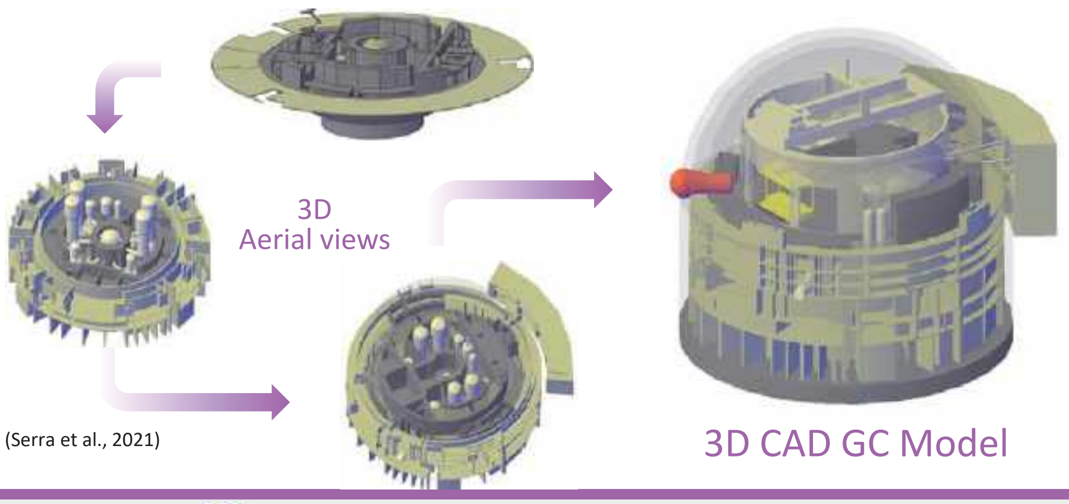


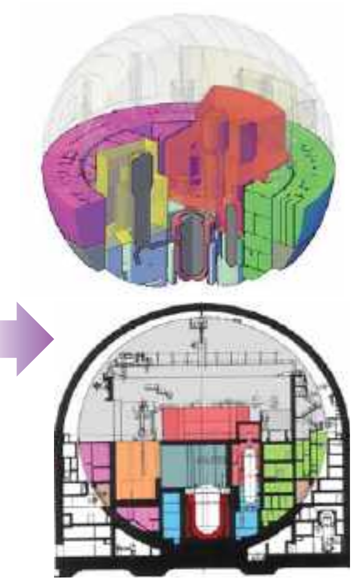
- Mitigation means designed JUST in-vessel
- No monitoring of CO in containment

The AMHYCO Project

Preliminary Results

- **On the analytical methodology**

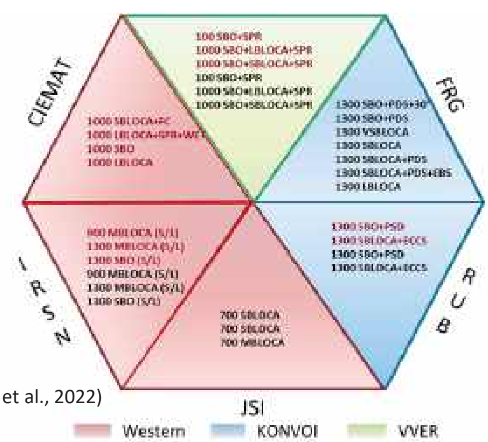




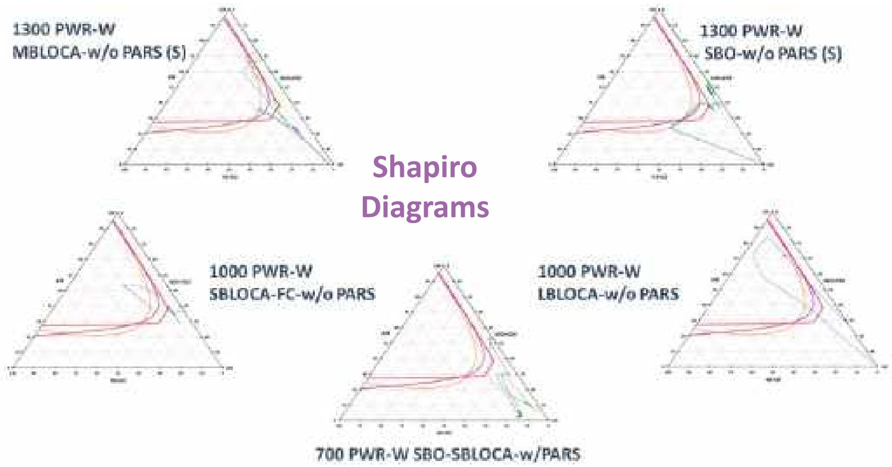
The AMHYCO Project

Preliminary Results

- **Accident sequences DB** already simulated.



(Herranz et al., 2022)



Final Remarks

Accurate Risk Assessments

Robust Accident Management

Nuclear Safety Enhancement

Reliable & Efficient Safeguards

Final Remarks

- **PIACE:** On the demonstration of an innovative, technology-independent DHR system.
  Challenges: applicability; scalability; testing.

- **MUSA:** On the uncertainty quantification of SA predictions.
  Challenges: Systematic analytical methodology; data analysis.

- **AMHYCO:** On the optimization of SAMGs to handle combustion risk in SA.
  Challenges: Systematic analytical methodology; testing; assimilation.

Thank you for your attention!

Acknowledgements

The authors are indebted to their project partners, who have been doing an extraordinary job under truly adverse circumstances, and to the EC for approving, supporting and monitoring these projects.

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May - 3 June 2022 | Lyon, France
17

ERMSAR 2024

- ERMSAR 2022 - KIT, Karlsruhe - An astonishing success!
- ERMSAR 2024 - KTH, Stockholm (Sweden) https://www.kth.se/en
- Rooms available in the main campus or AlbaNova University https://www.albanova.se/
- Mid-May, 2024 currently considered (3 full days).

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
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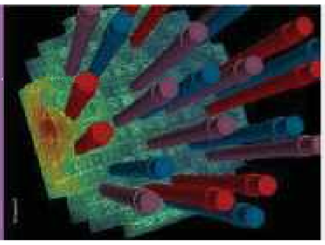


FISA 2022

30 May - 3 June 2022
Lyon, France

PROBABILISTIC SAFETY ASSESSMENT FOR INTERNAL AND EXTERNAL EVENTS ON NUCLEAR POWER PLANTS AND ON MITIGATION STRATEGIES / H2020 EUROPEAN PROJECTS: NARSIS, R2CA AND BESEP

Evelyne Foerster (CEA), Nathalie Girault (IRSN), Atte Helminen (VTT)

Three projects

New Approach to Reactor Safety ImprovementS, NARSIS, 2017-2022, Coordinator: Evelyne Foerster (CEA)

Reduction of Radiological Consequences of design basis and extension Accidents, R2CA, 2019-2023, Coordinator: Nathalie Girault (IRSN)

Benchmark Exercise on Safety Engineering Practices, BESEP, 2020-2024, Coordinator: Atte Helminen (VTT)

NARSIS

New Approach to Reactor Safety ImprovementS, NARSIS, 2017-2022, Coordinator: Evelyne Foerster (CEA)

Overview of the H2020-NARSIS project (2017-2022)

New Approach to Reactor Safety ImprovementS www.narsis.eu

- **18 partners** across Europe: academic & research organisations, operators, TSOs, SME
- **Main objectives:**
  - **Identifying gaps** between practice and needs **in existing PSA methodologies for external events and multi-hazard analyses**
  - **Improving parts of these methodologies,** based on & complementing other European projects:

ASAMPSA_E Advanced Safety Assessment Level 2 PSA

INFRARISK Novel indicators for identifying critical INFRAstructure at RISK from Natural Hazards

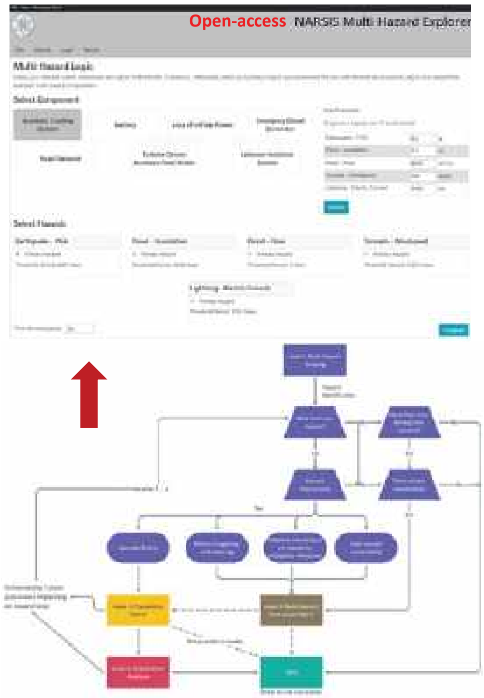
MATRIX New Multi-Hazard and Multi-Risk Assessment Methods for Europe

  - **External hazards & related secondary effects / combinations considered:**
    - ✓ Earthquake & secondary effects (excluding tsunamis),
    - ✓ Tsunamis
    - ✓ Riverine and coastal flooding (e.g., storm surge)
    - ✓ Extreme meteorological hazards (high winds, rainfall, heat waves, ice, hail)
    - ✓ Volcanoes (tephra)

Overview of the H2020-NARSIS project (2017-2022)

- **Methodology adopted for the scientific improvements:**
  - Full reviews of existing methodologies
  - Verification & testing of the applicability and effectiveness of the proposed developments within a safety assessment process
  - ➡ Using generic & real simplified NPP test cases located on real decommissioned sites

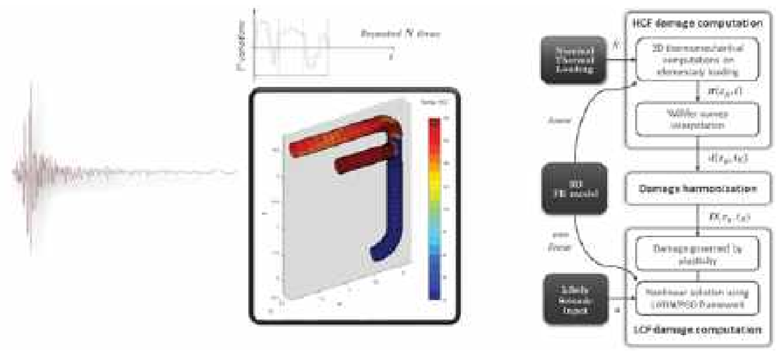
- **Main achievements:**
  - Ø **Better characterization of external hazards**
  - ➡ Focus on hazards identified as top priorities by the PSA end-user's community
  - Ø **Multi-Hazard assessment framework & scenarios**
  - ➡ Modelling of hazard combinations & related secondary effects useful for PSA (e.g., extreme weather correlated events)



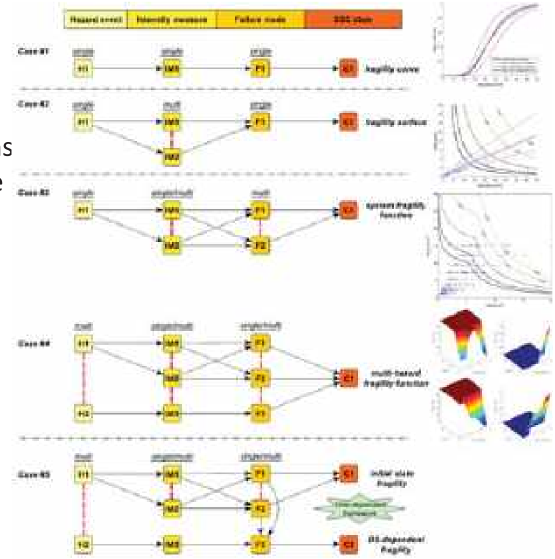
Overview of the H2020-NARSIS project (2017-2022)

- **Main achievements:**
  - **Better fragility assessment for the main critical SSCs:**
    - ✓ Multi-hazard scenarios
    - ✓ functional losses, human factors,
    - ✓ ageing pathologies (e.g., damaging phenomena, corrosion),
    - ✓ interdependencies under single or multiple external aggressions
    - ✓ cumulative effects (seismic PSA): aftershocks modelling, fatigue + earthquakes, soil-structure interactions

Earthquake + pre-existing damage (thermal fatigue)



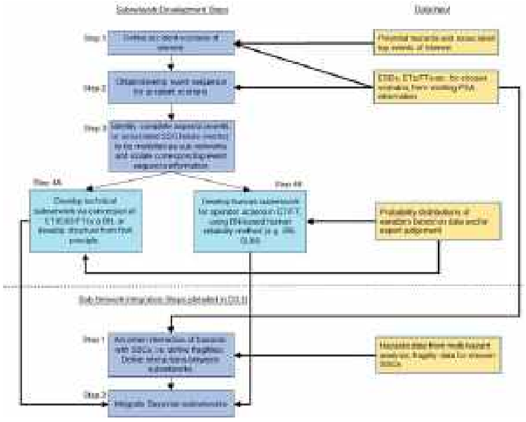
Multi-Hazard Fragility Framework (Bayesian Networks, vector-valued fragility)



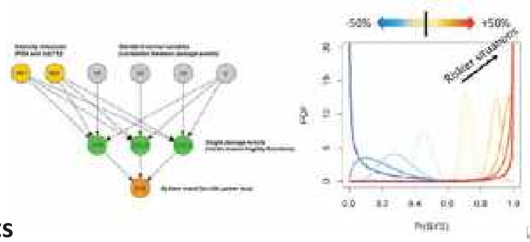
Overview of the H2020-NARSIS project (2017-2022)

- **Main achievements:**
  - ➢ **Multi-risk integration & uncertainty reduction: Bayesian Networks (BN)**
    - ✓ Support to risk-informed decision making and risk metrics comparison within extended PSA
    - ✓ Better processing and integration of expert-based information within PSA: investigating the applicability and benefits of using modern uncertainty theories to both represent experts' judgments in flexible manner and aggregate them to be used in a comprehensive manner.

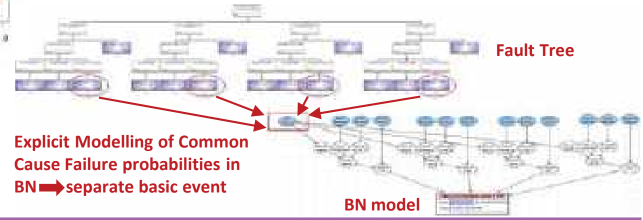
Integration of multi-hazards, technical & human aspects



Boosted Beta Regression method for BNs ➡ Probabilistic sensitivity analysis



  - ➢ **47 scientific reports**
  - ➢ **2 software tools :**
    - ✓ Open-access Multi-Hazard Explorer
    - ✓ Decision-Support prototype (SAMG demonstration)



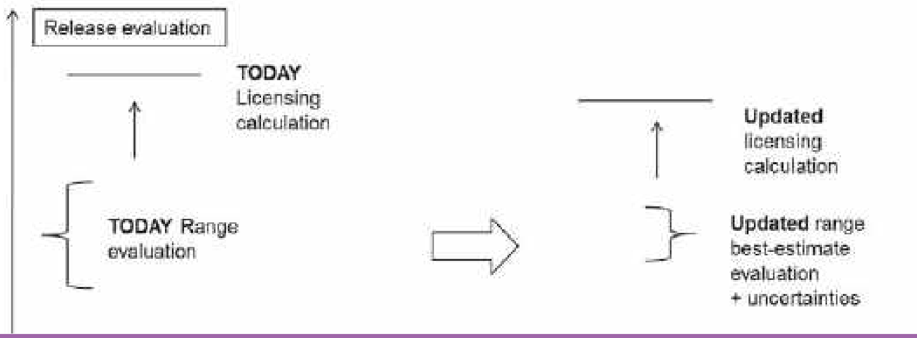
R2CA

Reduction of Radiological Consequences of design basis and extension Accidents, R2CA, 2019-2023, Coordinator: Nathalie Girault (IRSN)

Overview of the H2020-R2CA project (2019-2023)

Reduction of **R**adiological **C**onsequences of design basis & design extension **A**ccidents: https://r2ca-h2020.eu

- 17 partners in Europe: academic & research organisations, operators, TSOs
- Main objectives
  - Evaluate more realistic safety margins through RC evaluation of bounding scenarios (reduction of conservatisms & decoupling factors) + uncertainties
  - Increase NPP safety by developing AMPs and a smart tool for early diagnosis of accidents (incl. guidelines for new safety devices & some ATF evaluations)



- Scope
  - ✓ DBA& DEC-A conditions
  - ✓ LOCA & SGTR scenarios
  - ✓ PWRs, EPR, VVERs & BWR

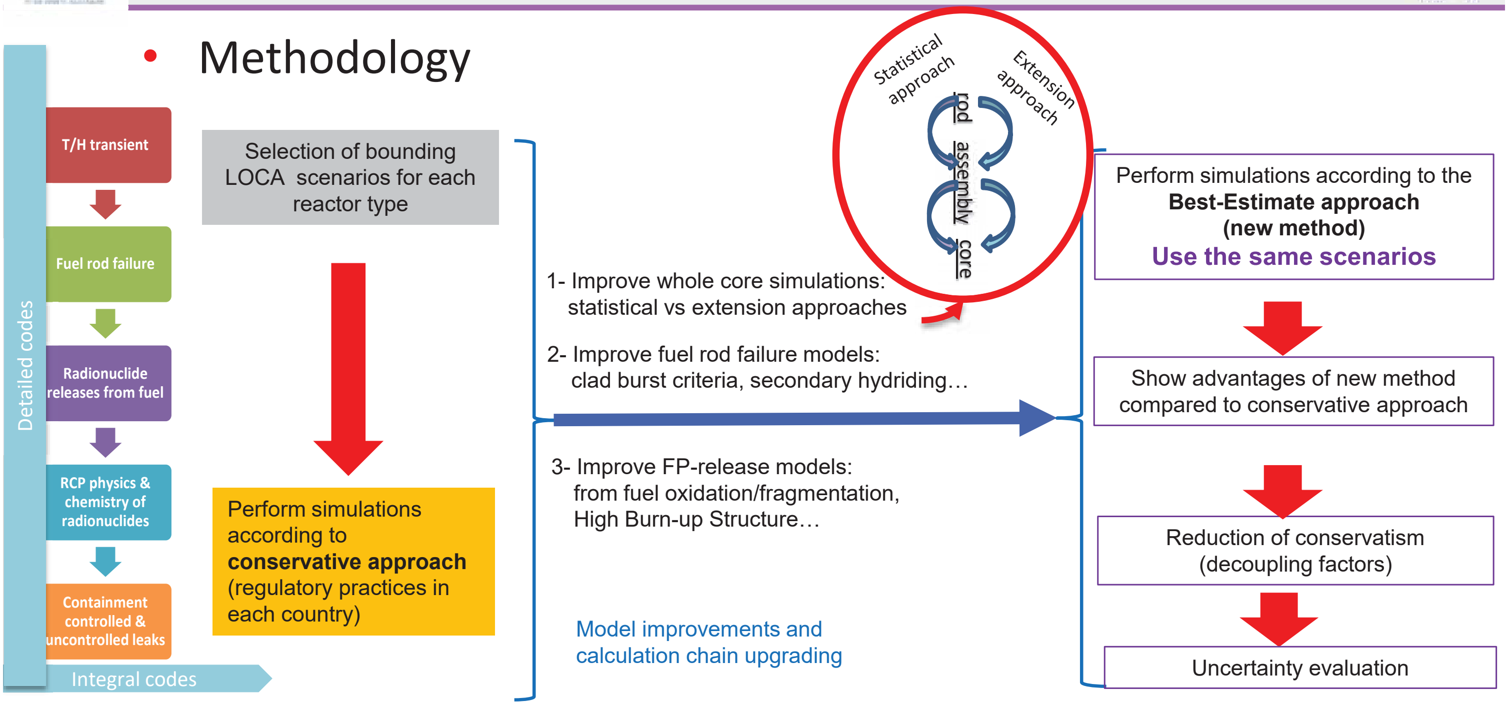
Overview of the H2020-R2CA project (2019-2023)

- Key challenging areas
  - Formulation of best-practices for RC calculations of LOCA and SGTR scenarios
    - ✓ Best-estimate approaches reducing some conservatisms & decoupling factors
  - Harmonisation of the RC evaluation methodologies for all existing and foreseen NPPs
    - ✓ Derivation of principles for EP&R action optimisation (i.e. for population protection measures)
  - Development of technological innovations in the reduction of RC (innovative devices, AMPs, diagnosis tools and E-ATFs)
    - ✓ Improvement of AMPs: new instrumentation, optimized procedure, neural network
  - Use of Artificial Intelligence functionalities to anticipate accidental configurations
    - ✓ Elaboration of an expert system based on AI for identification of rod defects from RCS activity variation

IRSN

Overview of the H2020-R2CA project (2019-2023)

- Methodology



IRSN

Overview of the H2020-R2CA project (2019-2023)

- Main expected Achievements
  - Improvements of a large variety of simulation tools (from mechanistic to integral) and calculation chains for RC evaluation through code coupling codes
  - Modelling improvements at all levels of the calculation chains from :
    - ✓Update of models regarding FP transport/behaviour & cladding/fuel evolution
    - ✓Use of models/tools at different scales: mechanistic/detailed to meso & integral tools
    - ✓Code couplings
  - More accurate evaluations of LOCA & SGTR RC evaluations with respectively:
    - ✓Better calculation of failed rod number: updated core modelling approaches (statistical or multi-scale core meshing & new correlations for clad failure criteria
    - ✓Better modelling of defective rod behaviour: improvements of iodine spiking models and establishment of clad failure criteria due to secondary hydriding
  - Demonstration of the capabilities of prognosis evaluation tools to anticipate accidental configuration through Artificial Intelligence functionalities
  - Evaluation of new devices (i.e. new safety devices, ATFs) & AMPs for increased NPP safety

BESEP

Benchmark Exercise on Safety Engineering Practices, BESEP, 2020-2024,
Coordinator: Atte Helminen (VTT)

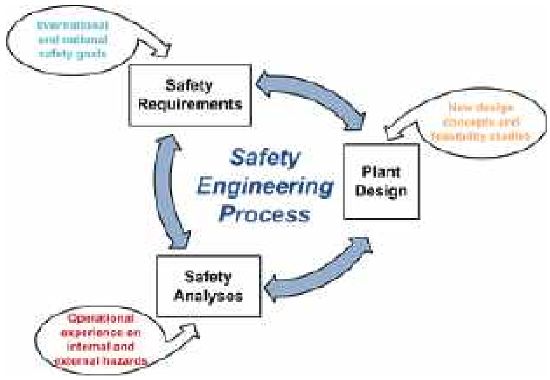
Overview of the H2020-BESEP project (2020-2024)

- **7 partners** across Europe: Research organisations, Licensees and TSOs
- **Main objective** of BESEP is to support safety margins determination by developing best practices for safety requirements verification against external hazards, using efficient and integrated set of Safety Engineering practices and probabilistic safety assessment
- **Web pages:** www.besep.eu

Overview of the H2020-BESEP project (2020-2024)

Key challenge area

- Safety Engineering process connects together the main elements of safety design: safety requirements , safety analyses and plant design
- In case there is a change in one of the main elements, the change should be reflected in the two other elements
- With better Safety Engineering process, modified safety requirements can be implemented to the actual plant design more efficiently

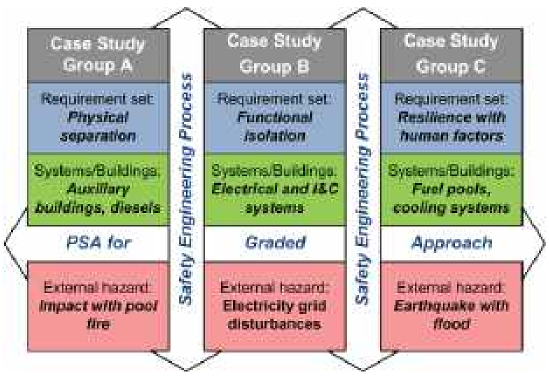


Overview of the H2020-BESEP project (2020-2024)

Methodology

Benchmark Exercise between project Partners:

1. Specification of case study requirements and allocation of requirements under specific topics creating a set of requirements
2. Development of pool of case studies having relevance to external hazards and specification of case study groups
3. Cross-case comparison within case study groups
   - Efficiency and integration of different safety analysis methods in Safety Engineering process to verify the compliance of safety margins and safety requirements
4. Cross-group comparison between case study groups
   - Amount of work and effort used in safety margins and requirement verification compared to the risk significance of external hazard to plant safety
5. Best practices and recommendation on closer connection of safety analysis methods



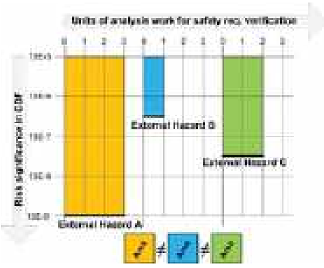
(Example ideas from project planning phase)

Overview of the H2020-BESEP project (2020-2024)

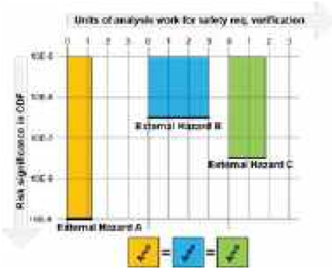
Expected key results

- Best practices for the verification of evolving and stringent safety requirements against external hazards
- Guidance on the closer connection of deterministic and probabilistic safety analysis and human factors engineering for the determination and realistic quantification of safety margins.
- Guidance on the creation of graded approach for the deployment of more sophisticated safety analysis methods, such as upgrades of simulation tools, while maintaining the plant level risk balance originating from different external hazards.

Situation before BESEP…



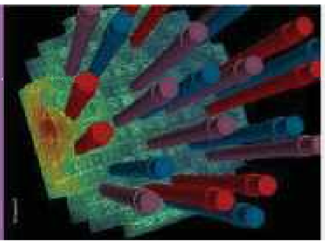
… and after BESEP



General conclusions of three projects

The three projects of EURATOM Horizon 2020 programme:

- Help improve the best practices for the safety assessment of internal and external events and for the planning of mitigation strategies
- Support the harmonisation of safety assessment methodologies between European countries applicable to different existing NPP designs and foreseen concepts, such as Small Module Reactors
- Help tighten cooperation between the different sides of nuclear industry, i.e. utilities, vendors, national safety authorities and technical support organisations
- Bring together experts from the different areas of safety assessment, such as Deterministic safety analysis, Probabilistic safety analysis and Human factors engineering
- Foster new experts for the industry, who eventually take the responsibility of continuous development in nuclear safety



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Lyon, France

THANK YOU!

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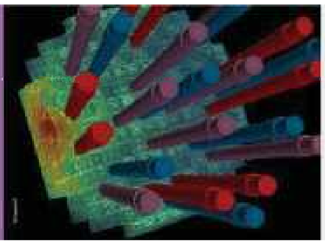
FISA 2022
EURADWASTE'22

SESSION 2: ADVANCED NUCLEAR SYSTEMS AND FUEL CYCLES

Co-chair: Hamid AIT ABDERRAHIM (BE, SCK-CEN)

Co-chair: Jan PANEK (EC, DG ENER)

Rapporteur: Teodora RETEGAN-VOLLMER (RO, Expert)



FISA 2022

30 May - 3 June 2022
Lyon, France

Review of Euratom projects on design, safety assessment, R&D and licensing for ESNII/Gen-IV reactor systems

B. Hatala (VUJE),
M. Ferreira (VTT), J.-L. Kloosterman (TU DELFT), K. Mikityuk (PSI), M. Šípová (CVŘ)

Introduction

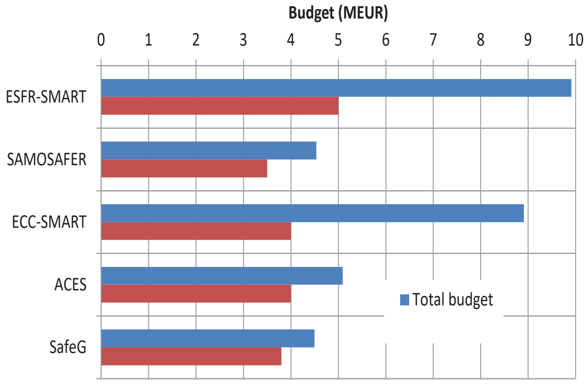
European Sustainable Nuclear Industrial Initiative (**ESNII**) considers:

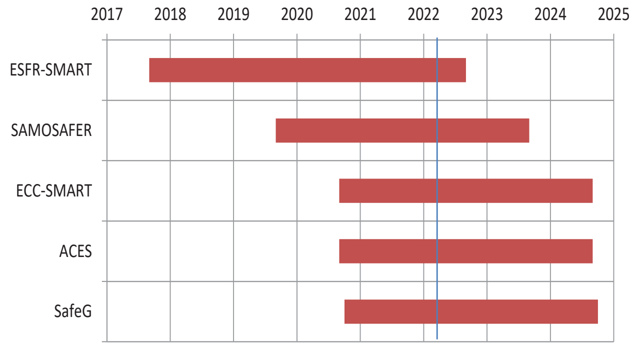
– Reference solution: Sodium Fast Reactor **ASTRID**;
– 1st alternative: Lead-cooled Fast Reactor **ALFRED** supported by LBE facility **MYRRHA**;
– 2nd alternative: Gas-cooled Fast Reactor **ALLEGRO**.

In addition the following Gen-IV systems are supported by Euratom:

– Gen-IV Molten Salt Fast Reactor **MSFR** (mentioned in SRA Annex as an attractive long-term option);
– Gen-IV Supercritical Water Cooled Reactor (**SWCR**);
– Gen-IV European Sodium Fast Reactor **ESFR**.

Four Generation-IV systems supported by the considered EU projects





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	SCK-CEN	ENGIE LABORELEC	PSI	UJV REZ	EVALION	VSCT	CTU	CV REZ	GRS	KIT	HZDR	BGF	UPM	CIEMAT	JRC	ENEN	VTT
ESFR-SMART			C						x	x	x		x	x	x		
SAMOSAFER			x					x		x					x		
ECC-SMART						x		C		x				x	x	x	x
ACES	x	x					x	x									C
SafeG				x	x		x	x				x					

	FR						HU		IT			
	IRSN	CEA	FRAMATOME	EDF	LGI	UNI DE LORRAINE	EK-CER	BME	ENEA	POLITO	POLIMI	UNI PISA
ESFR-SMART	x	x	x	x	x	x			x			
SAMOSAFER	x	x	x	x						x	x	
ECC-SMART								x				x
ACES	x	x		x								
SafeG		x					x	x				

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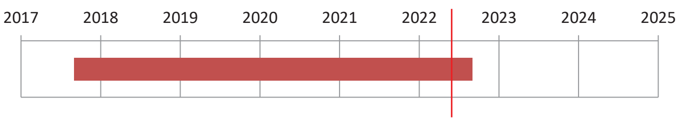
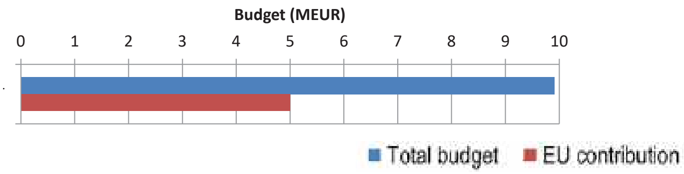
	IPUL	NRG	TU DELFT	NCBJ	RATEN	KTH	CHALMERS	VUJE	STU	IJS	ZAG	IPP CENTRE LLC	ENERGORISK	JACOBS	UNI CAMBRIDGE	UNI NOTTINGHAM	UNI SHEFFILD	NNL	SUM
ESFR-SMART	x						x							x	x			x	19
SAMOSAFER		x	C																12
ECC-SMART					x	x			x	x		x				x	x		16
ACES											x		x						10
SafeG				x				C	x					x	x		x		14

1. ESFR-SMART: fact sheet

Name: European Sodium Fast Reactor Safety Measures Assessment and Research Tools

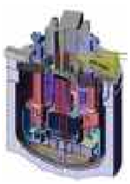


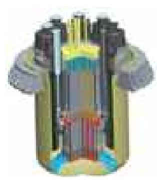


Domains:
- Design
- R&D
- Safety
- Licensing

ESFR-SMART
sodium fast reactor safety

Partners: 19
Countries: 9
Coordinator: PSI

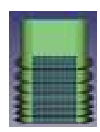

ASTRID

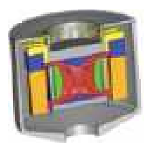

ALFRED


MYRRHA


ALLEGRO


ESFR


SCW-SMR

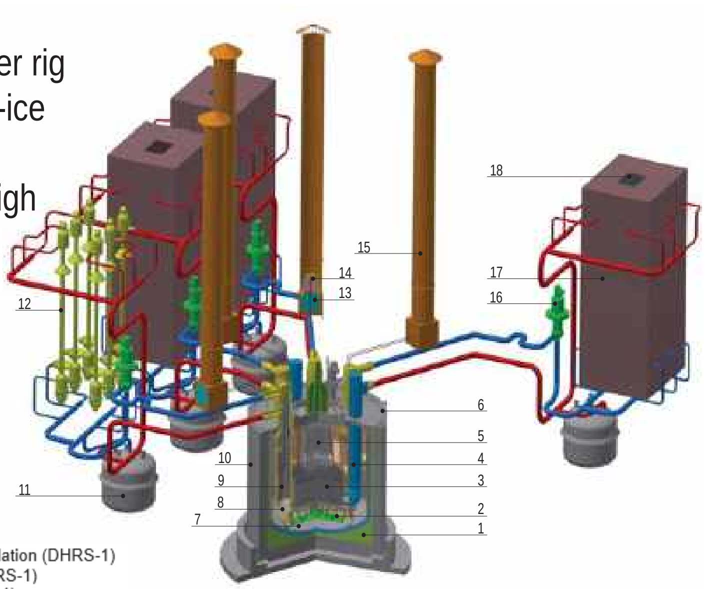

MSFR

1. ESFR-SMART: main goals

- Produce new experimental data to support calibration and validation of computational tools for each DiD level.
- Test and qualify new instrumentations to support their utilization in reactor protection system.
- Perform further calibration and validation of computational tools for each DiD level to support safety assessments of Gen-IV SFRs.
- Select, implement and assess new safety measures for commercial-size ESFR.
- Strengthen and link together new networks (sodium facilities and students).

1. ESFR-SMART: selected results

- Experimental programs:
  - CHUG: chugging boiling regime using steam-water rig
  - HAnSoLO: corium jet impingement using a water-ice system
  - JIMEC-I: ablation of a thick steel substrate with high temperature, high-velocity steel jet
- Benchmarking of codes:
  - Superphénix static and transient start-up tests
  - KNS-37 sodium boiling experiment
- Proposal of new safety measures
  - New core and system designs

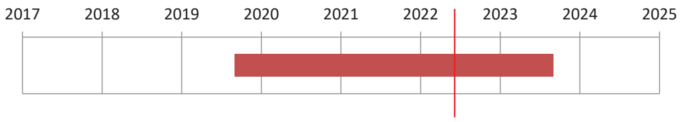


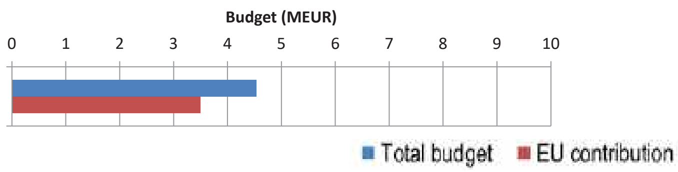
1: Insulation with steel liner
2: Core catcher
3: Core
4: Primary pump
5: Above-core structure
6: Pit cooling system (DHRS-3)
7: Main vessel
8: Strongback
9: IHX
10: Reactor pit
11: Secondary sodium tank
12: Steam generator
13: Window for air circulation (DHRS-1)
14: Sodium-air HX (DHRS-1)
15: Air chimney (DHRS-1)
16: Secondary pump
17: Casing of SGs (DHRS-2)
18: Window for air circulation (DHRS-2)

2. SAMOSAFER: fact sheet

Name: Severe Accident Modeling and Safety Assessment for Fluid-fuel Energy Reactors

SAMOSAFER





Domains:
- Design
- R&D
- Safety
- Licensing

Partners: 12
Countries: 7
Coordinator: TU DELFT

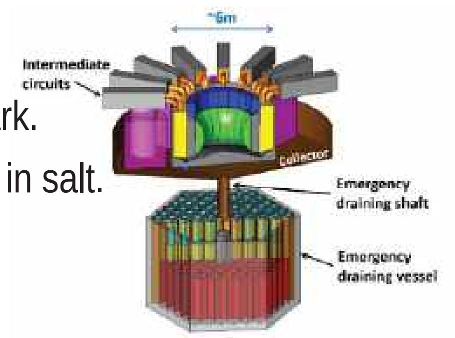
2. SAMOSAFER: main goals

Develop and demonstrate new safety barriers for more controlled behaviour of MSR in severe accidents, based on new simulation models and tools validated with experiments.

- Investigate and translate existing defence-in-depth safety approach to MSR
- Develop simulation code suite for neutronics, thermal hydraulics, thermo-physics modeling
- Develop and apply experimental setups for validation
- Design advanced barriers for severe accidents (freeze plugs, drain tanks, fission product extraction / immobilization)
- Update MSFR design

2. SAMOSAFER: selected results

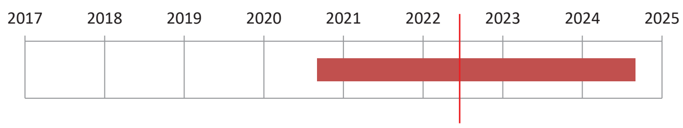
- Specific MSR oriented defence in depth approach established by analysing safety functions of all fuel salt locations in reactor and by defining number of containment barriers.
- Thermochimica software coupled to JRC-Molten Salt Data Base for thermodynamic assessments of various salts.
- Molecular dynamics studies done on LiF-ThF4 using a new forced-field model.
- Preliminary scheme for reprocessing chloride salts developed.
- Salt freezing and re-melting modeling started.
- SIMMER code extended and prepared for Castillejos benchmark.
- SWATH-S facility extended to study radiation heat phenomena in salt.
- Design drawings of core and passive DHR system done.
- Summer school organized.

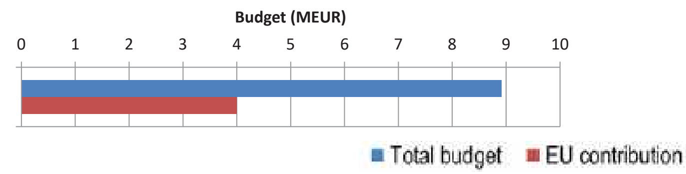


3. ECC-SMART: fact sheet

Name: Joint European Canadian Chinese development of Small Modular Reactor Technology

ECC smart





Domains:
- Design
- R&D
- Safety
- Licensing

Partners: 16
Countries: 12
Coordinator: CV REZ

3. ECC-SMART: main goal

Provide methodologies for safety evaluations and improvements for SCW-SMR, including experimental validation

– Assess corrosion behaviour of most promising candidates for SCW-SMR structural materials
– Define design requirements for SCW-SMR technology
– Develop and validate codes and assess proposed SCW-SMR concepts using these codes
– Provide reactor physics analysis of preliminary core layout
– Develop pre-licensing study and guidelines for safety demonstration

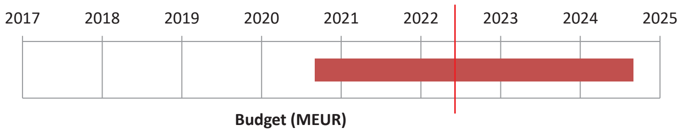
3. ECC-SMART: selected results

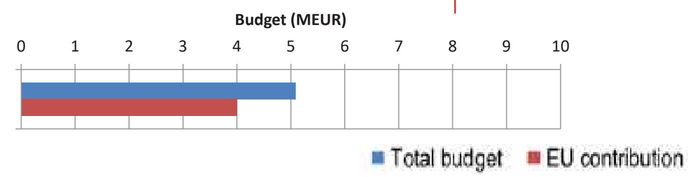
– Material testing: test matrix established with about 700 specimens:
  - Stainless steel 310S and alloy 800H selected as the most perspective material for fuel cladding;
  - experimental AFA (alumina forming austenitic alloy) supplied by China (USTB).
  - Most of specimens manufactured

– Innovative design of a small modular reactor cooled by SCW proposed based on HPLWR (high pressure light water reactor) using Canadian and Chinese experiences

4. ACES: fact sheet

Name: Towards improved assessment of safety performance for long-term operation of nuclear civil engineering structures





Domains:
- Design
- R&D
- Safety
- Licensing

Partners: 10
Countries: 6
Coordinator: VTT

4. ACES: main goals

- Improve understanding of ageing and deterioration of concrete for existing and next-generation NPPs
- Demonstrate and quantify inherent safety margins introduced by the conservative approaches used during design and defined by codes and standards
  - Assess corrosion of embedded liners in concrete
  - Characterise, predict and monitor ISR in concrete
  - Predict delayed strains of containment building
  - Assess performance of irradiated concrete

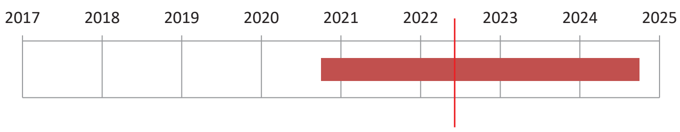
4. ACES: selected results

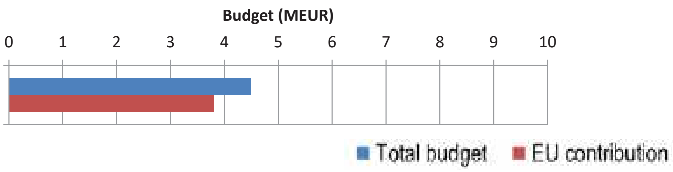
- Review of state-of-the-art of quantitative assessment of ageing of concrete SSC in NPPs.
- Improvement of phenomenological understanding and optimization of earlier detection of corrosion.
- Assessment of concrete structures affected by internal swelling reactions.
- Validation of existing constitutive laws and structural modelling approaches regarding the simulation of containment behaviour during operational phases.
- Generation of critical data currently missing from open literature on neutron-irradiation induced degradation of concrete aggregates relevant for European NPPs.

5. SafeG: fact sheet

SafeG

Name: Safety of GFR through innovative materials, technologies and processes





Domains:
- Design
- R&D
- Safety
- Licensing

Partners: 14
Countries: 7
Coordinator: VUJE

5. SafeG: main goal

- Continue development of ALLEGRO for demonstration of gas-cooled fast reactor technology
- Develop driver and refractory cores satisfying performance and safety requirements
- Assess materials with better performance for primary circuit
- Assess decay heat removal capabilities
- Fuel qualification

5. SafeG: selected results

– Core safety – significant progress beyond the state of the art of GFR core safety has already been made (start-up core optimization was completed). Further work will include optimization of reactivity feedback coefficients and irradiation capabilities of the ALLEGRO core designs.

– Automatic shutdown system – Current design will be updated, using state-of-the art knowledge that is possessed by the consortium members who will work on this task.

– DHR system – So far, decay heat removal for GFRs has been solved in a very similar way for all the reference concepts. Within SafeG, effort will be put into development of innovative DHR solution based on cutting-edge technology

Summary

- 5 EU project since 2017
- 4 ESNII/Gen-IV reactor systems
- 33 MEUR of total budget including 20 MEUR of Euratom contribution.
- 47 organizations from 19 countries
- Design, R&D, safety and licensing aspects

Thank you for your attention

ASTRID ALFRED MYRRHA ALLEGRO ESFR SCW-SMR MSFR

PRESENTATION OF THE EUROPEAN PROJECT PUMMA DEVOTED TO PLUTONIUM MANAGEMENT IN THE WHOLE FUEL CYCLE

FISA 22 conference, Lyon,
30 May – 3 June

N. CHAUVIN (CEA), F. ÁLVAREZ-VELARDE (CIEMAT), V. BLANC (CEA), Z. HOZER (MTA-EK), S. VAN TIL (NRG), D. STAICU (JRC), C. MAHER (NNL), M. LAZAREVIC(LGI)

PuMMA
Plutonium Management for More Agility

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 945022.

Plutonium Management for More Agility

CONTEXT

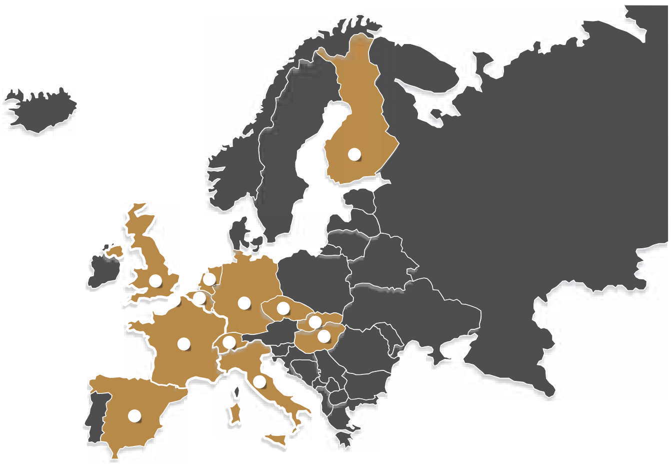
- **Federate the European community on MOX fuel around the challenges of advanced reactors (GENIV) and advanced fuel cycle.**

OBJECTIVES

- **Plutonium management in 4th generation reactors (SFR, GFR, LFR, ADS) → impact on fuel behavior, core safety, reprocessing and all the fuel cycle parameters.**
- **Experimental results & calculations on MOX pins** during representative **nominal conditions and during accidental conditions** that can lead to fuel melting and clad failure.
- Comparison of experimental irradiation in Material Testing Reactor (**MTR**) with the results of an irradiation in representative a fast neutron reactor (**SFR**).
- **Education & training** : maintain the expertise and the skills on the management of Pu in Europe involving young generation of researchers with the experts who had contributed to these projects : the CAPRA program, the EFTTRA group, the ADS community and the GIF and a lot of associated European projects over the last 30 years.

PuMMA

The PuMMA consortium



Belgium
- JRC
- SCK CEN

Czech Republic
- UJV

Finland
- VTT

France
- CEA
- FRAMATOME
- EDF
- LGI

Germany
- KIT

Hungary
- BME
- MTA EK

Netherlands
- NRG

Italy
- ENEA
- POLIMI

Slovakia
- VUJE

Switzerland
- EPFL
- PSI

Spain
- CIEMAT

United Kingdom
- NNL
- JACOBS

BUDGET : E.U. FUNDINGS = 3,8 M€ TOTAL = 7M€

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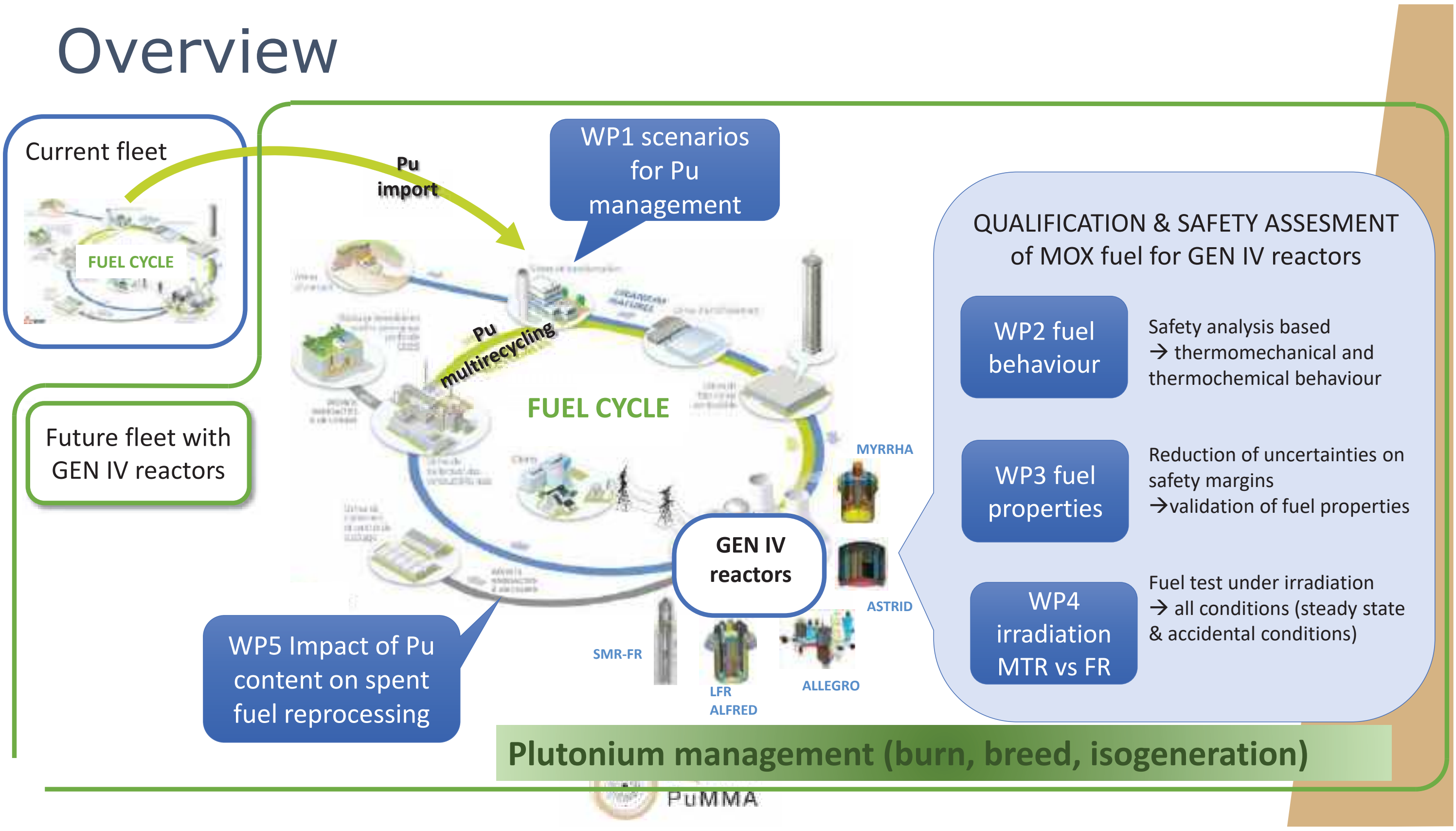
Overview

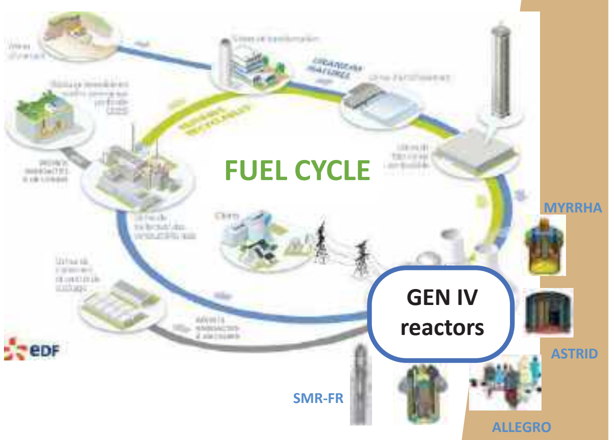


PuMMA

WP1 Study of plutonium management in connection with the fuel cycle : scenario studies

OBJECTIVES

- Highlight the flexibility of the GEN-IV reactors on the management of the plutonium: breeder, burner, isogeneration. Performances and impact on fuel cycle and reactor.
- Consideration of the transition scenario from LWR to fast GEN-IV reactors to evaluate the plutonium to be taken into account in fast reactor fuels: composition and isotopy.
- Study of the impact on all operations of the cycle: manufacturing, storage, transportation, reprocessing, core design, fuel behavior. Economic impact.
- Sensibility studies with uncertainty propagation



PuMMA

WP1 Study of plutonium management in connection with the fuel cycle : scenario studies

RESULTS ACHIEVED

- Definition of input data regarding the reactors for the scenario studies
- Selection of the scenarios to be studied

Deliverables
D1.1 Report on Input Data of GenIV reactors is a confidential report led by BME produced and delivered at M12. It includes the general information and appropriate references of the Gen-IV reactors that will be used in the rest of the WP1 tasks. These reactors include the ESFR, ELSY, ALFRED, GFR and ALLEGRO critical reactors and the EFIT subcritical system. Burner, breeder and isogeneration versions are included for some of these reactors, in particular ALFRED and ESFR. The information contained for each particular design includes the thermal power, the efficiency, the fuel/cladding/coolant materials, the Pu enrichment and the actinide mass at the beginning of the irradiation, the number of fuel assemblies, the average burn-up and the irradiation time. This information has been gathered from the references and the participation of some of the PUMMA partners in other projects, excepting for the case of the ESFR and ALFRED burner versions, specifically developed for this task.

30/05/2022

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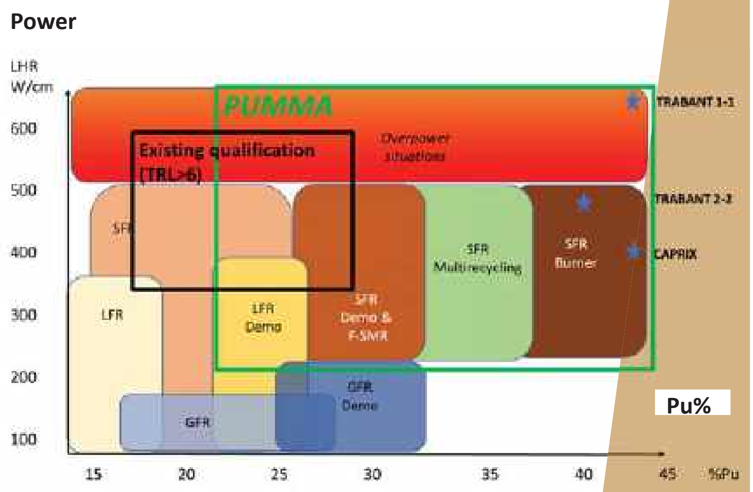
WP2 Qualification Of Mox Fuel Behaviour For GenIV Systems

Objectives

- Extend fuel qualification for high Pu%
- Extension of validation domain of FPC with 3 irradiations of the same fuel (45%Pu) irradiated in MTR (nominal and overpower) and in SFR (nominal):
  - calculations with fuel performance codes
  - post irradiation examinations
- Methodology for safety analysis of fuel pins with high plutonium content.



New approach

- Starting with a benchmark exercise in order to define the PIE programme for the validation of FPC.

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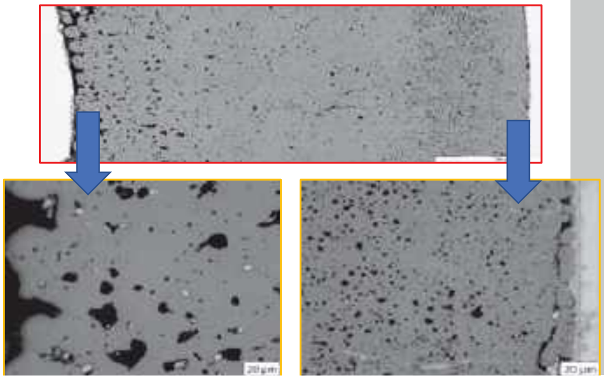
WP2 Qualification Of Mox Fuel Behaviour For GenIV Systems

Results achieved

- Irradiation conditions of CAPRIX, TRABANT1, TRABANT2
- Starting benchmark with several Fuel Performance Codes
- 3 PIE programmes with schedules

CAPRIX MOX at 45Pu%, L. Fayette CEA-LECA



Deliverables
D2.1.1 is a confidential report on CAPRIX irradiation conditions in PHENIX produced and delivered at M12, led by NRG. The CAPRIX pins were irradiated in PHENIX from 49th to 53rd cycle. The characteristic neutronic and thermal-hydraulic quantities of the irradiation were realized with the Monte Carlo code TRIPOLI4 and the thermal-hydraulic code TRIO MC.
D2.1.2 is a confidential report on TRABANT 1 pin 1 irradiation conditions in HFR produced and delivered at M12, led by NRG. The irradiation of TRABANT-1 pin 1/1 was performed during 12 HFR cycles that was divided into two sets of 6 reactor cycles of approximately ~30 days each.
D2.1.3 is a confidential report on TRABANT2 pin 2 irradiation conditions in HFR produced and delivered at M12, led by NRG. The TRABANT-02 experiments, containing the pin of interest for this study (pin 2/2), started irradiation in November 2001 and proceeded for two cycles: 01-11 and 01-12. After a significant delay, the irradiation continued for one more cycle in 2005 after which the irradiation was discontinued. A total of 74 Full Power Days was achieved in the HFR.

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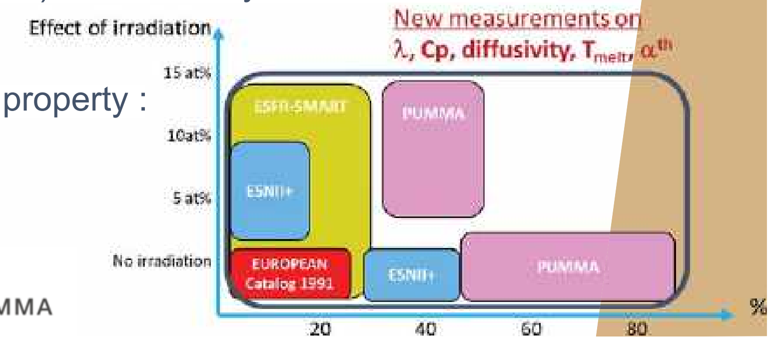
WP3 Fuel Properties With High Pu Content: Measurements and Modelling

Objectives

- Reduce uncertainty in safety evaluation by reducing uncertainties on fuel properties
- Measurements on MOX properties : λ, Cp, diffusivity, T_{melt}, α^{th} as a function of density, Pu content, O/M and burn-up on non-irradiated and irradiated fuels
- Monte Carlo calculations to determine thermal properties of MOX fuel with parameter dependency
- Thermodynamic modelling in support thermal properties evaluation
- Recommandation on mechanical properties : elastic (Young modulus, Poisson ratio) and non elastic (creep, plasticity and rupture) under steady state and accident.

New approach

- Experimental programme defined for each property :
  - Extension of validation
  - Liability of safety margins



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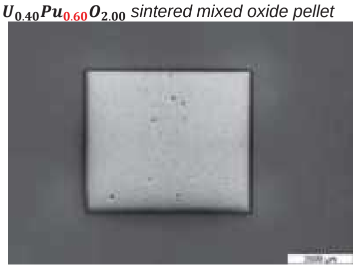
WP3 Fuel Properties With High Pu Content: Measurements and Modelling

RESULTS ACHIEVED

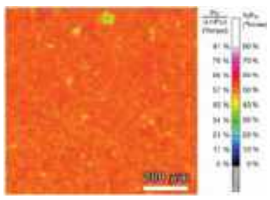
- Atomic calculations of thermal properties : start the activity with Cp=f(O/M)
- Elastic properties recommendations : start of the activity
- Experimental programme : first fabrications and characterization of MOX at 60, 65, 70 Pu%. Measurements of melting temperature of PuO_2

Optical microscopy observation of the obtained $U_{0.40}Pu_{0.60}O_{2.00}$ sintered mixed oxide pellet



Characteristics:

- ✓ Monophasic and stoichiometric $U_{0.40}Pu_{0.60}O_{2.00}$ mixed oxide
- ✓ Clean microstructure without cracks
- ✓ Homogeneous cationic distribution
- ✓ Dense pellet (96% of d_{theo})



Pseudo-quantitative mapping of the Pu distribution determined by Electron Probe Micro-Analysis

PhD MM. Desagulier, CEA - Atalante

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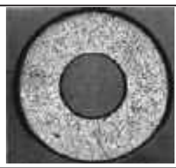
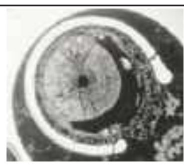
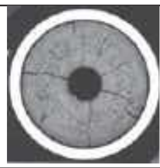
WP4 Comparison of irradiation results in fast spectrum vs thermal spectrum (MTR)

FRESH FUEL	Irradiation in MTR – nominal conditions TRABANT 2	Irradiation in MTR – fuel melting + clad failure TRABANT1	Irradiation in FAST REACTOR CAPRIX
			

Objectives:

- Comparison of irradiation results in MTR and SFR
- Analysis of the advantages / disadvantages of SFRs / MTRs for future irradiation programs
- Contribution of MTR and SFR irradiations to the fuel qualification (TRL) with different irradiation devices

New approach :

- Same fuel irradiated in MTR (HFR) and FR (Phenix): comparison of results
- Contribution of MTR for off-normal condition tests.

WP4 Comparison of irradiation results in fast spectrum vs thermal spectrum (MTR)

RESULTS ACHIEVED

- Comparisons of pin irradiation conditions in MTR vs SFR
- Inventory of devices for experimental irradiation in MTR and SFR : new template for device characteristics

Deliverables
D4.2 Irradiation condition requirements for FR fuel qualification and the applicability of FR and MTR (preliminary version submitted M16; final version due M38) Deliverable goals and dates were modified in first phase of project, when details were discussed. This deliverable contains the boundary conditions and parameters to which the modelling efforts will be evaluated. These parameters are identified early in the project and are summarized in a preliminary version of the deliverable (could also have been a technical note, but partners indicated it felt better to put it in the deliverable). Preliminary version is completed (M16) and is formalization is underway. The deliverable will be finalized after an evaluation from the modelling efforts is included.

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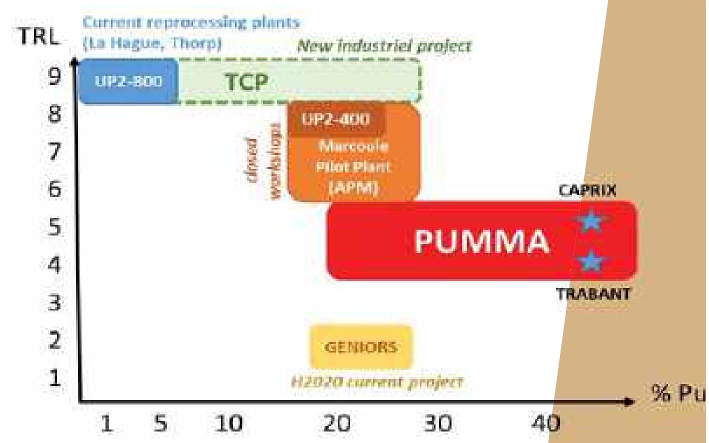
WP5 Qualification Of MOX Fuel Dissolution

Objectives:

- Extension of dissolution qualification to high Pu% spent fuel
- Dissolution test at a lab scale with irradiated CAPRIX/TRABANT fuels in order to evaluate the impact of high Pu content (>30%) on Pu dissolution rate and FP distribution in solid residues
- Dose evaluation of extractant

New approach :

- Test on fresh fuel and then on irradiated fuel for process optimisation



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WP5 Qualification Of Mox Fuel Dissolution

Results achieved

- Definition of experimental tests conditions on fresh and irradiated fuels at CEA-Atalante (MOX at 45%Pu fresh and irradiated CAPRIX) and NNL (MOX powders)
- Several tests achieved, results to be interpreted

Non irradiated CAPRA pellets after dissolution. CEA-Atalante

Deliverables
D5.1 – Coordination of Pu-active and HA dissolution experiments (NNL, CEA, NRG) has been completed. The report summarises discussion between CEA, NRG and NNL to maximise commonality between experiments that will maximise comparability.

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WP6 Education and training, dissemination and communication

Objectives:

- To encourage mobility of PhD students, post-doc...;
- To organize workshops for PhD students, post-docs, researchers, designers, stakeholders, etc.;
- To improve educational tools and learning methodologies;
- To disseminate the outcomes of the project to a larger audience

PuMMA

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WP6 Education and training, dissemination and communication

Results achieved

- Identify the first secondments
- MOOC production – discussions about the format
- Database of courses: identify relevant past projects and workshops or seminars
- PUMMA workshop 1 on Fuel Cycle Scenarios held in Madrid
- Dissemination & communication

Euratom funded projects on fuel, reprocessing and fuel cycle scenarios

Project No	Framework Programme	TOPIC	Project Acronym	Project Title	Start Date
1	FP6-EURATOM-NUWASTE - Thematic priority - Management of radioactive	NUWASTE-2003-3.2.2.1-1 - Partitioning of actinides and fission products from high-level nuclear	EUROPART (it is the merged	EUROpean research program for the PARTitioning of minor	01/01/2004
2	FP6-EURATOM-NUWASTE - Thematic priority - Management of radioactive	NUWASTE-2004-3.2.2.1-1 - Transmutation of high-level nuclear waste in an Accelerator Driven	EUROTRANS (Its sister project of	European research Programme for the transmutation of high	01/04/2005
3	FP7-EURATOM-FISSION - EURATOM: Nuclear fission and radiation protection	Fission-2008-1.2.2 - Transmutation fuels and targets and their reprocessing	FAIRFUELS	FAbrication, Irradiation and Reprocessing of FUELS and targets for	01/02/2009
4	FP7-EURATOM-FISSION - EURATOM: Nuclear fission and radiation protection	Fission-2011-2.3.1 - R&D activities in support of the implementation of the Strategic	PELGRIMM	PELlets versus GRanulates: Irradiation, Manufacturing &	01/01/2012
5	H2020-Euratom-1.2. - Contribute to the development of solutions for the	NFRP-5 - Materials research for Generation-IV reactors	INSPYRE	Investigations Supporting MOX Fuel Licensing in ESNII	01/09/2017
6	FP7-EURATOM-FISSION - EURATOM: Nuclear fission and radiation protection	Fission-2013-2.3.1 - Support to the development of joint research actions between national programmes	MATISSE	Materials' Innovations for a Safe and Sustainable nuclear in	01/11/2013
7	FP7-EURATOM-FISSION - EURATOM: Nuclear fission and radiation protection	Fission-2007-1.2-01 - Partitioning processes for viable recycling strategies	ACSEPT	Actinide reCycling by SEParation and Transmutation	01/03/2008

Database of courses

30/05/2022

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Project Long term Results

- Demonstrate that fast reactors with the associated fuel cycle is the best way for plutonium management with flexibility and sustainability
- Provide new results for Improving the knowledge in all the steps of the fuel cycle
- Associate the new generation of researchers

PuMMA

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Thank you!

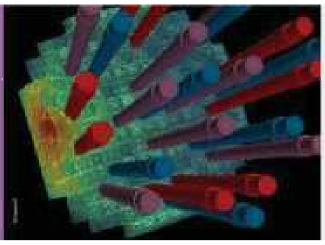
Contact us for more information!

www.pumma-h2020.eu

contact@pumma-h2020.eu

pumma-h2020

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 945022.



FISA 2022

30 May - 3 June 2022
Lyon, France

PATRICIA, PASCAL (and ANSELMUS) Partitioning and Transmutation, contribution to an EU strategy of HLM management

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May - 3 June 2022 | Lyon, France

Projects

PATRICIA	PASCAL	ANSELMUS
Partitioning And Transmuter Research Initiative in a Collaborative Innovation Action	Proof of Augmented Safety Conditions in Advanced Liquid-metal-cooled systems	Advanced Nuclear Safety Evaluation of Liquid Metal Using Systems
H2020 2020-2024 8,9 M€ 6,5 M€ EU	H2020 2020-2024 4,6 M€ 3,8 M€ EU	EURATOM2027 2022-2026 4,8 M€ 3,5 M€ EU
912 pm	436,5 pm	415,5 pm
Grant N°945077	Grant N°945341	Grant N°101061185

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May - 3 June 2022 | Lyon, France

PARTNERS

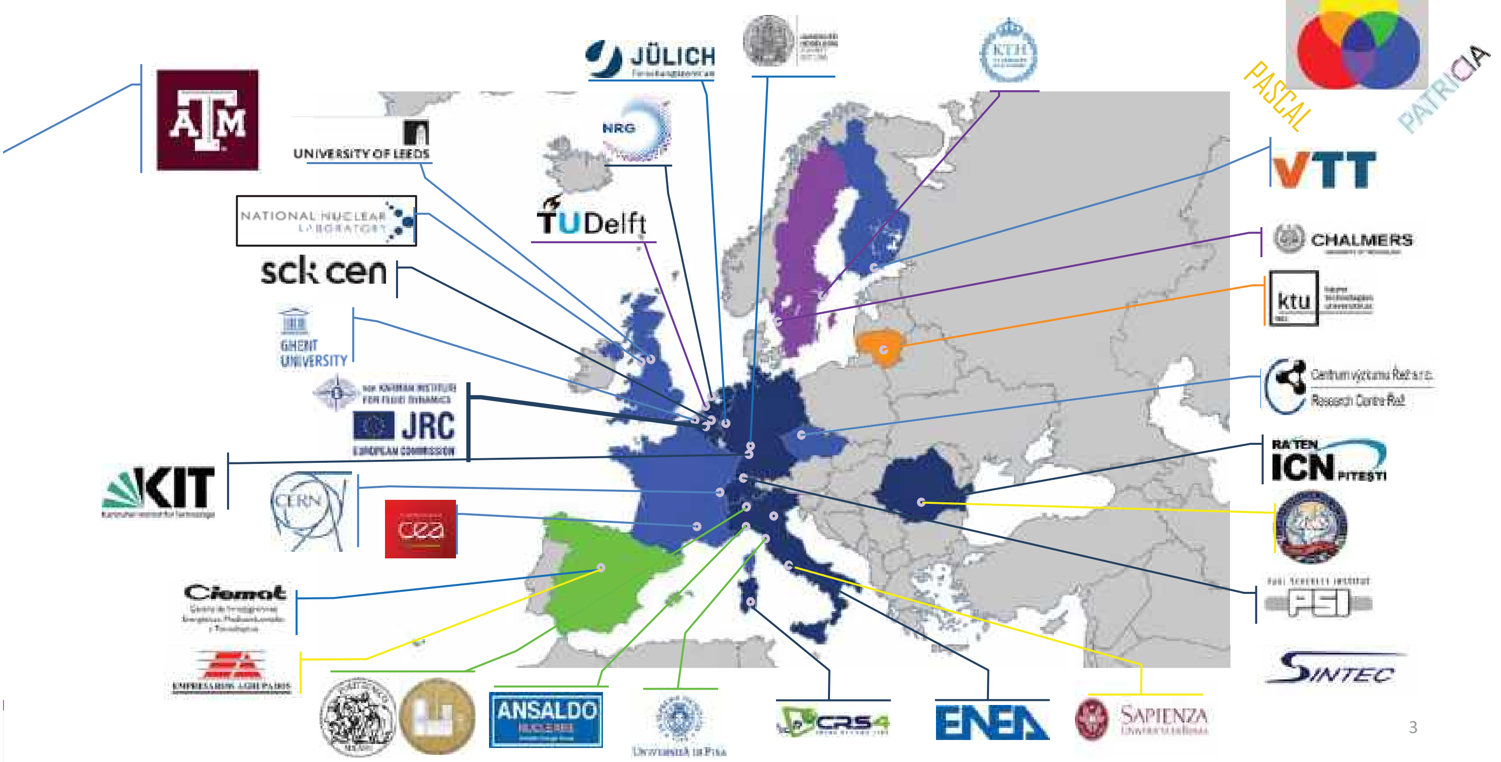


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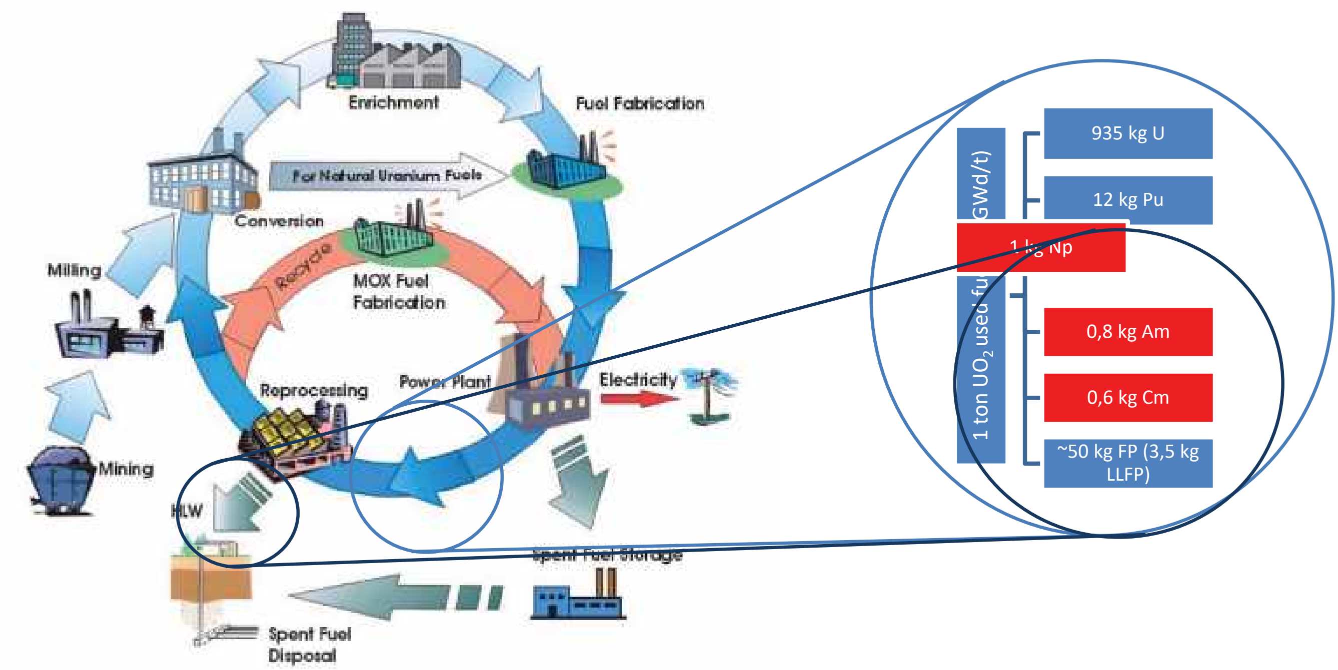
Figure: IAEA TECDOC-1613

Fuel Cycle



10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
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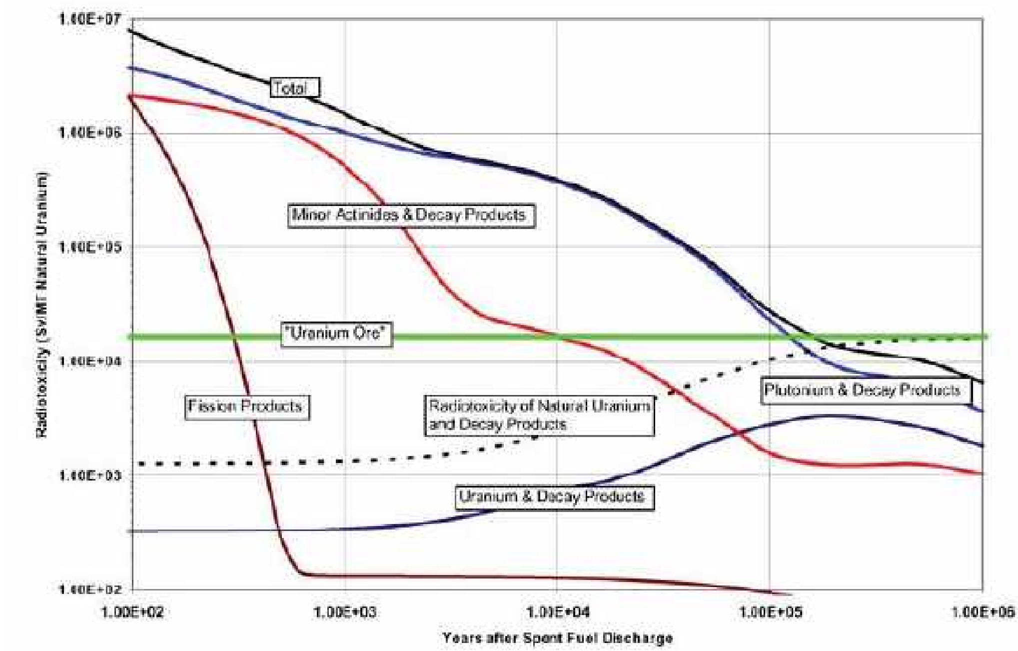
4

figure NEA-OECD

Radiotoxicity of spent fuel



Partitioning and Transmutation building blocks

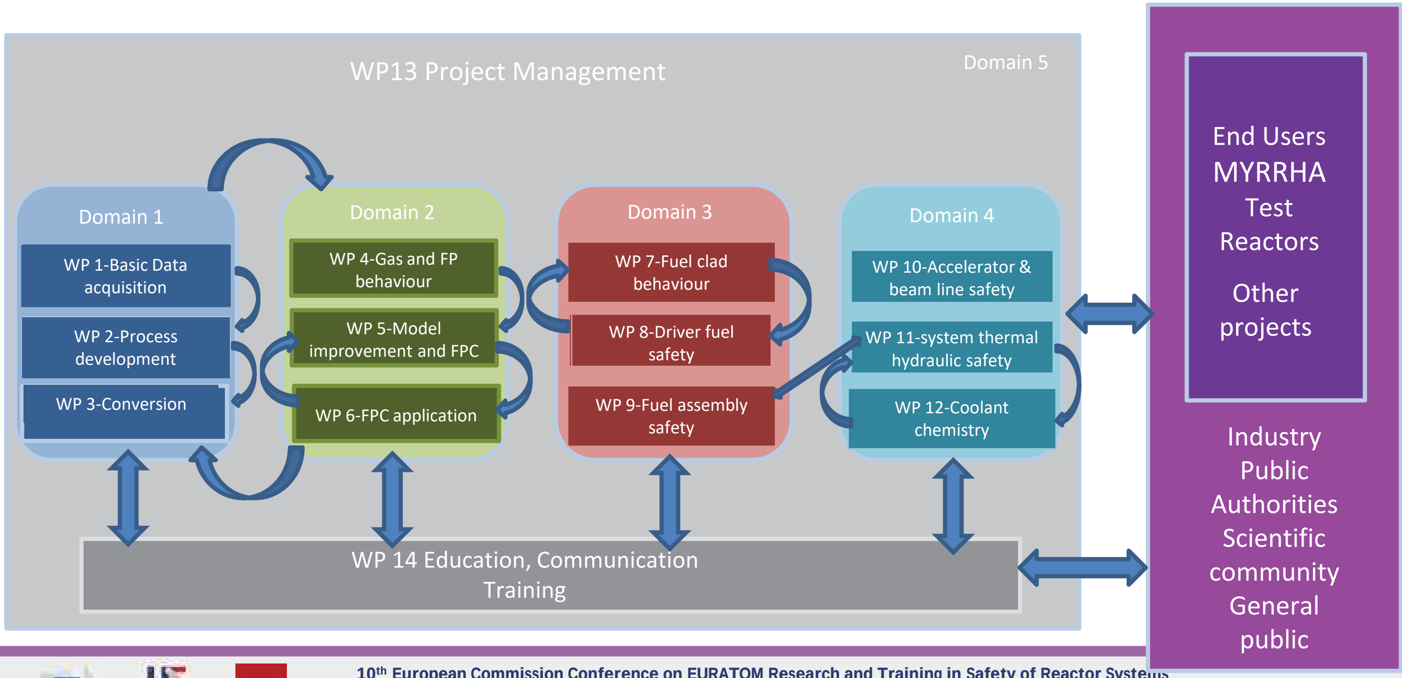
1. Advanced (multiple) reprocessing
   - Separate U, Pu, Am, Np, Cm, fission products
2. Transmuter fuel
   - Create MA bearing fuel
   - Understand behaviour
3. Transmuter
   - Build safe machine that can burn MA
   - Fast neutrons needed
     - Accelerator driven system
     - Fast critical reactor
4. Transmuter fuel reprocessing

Previous projects context

PATRICIA Project

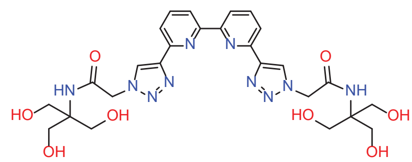
- Approach
  - Joint project between the Partitioning, Transmutation and Transmuter development communities
    - Fortify the international collaboration
    - Transmutation needs Partitioning and vice versa
- Methodology
  - Focus
    - Closing the fuel cycle
    - Building on existing experience
  - Covering
    - Advanced partitioning with focus on Am separation and conversion
    - Behaviour of MA (Am) bearing fuel under irradiation
    - Development of a dedicated transmuter demo following the MYRRHA track

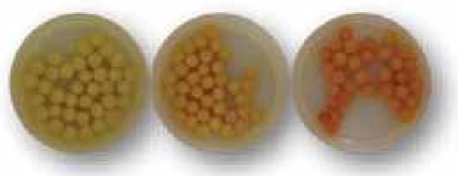
PATRICIA Project



DM1: Partitioning in PATRICIA

- Focus
  - separation of Am from the minor actinides
  - conversion of the Am solution form the partitioning process to a material suitable for fuel fabrication
- Topics
  - WP1 Basic data acquisition on americium and fission products behaviour with the AMSEL chemical systems
  - WP2 Process development
    - Development of simulation models
    - Flowsheet development (simulation & lab scale tests)
    - Process tests (with feed solution containing nominal Am concentration
  - WP3 Conversion to Am bearing fuel
    - Characteristics defined by DM2 (Cm & FP contamination & phys. properties)
    - Inert & actinide bearing matrix

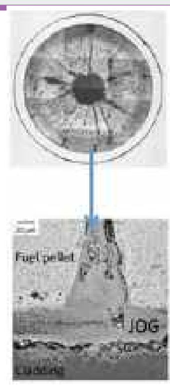


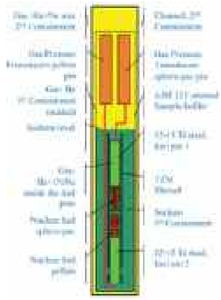


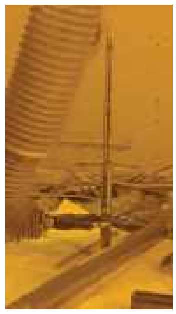
DM2: Transmutation in PATRICIA

– Focus
  - Behaviour of Am containing fuel under irradiation
  - Model development of Fuel performance codes

– Topics
  - WP4 Gas and fission products behaviour and thermo-chemical properties of Am bearing fuel: effects of irradiation
    – investigating, analysing and quantifying helium and fission gases and fission products production
    – behaviour during irradiation of Am-bearing fuels (PIE)
  - WP5 Improved modelling and fuel performance codes
    – develop and improve modelling and simulation tools
      » behaviour under irradiation of Am-bearing fuel itself
      » interaction with the reactor environment
  - WP6 Applications to simulations in normal conditions and off normal conditions
    – Design of future Am fuel test experiments







DM3: Driver fuel and core safety in PATRICIA

– Focus
  - safety related studies of the MYRRHA core and driver fuel input for the PSAR of MYRRHA

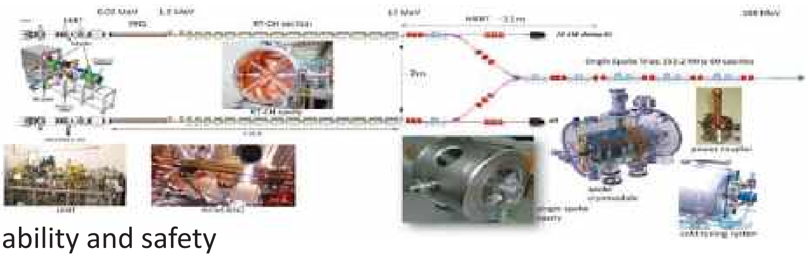
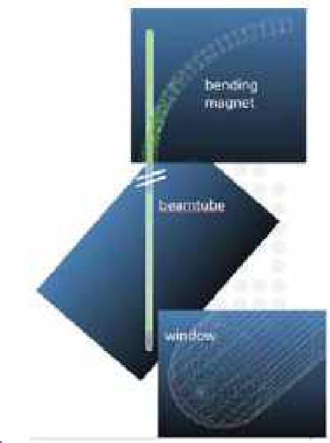
– Topics
  - WP7 fuel clad integrity under exposure to the Lead-Bismuth Eutectic
    – Integrated corrosion-deposition experiment on a heated fuel bundle
    – Mechanical properties of exposed cladding
  - WP8 fuel Safety
    – pin failure limits under transients
      » Detailed PIE of segments tested in MAXSIMA
    – Fuel coolant (LBE) interaction at 1650°C

DM3: Driver fuel and core safety PATRICIA

– Focus
  - safety related studies of the MYRRHA core and driver fuel as input for the PSAR of MYRRHA
– Topics
  - WP9 fuel assembly safety
    - Blocked wire spaced fuel assembly
      - » Investigation of Porous blocking
      - » Self heating blocking (fuel fragments)
    - Deformed wire spaced fuel assembly
      - » Reference experiments on defined geometries
      - » Numerical code validation


DM4: ADS System safety in PATRICIA

– Focus
  - safety of the ADS system
  - input for PSAR of MYRRHA
– Topics
  - WP10 Accelerator and beam line reliability and safety
    - Development of fault tolerance methodology
      - » Elaborate reliability model of driver linac
      - » Application to RF module and MINERVA linac
    - Beam window failure detection
      - » Po transport in vacuum
      - » Experiments with vapourised Hg and LBE with small leak

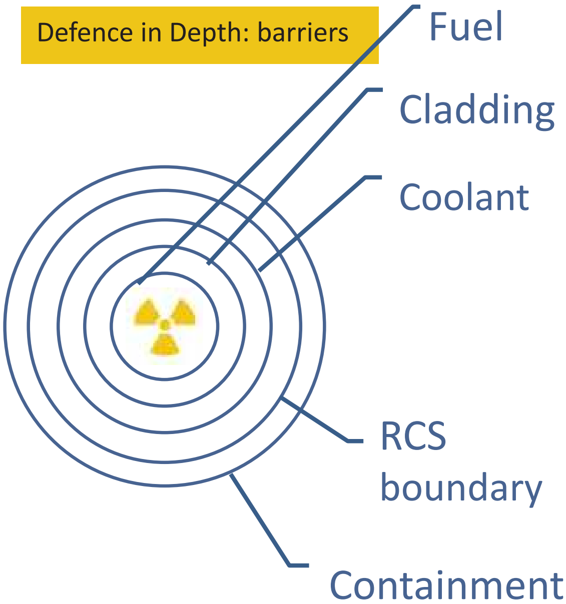
DM4: ADS System safety in PATRICIA

- Focus
  - safety of the ADS system
  - input for PSAR of MYRRHA
- Topics
  - WP11 Thermal hydraulic system safety
    - Stability of natural convection cooling in accident conditions
      - » Experiments CIRCE & ESCAPE
      - » Modelling (CFD & CFD+STH)
    - Heat transfer modelling in pool configuration
      - » "Engineering" heat transfer model development using AHFM
        - Implementation in Open Foam
      - » Use existing data & DNS simulations
  - WP12 Chemistry control experiments and modelling
    - Development and validation of coupled thermal-hydraulic-chemistry simulation tool
      - » code coupling
      - » Validation tests on existing experimental data
    - Radiological release
      - » Release and retention of Po, Cs, I and Te in LBE

KEMS device installed at JRC-KA

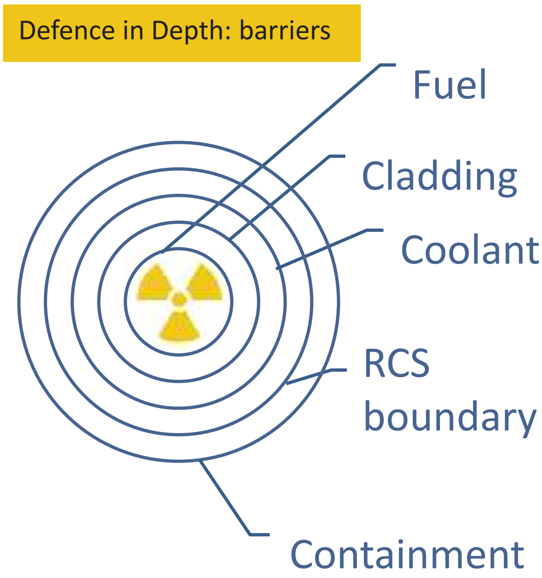
PASCAL Project

- Approach
  - Support ALFRED and MYRRHA pre licensing
  - Exploiting the inherent features of HLM cooling, and adding passive provisions, the possibility exists to exclude need for off-site emergency response planning
- Methodology
  - Quality experimental results to support the claimed performances in front of the safety authorities
  - Basic insights to enhance the mastering of less-known phenomena
  - Separate and integral effects data to validate software models and codes

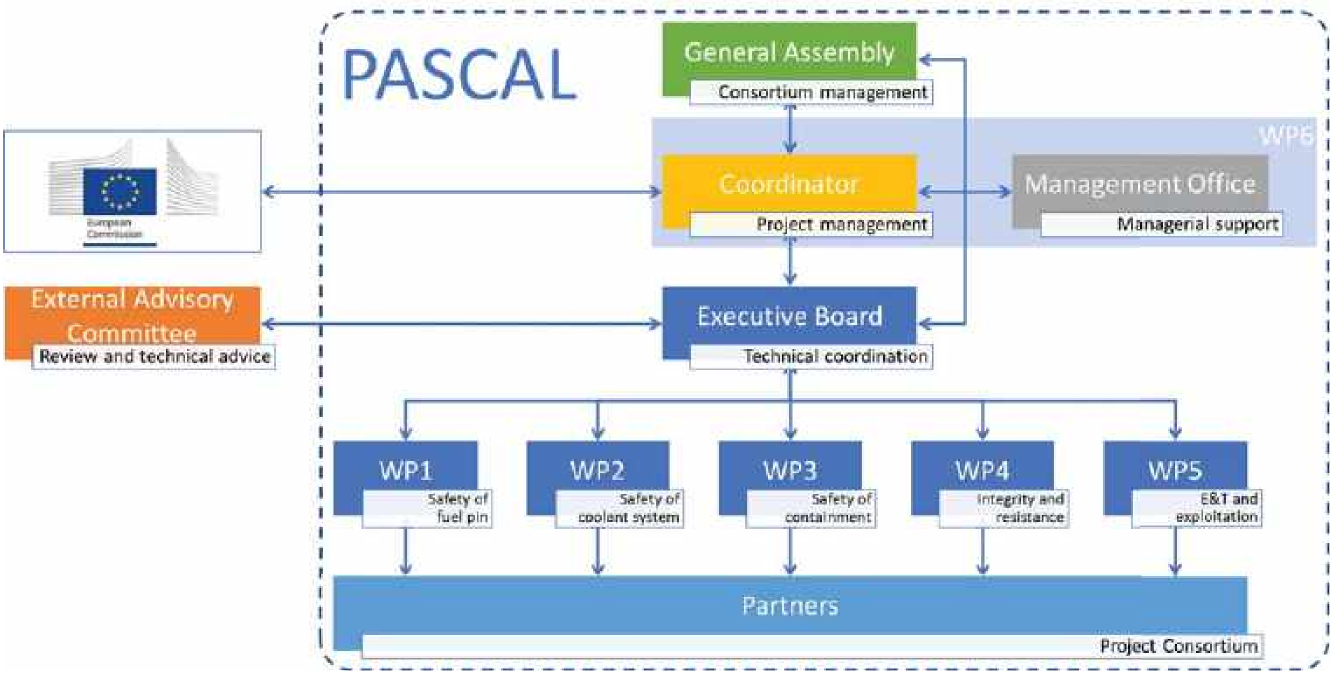


PASCAL Project

- Retention in fuel
  - New phenomena could be expected by interaction of the fuel (and matrices generated by the fuel) with HLMs
- Enclosure in cladding
  - Clad and FA integrity in HLM
- Retention in coolant
  - Assessment of very high fission products retention capabilities credited to HLMs.
- Enclosure in RCS boundary
- Confinement in building
  - Aerosols and volatile species from the coolant (in case of breach of the RCS boundary) characterize the anticipated conditions.



PASCAL Project



10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May - 3 June 2022 | Lyon, France

PASCAL WP1 Safety of the fuel pin

- Focus
  - Interaction of fission products and fuel with the coolant
- Topics
  - Structural and thermodynamic study of interaction products for
    - JOG-Pb/LBE
    - Pb/LBE-(radionuclides with long term radiological impact)
  - Interaction tests of
    - Pb/LBE-JOG/clad up to the clad melting temp
    - irradiated $(U,Pu)O_2$ and Pb/LBE
  - Study of
    - phase equilibria in {PbI-BiI-CsI}
    - release equilibria and kinetics of major fission products from {Pb/LBE+JOG} and {Pb/LBE+irradiated MOX}

PASCAL WP2 Safety of the coolant system

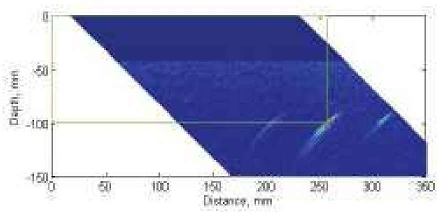
- Focus
  - Thermal-hydraulics in off-normal conditions
- Topics
  - Thermal-hydraulic study of asymmetric flow conditions in the pool
    - experimentally, in E-SCAPE
    - numerically, by CFD analysis
  - Thermal-hydraulic study of heat exchange in a grid spaced fuel bundle with deformed pins
    - experimentally, in a new ad hoc water loop
    - numerically, by sub-channel and CFD analysis

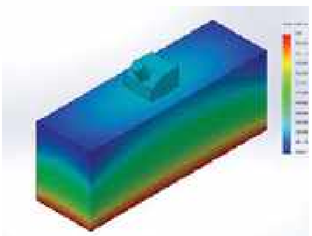
PASCAL WP3 Safety of the containment

- Focus
  - Release of radionuclei from the coolant
- Topics
  - Study of fission product release from HLM and deposition from the gas phase, relative to
    - Cesium and Iodine evaporation
    - Tellurium evaporation
    - evaporated fission products molecules with cover gas
  - Study of Pb/LBE aerosol formation and transport
    - experimentally
    - numerically, extending the models integrated in the containment modules of severe accident codes

PASCAL WP4 Integrity and resistance

- Focus
  - Integrity of the barriers
- Topics
  - Study of flow-induced vibrations in grid-spaced fuel bundles
    - experimentally, in HELENA
    - numerically, by CFD analysis
  - Study of sloshing effects in a pool
    - Experimentally, in SHAKESPEARE
    - numerically, by CFD analysis
  - Development of under-HLM integrity inspection device, by
    - comparison of HLM impact on normed tests
    - calibration of detection through pre-cracked samples inspection in HLM

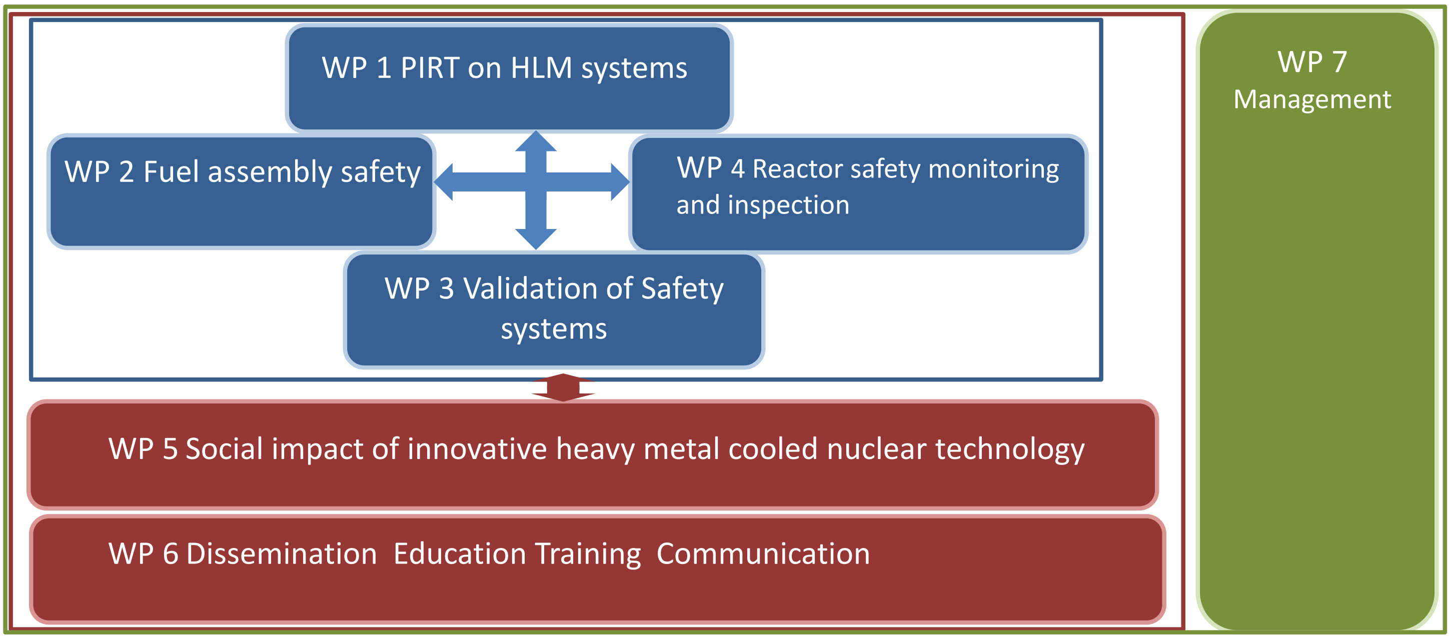




ANSELMUS Project

- Approach
  - Support ALFRED and MYRRHA pre licensing
  - Use maturity of design to take concrete steps towards PSAR
- Methodology
  - Use state of the art and design status to do thorough PIRT
  - Focus on key safety issues
  - Validation of safety related components and procedures
  - Outlook towards society

ANSELMUS Project



ANSELMUS WP1 PIRT on HLM systems

- Focus
  - Thorough PIRT analyses as starting point for safety evaluation
- Topics
  - PIRT methodology and development
  - Reference design and initiating events
    - Selection for the reference designs of MYRRHA and ALFRED to be used
    - Selection of initiating event
  - Numerical evaluation of selected scenarios
  - R&D roadmap for V&V needs

ANSELMUS WP2 Fuel Assembly safety

- Focus
  - Safety related experiments for grid and wire spaced fuel assemblies
- Topics
  - Grid spaced fuel bundle heat transfer characterization in lead
    - Experiments in liquid Pb using the HELENA loop
    - Numerical modelling
  - Wire spaced fuel bundle heat transfer
    - Generation of a database of experiments with wire spaced bundle
    - Measurements with a wire spaced fuel bundle in water representative of MYRRHA
      - » Use laser sheet to characterise velocity field
    - CFD modelling of the (NRG)
    - Assessment of CFD uncertainty and guidelines for CFD simulations

ANSELMUS WP3 Validation of Safety systems

- Focus
  - Validation or development of key Safety related systems
- Topics
  - Safety rod validation (SCK CEN, CRS4)
    - POP tests of MYRRHA safety rods in flowing LBE using COMPLOT
    - Numerical simulations supporting the COMPLOT safety rod experiment
  - Failed fuel pin detection
    - Analysis of noble gas inventory in MYRRHA
    - Noble gas transport tests in Pb and LBE
    - Tag gas mixture selection and capsule conceptual design for MYRRHA
    - Noble gas detection experiments using fission product Gas-jet Facility
  - Validation of oxygen control systems
    - Oxygen control system in LBE selection and test in MEXICO facility
    - Oxygen control system in Pb selection and test in HELENA

ANSELMUS WP4 Reactor safety monitoring and inspection

- Focus
  - Development of NDUS inspection for LFR up to 400°C
- Topics
  - Inspection strategy
  - NDT inspection at high temperatures
    - Selection of high temperature US sensors
    - NDT inspection tests in Pb
  - Inspection tools
    - specifications of inspection tools in MYRRHA and ALFRED

WP4 Social Impact of Innovative HLM cooled technology

ANSELMUS

– Focus
  - Assessment of the impact of HLM cooled systems on society
– Topics
  - Energy use
    - Identification of key parameters, modelling and components definition
    - Techno-economic analysis
    - Financing and business model
  - Social and ethical considerations of advanced nuclear technology
    - Sociotechnical integration in research labs
    - Mapping societal values linked to the development of advanced nuclear technologies
    - Public views on advanced nuclear reactors

EDUCATION AND TRAINING

- Data management plan for the FAIR approach
- Dissemination and exploitation of the results
- Education & Training
  - Education and training of researchers by summer schools and workshops
  - PATRICIA
    - Large focus on PhD support with dedicated financing for PhD
    - International workshop in conjunction with established conference
    - High-School level booklet on nuclear waste and transmutation
    - Meet the pupils days
  - PASCAL
    - Hands on training of students and young researchers through mobility grants
  - ANSELMUS
    - Stakeholder interaction
      - Communication to general public
      - Short films on the use of liquid metal –Youtube platform
      - Stakeholder workshop

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SCK CEN
Belgian Nuclear Research Centre
Studiecentrum voor Kernenergie
Centre d'Etude de l'Energie Nucléaire

Foundation of Public Utility
Stichting van Openbaar Nut
Fondation d'Utilité Publique

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Research Centres:
Boeretang 200 - 2400 MOL - Belgium
Chemin du Cyclotron 6 - 1348 Ottignies-Louvain-la-Neuve - Belgium

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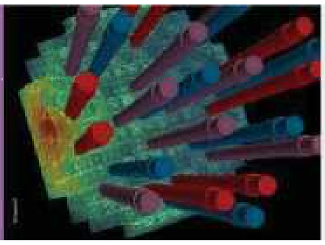

FISA 2022

30 May - 3 June 2022
Lyon, France

TOWARDS A SINGLE EUROPEAN SRIA ON NUCLEAR MATERIALS FOR ALL REACTOR GENERATIONS THROUGH DEDICATED PROJECTS

Lorenzo Malerba[1], Pietro Agostini[2], Massimo Angiolini[2], Marjorie Bertolus[3]

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[2]*ENEA-FSN-ING Division, C.R. Brasimone 40032, Camugnano, Italy. E-mail: pietro.agostini@enea.it*
[3]*CEA, Energy division, DES, IRESNE, DEC, Centre de Cadarache, F-13108, Saint-Paul-lez-Durance, France. E-mail: Marjorie.bertolus@cea.fr*

Outline

- ORIENT-NM and the all-generation nuclear materials SRIA
- EERA-JPNM portfolio in H2020: GEMMA, INSPYRE, M4F
- GEMMA results
- INSPYRE results
- M4F results

What is ORIENT Nuclear Materials?

Organisation of the European Research Community on Nuclear Materials (ORIENT-NM) is a Coordination and Support Action partially funded by Euratom, WP 2019-20, NFRP-08

Goals as from the call:

- Consolidate the domain of nuclear materials in Europe
- Avoid duplication, improve complementarity
- Involve EERA (JPNM) and SNETP (NUGENIA)

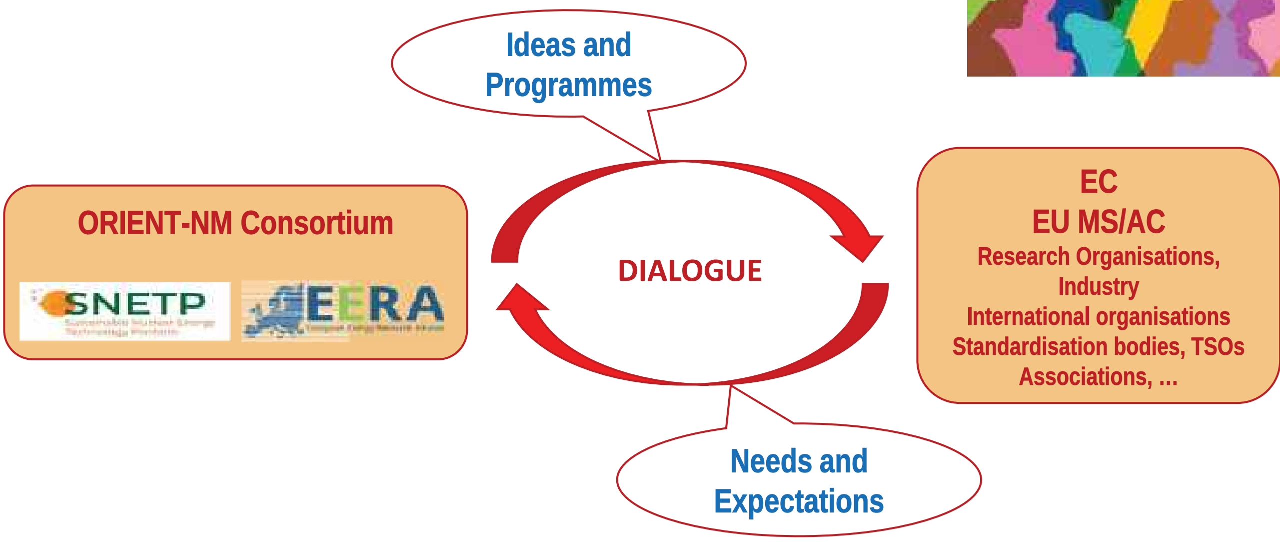
In practice:

- Explore the ground for a European Partnership* on nuclear materials

ORIENT-NM Budget:
Total: 1.6 M€
Euratom contribution: 1.1 M€

**European Partnerships in HEU replace among others H2020 European Joint Programmes, EJP*

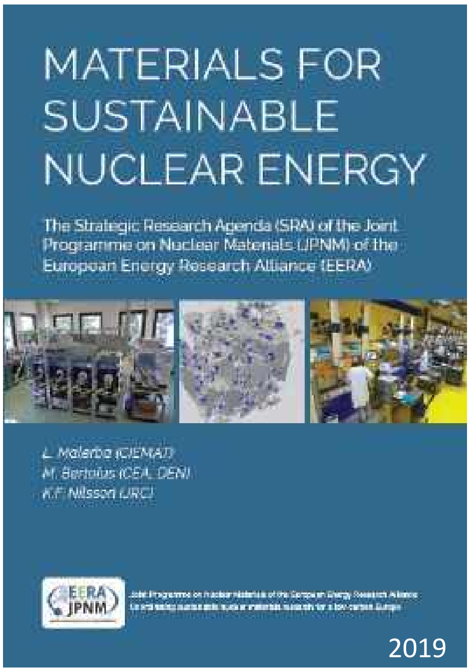
How is ORIENT-NM working?



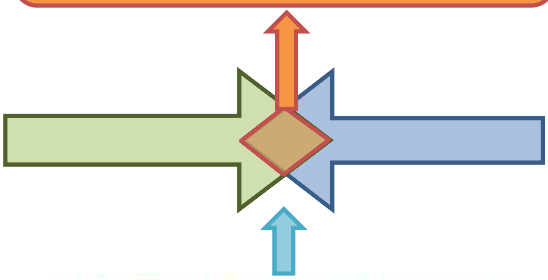
What is ORIENT-NM producing?

1. Single Vision Strategic Reasearch Agenda on Nuclear Materials <u>for the benefit of ALL reactor generations</u> until 2040
2. Most suitable governance, structure and implementation design for the European Partnership
3. Plan of interaction of the European Partnership with all interested stake-holders

The roots of ORIENT-NM's SRIA



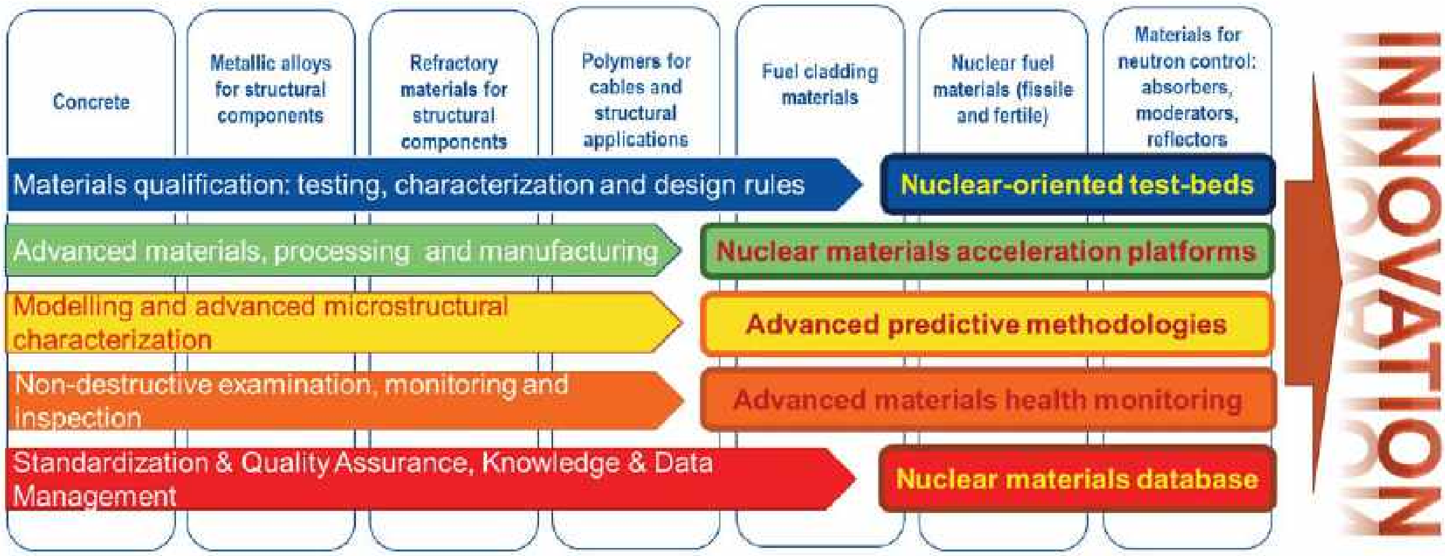
ORIENT-NM SRIA
https://doi.org/10.3390/en15051845



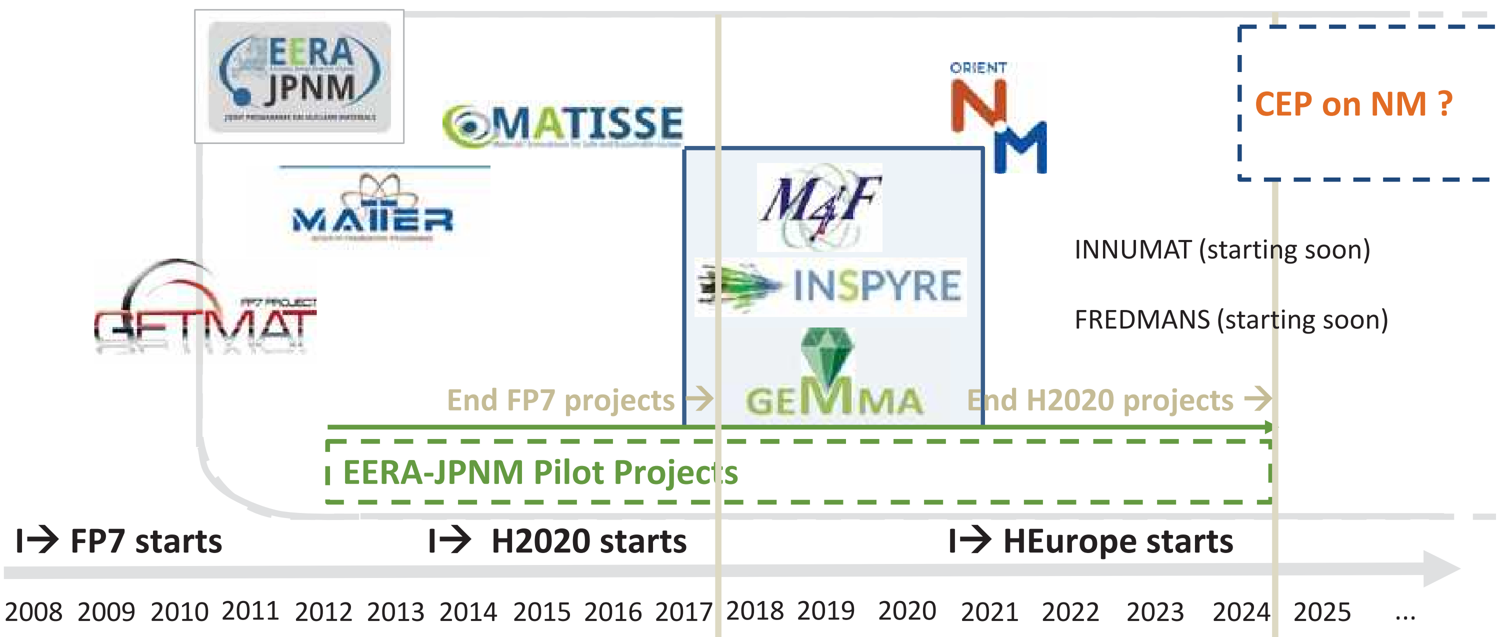
technology-agnostic approach

The ORIENT-NM SRIA in a nutshell

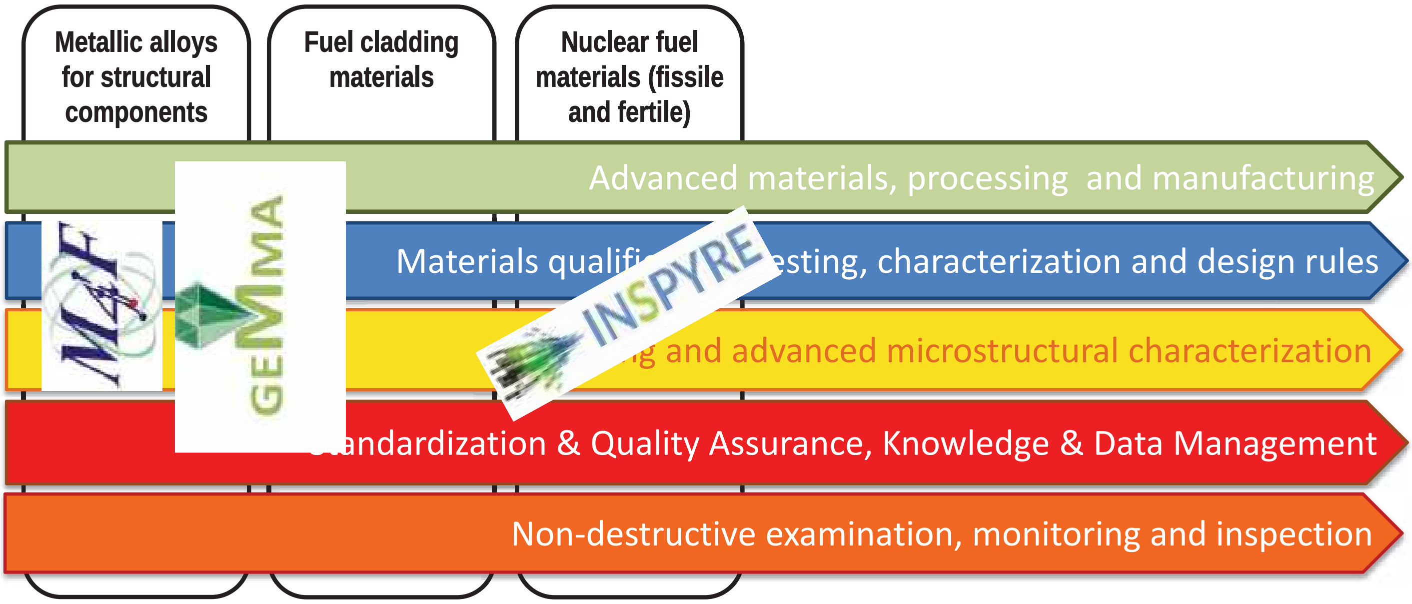
Technology independent matrix:
Materials classes and cross-cutting research lines are of relevance for any reactor generation
Emphasis is given to modern materials science practices that rely on advanced digital tools and techniques



EERA Joint Programme on Nuclear Materials: Research Project Portfolio



GEMMA, INSPYRE and M4F: examples of SRIA research lines' application



GEMMA: GenIV Materials Maturity

H2020 Project (2017-2021): 6.6/4.0 M€, 23 participants, coord. P. Agostini (ENEA)

GEMMA deals with EU GEN IV material issues, reflecting the EERA JPNM three-fold approach to materials studies

	Compatibility with coolants	Neutron Irradiation effects
Materials Characterization in view of codification	WP2: Welding development and characterization WP4: Compatibility with HLM and He coolant	
Materials Modelling	WP4: Compatibility with HLM and He coolant	WP3: Irradiation effects: modelling and experiments
Innovative Material Solutions	WP1: Advanced corrosion mitigation strategies	

Large amount of experimental data have been generated.

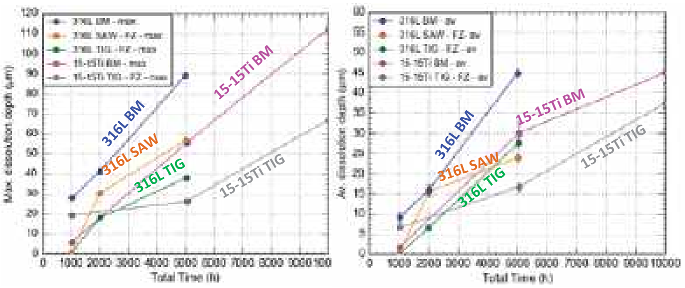
Useful rules, for system and component designers, have been deduced.

The data are expressed in a suitable way for inclusion in the Design Rules of the RCC-MRx code

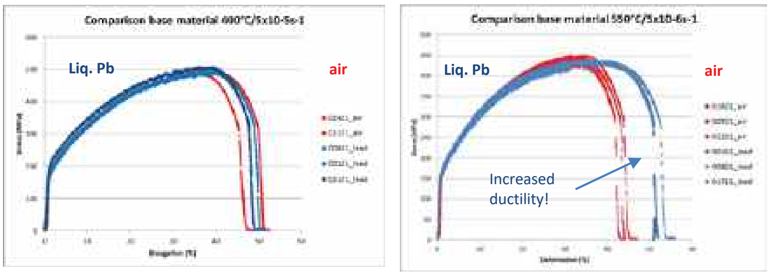
The generated data have been stored in JRC repository MAT-DB http://www.eera-jpnm.eu/gemma

Qualification of existing materials: compatibility with liquid Pb

GOOD BEHAVIOUR OF WELDED AUSTENITIC STEELS VERSUS BASE MATERIALS (static tests in Pb @ 480°C and low Ox)



NO LIQUID METAL EMBRITTLEMENT IN 316L IN CONTACT WITH LIQUID Pb

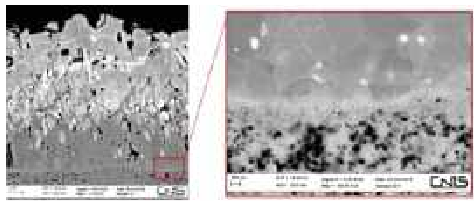


NEGLIGIBLE CORROSION AFTER 16000h IN FLOWING Pb @ 480°C and low Ox, BOTH BASE MATERIAL AND WELDS

316L 16000 h | TIG 316L 16000 h | SAW 316L 16000 h | 15-15 Ti 16000 h

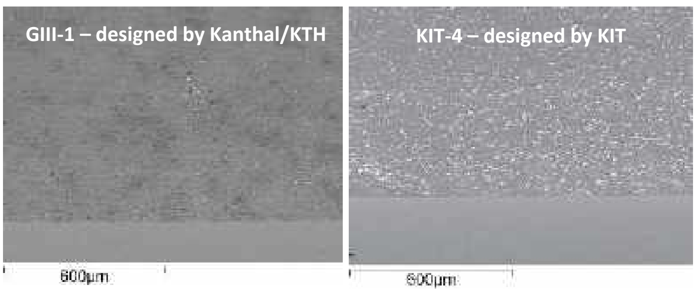
CORROSION RATE INCREASES AT HIGH T (550ºC)

At 550°C Pb wets magnetite's grain boundaries, creating fast diffusion paths for oxygen, which increases corrosion



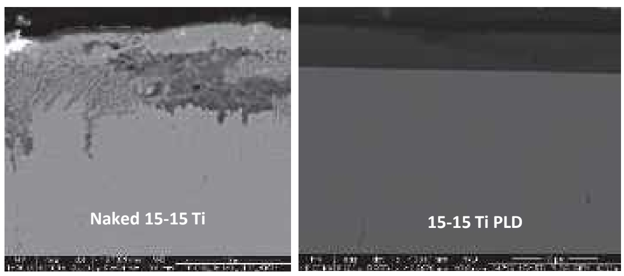
Advanced materials: Alumina Forming Steels and Coatings

ALUMINA FORMING AUSTENITIC STEELS (AFA)



NO INDICATION OF CORROSION ATTACKS AFTER EXPOSED IN STAGNANT LIQUID LEAD AT 600°C FOR 1000H.

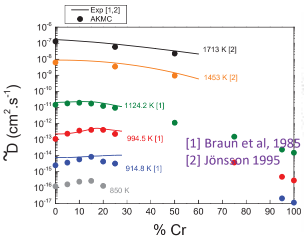
AL_2O_3 CERAMIC COATINGS ON STEELS



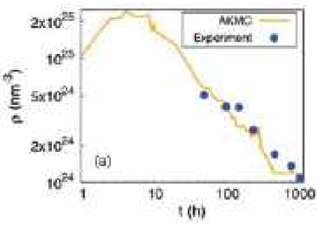
PULSED LASER DEPOSITED (PLD) ALUMINA COATING CONFIRMS GOOD PROTECTION ON 15-15 TI AT 550°C (LOW OXYGEN, FLOWING PB 4000 H)

Advanced physcal modelling and data management

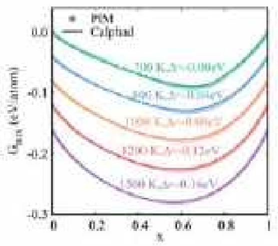
Atomistic kinetic models fitted to ab initio computations simulate correctly thermodynamic-driven processes in Fe-Cr and Fe-Ni alloys



Fe-Cr Interdiffusion Coefficients



α-α' decomposition size and number of precipitates



Free energy of mixing G_mix from equilibrium Monte Carlo simulations in Fe-Ni alloys, including effect of magnetism – good agreement with experiment-fitted data

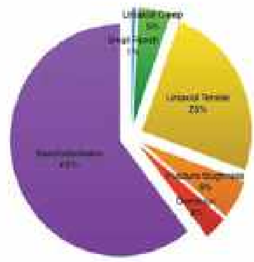
Repository of GEMMA Experimental Data @ https://odin.jrc.ec.europa.eu

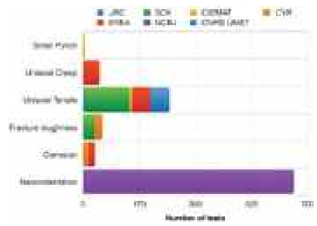
Test	N.
Small Punch	7
Uniaxial Creep	53
Uniaxial Tensile	270
Fracture toughness	60
Corrosion	37
Nanoindentation	656
Tot	*1083*

1083 validated test results with metadata:

- source
- material pedigree
- specimen
- test conditions.

All GEMMA data are citable with DataCite DOIs.





INSPYRE: Investigations Supporting MOX Fuel Licensing in ESNII Prototype Reactors

H2020 Project (2017-2022): 9.4/4.0 M€, 14 participants, coord. M. Bertolus (CEA)

INSPYRE **STRATEGIC OBJECTIVES**

- Make major breakthrough in understanding and describing fast reactor MOX behaviour under irradiation in a large variety of conditions by coupling
  - Separate effect experiments
  - Multiscale and thermodynamic modelling
  - PIE results on neutron-irradiated fuel from past campaigns
- Focus on four operational issues: Margin to fuel melting; atom transport and fission product behaviour; mechanical properties; fuel thermochemistry and interaction with the cladding
- Advance predictive capabilities of fast reactor fuel performance codes by:
  - Transferring knowledge acquired into operational tools
  - Bringing together experts to develop and capitalize on the synergy between the various approaches
- Transfer results and approach of proposal to users and develop training to prepare next generation of researchers

http://www.eera-jpnm.eu/inspyre/

Advances in the understanding and simulation of nuclear fuels

HIGHLIGHTS

Analysis of available data and models and identification of gaps

Assessment of current versions of fuel performance codes on previous irradiation experiments

Development of new experimental set-ups in hot labs enabling characterization of Pu and Am oxides

Thermochemical behaviour of MOX

- Experiments and models for U-Pu-Am oxides and fission products for improved thermodynamic description of U-Pu-Am-O and Cs-I-Te-Mo-U-Pu-O
- Experimental study of MOX/steel interaction at high temperature
- Improved correlations for melting temperature and thermal conductivity of irradiated MOX and Am-bearing MOX

Thermomechanical properties of UO_2 and MOX

- Combined experimental and modelling study of mechanical properties of fresh UO_2 and MOX fuels
- Modelling of impact of primary damage on mechanical properties
- Investigation of thermal and irradiation induced creep of UO_2
- Physics-based mechanical models for creep and rupture of MOX fuel in normal and off-normal conditions

Atomic transport properties and fission gas behaviour

- Modelling of thermal and irradiation-induced defects in MOX
- Study of the MOX fuel self-diffusion from the atomic to the macroscale
- Combined modelling and experimental study of fission gas behaviour in UO_2
- TEM characterisation of irradiated MOX
- Physics-based models of inert gas behaviour in high burn-up structure and in transient conditions

Implementation of data obtained and models developed in fuel performance codes were applied to irradiation experiments representative of ESNII reactor cores

High importance given to Education & Training activities

Summer schools to disseminate results and approach toward young researchers

- May 2019: Nuclear fuel cycle in Delft (The Netherlands)
- November 2020: European School on Nuclear Materials Science 2020, online

Collaboration with other European initiatives

Organization or co-organization of workshops to disseminate results and approach to nuclear materials research community and users

- Co-organisation of MMSNF-Nufuel 2019 in PSI
- Financial support to Nufuel 2021 in Bangor (UK)
- Organisation of the final international workshop

Training through research:

20 PhDs and Post-Docs invovled in the technical activities of the project

Mobility scheme: support of travel & accommodation costs to foster exchange of researchers between partner institutes of the project and give access to facilities or expertise

M4F: Multiscale Modelling for Fusion and Fission Materials

H2020 Project (2017-2021): 6.5/4.0 M€, 20 participants, coord. L. Malerba (CIEMAT)

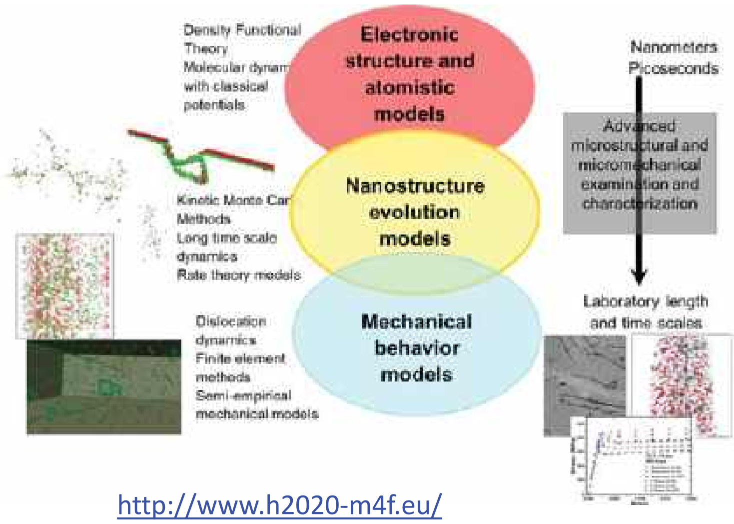
GUIDING OBJECTIVES

Bring together fusion & fission materials communities

Develop physical understanding and predictive models of the origin of **localised deformation** under irradiation and its consequences on the mechanical behaviour of components

Develop a methodology to use **ion irradiation as a tool** to evaluate radiation effects on microstructure and mechanical behaviour of materials, minimising artefacts with respect to neutron irradiation experiments

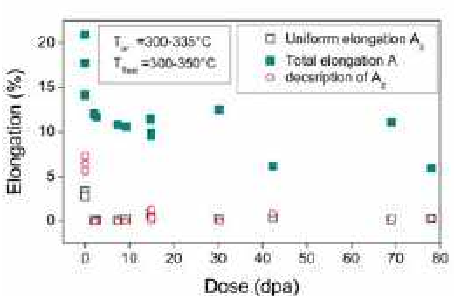
MULTISCALE MODELLING APPROACH



http://www.h2020-m4f.eu/

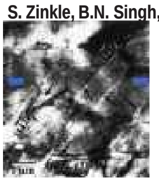
Localisation of deformation: problem and results

E. Gaganidze, J. Aktaa, Fusion Eng. Des. 88 (2013)



Problem:
Current design rules consider the elongation as only indicator of ductility → F/M steels are unusable according to this criterion!

S. Zinkle, B.N. Singh, J. Nucl. Mater. 351 (2006)



Traditionally loss of elongation is attributed to creation of clear bands free of defects, removed by moving dislocations, observed in Fe

Electron microscopy on Eurofer97 in M4F suggests that in some grains loops are absorbed with dislocation wall formation → preferential channels for plastic deformation causing softening

- **Three models were developed in M4F to address the problem of the effect of dislocation channel formation on mechanical behaviour in 9%Cr Fe alloys :**
  - Mean field continuum model at aggregate level
  - Full field continuum model, also at aggregate level
  - Constitutive equations enabling FEM at component level
- **Dose dependent formation of shear bands was correctly predicted**

Tools to assess the effect of plastic flow localisation at the component level were produced, which are of use to produce design rules for both fission and fusion

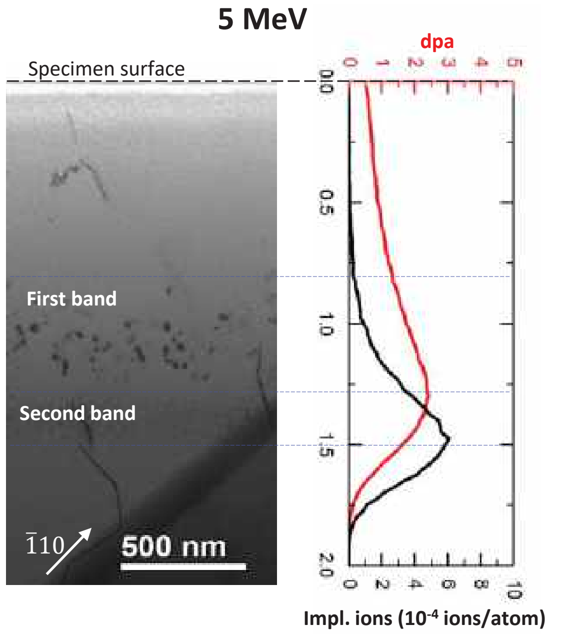
Good practices for ion irradiation

- **Ion irradiations were performed applying different parameters**
  - Different ion energy, focused beam versus rastering, different doses and temperatures, but same materials
  - Most difficult variable to control: C contamination

  This clarified several effects and suggested good practices to mimick neutron irradiation

- **Three new different microstructure evolution models have been developed, each offering new modelling opportunities, not available before**
  - Simulation of the whole ion penetration thickness
  - Simulation of Cr concentrated alloys including precipitation
  - Simulation of the effect of minor solutes

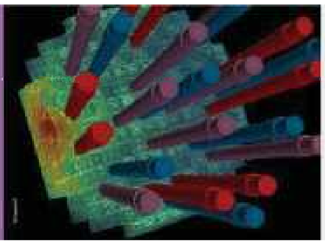
- **Good practices to assess the mechanical properties of ion irradiated materials using nanoindentation** have been drafted
  - Standards for testing have reached the level of a **CEN workshop** and relevant publication



Standard pattern versus depth have ben identified

Concluding remarks

- A Nuclear Materials Strategic Research and Innovation Agenda that serves all reactor generations is being produced
- It is based on the application of modern materials science practices that are being used in many other fields, too, which pivot around advanced digital tools and techniques
- The SRIA foresees accordingly 5 research lines, that are expected to host projects on, a priori, any of the 7 nuclear materials classes that have been identified
- The three just concluded EERA JPNM projects, GEMMA,INSPYRE, and M4F, are examples that fall within the identified research lines
- They show that:
  - Similar approaches are common to different materials and applications
  - Cross-cutting issues between fission and fusion exist in the field of materials and can be addressed together



FISA 2022

30 May - 3 June 2022
Lyon, France

Nuclear Cogeneration with High Temperature Reactors

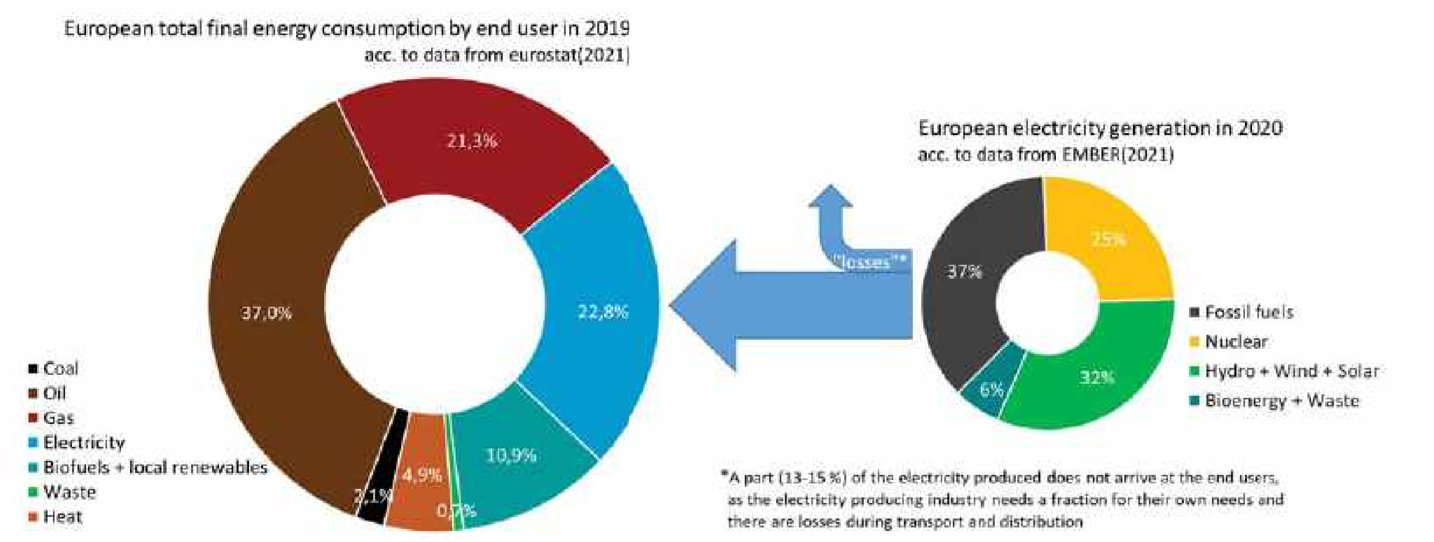
Józef Sobolewski
National Centre for Nuclear Research (Poland)

SNETP Sustainable Nuclear Energy Technology Platform

NC2I Nuclear Cogeneration Industrial Initiative

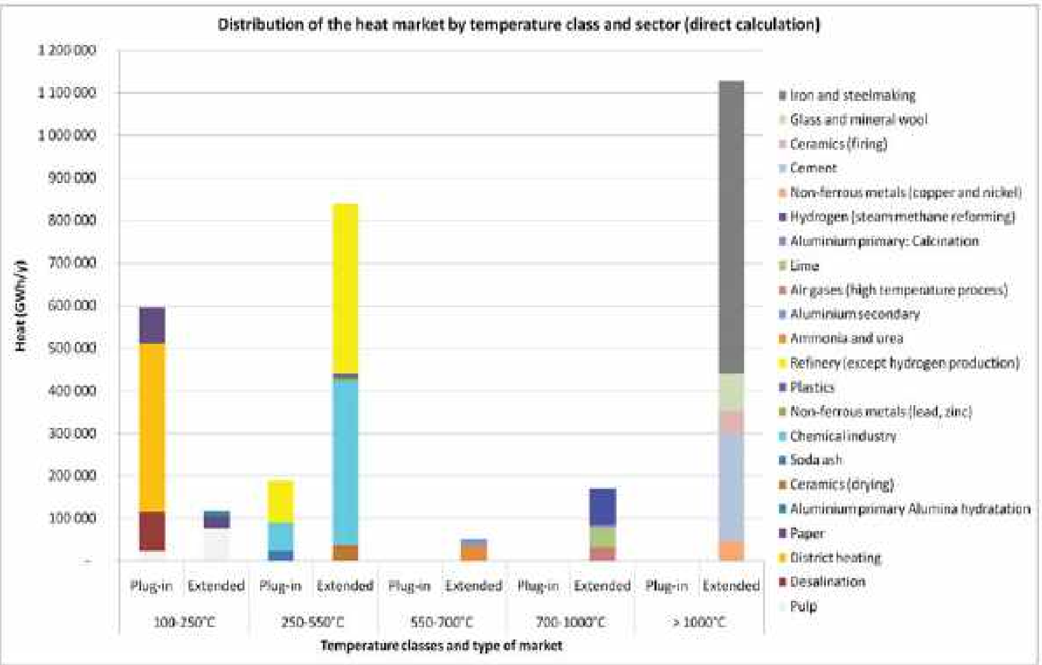
NATIONAL CENTRE FOR NUCLEAR RESEARCH ŚWIERK

European total final energy consumption by end user



Eurostat energy statistics 2019 (May 2021): Energy statistics - an overview - Statistics Explained (europa.eu)
EMBER EU Power Sector in 2020: EU Power Sector 2020 - Ember (ember-climate.org) or Agora Energiewende and Ember (2021): "The European Power Sector in 2020: Up-to-Date Analysis on the Electricity Transition", C. Redl, F. Hein, M. Buck, P. Graichen and D. Jones, Jan 2021, 202/02-A-2021/EN

Distribution of the European heat market by temperature class and sector



Plug-in market: heat is supplied via steam networks in the range 100-550˚C.
The range 250-550˚C represents approx. 87 GWth in Europe alone.
Extended market: remaining heat market

A. Bredimas: Market study on energy usage in European heat intensive industries, FP7 Euratom project EUROPAIRS, D131, Rev. 2, 05/2011.

15th Strategic Energy Technology Plan (SET Plan) conference

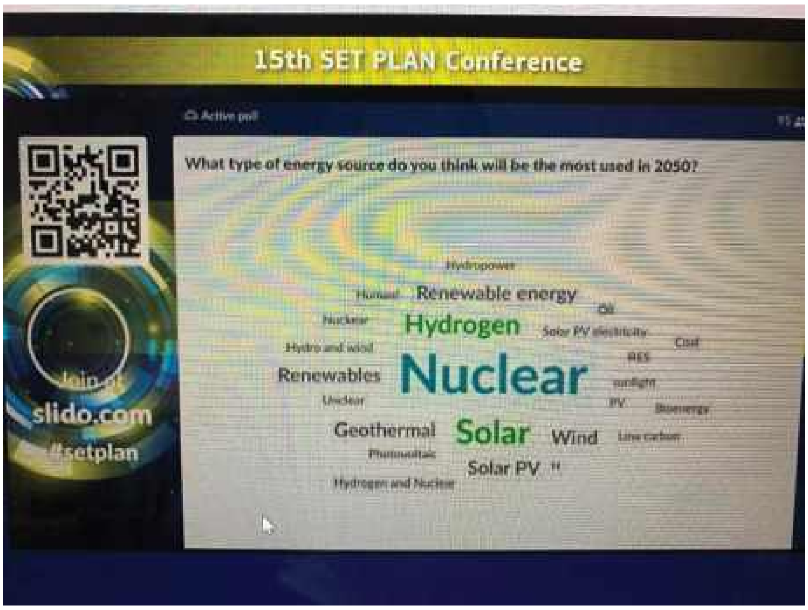
Bled (Slovenia) on the 25th and 26th of November 2021.

"Research and Innovation to deliver a just and sustainable energy transition".

- This event attracted over 500 participants (2/3 online and 1/3 on-site), which made it a major international research and innovation event beyond the EU alone. Among the participants, over 300 represented companies.
- This interactive event allowed polling attendees about their opinion. The most common answers were visualized in the form of a word cloud with the most quoted energy source represented by the largest letters in the centre.

For participants the most used source of Energy in 2050 will be

NUCLEAR



https://snetp.eu/2021/12/20/nc2i-chair-attended-the-15th-set-plan-conference/

HTGR, a promising technology to contribute to Green Deal objectives

HTGR (High Temperature Gas-cooled Reactor) technology is mature and available for early implementation.

- Several test reactors and industrial prototypes
- In the last 2 decades in Europe
  - Several design projects
  - Large progress in the technology
    - National R&D programmes
    - Euratom funded projects (17 projects)
    - International cooperation (Generation IV International Forum)
- An industrial prototype, HTR-PM, started operation in China last year.

Modular HTGR

GEMINI+ selected for funding in the frame of the 2016 call of H2020

- 3.5 years project, 4 M€
- Started in September 2017, completed in February 2021
- Initiated by the (European) Nuclear Cogeneration Industrial Initiative (NC2I) for implementing its strategy meant

High Temperature Gas-cooled Reactor

- Modular design & construction
- Wide possible power range up to several hundred MWth
- Coolant – Helium
- Moderator – Graphite
- Fuel based on TRISO particles dispersed in a graphite matrix
- Outlet temperature up to 750˚C (qualified existing industrial materials), 900-1000˚C (with advanced materials).

Safety

- Very favourable safety features: high thermal inertia, refractory materials, leak tight fuel up to very high temperature
- Safety based on inherent physical properties of the reactor and purely passive behaviour (no need of action from personnel or from any powered automatic device).
- Temperature of the fuel kept without any action need below limits that would threaten its integrity. No physical possibility of core melting and of high radioactive release
- No exclusion zone around the nuclear plant: possibility to locate the nuclear plant close to the industrial site
- Elimination of many redundant active safety systems existing in present reactors: an asset for competitiveness

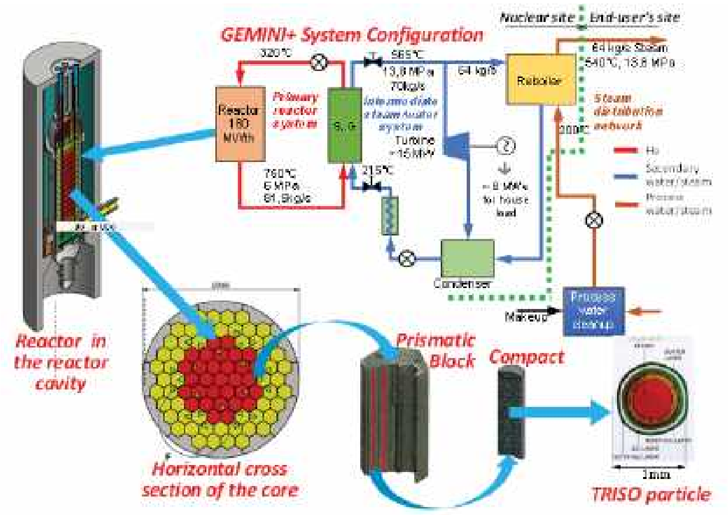
https://iopscience.iop.org/article/10.1088/1742-6596/2048/1/012043; https://iopscience.iop.org/article/10.1088/1742-6596/2048/1/012030; https://iopscience.iop.org/article/10.1088/1742-6596/2048/1/012004

Main achievements of GEMINI+

GEMINI+ was designed to support early demonstration of industrial nuclear cogeneration of electricity and steam in Poland using an inherently safe HTR.

Main results:

- Flexible standard design that can address needs for process steam in industry.
- Safety approach meeting present highest safety standards.
- Identification of residual technology gaps.
- Better understanding of industrial application needs: Importance of hydrogen for industrial applications.
- Proposals for integration of high temperature nuclear cogeneration systems in global or local energy systems.



GEMINI+

GEMINI For Zero Emission

Acronym: GEMINI 4.0

Topic: HORIZON-EURATOM-2021-NRT-01-05 Nuclear Research and Training, Safety of HTGRs

- Type of Action: EURATOM-RIA
- Duration: 36 months (2022 – 2025)
- No of partners: 22+, Lead – Framatome SAS
- Current status: Preparation of the Grant Agreement and Consortium Agreement
- Begin (KoM): June 2022
- Budget: 3.13 M€

Specifically

GEMINI 4.0 proposal received the SNETP label (Nr. 2021NC2I0006)

GEMINI 4.0 objectives

- Improvement of the design, by:
  - Resolving safety/licensing issues in Safety Options Report (SOR)
  - Core optimisation, Closing selected technology gaps
- Extension of applications: poly-generation, special focus on hydrogen plant,
  - Propose several comprehensive applications (coupling)
  - Provide technological schemes supported with techno-economic analyses
  - Safety and licensing of coupled systems
- Fuel for HTGRs in Europe
  - Plan for the development of European fuel cycle
  - Reference fuel, possible alternative fuels
- Licensing readiness
  - Assessment of the SOR by TSOs and regulators
  - Support potential candidate countries in the licensing of HTGR system
- Enhancing awareness of nuclear cogeneration
  - Develop and activate communication plans in different EU countries

GOSPOSTRATEG-HTR (GoHTR)

- GOSPOSTRATEG - strategic Polish program of scientific research and development (R&D) work "Social and economic development of Poland in the conditions of globalizing markets"
- Title: Preparation of legal, organizational and technical instruments for the HTR implementation (Gospostrateg1/385872/22/NCBR/2019)
- Finance: National Centre for Research and Development (approximately €4M)
- Duration: January 2019 – March 2022
- Consortium: Ministry for Climate and Environment, National Centre for Nuclear Research and Institute for Nuclear Chemistry and Technology.

Objectives

Preparation to the licensing process
- Pre-conceptual design
- Facility concept
- Analysis methodology

Material tests
- Implementation of testing procedures
- Identification materials for tests
- Irradiations in the MARIA reactor

Legal, social, economic and industrial aspects of the project
- Legal regulations for the HTR investments implementation
- Public and industrial communication

https://www.mdpi.com/1996-1073/15/6/2084

GOSPOSTRATEG-HTR programme

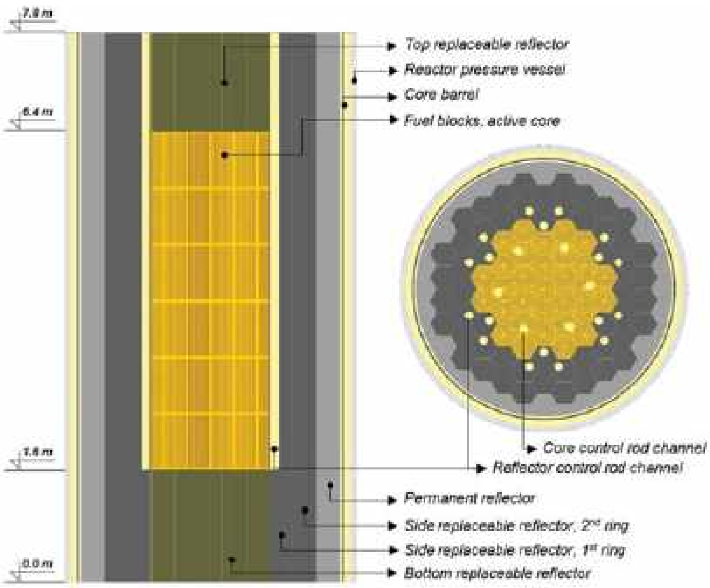
Phase A

- Development of methods for diagnostics of structural materials in the HTR construction;
- Development of methods for testing of structural materials in a nuclear reactor, and equipment for the execution of tests in the core;
- Research and analysis of selected chemical aspects of the production and use of TRISO fuel in the HTR nuclear reactor;
- Comprehensive analysis of the necessary changes to the legal environment and the potential benefits of social, economic and industrial units for the Polish economy.

Phase B

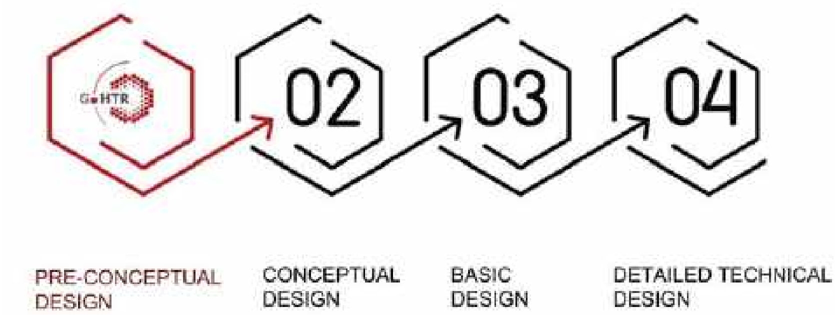
- Preparation licensing process (certification) of HTGR reactors on the example of a research reactor;
- Preparation draft of legal regulations for the HTR investments implementation; developing a strategy in the social, economic and industrial aspects of the project;
- Piloting of test procedures for the use of construction materials for the HTR reactor design, including tests in the Maria reactor core;
- Preparation of technical and economic assumptions for the construction of a fuel production unit for high-temperature reactors.

Pre-conceptual core design



NCBJ-MEiN Programme – HTGR Basic Design

- Contract No 1/HTGR/2021/14 between the National Centre for Nuclear Research and the Ministry of Education and Science entitled “Technical description of the HTGR gas-cooled high-temperature research nuclear reactor” signed on May 12, 2021 in Świerk. It is intended for the implementation of another batch of design works for the experimental HTGR, being also the technology demonstrator.
- The contract determines that the conditions for the construction of a high-temperature research reactor in Poland will be created within three years and that the conceptual design and further most of the basic design of such a device will be prepared. The reactor will be a prismatic type HTGR using TRISO fuel producing approximately 30-40 MWth at an outlet temperature of 750 ^{o}C.
- Time: 1.06.2021 – 1.06.2024.
- Value: approximately €14M



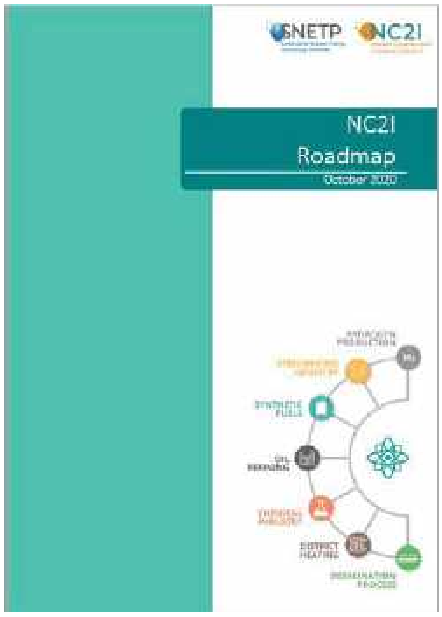
NCBJ-MEiN Programme – HTGR Basic Design

Scope of the project:

- Preparation of laboratory facilities with the necessary accreditations and a quality management system necessary to perform research in view of licensing materials for HTGR technology.
- Performing tests of materials that can be used for the construction of HTGR, in terms of compliance with the requirements of HTGR technology.
- Development of the basic design of the HTGR reactor (basic / preliminary design according to IAEA-TECDOC-881).
- Performing verification simulations for the project and preliminary HTGR safety report in accordance with the requirements of the Regulation of the Council of Ministers from 2012.
- Preparation of selected elements of the preliminary safety report (CSR) for HTGR in accordance with the Regulation of the Council of Ministers (as above).

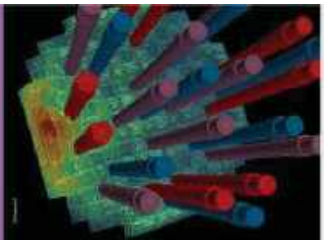
A Roadmap for the Deployment of Industrial Nuclear Cogeneration in Europe

- NC2I aims to make a significant contribution to European priorities by providing clean and competitive energy beyond electricity by facilitating the deployment of nuclear cogeneration plants.
- HTGR is mature enough to be deployed by the end of this decade for process heat supply
- If the deployment is performed in a steady, but realistically feasible way, nuclear can bring a significant contribution to curb industry emissions by 2050.



https://snetp.eu/wp-content/uploads/2020/10/NC2I-roadmap-October.pdf

Thank You



FISA 2022

30 May - 3 June 2022
Lyon, France

ARIEL & SANDA Nuclear Data Actitivies

C. Franzen[1], A.R. Junghans[1], E. Gonzalez[2], A.J.M. Plompen[3]

1) Helmholtz-Zentrum Dresden – Rossendorf (HZDR), Bautzner Landstrasse 400, D-01328 Dresden, Germany
2) Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas (CIEMAT)
Avda. Complutense, 40, 28040 Madrid – Spain
3) European Commission Joint Research Centre – JRC Retieseweg 111, B-2440 Geel/Belgium

Accelerator and Research reactor Infrastructures for Education and Learning ARIEL

SANDA

Supplying Accurate Nuclear Data for energy and non-energy Applications

HORIZON2020

ARIEL factsheet

Grant agreement ID: 847594

CORDIS

Funded under:
H2020-Euratom-1.8 (NFRP-2018-7)

EC budget contribution:
2 M€

Coordinated by:
HZDR

Project type:
Coordination & Support Action

Partners:
25 from 15 countries

Project duration:
54 months

Start /End date:
September 1, 2019 – **February 29, 2024**

Management Board (MB):
A. Junghans (HZDR), A. Plompen (JRC), R. Nolte (PTB), C. Guerrero (USE), H. Penttilä (JYU)
Project Advisory Committee (PAC):
D. Cano-Ott (CIEMAT), R. Capote (IAEA), R. Jacqmin (CEA), M. Kerveno (CNRS), G. Van den Eynde (SCK*CEN)

Accelerator and Research reactor Infrastructures for Education and Learning ARIEL

European Commission | Horizon 2020 European Union funding for Research & Innovation

www.ariel-h2020.eu

Accelerator and Research reactor Infrastructures for Education and Learning ARIEL

ARIEL Objectives

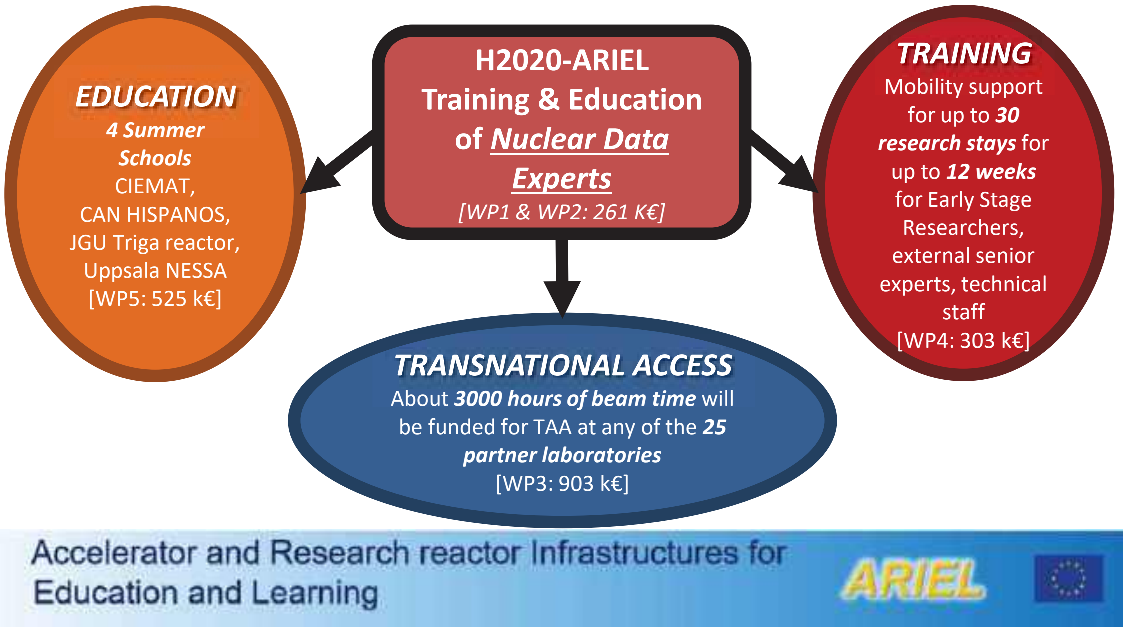
Provide young scientists, researchers and experts with access to high quality nuclear research and training facilities.
Experiments in international teams: Hands-on training for students in the graduate and postgraduate level - lead to PhD and master theses.

- Integration of the full nuclear data cycle by collaboration with JEFF (OECD/NEA), IAEA, and TSO's e.g. IRSN
- Collaboration with research reactor facilities MTK-EA, JGU, SCK*CEN, ILL, CVR
- Increase number of students in the nuclear data field; especially with the help of ENEN
- Increase support for early stage researchers
- Inclusion of technical staff (engineers, operators) in ARIEL activities

Accelerator and Research reactor Infrastructures for Education and Learning
ARIEL

SUMMARY OF H2020-ARIEL FACILITIES AVAILABLE FOR TAA		ACCELERATORS																			RESEARCH REACTORS				
		e⁻ BEAMS		ION BEAMS																					
		nELBE@HZDR	GELINA@JRC	MONNET@JRC	n_TOF@CERN	AIFIRA@CNRS	ALTO@CNRS	GENESIS@CNRS	NFS@GANIL	CEA-DAM	FNG@ENEA	PTB	FNG@NPI	HISPANOS@CNA	NESSA@UU	U. Oslo	NPL	IFIN-HH	JYU	AMANDE@IRSN	BRR@MTA-EK	BR1@SCK·CEN	TRIGA@JGU	LR-0/LVR-15@CVR	RHF@ILL
Neutrons	Cold (<25 meV)																				■		■		■
Neutrons	Thermal (‹E_n›=25 meV)		■	■										■			■			■	■	■	■	■	■
Neutrons	Epithermal (25 meV – 100 keV)		■	■	■	■				■		■		■			■			■	■	■	■	■	■
Neutrons	Fast (0.1-20 MeV)	■	■	■	■	■	■	■	■	■	■	■	■	■	■		■			■	■	■	■	■	■
Neutrons	Very fast (>20 MeV)				■				■				■												
Neutrons	Pulsed beam	■	■	■	■		■		■	■		■	■	■	■					■			■		
Neutrons	Time-of-flight	■	■	■	■		■		■	■		■	■	■						■					
Charged particles						■	■									■		■							
Radioactive beam							■												■						■

Accelerator and Research reactor Infrastructures for Education and Learning
ARIEL



Status

- Education and Training: 195 weeks endorsed in 25 proposals
  8 visits (78 weeks) completed
  45 weeks available
- Transnational access to neutron beam facilities:
  1433 beam time hours endorsed after PAC 5 for 17 experiments
  596 hours delivered (7 experiments)
- COVID has restricted the transnational access and Education and training activities. The visits of early stage researchers were resumed. The experiments still have to catch up.

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May - 3 June 2022 | Lyon, France

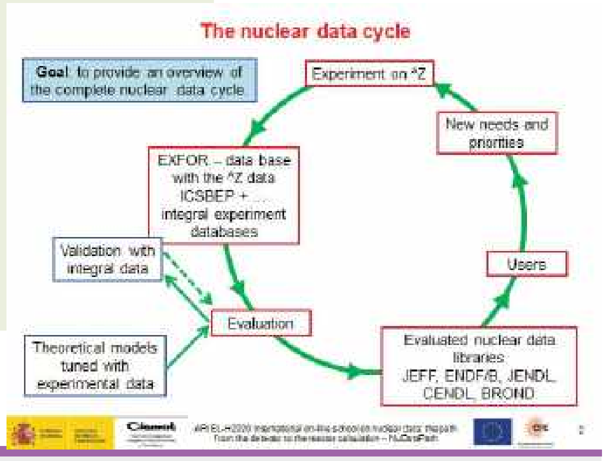
ARIEL schools

2/2022 @CIEMAT, Madrid, Spain
Nuclear data: the path from the detector to the reactor calculation
(24 participants) https://agenda.ciemat.es/event/3201/

9/2022 @CNA, Seville, Spain
Hands-on school on the production, detection and use of neutron beams
(18-24 participants)

10/2023 @JGU, Mainz, Germany
Lab course in Reactor Operation and Nuclear Chemistry
(10 participants)

6/2023 @University of Uppsala (Sweden)
EXTEND'2023 summer school
(25 participants)



SANDA

SUPPLYING ACCURATE NUCLEAR DATA FOR ENERGY AND NON-ENERGY APPLICATIONS

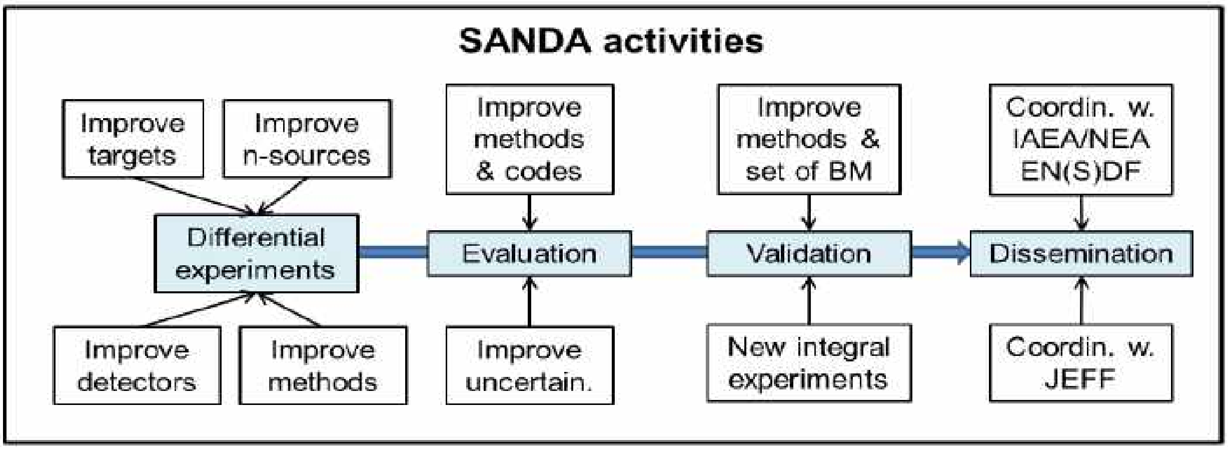
H2020 Grant Agreement number: 847552
A project for the EURATOM WP2018 for NFRP-2018-4

Project Start date: 01/09/2019
Duration: 48 months
Requested contributions: 3.5 MEuros

35 Partners: *CIEMAT*, Atomki, CEA, CERN, CNRS, CSIC, CVREZ, ENEA, HZDR, IFIN-HH, IRSN, IST-ID, JRC, JSI, JYU, KIT, NPI, NPL, NRG, NTUA, PSI, PTB, SCK-CEN, Sofia, TUW, UB, ULODZ, UMAINZ, UMANCH, UOI, UPC, UPM, USC, USE, UU.
from 18 countries (Au, Be, Bu, Cz, Fi, Fr, Ge, Gr, Hu, It, Ne, Pol, Por, Ro, Sln, Sp, Sw, UK)

Coordinator: CIEMAT

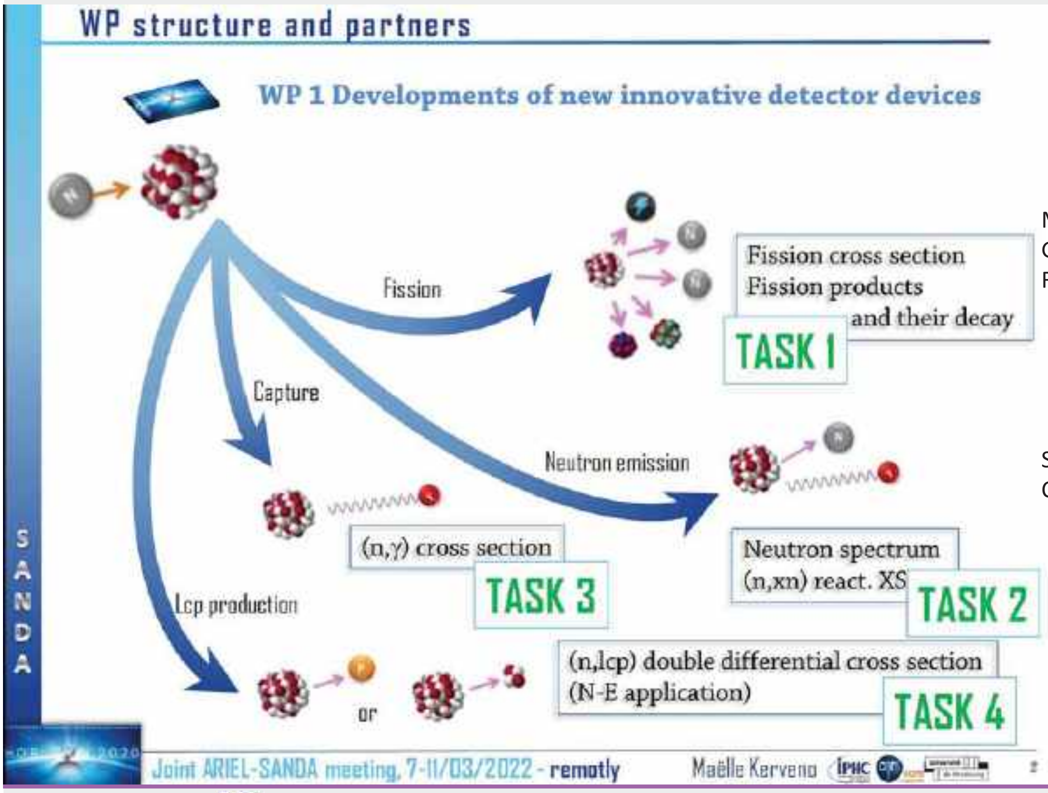
SANDA activities



- Relevant experiments for microscopic nuclear data improvement of nuclear safety
- Full nuclear data cycle: Nuclear data evaluation and validation
- NEA/OECD and IAEA high priority lists

Nuclear data measurements

- average **neutron multiplicity** of ^{235}U(n,f) and the **fission cross sections** of the ^{230}Th(n,f), ^{241}Am(n,f) and ^{239}Pu(n,f) reactions;
- **neutron capture cross sections** of the ^{239}Pu(n,γ) and ^{92,94,95}Mo(n,γ) reactions;
- neutron **elastic and inelastic scattering** and **neutron multiplication** cross sections for the nuclides ^{14}N,^{35,37}Cl, ^{209}Bi, ^{233}U, ^{238}U and ^{239}Pu;
- **decay data** of ^{95}Rb, ^{100gs}Nb, ^{102m}Nb, ^{103}Tc, ^{140}Cs with Total Absorption Gamma-ray spectrometry and of ^{106}Ru, ^{153}Sm, ^{166}Ho, ^{186}Re, ^{212}Pb, ^{225}Ac and ^{223}Ra half-lives and branching ratios for reactor and medical applications;
- **fission yields** and related distributions from neutron induced fission of ^{235}U at LOHENGRIN (ILL) and PI-ICR at IGISOL and (p,2p) inverse kinematics fission reactions for ^{238}U and ^{237}Pa;
- **spectrum-averaged cross sections** for the ^{117}Sn(n,inl)^{117m}Sn and ^{60}Ni(n,p) reactions in a ^{252}Cf spectrum for **dosimetry**, ^{12}C double differential cross sections relevant for hadron therapy and the production cross sections of β+ emitters ^{11}C, ^{13}N, ^{15}O, ^{30}P for proton-induced reactions up to 250 MeV energy (non-energy applications);



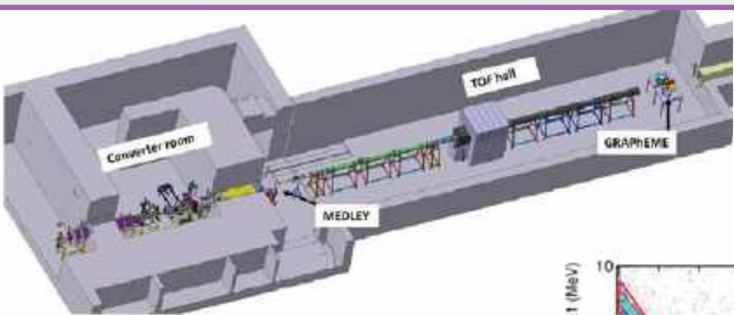
Micromegas TPC (CEA)
Gaseous proton recoil telescopes (CNRS)
Falstaff fission yield studies (CEA)

SCONE detectorTPC (CEA)
Compact fast neutron spectrometer (CEA)

CLYC (CERN)
I-TED (CERN)

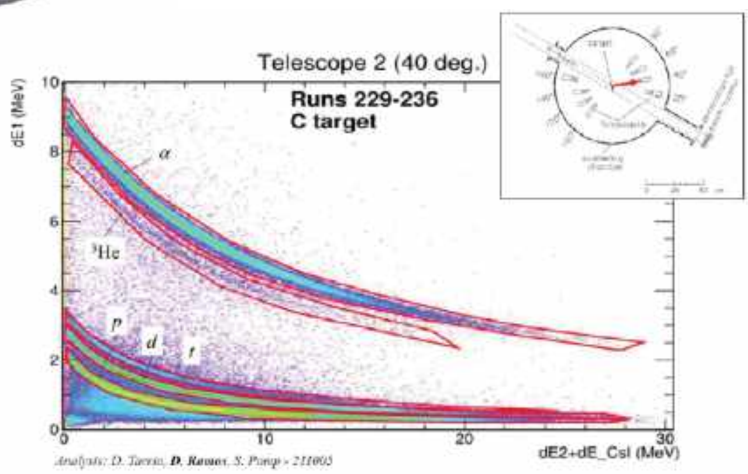
Si- proton recoil telescopes (PTB,HZDR)

First Experiments at Neutrons for Science at GANIL

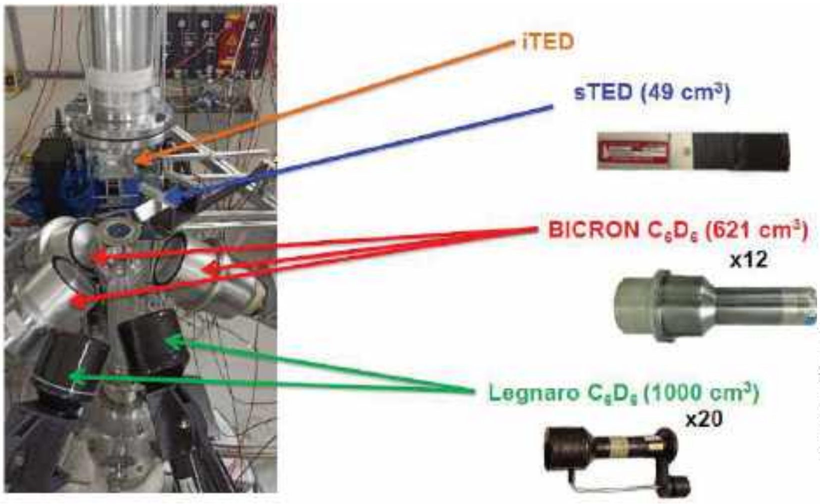


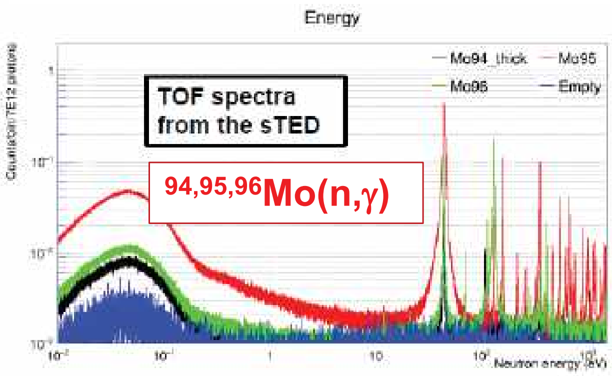
Light charged particle detection $^{12}C(n,x)$ at NFS
(A. Prokofiev et al, Uppsala University)

Medley vacuum chamber



SANDA
WP1-TASK3
Test of different capture detectors for the n_TOF EAR2 (@CERN)

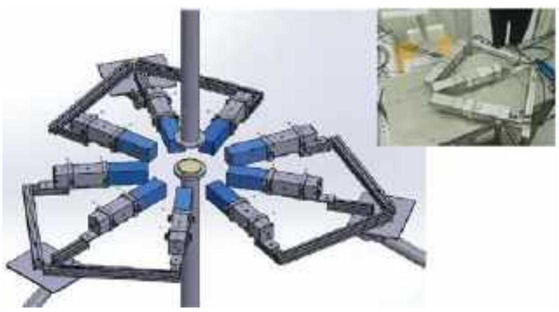




Measurements of ^{94,95,96}Mo(n,γ) at n_TOF (EAR1) using sTED innovative detectors

SANDA
WP1-TASK3
Development of advanced capture detectors

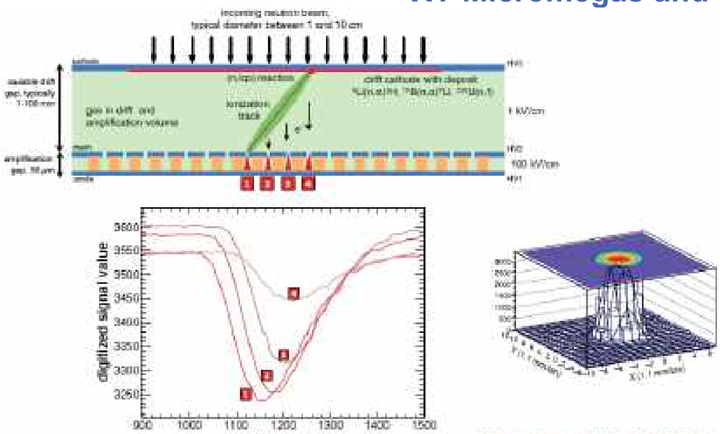
sTED



Full i-TED detector completely assembled, commissioned and prepared for first (n,g) experiments in 2022

SANDA WP1-TASK 1 & 4

XY-Micromegas and LCP measurements



M. Diakaki et al. NIMA 903 (2018) 4

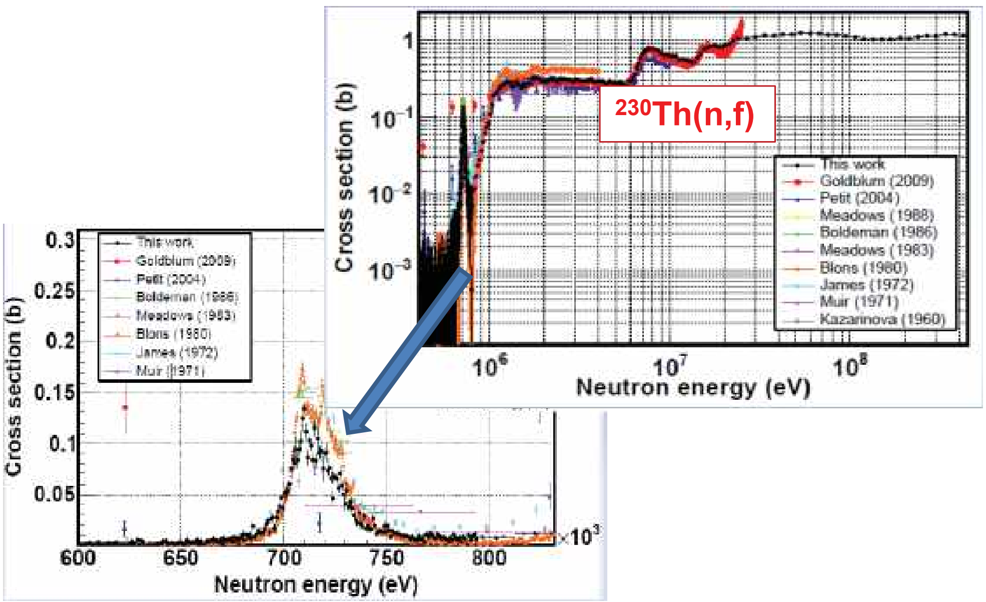
XY-Micromegas

active area 10 x 10 cm²

Scattering chamber from PIAF to n_TOF

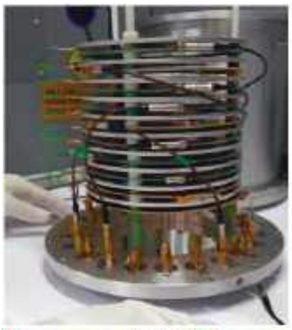
SANDA WP2

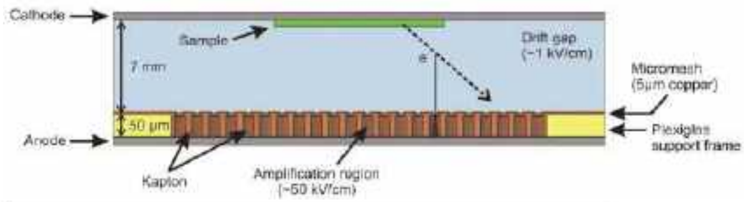
^{230}Th(n,f) cross-section measurements

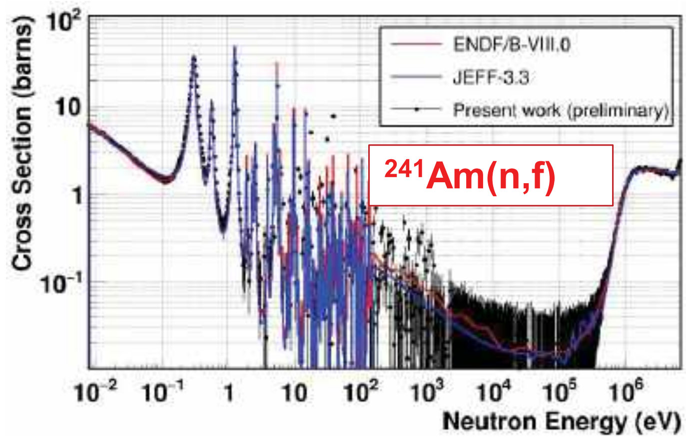


SANDA WP2

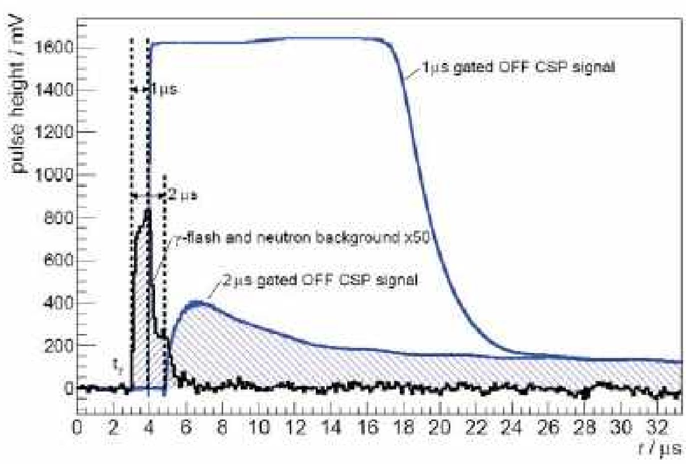
^{241}Am(n,f) cross-section measurements at n_TOF EAR2@CERN







Nanosecond-gating at pulsed radiation sources



Switching detector output to ground to avoid Instantaneous radiation (gamma-flash) at pulsed Radiation sources.

➔ Sensitivity greatly increased for later neutron-induced signals for time-of-flight measurements

--- directly measured current (no preamplifier)

--- Charge sensitive preamplifier output. Input grounded for 1 or 2 microseconds.

Sebastian Urlass et al., *Nuclear Instruments and Methods in Physics Research A 1002,* p. 165297, 2021

Conclusions

- ARIEL and SANDA support the measurement, evaluation and validation of nuclear data that will improve the safety of present reactors and improve the precision and efficiency of the new advanced reactor and fuel cycles designs and of the applications of nuclear technologies.
- Response to the high priority request list of nuclear data (HPRL) collected by the international organizations IAEA and NEA/OECD from inputs and discussions with nuclear data users and producers.
- About 6 to 12 months delays accumulated due to COVID still both projects have already achieved significant results to develop and improve detectors, commission new neutron sources, perform some new measurements, and to improve the tools and environment for evaluation and validation.

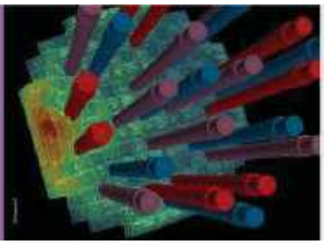

FISA 2022
EURADWASTE'22

SESSION 3: EDUCATION AND TRAINING, RESEARCH INFRASTRUCTURES, LOW DOSE RADIATION PROTECTION, DECOMMISSIONING AND INTERNATIONAL COOPERATION

Co-chair: Tatiana IVANOVA (FR, OECD/NEA)

Co-chair: Roger GARBIL (EC, DG RTD)

Rapporteur: Said ABOUSAHL (FR, Expert)



FISA 2022

30 May - 3 June 2022
Lyon, France

EDUCATION, TRAINING AND MOBILITY, KNOWLEDGE MANAGEMENT: TOWARDS A COMMON EFFORT TO ENSURE A FUTURE WORKFORCE IN EUROPE AND ABROAD

G. PAVEL, J. STARFLINGER, C. DEMAZIÈRE,
K. SIMOLA, M. NĚMEC, Š. ČERBA

Introduction

- Nuclear power is a (very!) long-term commitment. Each unit may be with us for 100 years or more.
- Long-term sustainability of nuclear power calls for the long-term use of the best available people, science, knowledge, technologies and operational experience.
- It became quite challenging to attract, develop and retain young talents in the nuclear field.
- Common European approach and continuous activities:
  - Develop and implement attractive modern teaching methods and hands-on experience
  - Providing mobility to students and other young nuclear talents
  - Develop knowledge management actions for benefit of future nuclear generation

European Activities on E&T and KM

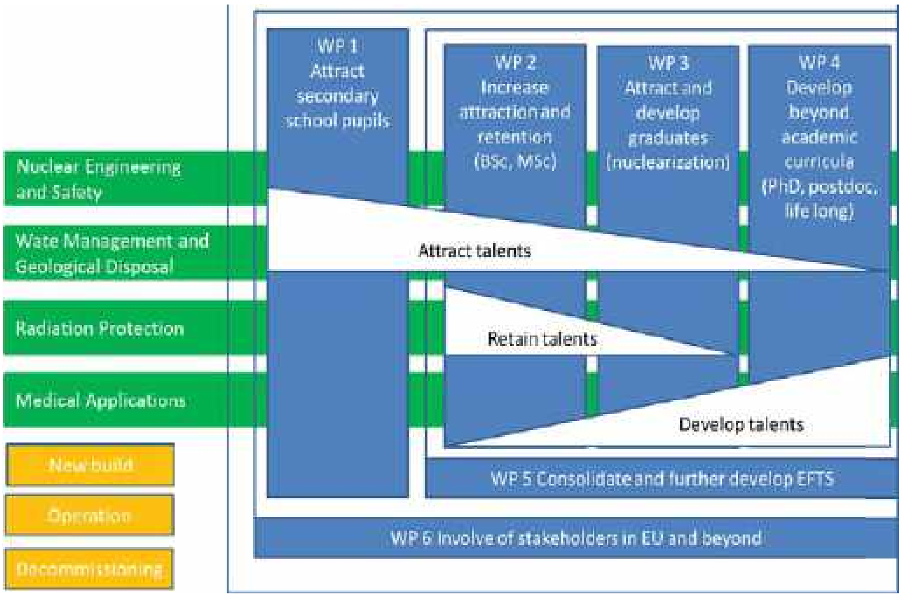
Overview:

- **ENEN+**: Attract, Retain and Develop New Nuclear Talents Beyond Academic Curricula. Duration: 2018-2021
- **A-CHINCH**: Augmented Cooperation in Education and Training in Nuclear and Radiochemistry. Duration: 2019-2022
- **GRE@T-PIONEeR**: Graduate Education Alliance for Teaching the Physics and Safety of Nuclear Reactors. Duration: 2020-2023
- **ENEEP**: European Nuclear Experimental Educational Platform. Duration: 2019-2022
- **PIKNUS**: Pilot action on knowledge management in the area of nuclear Safety. Duration: 2020-2023

enen+ Objectives

- ***Attract*** **new talents** to careers in nuclear.
- ***Develop*** the attracted talents beyond academic curricula.
- Increase the ***retention*** of attracted talents in nuclear careers.
- ***Involve*** the nuclear stakeholders within EU and beyond.
- ***Sustain*** the revived interest for nuclear careers.

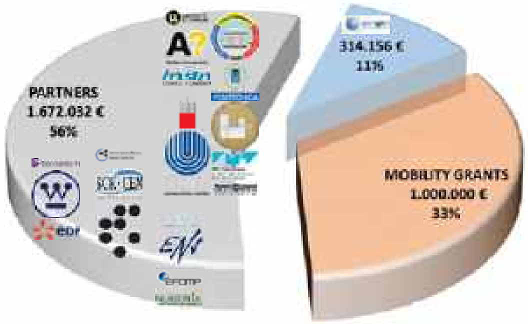
Outline of enen+



3 years: Oct 2017-Sept 2020 (extended due to COVID19)

Total costs: 3.2 €

EC Contribution: 2.9 M€



Key Contributions of enen+

- Attractive e-materials on nuclear profession
- EU wide competition for high school students
- Support for learners in all career phases:
  - Career guidance
  - Support for mobility (funding & access)
- Voluntary accreditation (ECTS, ECVET≈SAT)
- Sustainable mobility fund
- Improved communication with industry and decision makers
- EU strategy for Nuclear Education, Training and Knowledge Management

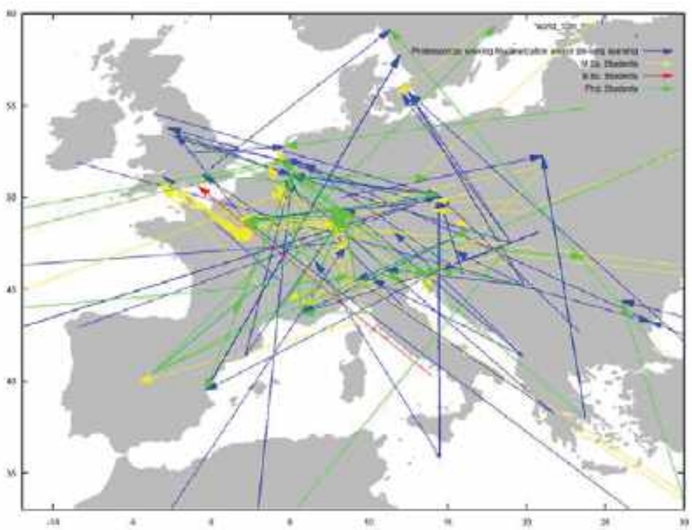
enen+ : Actions for secondary school pupils

Attractive e-information in multiple languages

First European Nuclear Competition and Summer Camp
25 participants from 10 countries

enen+ : Mobility Actions

- Mobility is a very valuable measure to support E&T
- Data:
  - 553 people (B.Sc., M.Sc., PhD, young professionals)
  - 17,375 days of training
- **Direct benefit for European citizens!**
- Top Hosts:
  - JRC Petten, Geel, Karlsruhe



AUGMENTED CINCH

Augmented cooperation in education and training in nuclear and radiochemistry

A-CINCH: Teaching Nuclear

Cooperation in education development in the A-CINCH Consortium

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May - 3 June 2022 | Lyon, France

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A-CINCH

General data

- Project number: H2020 - 945301
- Consortium of **17** institutions from **13** countries
- www.cinch-project.eu
- Budget:
  - **Total 3,220,856.00 EUR**
  - **Maximum EC contribution: 2,490,000.00 EUR**
- Duration: **36** months
  - **Signature date May 27, 2020**
  - **October 2020 – September 2023**
- Representatives:
  - **EC Project Officer: Ms Katerina Ptáčková**
  - **Coordinator: Czech Technical University in Prague – Assoc. Prof Mojmír Němec**

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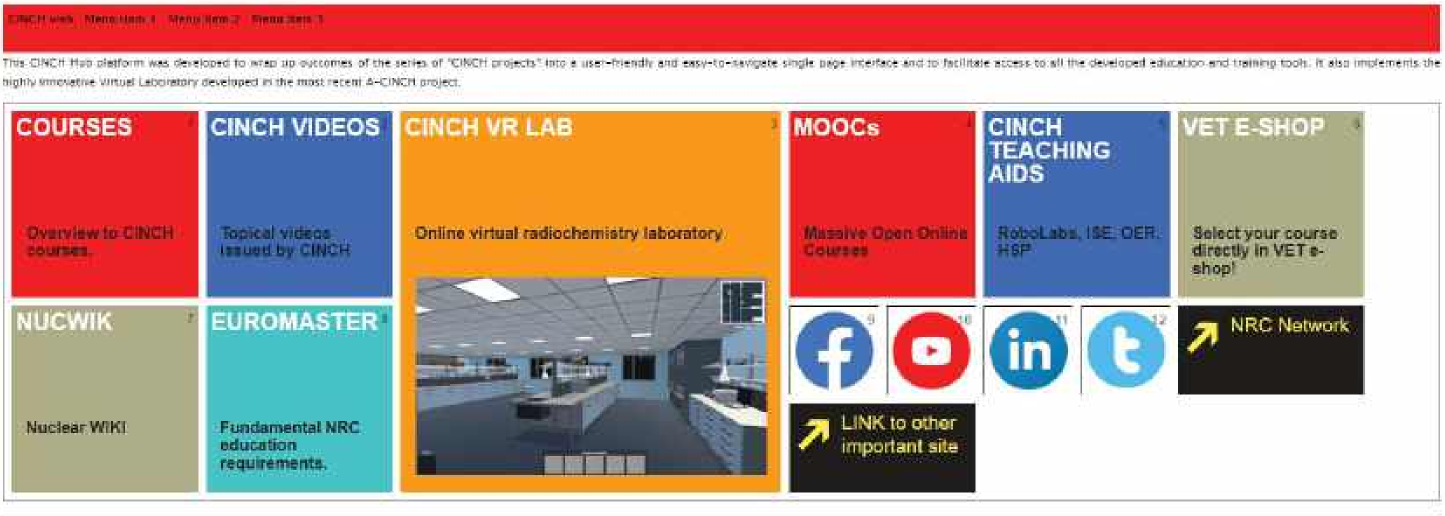
A-CINCH

CINCH HUB



A-CINCH

Objectives, tools and teaching techniques

- **CINCH HUB** incorporates (1)
- **VR-LAB,** 3D virtual reality NRC laboratory
- **MOOC**s, Massive Open Online Courses https://www.pok.polimi.it/
- **CINCH MOODLE**, e-learning platform for Nuclear Chemistry https://moodle.cinch-project.eu
- **RoboLab**s - remote operated robotic experiments https://nucwik.com/exercises/robolab
- **ISE**, Interactive Screen Experiments
- **NucWik** database of teaching materials https://nucwik.com

- **CINCH HUB** incorporates (2)
- **Flipped Classroom** concept, providing improved interaction between teachers and students
- **HoT -** Hands-on-training courses in “real” radiochemistry laboratories across Europe
- **CINCH VET e-shop,** CINCH Vocational Education and Training e-shop offering, presenting and organising all types of NRC courses https://eshop.cinch-project.eu
- **High School Teaching Package**, **Summer Schools** for high school students, **Teach the Teacher** package, **Lab on Tour** toolkit for expanding nuclear awareness.

A-CINCH

AUGMENTED CINCH

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GRE@T-PIONEeR

- **GRE@T-PIONEeR**: Graduate Education Alliance for Teaching the PhysIcs and safety of NuclEar Reactors
- Project running between November 1st, 2020 and October 31st, 2023
- **10 European partners**

GRE@T-PIONE∃R

www.great-pioneer.eu

@GREATPIONEeR_EU

@GREAT-PIONEER

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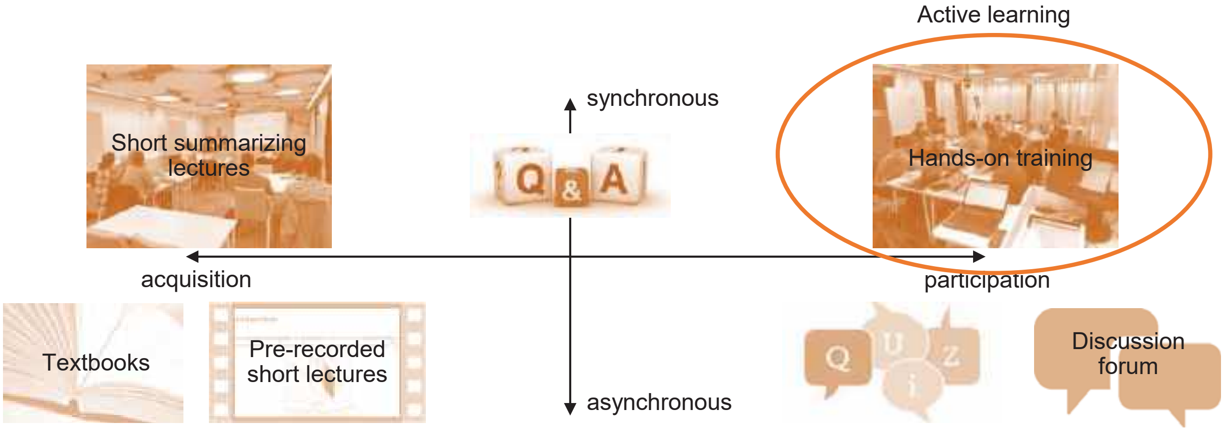
GRE@T-PIONEeR

- **Learning** is an **incremental process**
- **Several dimensions**:



Hrastinski, S. (2008). Asynchronous and synchronous e-learning. Educause Quarterly, 31(4), 51-55.

GRE@T-PIONEeR

- **Learning** is an **incremental process**
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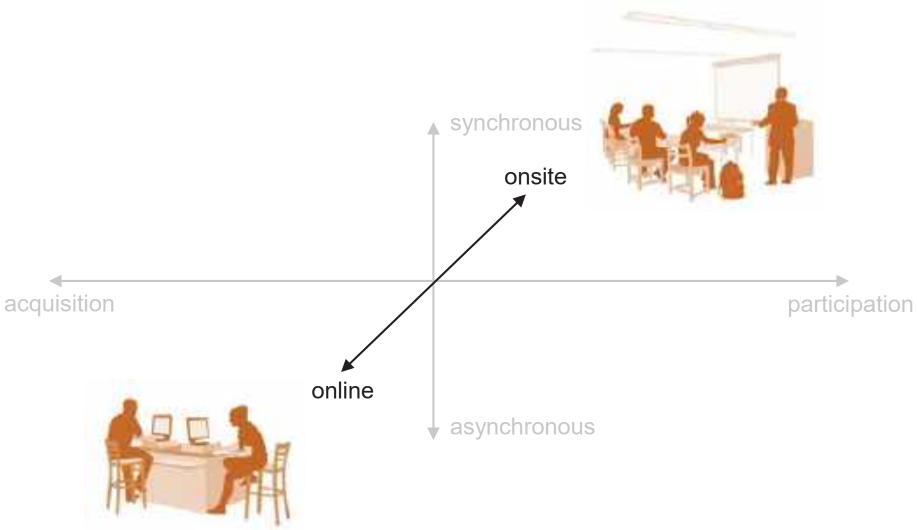
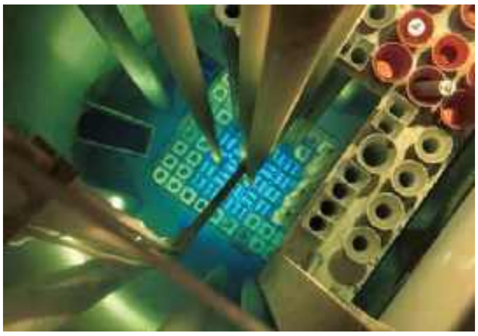


GRE@T-PIONEeR

- GRE@T-PIONEeR making use of **flipped classrooms** in a **hybrid learning environment** and promoting **active learning**
- **Hands-on** exercises:
  - Relying on the use of 3 **training reactors**:

AKR-2
TUD, Dresden, Germany

CROCUS
EPFL, Lausanne, Switzerland



BME Training Reactor
BME, Budapest, Hungary

GRE@T-PIONEeR

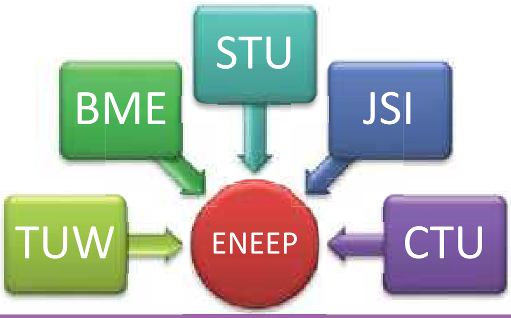
- **Hands-on** exercises:
- Relying on **computer-based modelling** and **simulations**:
  - Either **using existing tools** (commercial and open-source)
  - Or **implementing algorithms** in computing environments

GRE@T-PIONEeR

- **6 course modules** being developed:
  - Nuclear cross-sections for neutron transport
  - Neutron transport at the fuel cell and assembly levels
  - Core modelling for core design
  - Core modelling for transients
  - Reactor transients, nuclear safety and uncertainty and sensitivity analysis
  - Radiation protection in nuclear environment
- Teaching materials **being developed**
- First course modules to be offered in **November 2022**

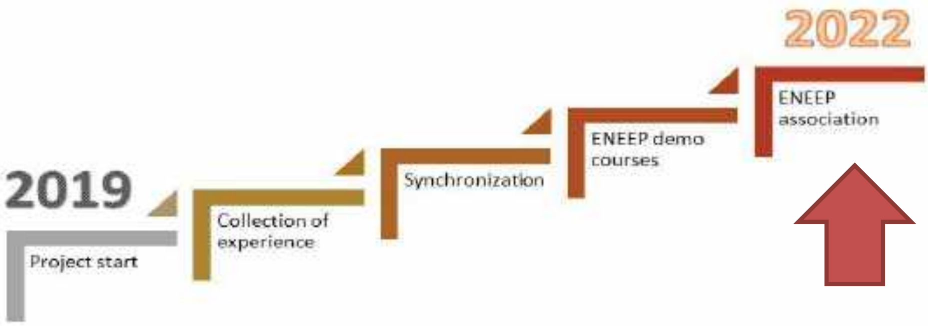
ENEEP – European Nuclear Experimental Educational Platform

- An essential element in the implementation and safe operation of nuclear facilities is a knowledgeable and skilled workforce.
- The desired nuclear specific skills and experience of workforce cannot be built without an experimental hands-on nuclear E&T.
- The personnel to run a nuclear power plant should be categorized as *nuclear personnel*, *nuclearized personnel* and *nuclear-aware personnel*.
- For all above defined categories <u>hands-on experience need to be provided.</u>
- To address these challenges the European Nuclear Experimental Educational Platform is established.
- There are five project partners, from Central Europe, each operating a research reactor or specialized laboratories.



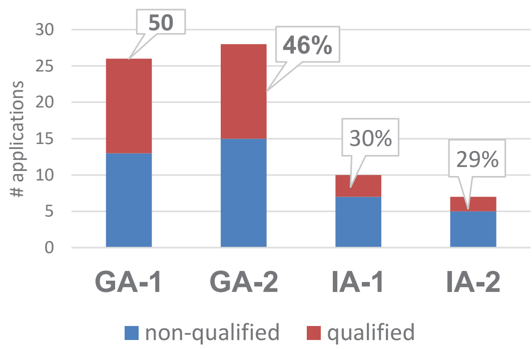
ENEEP – European Nuclear Experimental Educational Platform

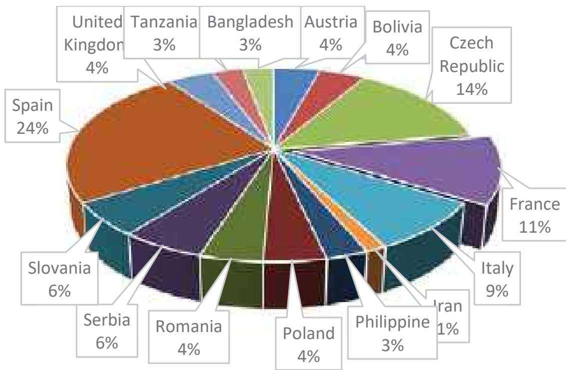
- To improve the level of education and to attract new talents to nuclear, research programs, international cooperation and the involvement of industry and R&D organizations is required.
- ENEEP brings nuclear E&T closer to almost everyone.
- ENEEP E&T activities are based on experiments utilizing research reactors and laboratories of nuclear physics, material science and radiation protection.
- there are no specific limitations on the educational background of trainees and students, the level of training can be tailored.



ENEEP – European Nuclear Experimental Educational Platform

- As one of the most important objectives of the project, the demonstration of educational and training capabilities of the ENEEP was carried out through dedicated educational activities:
  - GA1 - *Safe and Secure Operation of Nuclear Installations*
  - GA2 - *Experimental Reactor physics*
  - IA1 - *Experiments on the Training Reactor*
  - IA2 - *Experimental Study of the TRIGA Fuel Characteristics*

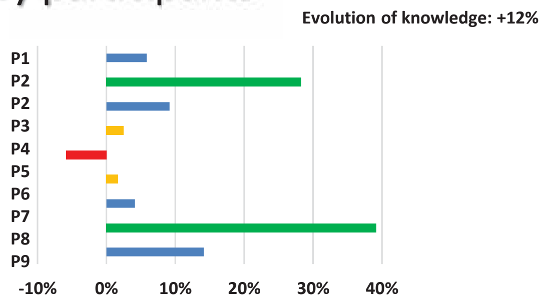




ENEEP – European Nuclear Experimental Educational Platform

- Evaluation of group and individual activities by participants

Items of the evaluation	GA-1	GA-2	IA-1
General content of the course	93.8 %	96.3 %	87.5 %
Meeting the objectives of the course	89.9 %	95.8 %	100.0 %
Applicability of the acquired knowledge	92.9 %	91.7 %	83.3 %
Organization and logistics	92.9 %	93.5 %	80.0 %
Quality of lectures	95.2 %	87.5 %	100.0 %
Overall rating	**93.0 %**	**93.2 %**	**88.9**



ENEEP – European Nuclear Experimental Educational Platform

- The main goal of the ENEEP project is to establish coordinated and sustainable access to the infrastructure also beyond the project.
- In 2022 ENEEP non-profit association will be established.
- The association will create a management, communication and promotion umbrella above all institutions and activities.
- The association will represent all member institutions under one brand.
- In 2022 also another round of demo courses will be organized:
  - „Train the trainers" – 10 p – 3 days
  - „Train the lecturers" – 10 p – 3x3 days
  - „Train the students" – 10 p – 5 days

#ENEEP

www.eneep.org www.facebook.com/eneep.org www.linkedin.com/groups/13834594/

PIKNUS

PIKNUS – **PI**lot action on **K**nowledge management in the area of **NU**clear **S**afety

Administrative arrangement between DG RTD and JRC to create a **knowledge management platform** in order to:

- Improve synergies between Euratom funded Direct and Indirect actions*
- Improve accessibility to Euratom funded research results
- Offer a collaboration platform for European research community

PIKNUS is a **pilot project**, with **focus on materials' ageing in Generation II-III NPPs (~ Nugenia TA4)**.

- However, the search tool will cover all JRC and CORDIS/EURATOM deliverables.

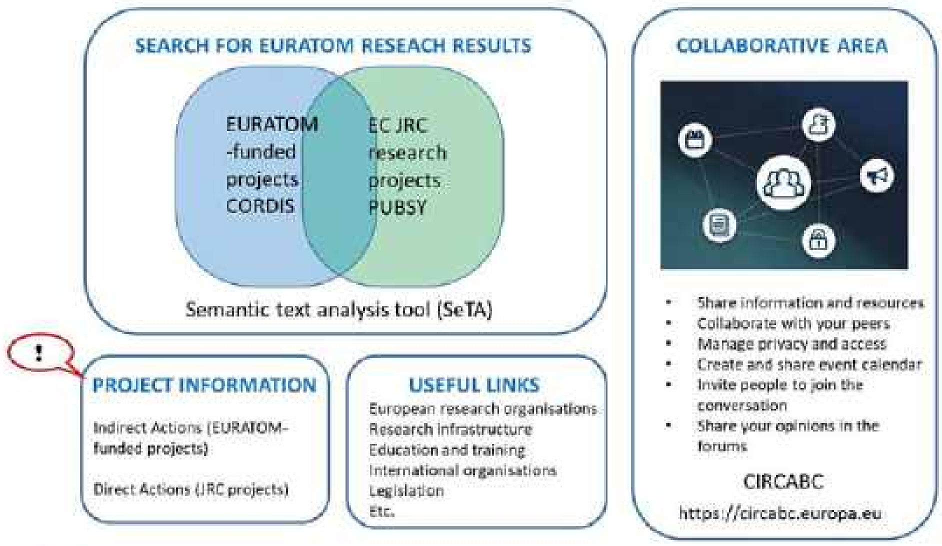
PIKNUS in **NOT** a data repository

- PIKNUS can offer links / help to find where e.g. experimental data is available, but they are not stored in the system.

*Indirect actions = Euratom research activities undertaken by multi-partner consortia
Direct actions = Euratom research activities undertaken solely by the JRC

PIKNUS

PIKNUS – **PI**lot action on **K**nowledge management in the area of **NU**clear **S**afety



! Pilot project focuses on materials ageing in Generation II-III reactors (Nugenia TA4)

PIKNUS

Examples of possible use cases of the platform:

- A researcher/student looking for bibliography and references for her or his research uses the platform
  - to retrieve information about the latest results from European funded projects
  - to retrieve related datasets ready to be used (connection to the EU Open Data Portal)
- A researcher developing a new research proposal uses the platform to
  - identify those knowledge gaps where new research would be most beneficial
  - to identify potential research partners and laboratories that could complement and enhance the research initiative
- A group of researchers use the platform to develop their research proposal using the collaborative space

PIKNUS

Website development on-going:

- Back-end: tailoring of JRC-developed semantic text analyser tool (SeTA) to the needs of the platform, to retrieve documents from CORDIS and JRC PUBSY
- Front-end: development of the user interface, visualisation, access tools, interactive workspace

First version of the system expected to be available for testing in autumn 2022

After the pilot phase:

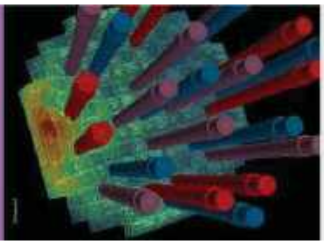
- Extending the platform to cover other areas of NPP safety research? Extending the platform to include activities related to new reactor types (SMR & Gen IV)?
- Waste management? Radiation protection? Security and safeguards?

Summary

- Continuous and future-oriented education and training as well as knowledge management for young talents are required for the safe and reliable operation of nuclear reactors or nuclear facilities in Europe.
- The projects ENEN+, A-CHINCH, GRE@T-PIONEeR, and ENEEP are outstanding examples by providing modern and attractive education and teaching material to students and life-long learners.
- PIKNUS pilot aims at creating a collaborative KM platform for European research community with improved access to Euratom funded research results.
- **Attracting, developing and retaining young nuclear talents is one of our key tasks for this decade to successfully decarbonize our European energy system!**

Acknowledments

The projects received funding from the EURATOM Research and Training programme under the following grant agreements: ENEN+: N° 755576, A-CHINCH: N° 945301, GRE@T-PIONEeR: N° 890675, ENEEP: N° 847555. PIKNUS represents an administrative arrangement between DG RTD and JRC as part of the Euratom Work Programme 2019-2020.
In addition, A-CHINCH also receives funding from the Norwegian Research Council under the grant agreement No. 313053.



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Thank you for your attention!
Questions?

J. STARFLINGER
Past-President of the European Nuclear Education Network (ENEN)

www.enen.eu

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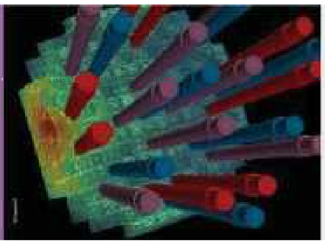

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MEDICAL APPLICATIONS OF IONIZING RADIATION AND RADIATION PROTECTION FOR EUROPEAN PATIENTS, POPULATION AND ENVIRONMENT

Isabelle Thierry-Chef[1,2,3], Elisabeth Cardis[1,2,3], John Damilakis[4], Guy Frija[5], Monika Hierath[6], Christoph Hoeschen[7] on behalf of the HARMONIC, MEDIRAD, SINFONIA and EURAMED rocc-n-roll consortia members.

[1]Barcelona Institute of Global Health (ISGlobal), [2]University Pompeu Fabra,[3]CIBER Epidemiologia y Salud Pública, Spain
[4]University of Crete, Greece, [5]Université Paris Descartes, France, [6]EIBIR gemeinnützige GmbH, Austria,[7]Otto-von-Guericke University, Germany

INTRODUCTION

- Medical applications of ionizing radiation (IR) play a crucial beneficial role in
  - efficient health care
  - diagnosis and treatment of many diseases.
- Represent the largest man-made source of radiation exposure to the population
- Risks are associated with ionizing radiation (cancer and non-cancer effects).
- it is particularly important to optimize their use and the doses they entail.

EURATOM FUNDED PROJECTS

EURATOM has funded four large-scale projects in the last 6 years

MEDIRAD Harmonic SINFONIA EURAMED ROCC-N-ROLL

to:

- improve estimates of the detrimental effects of medical applications;
- provide evidence-based input and new approaches to optimize their use and the resulting doses;
- improve benefit of medical applications of IR and reduce associated risks to patients and medical professionals; and
- ultimately provide evidence for further updating of the current BSS.

OVERALL OBJECTIVES

The projects contribute in a complementary fashion to

- optimizing medical applications of IR;
- improving our understanding of radiation effects; and
- generating evidence-based recommendations both for research and for clinical practice to the main stakeholders

They are particularly pertinent to the issue of RP in medicine

They cover the most important sources of diagnostic and therapeutic medical radiation to

patients

especially children

and workers

Implications of Medical Low Dose Radiation Exposure

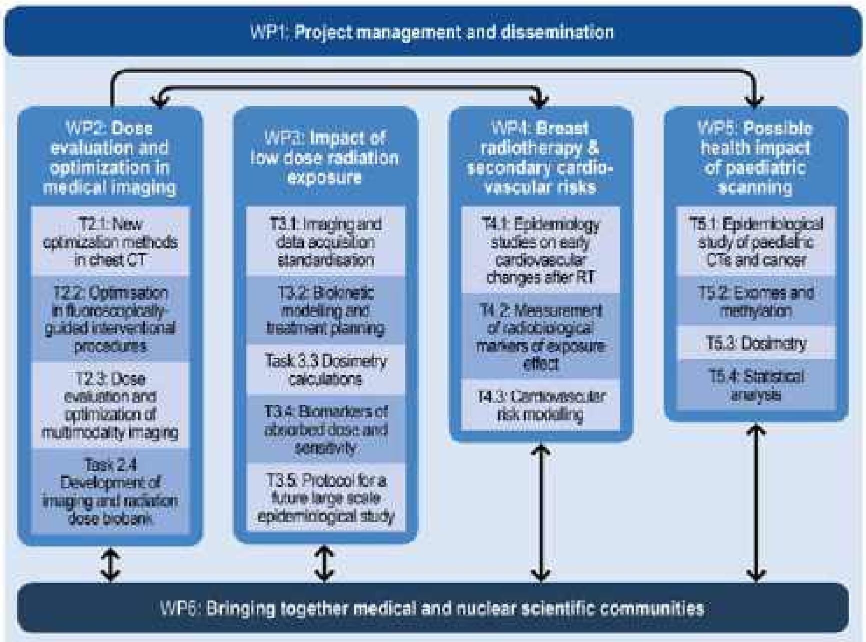
MEDIRAD

Key research objectives summarised in 3 pillars

- **Pillar 1:** Development of innovative tools to increase the efficiency of future radiation protection research activities and support good clinical practice.
- **Pillar 2:** Improvement of the understanding of low-dose ionising radiation risks associated with major medical radiation procedures.
- **Pillar 3:** Development of recommendations based on research results and establishment of information exchange infrastructure to facilitate consensus.

http://www.medirad-project.eu/

MEDIRAD



Diagnostic and therapeutic applications

- Diagnostic:
  - chest CT & Multimodality imaging
  - pediatric CT scanning
- Fluoroscopy : patients and staff
- Radiotherapy:
  - Breast cancer RT
  - Radioactive iodine for thyroid cancer

Multidisciplinarity of the team

- Clinicians (pediatric oncologists, radiation oncologists, cardiologists, radiologists)
- epidemiologists and biologists
- medical physicists
- sociologists

\+ patients & regulators in stakeholder group.

MEDIRAD Key Scientific Results

Image quality and doses

- Tool to determine image quality to maximise optimisation of RP in medical imaging;
- First European imaging and dose repository;
- Standardised quantitative I-131 imaging for dosimetry;
- Dose calculation tools for CT scanning and molecular radiotherapy;

Biomarkers

- Identification of important cardiac imaging and circulating biomarkers of radiation-induced cardiovascular changes after breast RT;
- Identification of potential biomarkers of susceptibility to low-dose RIC*.

RIC: Radiation Induced Cancer

MEDIRAD Key Scientific Results

Risk estimation

- Prediction model to assess risk of acute coronary events after RT in individual breast cancer patients, based on 3D cardiac dose distributions;
- New multinational cohorts of breast cancer patients:
  - To investigate cardiac changes arising in the first 2 years after RT
  - To investigate long term cardiac complications of RT
- Extended follow-up of key European paediatric-CT cohorts
  - To refine estimates of radiation induced cancer risk

MEDIRAD RECOMMENDATIONS

1. CONSOLIDATION OF PATIENT DATA REPOSITORIES ACROSS EUROPE
2. OPTIMISATION OF RADIATION-BASED PROTOCOLS FOR MEDICAL DIAGNOSTICS OR THERAPY
3. FURTHER OPTIMISATION OF RADIATION PROTECTION FOR PATIENTS AND MEDICAL WORKERS
4. FUTURE RESEARCH ON MEDICAL RADIATION PROTECTION IN EUROPE

HARMONIC

In **therapeutic use** of ionising radiation, benefits to the patient largely outweigh the risk

However, late effects of exposure are important to understand in children with increased survival

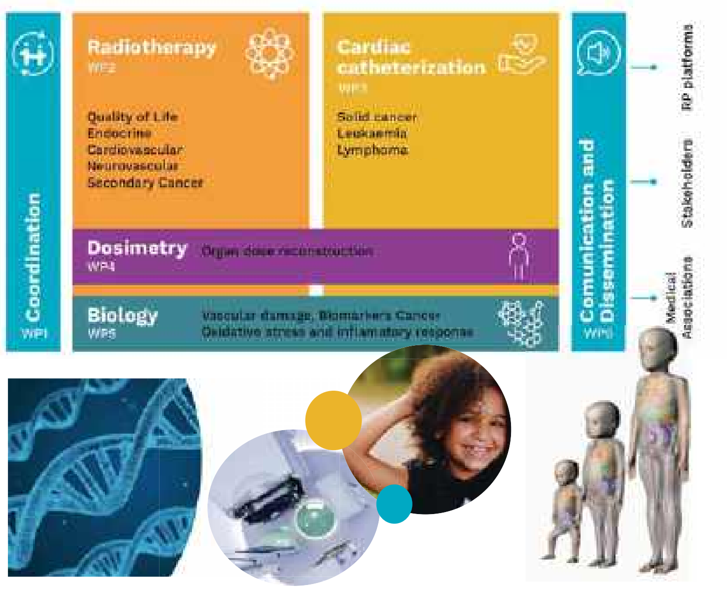
Objectives

Better understand the long-term health effects of medical exposure to ionising radiation in children:

- Cancer patients treated with modern radiotherapy modalities
- Cardiac patients treated with X-ray guided imaging procedures

HARMONIC

Organisation



Cohorts

Radiotherapy

CENTER	RETROSPECTIVE INCLUSION TIME PERIOD	RETROSPECTIVE INCLUSION No. PATIENTS	PROSPECTIVE INCLUSION TIME PERIOD	PROSPECTIVE INCLUSION No. PATIENTS	TOTAL
KU Leuven	2008-2020	320	2021-2023	90	410
Aarhus	na	0	2021-2023	**18/90**	90
Buckesse	na	0	2021-2023	90	90
G. Roussy	2013-2020	380	2021-2023	180	560
UK Essen	2013-2020	330/1140	2021-2023	**16/360**	1500
OVERALL		1840		810	2660

In blue, are centers including photon therapy patients

In bold, are numbers of patients already included (as of April 5th 2022)

Cardiology

COUNTRY	AGE (YEARS)	START OF ACCRUAL & FOLLOW-UP	NUMBER OF HOSPITALS	END OF ACCRUAL	END OF FOLLOW-UP	ALREADY IN	EXPECTED COHORT SIZE
BELGIUM	0-18	2004	3	2020	2020	1341	6,000
FRANCE	0-16	2000	15	2013	2016	18600	19,000
GERMANY	0-18	2004	2	2020	2020		4,000
	0-18	2004	health care database	2020	2018		30,000
ITALY	0-18	2017	2	2021	2022	384	1,000
NORWAY	0-18	1975	1 (Oslo)	2022	2022	4817	6,000
SPAIN	0-21	1995	1 to 2	2021	2020		5,000
UK	0-22	1991	6	2020	2020	20464	30,000
						~45600	**~100,000**

SINFONIA

Objective

The main objective of the 4-year SINFONIA project is to develop novel methodologies and tools that will provide a comprehensive risk appraisal for detrimental effects of radiation exposure on patients, workers, carers and comforters, the public and the environment during the management of patients suspected or diagnosed with lymphoma and brain tumours.

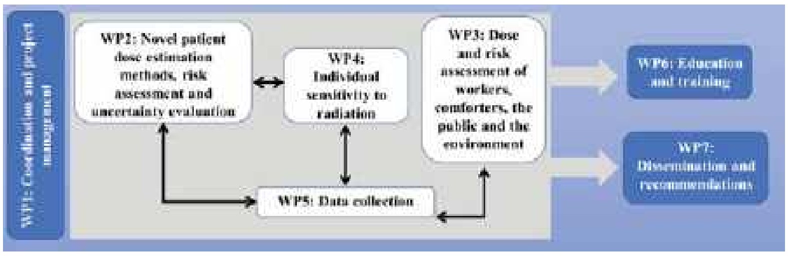
Specific Objectives

- Development of innovative AI-powered tools for quick and accurate estimation of organ doses from X-ray and nuclear medicine examinations
- Risk appraisal of radiation-induced malignancies
- Development of a novel framework to estimate personalised organ-specific dose from scatter radiation in photon-based radiotherapy, neutron-radiation and imaging in radiation therapy

SINFONIA

Specific Objectives

- Dose and risk assessment of staff, comforters, the public and the environment
- Establishment of the extent of variability in radiation sensitivity between patients and development of biomarkers to identify patients susceptible to radiotherapy-induced second malignant neoplasms
- Development of a data repository for imaging and non-imaging data and deployment of the AI models
- Recommendations and education and training



Main results so far:

Please visit

SINFONIA's poster

EURAMED Rocc-n-roll

- EURAMED rocc-n-roll is a coordination and support action project (running from September 2020 to August 2023) initiated to develop a strategic research agenda (SRA) for medical applications of ionizing radiation and the corresponding radiation protection as well as a corresponding roadmap.
- This will be developed by a consortium of 29 partners and a large advisory board trying to take into account the ideas and opinions of all relevant stakeholders. To guarantee that many publicly available workshops will be held.
- The SRA and roadmap will fit in for example into the SAMIRA action plan by the EC as well as the Europe's Beating Cancer Plan
- The SRA will include and be partly based on aspects of the MEDIRAD recommendations and the results of the other three projects. The idea will be to develop a SRA focussed on a patient-centred approach.

EURAMED Rocc-n-roll

- The current approach for the structure of the SRA looks like this:

Abstract
Keywords
Introduction
1. Medical challenge and corresponding research needs (21 pages max)
2. The corresponding Radiation Protection approaches (27 pages max)
3. Organisational requirements and corresponding research (19 pages max)
Conclusion (1 page max)
Summary list of proposed research topics and measures (max 3 pages)
References

Multidisciplinatity of the team

- Clinicians (pediatric oncologists, radiation oncologists, cardiologists neuroradiologists, nuclear medicine specialists, radiologists),
- epidemiologists,
- biologists,
- iT experts,
- medical physicists,
- physicists from nuclear research sites
- social scientists,
- patients / patient representatives,
- Regulators
- Representatives of radiation protection organisations

CHALLENGES

Maximise benefits & minimise potential adverse effects of IR exposure:

- More research than ever is needed regarding potential benefits to patients given the growing use of medical applications of ionising radiation;
- It is crucial to develop **interdisciplinary approaches** between
  - the radiation protection community
  - the health community
  - the digitization community,

  especially when referring to the rapid developments and new possibilities improving patient care harmonized within Europe.
- There is an urgent need for developing **European-wide**
  - interconnected dose, imaging and biological data repositories
  - sustainable infrastructures for long-term clinical epidemiological patient follow-up

IMPACTS

- Our four projects impact radiological protection in the medical community by
  - developing improved dosimetry and optimization tools
    to provide, in real time, more accurate and personalised dose assessment
  - conducting more precise estimation of the dose-risk relationship
    for the benefit of the patients, staff and the general population.
- The RP and medical communities are joining forces to understand the relationship between ionising radiation exposure from diagnostic and therapeutic procedures and risk of cancer and non-cancer effects in specific populations
- Research on biomarkers of sensitivity to identify patients with potential higher risk of short, medium or long-term radiation induced effects and improve patient-care on an individualised medicine basis.

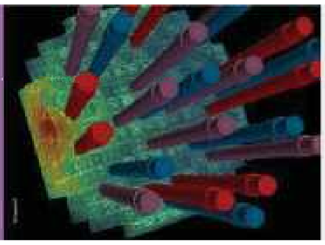
CONCLUSIONS

- The four EU projects rely on interdisciplinary consortia:
  - partners from different regions to integrate regional differences,
  - close collaboration between the different disciplines to achieve reliable and meaningful results.
- Results have the potential to be transferred into clinical practice and daily medical use:
  - easy applicable tools
  - education and training recommendations.
- Research on medical applications of ionizing radiation and radiation protection has a great potential for better and safer healthcare for the individual patients.
- Further research, into new applications, to improve medical care and the quality of life of patients is necessary.
- Special consideration needs to be given to data protection, especially taking into account the potential benefits of safely used AI applications in radiation-based medicine.

Thank you for your attention !

On behalf of the Consortia:

MEDIRAD Harmonic SINFONIA EURAMED ROCC-N-ROLL



FISA 2022

30 May - 3 June 2022
Lyon, France

RadoNorm

Towards effective radiation protection based on improved scientific evidence and social considerations – focus on radon and NORM

Ulrike Kulka (on behalf of RadoNorm consortium)

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 900009.

Challenges of Euratom HORIZON2020 NFRP-12

- **Protecting people and the environment** from the potentially harmful effects of ionising radiation.
- Harmonisation of EU planning of **response to a potential radioactive contamination**.
- Basing norms on **proper scientific knowledge** of radiation protection.
- Management of **radioactive waste and the safe decommissioning** of nuclear installations.

Objectives of RadoNorm

- To support European member states in the **implementation of the European Basic Safety Standards (BSS)** at the legal, executive and operational level.
- To significantly **reduce scientific, societal as well as technical uncertainties** in all steps of the radiation risk management cycle for radon and NORM exposure situations.
- To **improve radiation protection** by
  - initiating, supporting and performing multidisciplinary, innovative, integrated **research and technical developments**,
  - integrating **education and training** in the research and development work of the project,
  - **disseminating** the project achievements through special actions targeted at the public, other stakeholders including regulatory authorities and policy makers

RadoNorm in a nutshell

Title: Towards effective radiation protection based on improved scientific evidence and social considerations - focus on radon and NORM

Grant Agreement Number: 900009

Deliverables: 85

CALL: NFRP-2019-2020-12
Further integrating Radiation Protection research in the EU

57 Beneficiaries

Acronym: RadoNorm

20 Member States plus Norway and Switzerland

60 Month
Starting Date: 1 Sept. 2020
End date: 31 Aug. 2025

Budget: 18 Mio EUROS

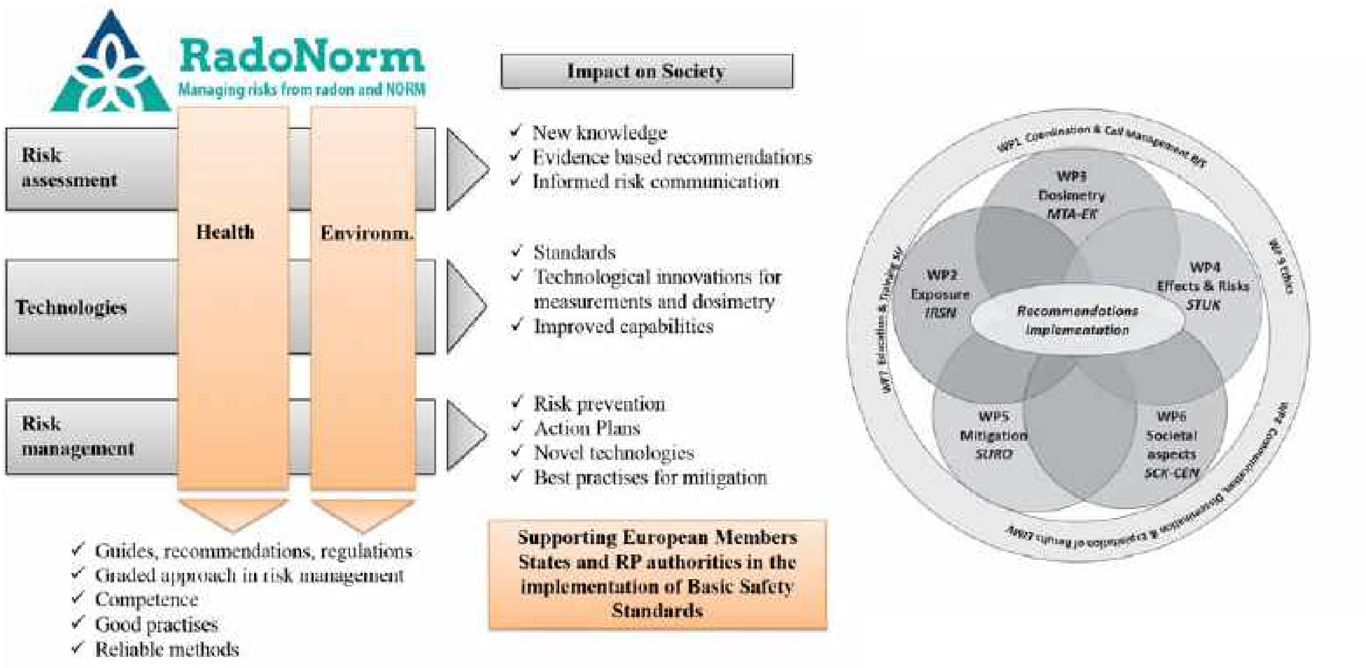
Type of action: Research and Innovation action (RIA)

Project coordinator: BfS
BUNDESAMT FUER STRAHLENSCHUTZ

RadoNorm partners

N°	Beneficiary	Role	Full official name
1	BfS	CO	BUNDESAMT FUER STRAHLENSCHUTZ
2	IRSN	BEN	INSTITUT DE RADIOPROTECTION ET DE SURETE NUCLEAIRE
3	EK	BEN	ENERGIATUDOMANYI KUTATOKOZPONT
4	STUK	BEN	SATEILYTURVAKESKUS
5	SURO	BEN	STATNI USTAV RADIACNI OCHRANY v.v.i.
6	SCK CEN	BEN	STUDIECENTRUM VOOR KERNENERGIE / CENTRE D'ETUDE DE L'ENERGIE NUCLEAIRE
7	SU	BEN	STOCKHOLMS UNIVERSITET
8	EIMV	BEN	Elektroinstitut Milan Vidmar
9	UMB	BEN	UNIVERZITA MATEJA BELA V BANSKEJ BYSTRICI
10	EPA	BEN	ENVIRONMENTAL PROTECTION AGENCY OF IRELAND
11	UANTWERP	BEN	UNIVERSITEIT ANTWERPEN
12	MERIENCE	BEN	MERIENCE SCP
13	CSTB	BEN	CENTRE SCIENTIFIQUE ET TECHNIQUE DU BATIMENT
14	AGES	BEN	OSTERREICHISCHE AGENTUR FUR GESUNDHEIT UND ERNAHRUNGSSICHERHEIT GMBH
15	KIT	BEN	KARLSRUHER INSTITUT FUER TECHNOLOGIE
16	PTB	BEN	PHYSIKALISCH-TECHNISCHE BUNDESANSTALT
17	RPI	BEN	PRIVATE JOINT STOCK COMPANY RADIATION PROTECTION INSTITUTE OF THE ACADEMY OF TECHNOLOGICAL SCIENCES OF UKRAINE
18	RIVM	BEN	RIJKSINSTITUUT VOOR VOLKSGEZONDHEID EN MILIEU
19	UHasselt	BEN	UNIVERSITEIT HASSELT
20	DCS	BEN	KRAEFTENS BEKAEMPELSE
21	TCD	BEN	THE PROVOST, FELLOWS, FOUNDATION SCHOLARS & THE OTHER MEMBERS OF BOARD OF T COLLEGE OF THE HOLY & UNDIVIDED TRINITY OF QUEEN ELIZABETH NEAR DUBLIN
22	DH	BEN	Department of Health
23	UH	BEN	HELSINGIN YLIOPISTO
24	UEF	BEN	ITA-SUOMEN YLIOPISTO
25	UGR	BEN	UNIVERSIDAD DE GRANADA
26	LUMC	BEN	ACADEMISCH ZIEKENHUIS LEIDEN
27	HZDR	BEN	HELMHOLTZ-ZENTRUM DRESDEN-ROSSENDORF EV
28	INSP	BEN	INSTITUTUL NATIONAL DE SANATATE PUBLICA
29	CIEMAT	BEN	CENTRO DE INVESTIGACIONES ENERGETICAS, MEDIOAMBIENTALES Y TECNOLOGICAS-CIEMAT
30	UB	BEN	UNIVERSITAT DE BARCELONA
31	CVUT	BEN	CESKE VYSOKE UCENI TECHNICKE V PRAZE
32	SUJCHBO	BEN	STATNI USTAV JADERNE, CHEMICKE A BIOLOGICKE OCHRANY VVI
33	UAVR	BEN	UNIVERSIDADE DE AVEIRO
34	UPorto	BEN	UNIVERSIDADE DO PORTO
35	CEA	BEN	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES
36	CEPN	BEN	CENTRE D'ETUDE SUR L'EVALUATION DE LA PROTECTION DANS LE DOMAINE NUCLEAIRE
37	INSERM	BEN	INSTITUT NATIONAL DE LA SANTE ET DE LA RECHERCHE MEDICALE
38	HES-SO	BEN	HAUTE ECOLE SPECIALISEE DE SUISSE OCCIDENTALE
39	LMU	BEN	LUDWIG-MAXIMILIANS-UNIVERSITAET MUENCHEN
40	UP	BEN	UNIVERSITE DE PARIS
41	HMGU	BEN	HELMHOLTZ ZENTRUM MUENCHEN DEUTSCHES FORSCHUNGSZENTRUM FUER GESUNDHEIT UND UMWELT GMBH
42	ISS	BEN	ISTITUTO SUPERIORE DI SANITA
43	GIG	BEN	GLOWNY INSTYTUT GORNICTWA
44	TAU	BEN	TAMPEREEN KORKEAKOULUSAATIO SR
45	UBern	BEN	UNIVERSITAET BERN
46	IDIBAPS	BEN	CONSORCI INSTITUT D'INVESTIGACIONS BIOMEDIQUES AUGUST PI I SUNYER
	HCB	LinkTH	HOSPITAL CLINIC DE BARCELONA
47	IGR	BEN	INSTITUT GUSTAVE ROUSSY
48	UCAM	BEN	THE CHANCELLOR MASTERS AND SCHOLARS OF THE UNIVERSITY OF CAMBRIDGE
49	IST ID	BEN	ASSOCIACAO DO INSTITUTO SUPERIOR TECNICO PARA A INVESTIGACAO E DESENVOLVIMENTO
50	SSM	BEN	STRALSAKERHETSMY
51	GSI	BEN	GSI HELMHOLTZZENTRUM FUER SCHWERIONENFORSCHUNG GMBH
52	CNRS	BEN	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE CNRS
53	DSA	BEN	DIREKTORATET FOR STRALEVERN OG ATOMSIKKERHET
54	NIPH	BEN	FOLKEHELSEINSTITUTT
55	NMBU	BEN	NORGES MILJO-OG BIOVITENSKAPLIGE UNIVERSITET
56	EORTC	BEN	EUROPEAN ORGANISATION FOR RESEARCH AND TREATMENT OF CANCER AISBL

Impact of RadoNorm on RP of humans and the environment



WP2 Exposure

Leader: Laureline Fevrier, IRSN

Main objective

➢ To provide a better characterisation of the exposure of the population (public and workers) and biota to radon and other naturally occurring radionuclides (NOR).

Progress made in the first 18 months

- Protocols and methods for data collection and compilation were established.
- Initial experimental studies and field campaigns were started to better understand the influence of various environmental factors on the mobility of uranium and radium in soils.
- Critical reviews of exposure pathways were carried out for dose assessment of public and biota at NORM industrial/legacy sites.

WP3 Exposure

Leader: Balázs Madas, EK

Main objectives

➢ To provide data for epidemiological studies on absorbed doses and their uncertainties.

➢ To generate new knowledge related to the role of spatial dose distribution in radiation risk.

➢ To identify groups potentially more sensitive to radon exposure than the general public and quantify their sensitivity.

➢ To provide data for biological experiments on doses at different levels of biological organisation (dosimetry and microdosimetry).

Progress made in the first 18 months

- Existing literature has been reviewed to establish reasonable modelling scenarios and to develop a comprehensive model for the dose to embryo and foetus.
- *In vivo* dose distributions in human lungs have already been quantified to provide realistic exposure conditions for *in vitro* experiments with cell cultures.

WP4 Effects and Risk Assessment

Leader: Sisko Salomaa, STUK

Main objectives

- To generate new knowledge related to biological effects and responses after exposure to radon and NORM that have implications for risk assessment and radiation protection of humans and the environment.

Progress made in the first 18 months

- The most appropriate risk models were found for duration of smoking or pack-years modified by time since exposure. Analyses were conducted for the Czech studies and the French residential study.
- Ethical agreements and data transfer agreements between institutes were established.
- A procedure was developed for constructing adverse outcome pathways combining bioinformatics and integrative systems biology.

WP5 Mitigation

Leader: Aleš Froňka, SURO

Main objectives

- To improve radon mitigation systems efficiency and their sustainability.
- To develop strategies for final treatment of NORM residues/waste.
- To improve regulation tools and procedures in EU MS by compiling information on lessons learned and experience gained in mitigation of radon in buildings, workplaces and NORM industry facilities.

Progress made in the first 18 months

- Surveys were done to gauge the current regulatory approaches and international standards for systems and methods to control radon in workplaces and dwellings.
- A workshop was organised with industry representatives and relevant authorities dealing with radioactivity in water to understand mitigation measures applied in NORM-involving industries.
- 2 NORM-specific case studies were identified, that will be used to test the effectiveness of mitigation systems.

WP6 Societal Aspects

Leader: Tanja Perko, SCK-CEN

Main objectives

- To propose systematic and methodologically sound social scientific approaches to study radon and NORM.
- To improve public awareness of radon and NORM, evaluate methods to achieve behavioural change, and contribute to science based policy support for radiation protection from radon and NORM.

Progress made in the first 18 months

- A literature review was conducted and published regarding development of a strong social scientific methodological base and toolbox for studying radon and NORM.
- An evaluation of citizen science contributions to radon research was published.
- Two public opinion surveys were conducted in Belgium, both serving as a pilot study for improved scales of the modular surveys to be conducted in 11 countries.

WP7 Education & Training

Leader: Andrzej Wojcik, SU

Main objective

- To organise the education and training of PhD students and early career researchers (ECRs) in the area of radiation protection, particular in radon and NORM.

Progress made in the first 18 months

- 20 PhD students and 14 ECRs were recruited.
- Virtual meetings for PhD students and ECRs to present their research were organised.
- Five training courses were held.

WP8 Communication, Dissemination and Exploitation of Results

Leader: Nadja Železnik, EIMV

Main objectives

- To exchange and communicate information, results and ideas from the project with various stakeholders, including the general public, affected populations, regulatory organisations and international radiation protection communities.

Progress made in the first 18 months

- The "Strategy and plan for communication, dissemination and exploitation of results" was released.
- The RadoNorm website and feeds on Twitter, LinkedIn and YouTube were launched.
- The STORE^{db} is adapted to the requirements of the RadoNorm partners regarding data storage (development of a new OBO Foundry ontology to describe RadoNorm data).
- Mapping and establishment of relevant stakeholder's networks.
- First stakeholder workshop was held.

www.radonorm.eu

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May - 3 June 2022 | Lyon, France 13

Thank you for your attention

RadoNorm

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 900009.

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May - 3 June 2022 | Lyon, France

EUROPEAN RADIATION PROTECTION RESEARCH FOR THE EFFECTIVE PROTECTION OF PEOPLE AND THE ENVIRONMENT

HILDEGARDE VANDENHOVE, *ANDRZEJ WOJCIK, FILIP VANHAVERE, CHRISTOPH HOESCHEN*, BORIS BRKLJAČIĆ, *OLIVIER ISNARD, SUSAN HODGSON, ALMUDENA REAL, JEAN-CHRISTOPHE GARIEL*

FISA – Lyon, France – 31 May - 3 June 2022

MEENAS © 1

Let's talk about

- Importance of radiation protection
- Development and innovation needs in radiation protection
- Pivotal role of PIANOFORTE Partnership and MEENAS association
- Requirement of mutual interconnectivity

MEENAS © 2

Radiation protection research and innovation – enabler of technology and progress

- Purpose of RP
  - provide appropriate level of protection for humans and environment without limiting beneficial actions giving rise to radiation exposure → allowing to define the correct balance
  - connect to innovation processes early on (for not being perceived as purely regulatory obstacle)
- R&D&I in RP
  - enhance basic knowledge and enable development of new ideas, designs, services, products
  - contribute to advancement of use of ionising radiation and radiation protection rules & guidelines for better life & health
- RP of importance in a plethora of exposure contexts
  - Medical therapy and diagnosis using ionising radiation
  - Nuclear fuel cycle
  - (TE)NORM
  - Natural radiation – terrestrial, cosmogenic

Challenge-opportunity context

- Rapid development of applications making use of IR is beneficial for improvement of medical diagnosis and treatments, but also quality and safety need to be a priority
- Protection of human health and environment against impact of ionising radiation is at heart of Global and European strategies and an integral part of a sustainable economy
- Emergency preparedness needs continuous sustained cross border efforts, innovations & harmonisation
- Access to and development of research infrastructures, education and training (E&T) key to maintaining and developing excellence in research on safe use of IR and RP
- R&I key for improving radiation protection science-based regulation and standards and meeting stakeholders´ expectations

Towards a European joint programme in H-EU

EUROPEAN JOINT PROGRAMME FOR THE INTEGRATION OF RADIATION PROTECTION RESEARCH

CONCERT

European Joint Programme for the Integration of Radiation Protection Research

The 'European Joint Programme for the Integration of Radiation Protection Research-CONCERT' under Horizon 2020 is operating as an umbrella structure for the research initiatives of the platforms MELODI, ALLIANCE, NERIS, EURADOS and EURAMED. It is a co-fund action that aims at attracting and pooling national research efforts with European ones in order to make better use of public R&D resources and to tackle common European challenges more effectively in key areas of radiation protection research.

June 2015-May 2020

Developed a joint roadmap (JRM)

- Reflects broad spectrum of societal and scientific issues requiring consideration by RP R&I community
- Defines priority areas and strategic objectives till 2030
- Research challenges relevant from societal and radiation protection point of view, considering all exposure scenarios
- '*Game changers*': research issues with potential to substantially impact and strengthen the system of radiation protection

United European Radiation Protection Research

12 March 2020

Consortium of European Radiation Protection Research Platforms

MEENAS

MELODI • EURADOS • EURAMED
NERIS • ALLIANCE • SHARE

**Memorandum of Understanding
for an integrative approach to
European Radiation Protection Research
— MEENAS —
MELODI, EURADOS, EURAMED, NERIS, ALLIANCE, SHARE**

With > 200 entities, representation of European radiation protection (R&I) community

MEENAS

A vision for a Radiation Protection Research Programme in the Frame of Horizon Europe

Draft proposal for a European Partnership under Horizon Europe

Partnership for Radiation Protection Research

January 2021

The **Partnership for Radiation Protection Research** is intended, through a competitive open call system, to **consolidate and strengthen the EU's research and innovation capacity for improving radiation protection** of the population, workers and the environment.
We aim to further **enhance the science-based best level of protection** in relation with the safe use of ionising radiation for both power and non-power applications with a special emphasis on diagnostic and curative use of radiation in medicine and **in answer to societal needs**.

7

MEENAS

PIANOFORTE

PIANOFORTE: Partnership for European research in radiation protection: towards a safer use and improved protection of the environment and human health.

Ambition:

Improve radiological protection of members of the public, patients, workers and environment in all exposure scenarios and provide solutions and recommendations for optimised protection in accordance with BSS

60 months, 30 M€ EC funding + 16 M € → 65 % EC funding; R&I via Open Calls .

8

MEENAS

59 PARTNERS

- **33 POMs - PO/PM (programme owners and programme managers)** representing 24 countries (23 EU)
- **6 platforms** (ALLIANCE, EURADOS, NERIS, EURAMED, MELODI, SHARE) (will sign the GA and will be member of the GA)
- **5 Associated partners**

→ will sign the Grant Agreement (GA) and will be member of the General Assembly (GA)

- 15 Affiliated Entities

9

MEENAS

PIANOFORTE objectives

General Objective : To improve radiological protection of members of the public, patients, workers and environment in all exposure scenarios and provide solutions and recommendations for optimised protection in accordance with the BSS.
Multidisciplinary projects focusing on identified R&I priorities will be selected through competitive open calls.

Scientific

Innovate in ionising radiation based medical applications combating cancer and other diseases by new and optimised diagnostic & therapeutic approaches improving patient health & safety and supporting transfer of R&I outcome to practice.

Support regulations and implementation of the BSS and improve practices in the domain of low dose exposures of humans and the environment by better understanding and reducing uncertainties in risk estimates.

Maintain a sustainable expertise capability on radiation protection issues across EU by fostering availability, use & sharing of existing state-of-the-art infrastructures at European level & beyond and conducting education and training activities.

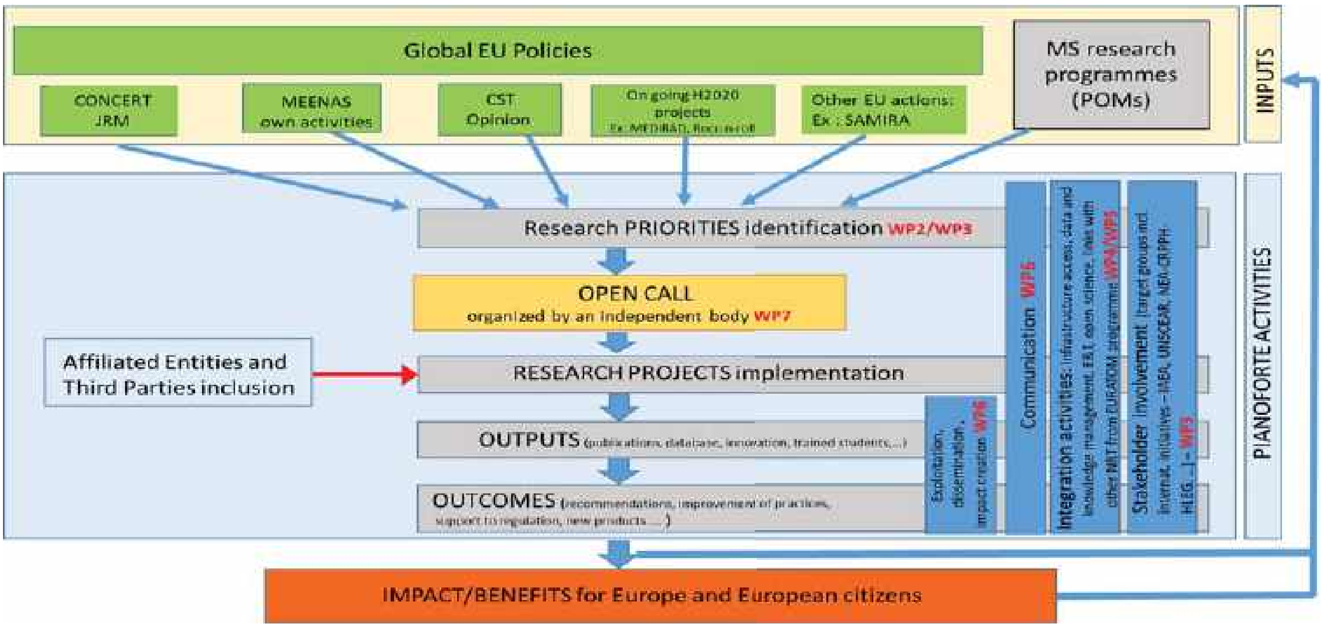
Integrative

Improve scientific understanding of the variability in individual radiation response and health risk of exposure

Provide scientific basis to recommendations, procedures & tools for assuring better preparedness to response & recovery from a potential radiological event or nuclear accident and improve know-how to manage legacy sites.

Involve all the relevant stakeholders at the different stages of the implementation of research projects and assure efficient dissemination, knowledge management and uptake of results

Project structure and approach



Links and collaboration opportunities with other topics of EURATOM Work programme 2021-2022

- NRT-01-01: Safety and operating nuclear power plants and research reactors → **Emergency preparedness**
- NRT-01-07: Development of tritium management in fusion and fission facilities → **Emergency management, Impact of tritium**
- NRT-01-10: Safe use and reliable supply of medical radionuclides → **Medical applications**
- NRT-01-12: European facility for nuclear research
  - o **OFFERR** – European Platform for Accessing NUclear R&D Facilities
  - o Identify relevant radiation protection and medical facilities
  - o Ensure link with PIANOFORTE infrastructure WP
- NRT-01-13: Towards a European nuclear competence area.→ **SteerCo + link to PF E&T WP4**

Links and collaboration opportunities with other topics of EURATOM Work programme 2021-2022

- NRT-01-02: Safety of advanced and innovative nuclear designs and fuels
  - ANSELMUS - Safety of advanced and innovative nuclear designs and fuels (SHARE)
- NRT-01-08 - Towards an aligned harmonised application of international regulatory framework in waste management and decommissioning
  - HARPERS – Harmonised practices, regulations and standards in waste management and decommissioning (SHARE)
- NRT-01-14 - Socio-economic issues related to nuclear technologies
  - ECOSENS - Economic and Societal Considerations for the Future of Nuclear Energy in Society (SHARE)
- NRT-01-16 Support for the Sustainable Nuclear Energy Technology Platform to address cross-sectoral challenges and non-power applications of ionising radiation
  - SNETPFORWARD project (MEENAS)

A call towards SNETP

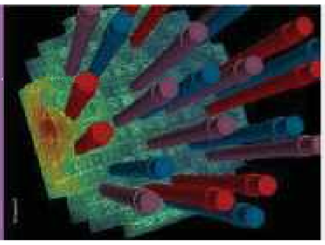
- **Fostering link SNETP-MEENAS**
- **Enhanced collaboration**

Links and collaboration opportunities with other topics of EU programme → creative linking

- Establish links with “Health”, “Civil security for society” and “Food, natural resources, agriculture and environment, biodiversity” clusters.
- Digital, Industry and Space work programme
  - Circular, ‘green’ and ‘sustainable’
    - REE, HM (Co) for ‘green’ technologies → NORM associated
  - Space
- Food, Bioeconomy, Natural Resources, Agriculture and Environment
  - Tracer studies for environmental processes
- Climate, Energy and Mobility
  - Circular, ‘green’ and ‘sustainable’
  - Tracer studies for environmental processes
- Health
  - Medical applications using IR
- DG-ENER - SAMIRA

Conclusions

- **MEENAS** was successfully established to integrate and enforce radiation protection R&I in Europe
- EURATOM-Horizon Europe **Partnership for Research in Radiation Protection** → important achievement, basis for integrated progress
- **Liaison** within the EURATOM and Horizon Europe programme (e.g. Health Cluster, DG SANTE, DG-ENER) essential to optimise and maximise our role in radiation protection R&I
- **Liaison with SNETP**
- **Funding for radiation protection R&I** linked with/limited to the EURATOM programme yet radiation protection is ubiquitous and quintessential also for Health and medical applications, Energy and Electricity production (REE, NORM), Space exploration, …
- Enhanced **Europe-wide multidisciplinary** collaboration, integration, networking among and between programmes is needed is critical to assure public (patient and medical personnel) health, welfare and progress.



FISA 2022

30 May - 3 June 2022
Lyon, France

SHARE: STAKEHOLDER BASED ANALYSIS OF RESEARCH FOR DECOMMISSIONING

JUNE 1ST 2022

Robert Winkler (CEA, France), Laura Aldave de las Heras (JRC, Germany), Emilio Garcia Neri (ENRESA, Spain), Anthony Banford (NNL, UK), Kurt van den Dungen (SCK CEN, Belgium) Pierre Joly (IE, France), Rékà Szőke (IFE, Norway), Federica Pancott (SOGIN, Italy), Anumaija Leskinen (VTT, Finland), Gintautas Poškas (LEI, Lithuania), Angelika Bohnstedt (KIT, Germany)

Project Overview

SHARE – **S**take**H**older based **A**nalysis of **RE**search for Decommissioning

Consortium of 11 European Stakeholders :

- CEA, France (Coordinator)
- ENRESA, Spain
- IFE, Norway
- KIT, Germany
- LEI, Lithuania
- NNL, United Kingdom
- SCK CEN, Belgium
- SOGIN, Italy
- VTT, Finland
- JRC, Karlsruhe
- EI, France

Timeline

Start, 1/6/2019

End, 28/3/2022

Extension, July 2021

Budget : 1.4 M€ (EU Grant NFRP-2018-5 847626)

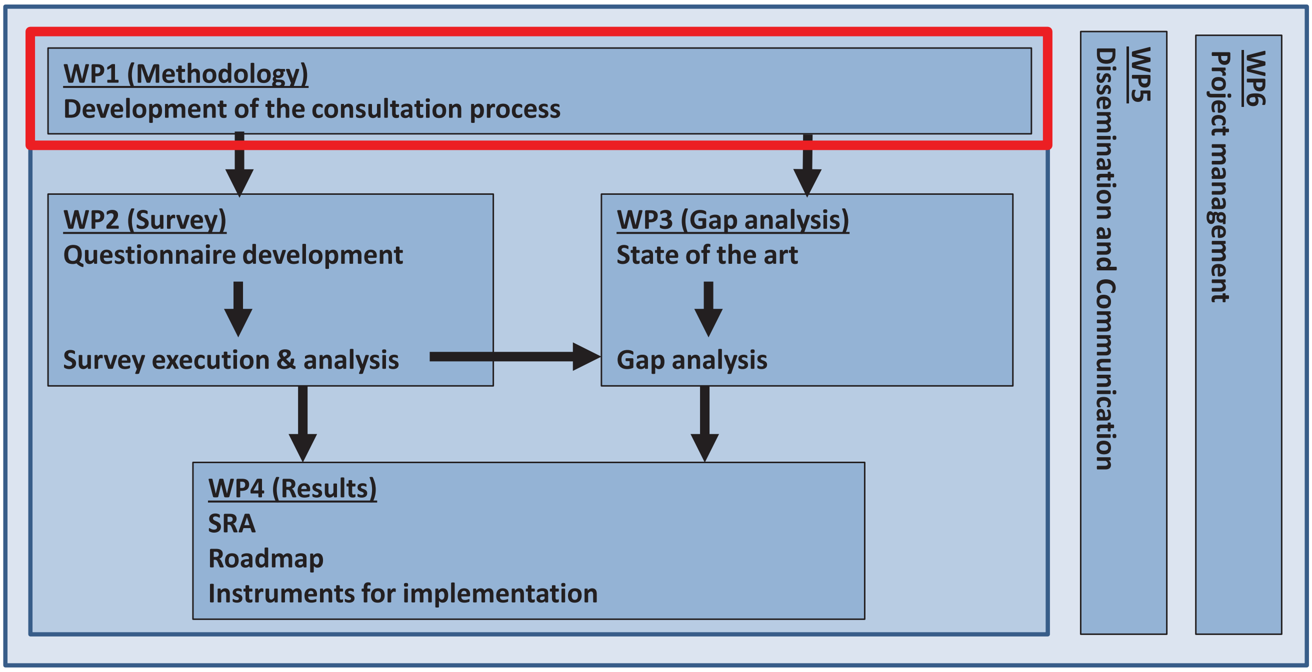
Contact (CEA): Robert Winkler (robert.winkler@cea.fr) & Anne Fornier (anne.fornier@cea.fr)

The main objectives

Main SHARE objective was to provide an **inclusive roadmap** for future research collaboration, for **Stakeholders** to jointly improve safety, reduce costs and minimize environmental impact **in the decommissioning of nuclear facilities**.

- Determine the **research needs** based on the opinions collected from Stakeholders in an inclusive process
- **Review the state of the art** in collaboration with the Stakeholders to **identify the gaps**
- Construct a **Strategic Research Agenda (SRA)** to fill the gaps with **activities** consolidated together with the Stakeholders that will feed a **roadmap of activities** for the next 10-15 years and will allow to propose **instruments for implementation** for the activities using identified mechanisms

The work packages

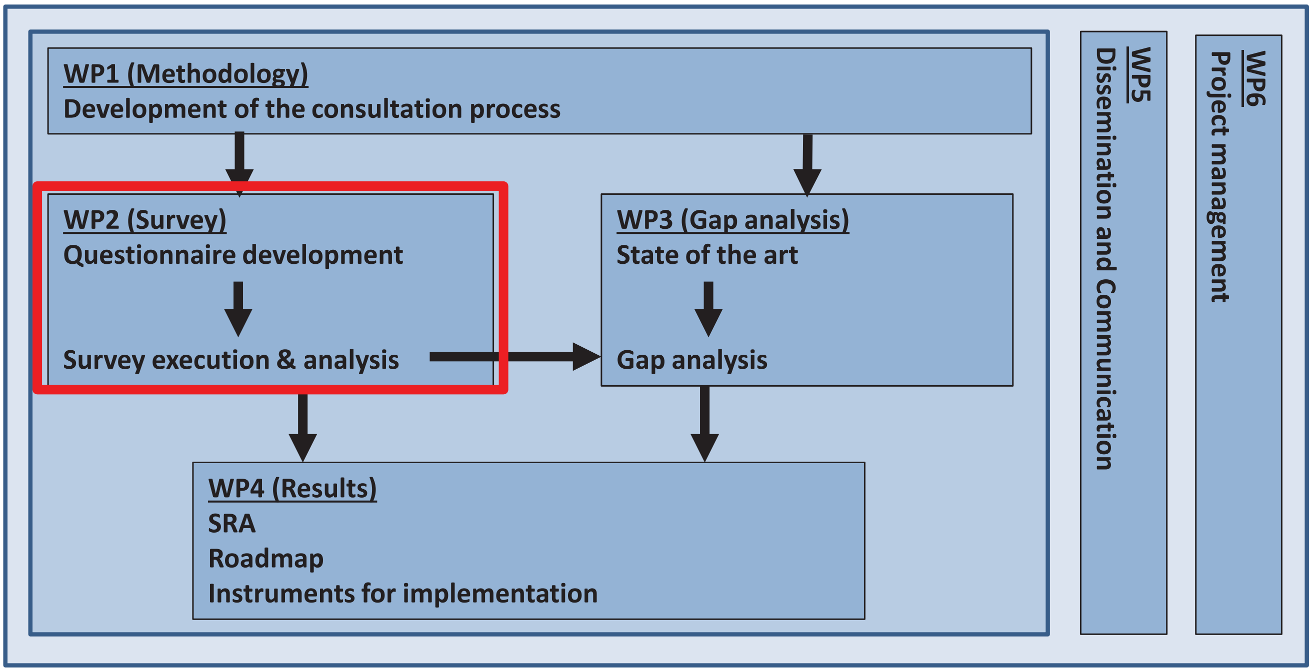


WP1: Methodology

Objectives

- Elaboration of a list of Stakeholders that is representative of the decommissioning industry
  - Consortium members established a list based on contacts and publicly available information (650 contacts)
  - Stakeholders' type (Industry, regulator…) and country are observed for representativity
- Development of a methodology of evaluation for the questionnaire
  - Work towards a weighting procedure for the items in the questionnaire
- Overall structure of the project
  - Work towards defining the interactions between deliverables

The work packages



WP2: Survey

Objectives

- Development of the questionnaire survey

⇨ Consortium developed a questionnaire that is endorsed by the Expert Review Panel

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May - 3 June 2022 | Lyon, France
7

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Objectives

- Development of the questionnaire survey

⇨ Consortium developed a questionnaire that is endorsed by the Expert Review Panel

- Survey execution

⇨ Online survey from March 2020 to July 2020

⇨ 224 filled out questionnaires from the 650 contacted stakeholder and additional comments in open section

  - ✓ Predefined questions in thematic areas with ratings on importance and urgency
  - ✓ Additional comments in open section

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
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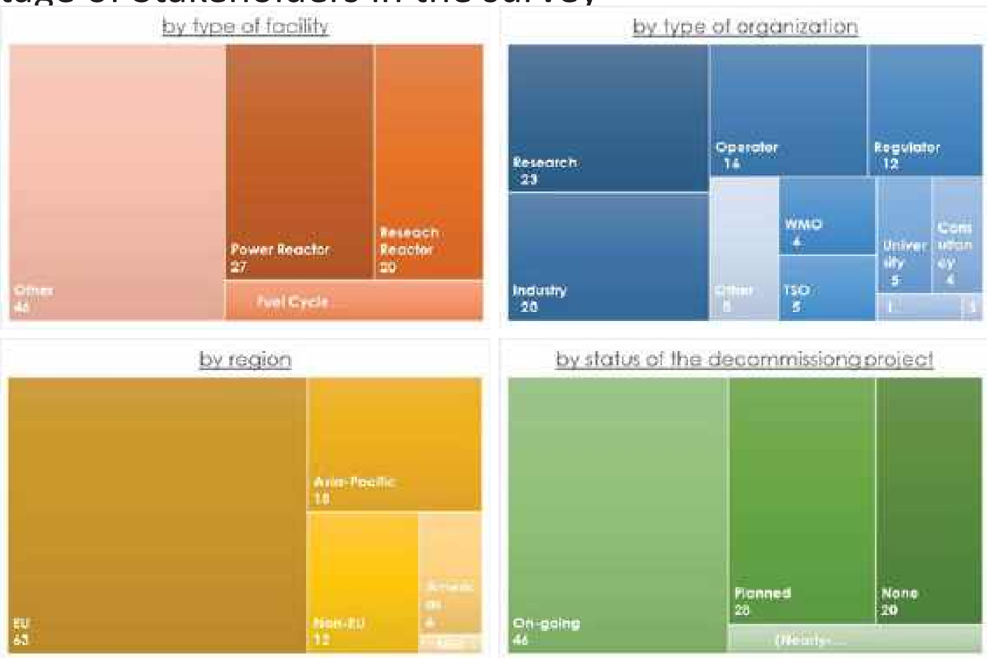
8

Representativity of responding stakeholders

Percentage of Stakeholders in the survey



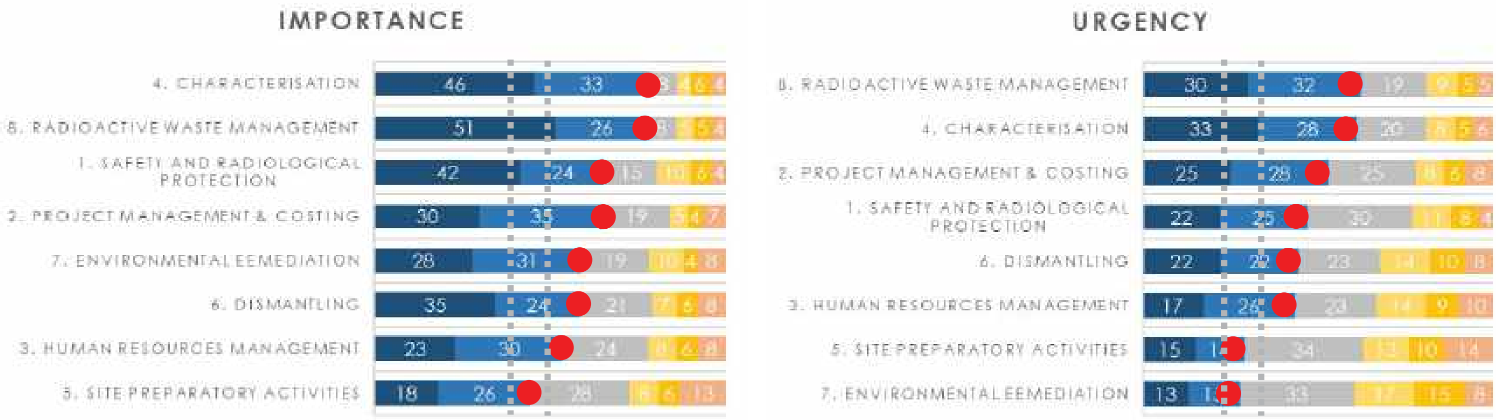
WP2: Survey

Objectives

- Development of the questionnaire survey
  - Consortium developed a questionnaire that is endorsed by the Expert Review Panel
- Survey execution
  - Online survey from March 2020 to July 2020
  - 224 filled out questionnaires from the 650 contacted stakeholder and additional comments in open section
- Survey analysis
  - Weighting of the ranking by (I) matching the contacted population and (II) type of stakeholder, status of the decommissioning project and region

Main outcome: Urgency and Importance ranking

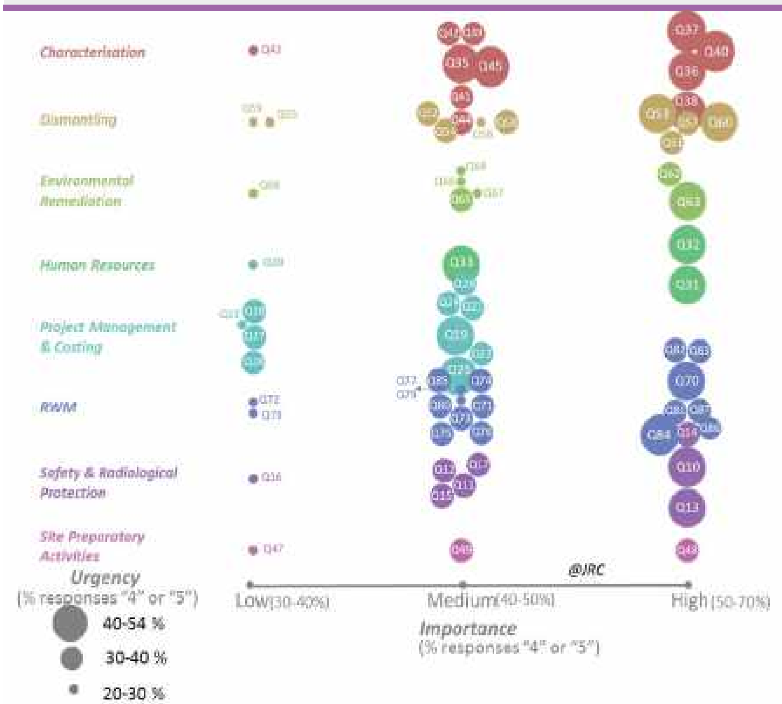
Top 2 ranking was found most relevant (ex. Thematic areas) indicated by a ●



- Generally Importance > Urgency
- Slight difference in priorisation but Q4, Q8, Q1 & Q2 more important than Q6, Q3, Q5 & Q7
- Three categories:

	High	Medium	Low
Importance	>50	50-40	<40
Urgency	>40	40-30	<30

For the sub-thematic areas

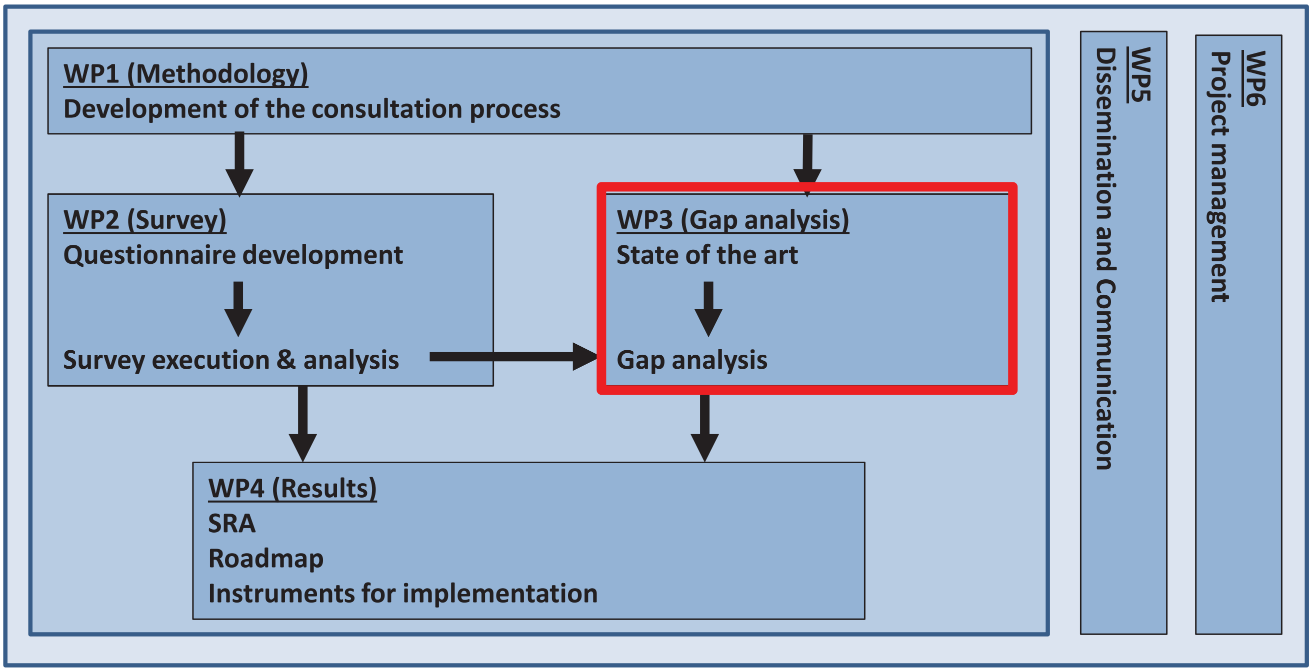


Interpretation:

- Each colour corresponds to a thematic area
- Each cricle correspond to a sub-thematic area (Q10-Q84)
- Bigger circles = higher urgency rating
- Circles further to the right = higher Importance rating
- Most of the time, for a given sub-thematic areas, importance and urgency have similar tendencies

Place	Importance		Urgency	
	Number	Title	Number	Title
1	Q36	Inventory assessment (Radiological and non-radiological)	Q36	*
2	Q53	In situ Radioactive Waste characterization and segregation	Q53	*
3	Q60	Robots and remote controlled tools for dismantling	Q32	General education for decommissioning
4	Q38	Characterization of activated components and areas (Concrete)	Q13	*
5	Q40	Technologies for hard to access areas (high walls, embedded components, harsh environment…)	Q38	*
6	Q37	Characterization of activated components and areas (Metal)	Q70	*
7	Q70	Management routes for materials including radioactive waste streams	Q37	*
8	Q13	Development for National regulatory guidance for Decommissioning (Clearance of structures and materials)	Q40	*
9	Q62	Clearance of surfaces and structures (interiors and exteriors)	Q60	*
10	Q63	Characterization methods and technologies to identify subsurface contamination	Q84	Material clearance (methodology and procedures)

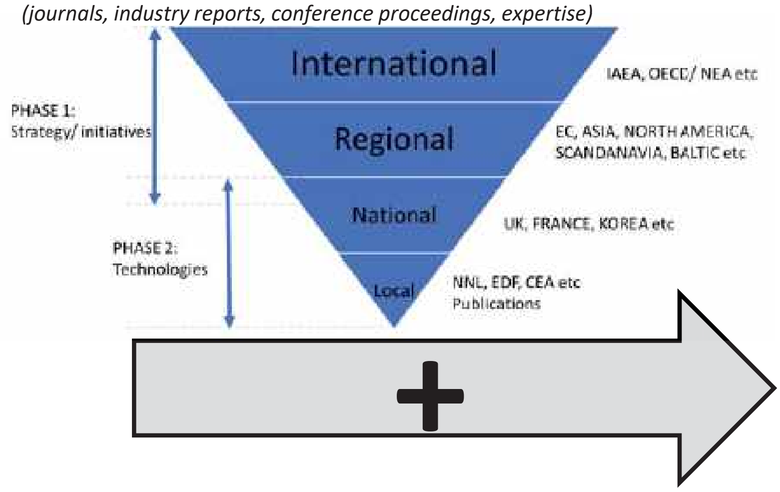
The work packages



WP3: Outcomes

Consortium literature review

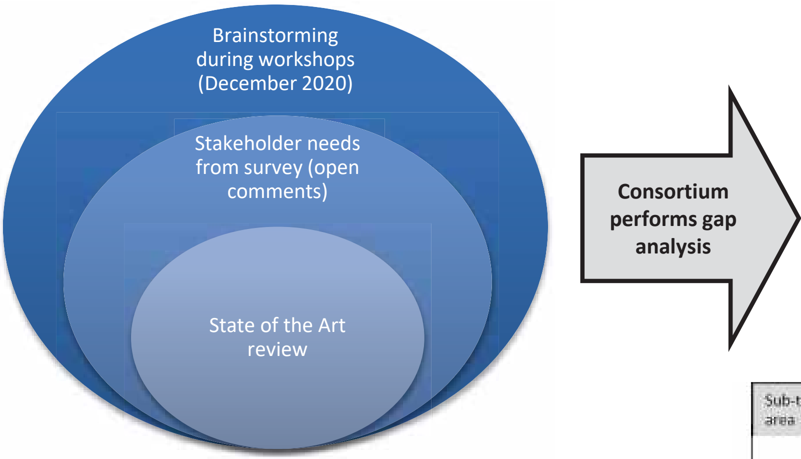
(journals, industry reports, conference proceedings, expertise)



Stakeholder workshop in October 2020

Extensive review on the existing practices and on-going developments in the 8 thematic areas

WP3 Main Outcome

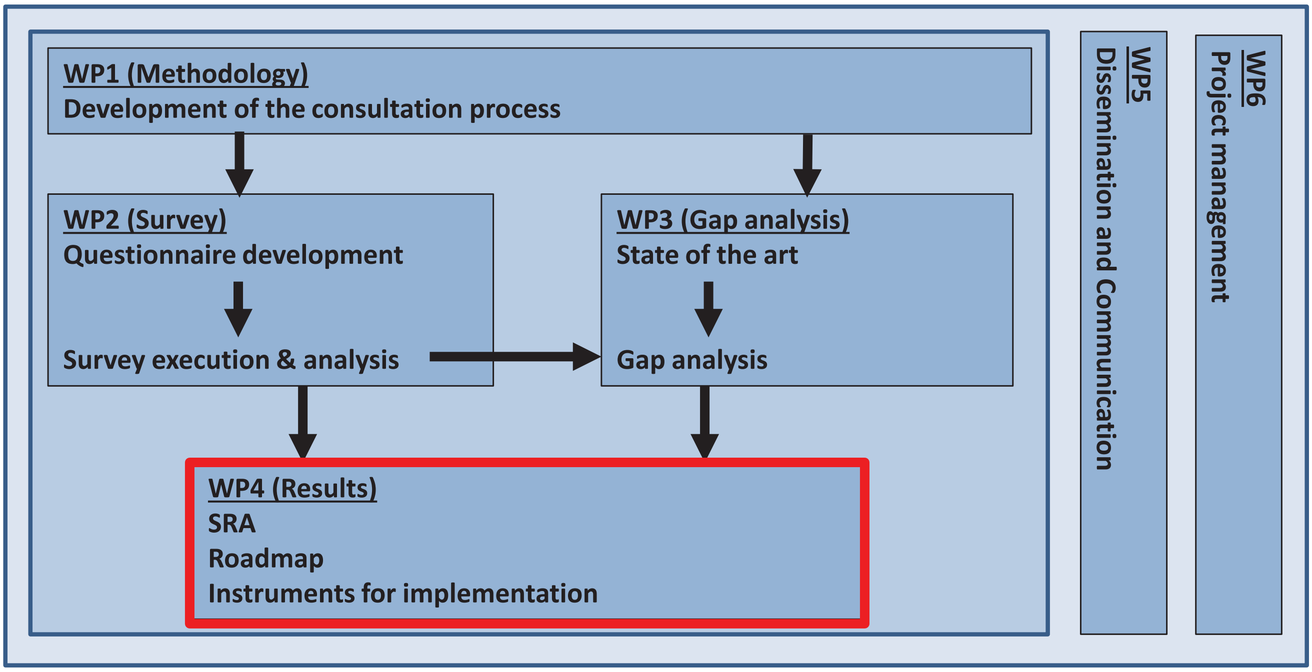


250 proposed actions for the 71 sub-thematic areas

- consolidated with the help of the stakeholders at DigiDecom 2021

Sub-thematic area	Needs or opportunities	Actions proposed		Type
Q59. Demolition of large, reinforced concrete structures	Safety reference	Benchmarking	for the safer techniques for demolition of large structures with reinforced concrete.	Guidance
		Guidance	for using remote demolition that provides worker safety.	Guidance
	Innovation and improvements in Laser technology	Benchmarking	for laser technology considering secondary waste minimisation and efficiency	Development
		Development	in laser technology by considering micro melting phenomenon	

The work packages



WP4: Strategic Research Agenda

Four Action Types

Implementation of RD&D	• Includes research, development, demonstration and deployment activities. • Includes underpinning activities such as benchmarking • Knowledge creation across all TRL levels
Knowledge Sharing	• Focuses on knowledge exchange ranging from knowledge management to dissemination activities • Includes best practices and networking
Education and Training	• Activities that aim to develop capabilities, skills and competences for the nuclear workforce
Harmonisation of Practices	• Opportunities and benefits of harmonisation in the areas of regulatory frameworks and technology development • Achieved by mutual agreement and consolidated by recommendations, directives and guidelines

Non-technological areas (Safety, project management, human resources)

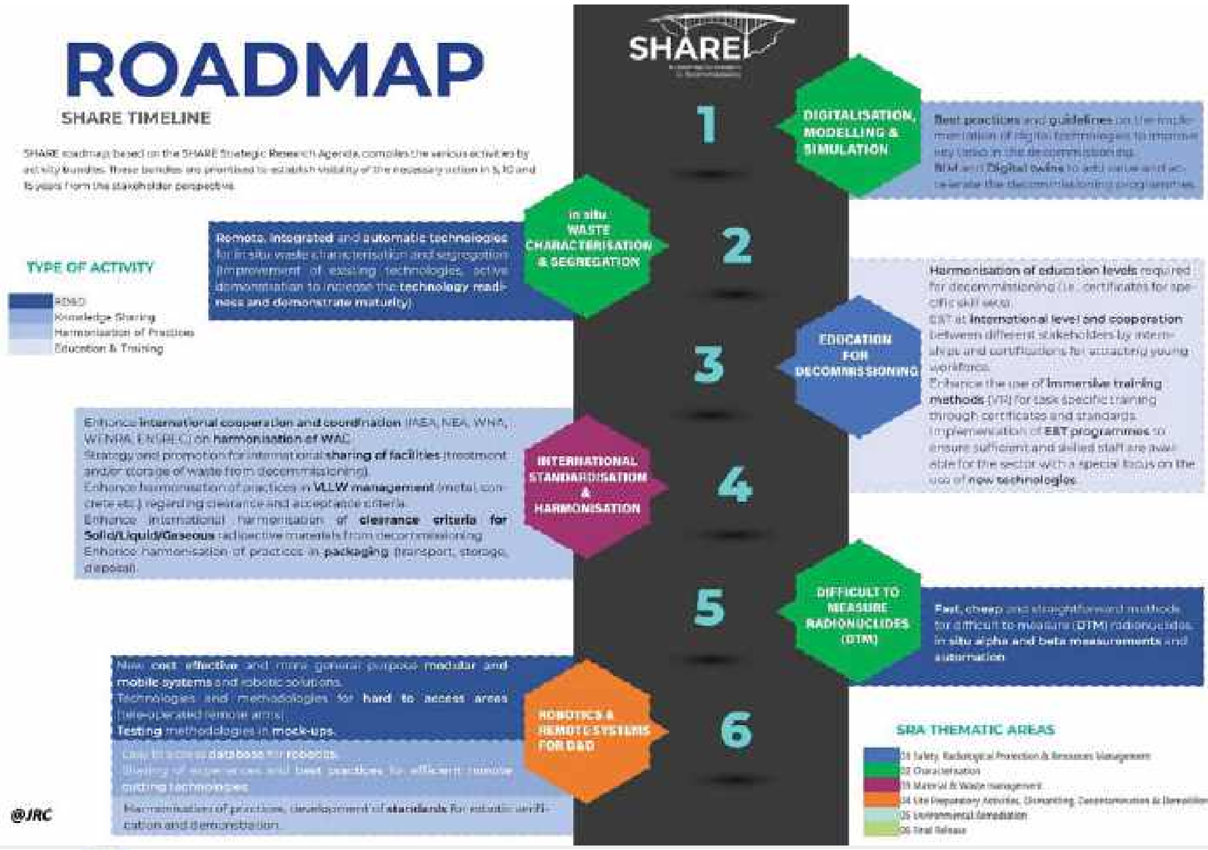
- Mainly cross-cutting activities (KS, HP, E&T)
- Education and recruitment of the next generation work force
- Development of adequate digital tools
- Development of cost estimation methodologies

Characterisation and Radioactive Waste Management

- Most important thematic areas
- Measurement optimisation (Difficult to measure RN, in-situ)
- Waste treatment and conditioning techniques
- Harmonisation of waste criteria

Dismantling, Decontamination and Environmental remediation

- Waste minimisation
- Improvement of efficiency, mobility and automation
- Sharing best practices and development of guidance



Outlook

- **On-going projects on some of the issues**

PLEIADES
Smarter Plant Decommissioning

eurad
European Joint Programme on Radioactive Waste Management

PREDIS

- **Encouraging stakeholders to initiate collaborative projects to provide solutions**

Thank you

Initiator and founder of SHARE
Christine Georges
Anne Fornier
Ludovic Vaillant
Fanny Fert

Pierre Joly
Romain Tricon-Duez

Emilio Garcia Neri
Jorge Borque Liñán

Réká Szőke
Istvan Szőke
Lucas Stephane

Laura Aldave de las Heras
Karin Casteleyn

Angelika Bohnstedt
Muhammad Junaid Ejaz Chaudhry
Simone Müller

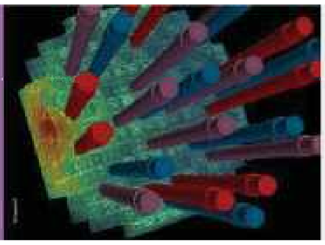
Gintautas Poškas
Povilas Poskas
Egidijus Babilas

Samantha Ree
Anthony Banford
James Dewar
Ed Butcher

Kurt Van Den Dungen
Luc Noynaert

Federica Pancotti
Rossella Sciacqua
Alessandro Mattioli

Anumaija Leskinen
Rafael Popper
Iiro Auterinen



FISA 2022

30 May - 3 June 2022
Lyon, France

Thank you for your attention!

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
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EUROPEAN COLLABORATIVE EFFORTS TO ACHIEVE EFFECTIVE, SAFE, AND COST-CONTROLLED DISMANTLING OF NUCLEAR FACILITIES

-

FISA, 01/06/2022

N. MALLERON (Cyclife SAS),M. GUERIN (EDF), D. ROULET (ONET), M. MICHEL (CEA), C. RIVIER (CEA), P. LEFEVRE (EDF), M.-B. JACQUES (CEA)

Summary

CONTEXT : DISMANTLING OF NUCLEAR REACTOR IN EUROPE

A BRIEF OVERVIEW OF EUROPEAN COLLABORATIVE PROJECT SUPPORTED BY EURATOM

ZOOM ON SOME ACHIEVEMENTS OF THE EURATOM'S PROJECTS AND PERSPECTIVES

Context

Source : European Commission

Stakes in power generation nuclear reactors dismantling

Graphite reactors: Many technical challenges due to huge dimension, thickness of concrete and steel, large amount of graphite to be safely retrieved

Other reactors (PWR, BWR, HWR…): technical feasibility has been established

In both cases, today's main practices are only partially industrial:

- Operation are mainly carried out manually
- Extensive use of personal protection measures
- Poorly reproductible nature of the operations
- Poor ratio between time consumed to perform the operations and time used to plane, monitor and control them

Euratom's projects

common goal

Move forward to an efficient, safe, cost-controlled and industrial way of dismantling using the full potential of the so-called « 4.0 industry » technologies :

- Digital technologies
- Automatised or semi automatised robotics
- Laser cutting
- …

Overview of the projects (1/5)

PLEIADES
Smarter Plant Decommissioning

PLatform based
on **E**merging and **I**nteroperable **A**pplications
for enhanced **D**ecommissioning process**ES**

- **3 years (01/10/2020 - 30/09/2023)**
- **14 partners from 7 countries**
- **Coordinated by CEA**

Overview of the projects (2/5)

INSIDER

Improved **N**uclear **SI**te characterisation for
waste minimisation in **D**ecommissioning
and Dismantling operations under
constrained **E**nvi**R**onment

- **4 years (06/2017 - 11/2021)**
- **18 partners from 10 countries**
- **Coordinated by CETAMA (CEA Energies Division)**

BS, cea, CMI, EDF, ENERGORISK, Geoenvironics, HZDR, JRC European Commission, JÜLICH, KIT, LGi, LNE, mta EK, NPL, ONET, PSI, SCK•CEN, Universidad del País Vasco

Overview of the projects (3/5)

Cyber physica**L** **E**quipment for unm**A**nned **N**uclear **DE**commissioning **M**easurements

- **3 years (03/2021 - 02/2024)**
- **11partners from 4 countries**
- **Coordinated by CEA list**

Overview of the projects (4/5)

Laser **D**ismantling Environmental and **S**afety **A**ssessment

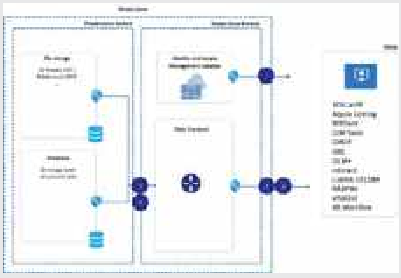
- **4 years (07/2020 - 06/2024)**
- **6 partners from 4 countries**
- **21 external stakeholders (Expert Group, End User Group and Support Group)**
- **Coordinated by ONET Technologies**

Overview of the projects (5/5)

INNOvative tools **FOR** dismantling of **GRAPH**ite moderated nuclear reactors

- **3 years (10/2020 - 09/2023)**
- **13 partners from 5 countries**
- **Coordinated by EDF**

Example of achievements

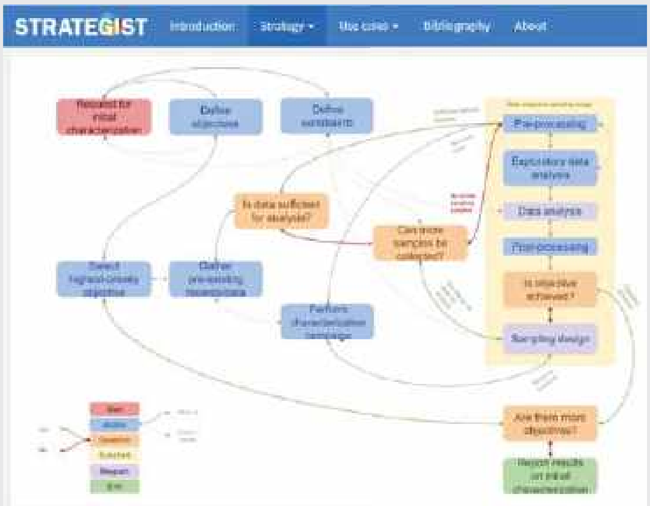


PLEIADES platform, which architecture aims at maximising the collaboration between its different software modules.

It is based on common ontology (a common language) and a common BIM-like database to make the interaction between the software as efficient as possible

→ 3D models of the three nuclear facilities provided by IFE (left), ENRESA (middle) and EDF (right) as use cases of PLEIADES platform:

Example of achievements

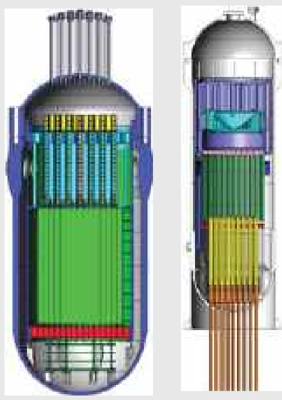


INSIDER developed digital tools to help in characterization phases implementation:

- **STRATEGIST** (**S**ampling **T**oolbox for **R**adiological **A**ssessment **T**o **E**nable **G**eo-statistical and statistical **I**mplementation with a **S**mart **T**actic): step-by-step guide to implement the sampling strategy for the characterization of contaminated sites (https://strategist.sckcen.be/)

- **INSPECT** (**I**n **S**itu **P**robe **S**election **T**ool): decision helping tool for the selection of the suitable detectors for the different D&D phases

Example of achievements



PWR BWR

Up to **200mm in thickness** in air (14kW laser power)

Three milestones achieved up to now:

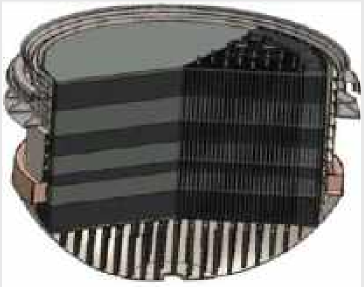
- ➢ Specifications for the dismantling of reactor components agreed.
- ➢ Qualification activities in the Technology Qualification Plan are completed.
- ➢ Technical countermeasures defined at laboratory scale.

Cutting tests (demonstrators) to be started from September 2023

Achievements during and beyond Inno4Graph

Design of a representative and full scale mock-up of the Chinon A2 graphite stack

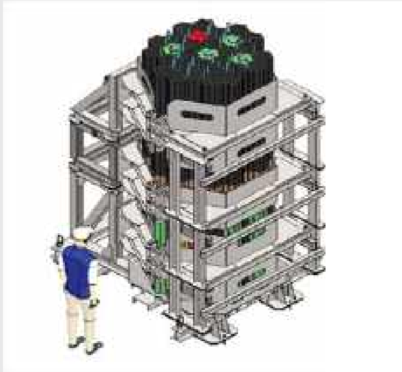
- To **minimise risks** of the complex and repetitive operations (several thousands bricks for a single stack) of the graphite core retrieval and **increase the probability of success**



Developments of methodologies and tools

Demonstration to stakeholders

Operator training



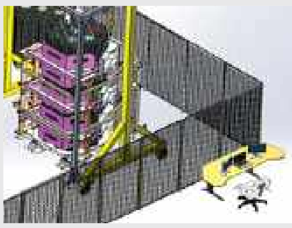
Development of alternative methodologies and tools during on-site operations

Achievements during and beyond Inno4Graph

- Testing programme is defined according to the **risk analysis associated to the graphite extraction scenario**
- Tests to be performed in the **Industrial Demonstrator** from 2022

Numerical simulations

Physical tests



Remote control tests
(from Industrial Demonstrator control room)

14

Conclusions and perspectives

5 projects, **1** common goal: to implement 4.0 Industry technologies in order to :

- Improve the knowledge reliability of the installations
- Minimise dose rates
- Facilitate the sharing of information between the stakeholders of a dismantling project

Beyond the traditional technical locks, **2** other challenges have been tackled:
- Tools and methodologies must be applicable to a maximum of various projects
- Drastic proof of safety and reliability of new technologies are required

As a result of the 5 projects :

- A unique common data and knowledge base
- New tools design or methods natively taking into account the needs of a maximum of dismantling operators. **10** different European countries are involved in the five projects, plus Switzerland, Ukraine, United-Kingdom and Japan through end-user groups.
- New test facilities have also been put in place and will allow the joint work undertaken to be continued.

→ All of this paves the way to further collaborative projects and developments, in order to continue to implement safe, reliable and efficient new technologies in European dismantling projects.

Further information: Websites and contacts

https://www.inno4graph.eu/
https://ldsafe.eu/
https://pleiades-platform.eu/
https://insider-h2020.eu/
http://cleandem-h2020.eu/

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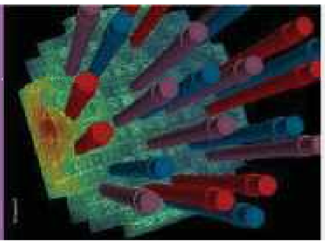
- **M.-B. JACQUES**, *CEA*, marie-benedicte.jacques@cea.fr

31/05/2022



FISA 2022

30 May - 3 June 2022
Lyon, France

KEY EUROPEAN RESEARCH INFRASTRUCTURES AT YOUR SERVICE NOW AND IN FUTURE

Petri Kinnunen, Gilles Bignan, Gabriel Pavel and
Victor Esteban-Gran

OASIS

Open access to JRC infrastructure

Benefits to users and the ERA

- Make JRC Research Infrastructures **available to external users**
- Give **access to material** requesting nuclear licence
- Provide **capacity building** to Member States and neighbour countries
- Bridge the **gap between science and Industry**
- **Dissemination** of knowledge, education and training,
- Foster **collaboration** in Europe

Benefits to the JRC

- Expand JRC **networking** capabilities
- Enter into **new key areas** of research
- Maintain JRC **scientific excellence**
- Raise the **value and visibility** of JRC research infrastructures
- Improving **JRC's testing** procedures and instruments.

https://ec.europa.eu/jrc/en/research-facility/open-access

OASIS

Objectives: Promotion of training and mobility activities in support of maintaining nuclear competences through the open access to JRC research facilities.

Start: 07/02/2020

Duration: 48 months

Budget: 750 000 €

- Free access to JRC nuclear infrastructure
- Financial Support to the user's stay can be offered to the selected projects (travel, accommodation, subsistence)
- Two schemes: short stay users and long stay users (primarily students)
- Fair and transparent method for allocating access

OASIS

JRC nuclear research infrastructure

☞ **EUFRAT** Nuclear data (Geel, BE)

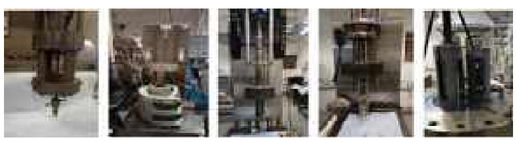
- 1. GELINA: **Neutron time-of-flight** for neutron measurements
- 2. MONNET: Tandem accelerator based **fast neutron source**
- 3. RADMET: Radionuclide **metrology** laboratories
- 4. HADES: **Underground laboratory** for γ-ray spectrometry

☞ **ACTINET** Actinides properties (Karlsruhe, DE)

- 1. PAMEC: Properties of **actinide materials** under extreme conditions
- 2. FMR: **Fuel and materials** research
- 3. HC-KA: **Hot cells**

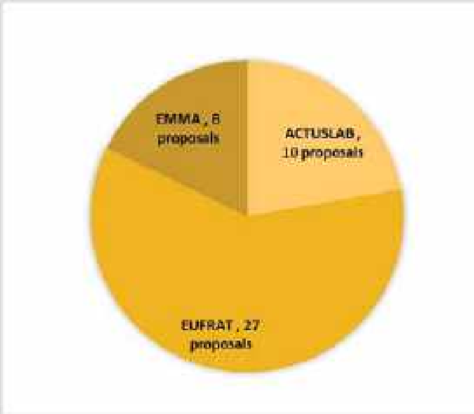
☞ **EMMA** Reactor materials (Petten, NL)

- 1. AMALIA: **Ageing of Materials** laboratory
- 2. LILLA: **Liquid lead** Laboratory
- 3. SMPA: **Structural Materials** Performance Assessment Laboratories
- 4. MCL: **Micro-Characterization** Laboratory
- 5. HFR-NB: High Flux Reactor **Neutron Beams** for residual stress measurements



OASIS

Open access calls: 45 proposals granted



- Call 2020: 43 proposals received (36 accepted, 6 reserve list (Userlab)
- Call 2021: 9 proposals received and accepted
- COVID restrictions had an important impact on the implementation

About 75 % of the projects include young researchers participation

TOURR

- Towards Optimized Use Of Research Reactors In Europe

- Duration 2020 – 2023
- 9 partners out of which 6 Research Reactors (RR) operators
- Response to the challenge of coordinating the optimization of the exploitation of available research reactors in Europe
- The primary objective is to develop a strategy for RRs in Europe and prepare the ground for its implementation with specific steps
  I. Assessment of the current status of European RR fleet
  II. Estimation of future needs of RR and neutron sources
  III. Plan for the upgrade of the RRs fleet
  IV. Plan to maintain the fleet
  V. Developing tools for optimal use of RR fleet
  VI. Rising awareness of decision makers and the public on the role of RR

TOURR

E.g. Step II: Estimation of future needs of RR and neutron sources

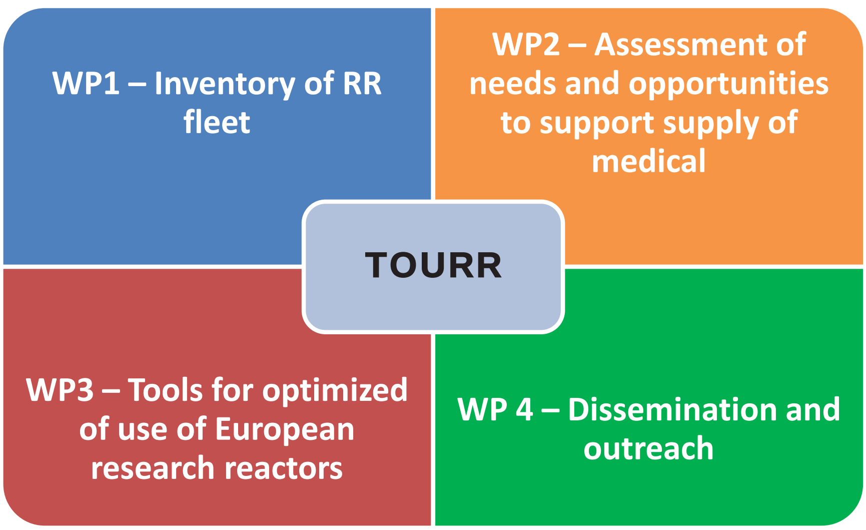
The main applications of the European RR fleet was classified into 5 categories:

a) Education and training,
b) Basic and fundamental research and its instruments,
c) Medical applications, including isotope R&D as well as beam applications,
d) Material testing, including fuel, structural material and related instrumentation,
e) Core physics testing for reactors in "zero power" installations

TOURR

- database providing information about applications, future plans, capacities of the RRs
- to perform domains: Research & Development, Medical applications and Education & Training.

- Mapping the needs for medical isotopes linked also to the new medical techniques



- strategy for optimized use of of RRs in Europe
- tools to support the implementation of the same strategy
- support the planning of refurbishment of existing research reactors or construction of new ones

- Informing and contacting relevant stakeholders and other interest groups

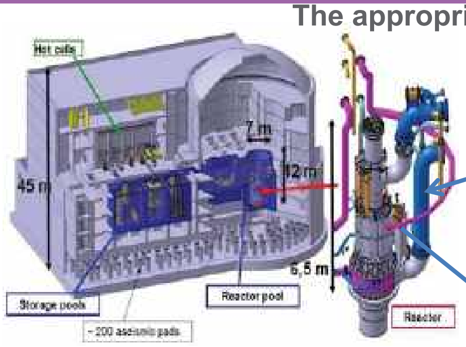
TOURR

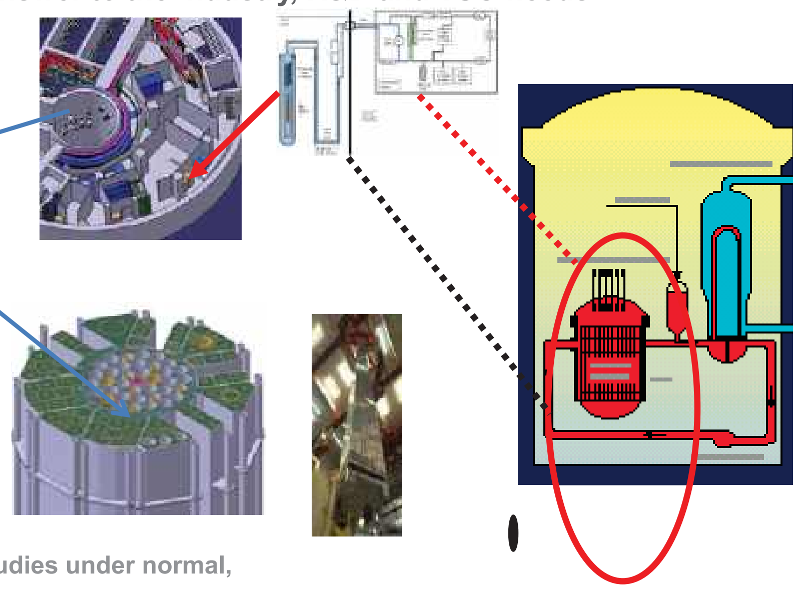
- The project is currently in the second year of its implementation.
- A survey was already conducted among European research reactors. Data received are from: Austria, Belgium, Czech Republic, France, Germany, Hungary, Italy, The Netherlands, Poland, Romania and Slovenia.
- A public report containing bulk considerations (to ensure confidentiality of the data transmitted to us by the RR) has been compiled and is available.
- Furthermore, three gap analysis on Research & Development, Medical applications and Education & Training has already been performed

www.tourr.eu

JULES HOROWITZ REACTOR

The appropriate answer to the Industry, R&D and TSO needs



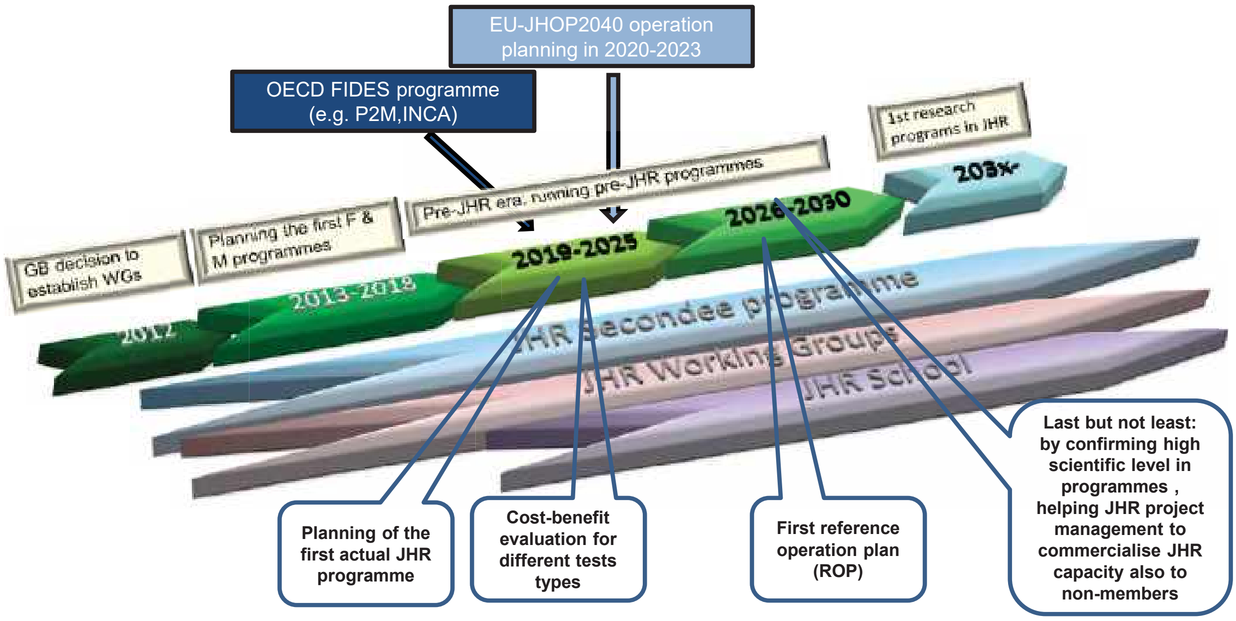


- **MTR allows to reproduce NPPs conditions for :**
  - Material screening
  - Material characterisation
  - Fuel element qualification
- **JHR Main Objectives:**

1] R&D in support to nuclear Industry (F&M studies under normal, incidental and accidental situations)
2] Radio-isotopes supply for medical application
3] A key tool to support expertise

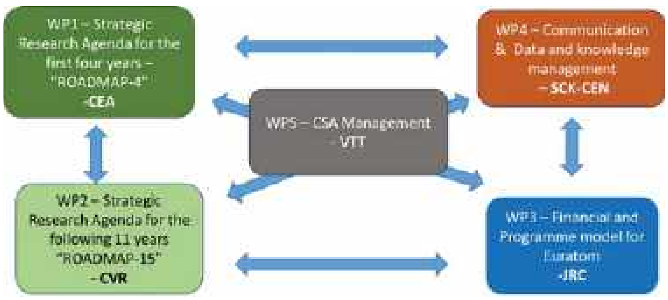
JULES HOROWITZ REACTOR

JHR time frame and tasks for co-operation (as of End-2021)

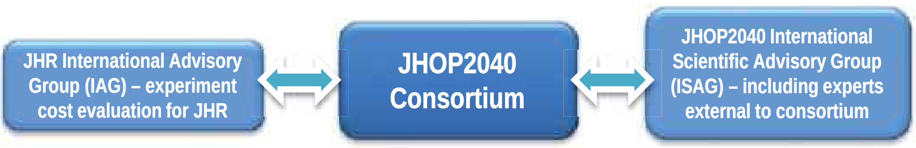


Jules Horowitz Operation Plan 2040 – JHOP2040

- Creation of the Roadmap covering at least 15 years from the start of the 1st irradiation campaign at the JHR to assure proper and effective use of the Euratom access rights (6% share)
  - Detailed irradiation plan for the 1st 4-years period.
  - Take into account availability of the specific experimental rigs at different stages of the JHR operation.
  - The Roadmap should comprise an analysis of the financial model to be used for funding irradiation experiments.



Grant Agreement No:	899360
EC Budget contribution:	1,100,501 EUR
Type of action:	Roadmap for use of Euratom access rights to Jules Horowitz Reactor experimental capacity
Duration (in months):	30
Schedule:	1st September 2020 – end 2023
Coordinator:	Petri Kinnunen, VTT Technical Research Centre of Finland Ltd



Jules Horowitz Operation Plan 2040 – JHOP2040

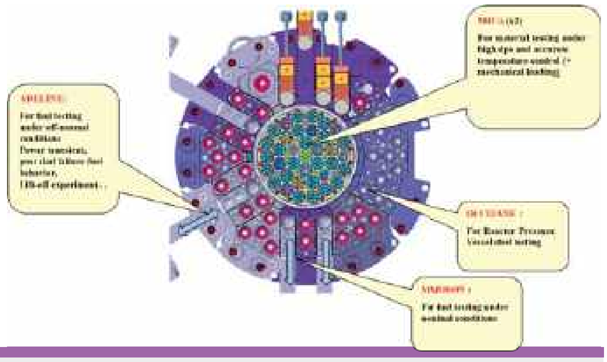
First 4-years irradiation period

- Latest information provided by the JHR consortium concerning the devices, irradiation locations, PIE facilities and transport capabilities has been created and updated – PUBLIC
- Final Synthesis Report First 4Yrs – PUBLIC

This work has been finalized.

Family	#	Topic	Type of materials	Reactor system of interest: PWR	BWR	WWER	SFR	LFR	ADS	HTR	SMR	CANDU	Fusion	Spent fuel storage (SP)	JHR exp. device	GLOBAL PROGRAM RANKING
RPV	1	Embrittlement: effect of neutron dose	low alloy steels, including MnMoNi (e.g. SA-533, Grade B, Class 1; SA-508, Class 2, 15MNi5), MnMo (e.g. SA-302, Grade B), CrMoV (e.g. 15Kh2MFA base metal, Sv-10KhMFT weld metal) and NiCrMo (e.g. 15Kh2NMFA), '18-8' stainless	x	x	x	x	x	x	x	x				OCCITANE	3
	2	Embrittlement: effect of neutron flux		x	x	x	x	x	x	x	x				OCCITANE	3
	3	Embrittlement: Effect of neutron spectrum		x	x	x	x	x	x	x	x				OCCITANE	2.5

Fuel test device (first fleet)	TO (mid N-1)	Year N (T0+1)	Year N+1	Year N+2	Year N+3	Year N+4
ADELINE		Tests for validation of the performance	Qualification of the experimental domain/non regression	Qualification of the experimental domain/non regression	Experimental programs : 2 tests dedicated to JHR Consortium (with the hypothesis of a total number of up to 6)	Experimental programs : 2 tests dedicated to JHR Consortium (with the hypothesis of a total number of up to 6)
		1 test ("ADE1" test) open to the validation of specific performance directly linked to Euratom needs	1 test ("ADE2" test) open to Euratom participation on some specific points when qualifying the experimental domain or checking the non-regression	1 test ("ADE3" test) open to Euratom participation on some specific points when qualifying the experimental domain or checking the non-regression	1 test ("ADE4" test) more specifically oriented on Euratom topics of interests	1 test ("ADE5" test) more specifically oriented on Euratom topics of interests
MADISON		Tests for validation of the performance	Qualification of the experimental domain/ non regression	Experimental programs : With the hypothesis of a total number of [illegible] experimental irradiation cycles per year	Experimental programs : With the hypothesis of a total number of [illegible] experimental irradiation cycles per year	Experimental programs : With the hypothesis of a total number of [illegible] experimental irradiation cycles per year
		2 cycles open to Euratom participation "MAD1" test	2 cycles open to Euratom participation "MAD2" test	2 cycles open to Euratom objectives "MAD3" test	2 cycles open to Euratom objectives "MAD4" test	2 cycles open to Euratom objectives "MAD5" test



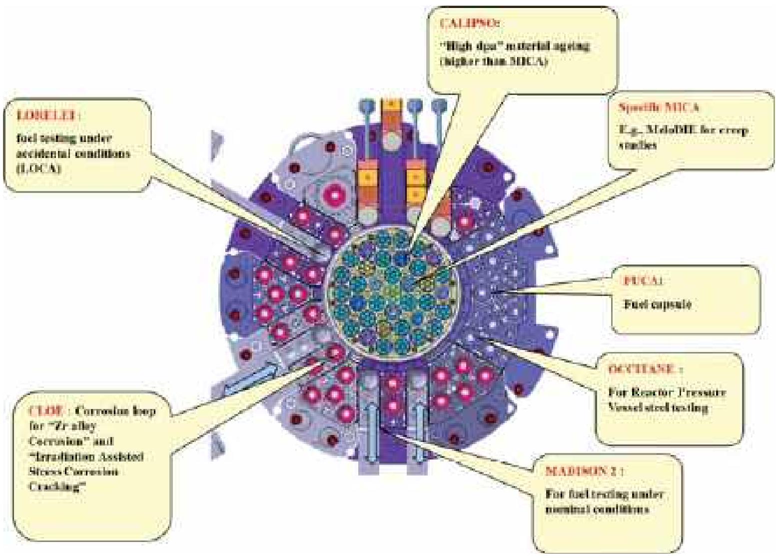
Jules Horowitz Operation Plan 2040 – JHOP2040

Long-term roadmap (after first irradiation period)

- Exposures with **intermediate discharges**, irradiations under **variable conditions**, irradiations in association with **loading or corrosion**
- Testing of nuclear fuels in **design basis accident / design extensions** conditions and innovative testing of nuclear fuels
- Testing of **sensors and other novel equipment** coming from the M&F needs

→Synthesis report on the plans for the material and fuel studies and technology development in the long term in April 2022.

This work is in progress.



Jules Horowitz Operation Plan 2040 – JHOP2040

Programme structure and Governance model

- Feedback for optimizing the next 4-year **Reference Operation Plan (ROP)**
- Resources analysis providing information on the **available and foreseen technologies**
- Guidance for the **development of new experimental devices** using first operation feedback
- **Cost breakdown model** giving the basis for evaluating the individual cost of each experiment.

www.jhop2040-h2020.eu/

JHR – Euratom stakeholders network

- Goal: to develop **stable and permanent communication links** with interested EU stakeholders ensuring the effective use of Euratom access rights
- Two groups of EU organisations; **members of the JHR consortium and non-members but interested**
- JHR-ESN objective: **structure, compile and consolidate their irradiation needs** for experiments at JHR in the frame of the available Euratom access rights
- Roles:
    - **Working groups**: mirroring the active JHR working groups
    - **Steering Committee**: EU members of the JHR Consortium and external members with geographical and functional diversity. Suggested CEA as permanent member of the SC.
    - **European Commission roles**: JRC as secretariat/coordinator; RTD as permanent observer

EURATOM ACCESS RIGHTS TO JHR

The EC (Euratom-JRC)- considering its contribution to the construction- gets:

- 6 % of guaranteed Access Rights to JHR experimental capability for the whole life of operation of the reactor
- 6 % of voting rights in the JHR Consortium.

- Access Rights can be cumulated to some extend from one year to the following in order to implement greater research programs in one specific year
- Access Rights are to be converted to Access Units, that take into account the experimental capacity of the JHR and the various factors associated to each experiment type

Preliminary weight factors of different experiment types in the JHR

Kind of experimentation	Fixed part			Variable part			Impact factor (Fuel consumption, performances,...)	"Weight" total
	Neutron flux factor	Equipment complexity factor	Utilities (water, electricity,...)	Volume factor	Operation complexity factor	Services (NDE, FP lab, hot cells,...)		
MADISON	1	3	2	1	3	2	---	12
ADELINE	1	3	1	1	2	2	---	10
MICA	1	2	1	1	2	0	1	8
specific MICA	3	2	1	1	2	1	2	12
LORELEI	2	3	2	1	3	3	---	14
OCCITANE	1	1	0	3	1	0	2	8
CALIPSO	3	2	2	2	3	3	1	16
CLOE	1	3	2	1	2	2	1	12
Fast reactor support	3	3	2	2	3	3	---	16
Boiling device	1	2	1	1	1	2	---	8

Access units per experiment and per cycle

EURATOM ACCESS RIGHTS TO JHR

Euratom access rights in practise:

- 6 % of Access Rights represents about 79 Access Units per year (6% of 1318).
- E.g., the EC with its 6 % Access Rights can have access each year to:
  - 7 to 8 Ramps type experiments using ADELINE device,
  - or 6 Fuel loop irradiation type experiments using MADISON device,
  - or 3 Material capsule type experiments.

Example of loading plan A.U. = Access Units			
Type of experiment	Associated Access Unit per experiment and per cycle	Number of JHR locations for the type of experiment considered	Cumulated number of Access Unit per year (on the basis of 7 cycles per year)
Fuel ramps studies (ADELINE)	10	3	210
Fuel loop steady-state studies (MADISON)	12	2	168
Fuel loop for LOCA studies (LORELEI)	14	0,3 (we consider only 3 LOCA tests per year)	30
Fuel capsule studies (FUCA)	10	4	280
Material capsule studies in core (MICA)	8	3	168
Advanced MICA in core	12	2	168
RPV studies in reflector (OCCITANE)	8	2	112
Corrosion studies (CLOE)	12	1	84
FR material studies	14	1	98
TOTAL	100		1318

Thank you for your attention

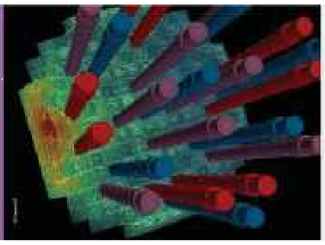

FISA 2022
EURADWASTE'22

JOINT CONCLUSION FISA 2022 / EURADWASTE '22

Co-chair: Philippe STOHR (FR, CEA)

Co-chair: Bernard MAGENHANN (EC, DG JRC)

Rapporteur: Henri PAILLERE (FR, Expert)



FISA 2022

30 May - 3 June 2022
Lyon, France

Joint conclusion FISA 2022 / EURADWASTE ’22:

FISA 2022 - Key messages and future perspectives

H. PAILLERE with input from
Ferry ROELOFS, Teodora RETEGAN VOLLMER and Said ABOUSAHL

Joint Introduction Session (1)

- **Challenging times/opportunities**: war in Ukraine, high energy prices – and climate change
  - A time to revisit the role of Nuclear Energy in our energy systems and its contribution to net zero
  - Eg. RepowerEU explicitly mentions nuclear energy for its contribution to strengthening security of energy supply, and as a potential source of low C hydrogen
  - More and more EU countries looking at nuclear ; EU investing in SMRs
- **Euratom treaty 65 years old**
  - Europe can be proud of its achievements, how it build up competence in the nuclear energy sector, from fission to fusion
  - EU regulatory framework for safety and radwaste management
  - European Commission wants to exploit synergies, across sectors – and financial instruments
  - Marie Skłodowska-Curie actions (25y old) opened to nuclear research
- This conference is an **opportunity to learn and share knowledge through the outcomes of Euratom research programmes**
  - Hear recommendations from the research community
  - Better inform policy-makers about the future potential of NE but also challenges to be addressed, for example the ageing workforce
- **A tribute to Bernard Bigot**, recognized scientist and promoter of nuclear research

Joint Introduction Session (2)

- **Rosalinde van der Vlies on behalf of Mariya Gabriel, Commissioner**
  - Research to build public confidence and acceptance, to make the nuclear sector more resilient and to attract young researchers
- **Claire Giry, Directrice Générale de la recherche et de l'innovation, France**
  - Nuclear science and technologies, an answer to the climatic crisis, the energy crisis and the health (cancer) crisis
- **Laurent Michel, Directeur General Energie et Climat, France**
  - Need for decarbonized energy (beyond decarbonized electricity): heat, H2
  - R&D challenges: Long Term Operation, High level waste and decommissioning, new technologies and construction
- **Rafael Mariano Grossi, DG IAEA**
  - Importance of knowledge sharing
  - Make (nuclear research) more visible to the public is how we demystify nuclear and allow people to make decisions based on science, rather than fear or ideology

Joint Introduction Session (3)

- **William D. Magwood, IV, DG OECD/NEA**
  - Today's crises are a wake-up call for the sleeping giant (nuclear energy), until recently considered an old technology with ageing staff
  - Have to go back to the 1960s to see so much excitement about nuclear energy
- **Francois Jacq, Administrateur Général, CEA**
  - New way of assessing the role of nuclear energy: integrated vision, complementarity between technologies, smart grids, flexibility of nuclear "offer": size, products
  - This leads to new research/innovation needs, importance of working together, especially at European level (example sharing infrastructures)
- **Baiba Miltoviča, European Economic and Social Committee**
  - Energy is more and more expensive → energy poverty
- **Marta Ziakova, Chair of the European Nuclear Safety Regulators Group**
  - Transparency and continuous enhanced nuclear safety are the two pillars of Nuclear Safety in Europe

Joint Introduction Session (4)

- **Yves Debazeille, DG FORATOM,**
  - without securing sufficient funding for research in the nuclear sector, the European Union will fall behind its competitors: serious consequences on EU targets related to climate, energy prices, and security of energy supply
  - It is time for Europe to rethink its position as a serious player in the nuclear sector.
- **Jadwiga Najder, Chair of the Young Nuclear Generation of ENS**
  - (Listen) to the perspectives of the youth
  - 36% of global nuclear workforce is 55y+

Session 1: Safety of Nuclear Installations (1)

- New nuclear reactors require **continuity in policy, a favorable regulatory context** and **financing mechanisms** reconciling revenue visibility and stable costs for customers.
- An **EU SMR partnership** is under preparation to support achieving **carbon neutrality** in Europe by 2050 and **sustainability** over the long term.
- With respect to safe and continued operation of current and future nuclear power plants:
  - Development, maintenance and preservation of **databases**, **advanced instrumentation**, advanced **destructive and non-destructive techniques**.
  - Development of **multi-scale multi-physics modelling and simulation tools**.
  - Simulation methods should be directly applicable to **industrial contexts**, **easy in use**, **robust**, **transparent**, available with **validated** software.
  - Exploiting and developing the use of transparent and robust **artificial intelligence** techniques.
  - Implementation of **uncertainty quantification** and **sensitivity analysis** as a standard.

Session 1: Safety of Nuclear Installations (2)

- It is important to improve the understanding of **phenomena influencing materials and components performance**.
- New code and fuel developments are encouraged in the field of **independent supply** for the existing and future VVER reactors in Europe.
- Experiments, instrumentation, and simulations should go hand-in-hand, **strengthening** each other and pushing each other **to the limits**.
- Novel **low enriched uranium fuels** for **research reactors** need to be tested and demonstrated for various high performance European research reactors.
- Guidelines to **design and implement new accident management procedures**, **validated simulation tools** (including **verification experiments**) and **safety devices** (including innovative passive safety systems) are expected and under development.
- There is a strong call to **set-up and maintain databases** collecting historic and new data for **validation and verification**.

Session 2: Advanced nuclear systems and fuel cycles (1)

- In this Session, some of the EURATOM Programme priorities were addressed, which are of paramount importance as these **projects and activities are contributing directly to the criteria for taxonomy compliance of nuclear projects** in line with the recommendations of the JRC report.

- Making nuclear energy more sustainable will require innovative thinking and technology breakthroughs allowing the **closing of the nuclear fuel cycle** as well as **advances in material science** and the **processing and disposal of nuclear waste**, including HLW.

Session 2: Advanced nuclear systems and fuel cycles (2)

- Realizing the **potential of nuclear energy to contribute fully to the decarbonization** of our energy system will require **extending the portfolio of nuclear technologies**, in large-scale installations as well as future SMRs, **beyond electricity production** towards other applications, such as heat and hydrogen production.

- This needs to happen **timely** and at the same time with full respect of utmost **priority on nuclear safety, transparency and public acceptance**.

Session 3: E&T, RI, LD radiation protection, decommissioning and int. coop. (1)

- This session focussed on **horizontal pillars**: Training, Education, Knowledge Management, Open access of European Nuclear Research Facilities
- **Synergies**:
  - Fusion and Fission (an opportunity to promote scientific exchange across communities within the Euratom Programme (Fusion/Fission)
  - Nuclear Medical Applications
  - Radiation Protection
  - Decommissioning

- Also a number of **posters** addressed these topics

Session 3: E&T, RI, LD radiation protection, decommissioning and int. coop. (2)

Education & Training / KM: attracting, developing and retaining young talents

- All the projects in sessions 1 and 2 have specific ET and KM components.
- **General Nuclear E&T** is done through projects such as ENEN+, or on thematic areas:
  - ENEN+ project: grant of more than 535 mobilities to BSc, MSc, PhDs and other young professionals to perform an E&T activity outside of their home country.
  - A-CINCH project: Augmented Cooperation in Education and Training in Nuclear and Radiochemistry, covers Nuclear wiki database of teaching materials Open Educational Resources to be shared, or Massive Open Online Courses.
  - ENEEP (European nuclear experimental education platform) demonstrates the European dimension of E&T activities, and a high attractiveness of the courses offers.
- **Knowledge Management**: a platform is being developed to improve the accessibility to the results of various EURATOM funded projects. The pilot project focuses on recent “materials projects”.

Session 3: E&T, RI, LD radiation protection, decommissioning and int. coop. (3)

Medical applications of ionizing radiation and radiation protection for European patients, population and environment

- Scientific evidence is to be comprehensively translated into procedure and practice guidelines as well as into policy recommendations, beyond the classical exploitation of scientific publications
- Several projects target applications of radiation in medicine:
  - Cancer treatment
  - Cardiology
  - Diagnostic exposures

Towards effective radiation protection based on improved scientific evidence and social considerations – focus on Radon and Naturally-Occurring Radioactive Materials

- RadoNorm aims at managing risks from radon and NORM exposure situations to assure effective radiation protection based on improved scientific evidence and social considerations.

Session 3: E&T, RI, LD radiation protection, decommissioning and int. coop. (4)

Radiation protection research and innovation

- MEENAS consortium of six European radiation protection research platforms behind PIANOFORTE partnership which aims to provide a European scientific and technological basis for a robust system of protection and consolidated science-based policy recommendations to decision makers.
  - In the long term, these efforts will translate into new and improved practical measures and better outcomes for the effective protection of people (public, workers, patients) and environment.

How to make the dismantling operations more efficient, safer and more cost-effective: SHARE - A roadmap for Research in Decommissioning

- Identifying the needs and opinions of stakeholders throughout the value chain. The project also considered existing and emerging innovative solutions, as well as international best practices in nuclear decommissioning.
- Need to rapidly bring to maturity technologies (digital technologies, automatised or semi-automatised robotics, LASER cutting). It is the common objective of the five European projects (INNO4GRAPH, LD-SAFE, PLEIADES, CLEANDEM and INSIDER).

Session 3: E&T, RI, LD radiation protection, decommissioning and int. coop. (5)

Supporting access to pan-European Research Infrastructures and International Cooperation

- OASIS: The current scheme of open ACCESS to JRC's infrastructure helps to bridge the gap between high and less wealthy institutions in the EU. The selection procedure is based on scientific merit of the proposals.
- The strategic planning for optimising the use of the research reactors (TOURR project) is on-going at the same time when one of the most important future research facility, namely the JHR, is under construction. On the other hand, the JHR will aim at new generation of research capacity with the wide experimental device fleet under construction.

The experiences gathered in the implementation of open access projects in previous and current Euratom research & training programmes, are a very good basis to be used for the design of future schemes, for all kinds of nuclear facilities.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ANNEX 2 - SIDE EVENTS

NUCLEAR INNOVATION PRIZE

Multicomponent Nuclear Fuel Cladding with Safety and Operational Benefits

Martin Sevecek[1], Ladislav Cvrcek[1], Jakub Krejci[2], Pavel Suk[1], Adela Chalupova[1] and Tereza Kinkorova[1]

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[2]UJP Praha, a.s., Nad Kaminkou 1345 156 10 Praha – Zbraslav, Czech Republic

Traditional Nuclear Fuel Cladding

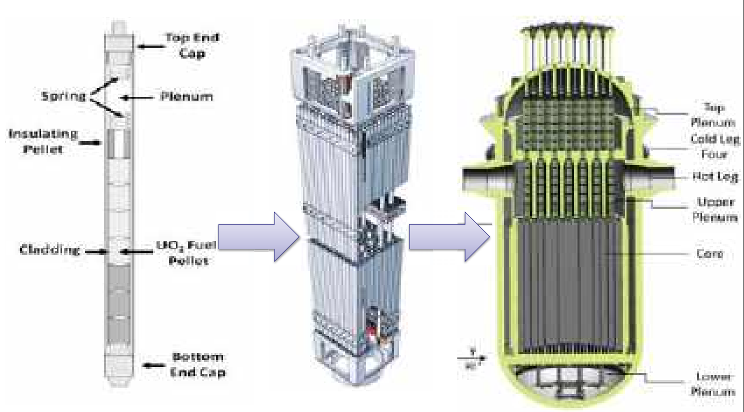
Zirconium-based alloys: The Only Cladding Material used TODAY!

✓ Reactor Physics: Low Neutronic Absorption and Scattering
✓ Heat Transfer: High Thermal Conductivity
✓ Mechanical Performance: High strength and ductility

BUT

❖ Hydrogen absorption and consequent embrittlement limit the amount of extractable energy
❖ Accelerated chemical reaction with steam producing excessive heat and releasing explosive hydrogen
❖ Rapid cladding embrittlement due to oxygen absorption during hypothetical accidents
❖ Cladding failure during Fukushima or Three Mile Island events

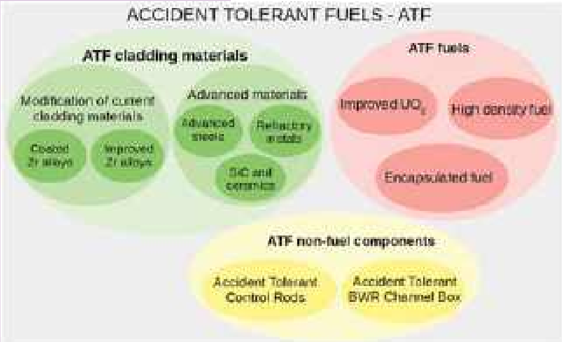
These motivate the development of Accident Tolerant Fuels



Accident Tolerant/Advanced Technology Fuels

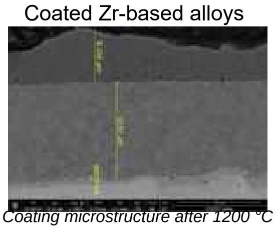
ATFs are advanced materials that can tolerate hypothetical severe accidents for a longer time period while maintaining or improving the fuel performance during normal operations.

Fuel, cladding and non-fuel core materials under consideration:



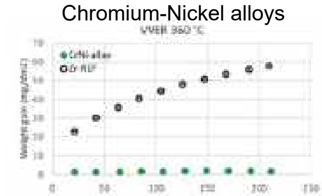
CLADDING CONCEPTS

Coated Zr-based alloys



Coating microstructure after 1200 °C transient test

Chromium-Nickel alloys



Corrosion kinetics of Cr-Ni alloy in simulated VVER environment

SiC/SiC composite

SiC cladding after steam oxidation test

FeCrAl alloys

FeCrAl/Mo coated cladding after creep test

Coated Zr-based Cladding

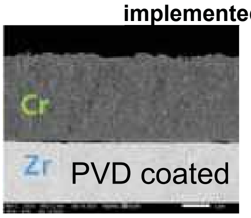
Many coating materials and designs were proposed and tested:

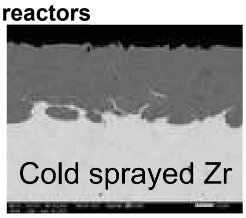
- Cr-based metallic coatings
- Ceramic coatings (carbides, nitrides)
- Hard fretting resistant coatings
- High-temperature resistant Si- and Al-based coatings

Material deposition shall be done at a lower temperature to avoid Zr annealing, several methods can be used:

- Physical Vapor Deposition methods (e.g. magnetron sputtering)
- Thermal spray techniques (e.g. cold spray (CS))
- Chemical and electrochemical methods

Cr PVD and CS coated Zr most advanced already implemented in commercial reactors

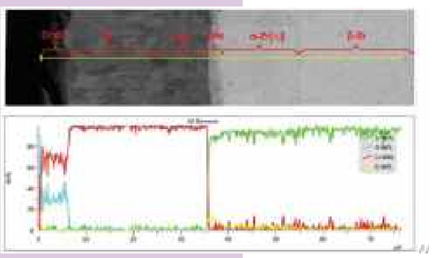




Several issues were identified for the Cr coated Zr-based claddings:

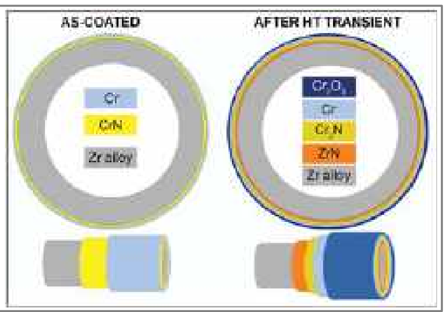
❖ Cr-Zr interdiffusion limiting the protectiveness of the coating and causing enhanced embrittlement of Zr
❖ Cr-Zr eutectic reaction at around 1330 °C
❖ Limited additional coping time due to inner oxidation and secondary hydriding

Multicomponent Coatings



✓ CrN acts as a diffusion barrier between Zr and Cr
✓ CrN interlayer delays the eutectic reaction
✓ CrN limits the interdiffusion and enhances ductility
✓ CrN reduces corrosion even with defective outer Cr
✓ CrN enhances fretting resistance of the coating system

❖ Ceramic CrN has limited ductility compared to Cr
❖ Free N_2 might enhance oxidation for a short time



MITIGATION AND REAL TIME MONITORING OF ACOUSTIC RESONANCES IN MAIN STEAM SYSTEMS OF NUCLEAR REACTORS

FISA 2022

David Galbally[1] , Jesus Hernando[2]

[1] Innomerics – Managing Director – Virgilio 25-A 28223 Pozuelo de Alarcon

[2] Iberdrola Nuclear Generation – Project Manager -Tomas Redondo 1 28033 Madrid

THE PROBLEM OF ACOUSTIC RESONANCES

The nuclear fleet worldwide has experienced a relatively high number of events related to damage sustained by different main steam components and reactor internals caused by acoustic resonances. In some cases, this damage has resulted in the malfunction of safety related equipment

Until now, elimination of acoustic resonances required costly modification of the main steam lines, in order to change the geometric dimensions governing the acoustic modes of the system

The innovation of the work presented in this application is twofold: first, the consortium formed by Iberdrola and Innomerics has developed a first-of-a-kind sleeve that can be integrated in the nozzle of safety relief valves in order to eliminate resonances without any need for modifying the main steam system. Second, a non-invasive real-time monitoring system has been developed, implemented and tested

REAL TIME MONITORING SYSTEM

The goal of the monitoring system is to achieve real-time reconstruction of the pressure field inside the main steam system of a nuclear reactor based on a limited number of non-invasive pressure measurements.

This system is capable of determining the amplitude of the pressure waves inside the main steam lines and providing valuable information to the plant operator in order to avoid continued operation in regions where the resonance intensity is capable of damaging the valves or other safety related equipment.

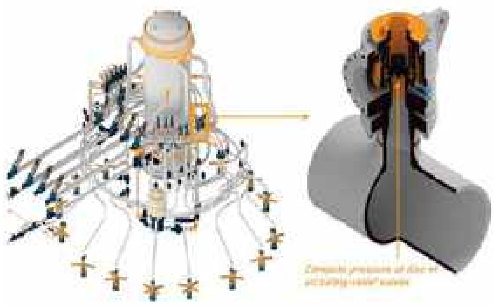


Figure 1. 3D Model of the main steam system of the boiling water reactor where the monitoring system was tested (left) and cross-section of one of the safety relief valves showing the valve disc where acoustic pressure due to resonances reaches its maximum value (right).

THE FOUR INGREDIENTS FOR REAL TIME MONITORING

A high-fidelity aeroacoustic model with over 10^6 degrees of freedom

A reduced order model that enables real-time computation of the outputs of interest

$$\begin{cases} \dot{p}(\boldsymbol{x},t) = f_r(p(\boldsymbol{x},t),u(\boldsymbol{x},t)) \\ y_r(t) = g_r(p(\boldsymbol{x},t),u(\boldsymbol{x},t)) \end{cases}$$

Sensor data collected from non-invasive sensors installed at different locations

Inverse problem formulation that allows reconstruction of the pressure field

$$u(\boldsymbol{x},t) = \arg\min \|g\|_2^2$$

s.t.

$$\dot{p}(\boldsymbol{x},t) = f_r(p(\boldsymbol{x},t),u(\boldsymbol{x},t))$$

where

$$g = p(x_{sensors},t) - p_{measured}(x_{sensors},t)$$

SCALE MODEL VALIDATION

A scale model test facility was built for testing and validating the monitoring system and the mitigation device that were developed during the project. Nondimensional similarity was used extensively in order to develop a test facility capable of replicating the aeroacoustic behavior of the full-scale steam system of a BWR while using air at ambient conditions as the test fluid.

In addition to scale model testing, CFD simulations were also performed in order to develop and validate the design of both the monitoring system and the resonance mitigation device.

Figure 2 Scale model of a complete main steam line; (2) detail of a single SRV branch line and (3) data acquisition system with 80 high-frequency dynamic pressure channels.

THE INSTRUMENTATION CHALLENGE

The main challenge for developing a monitoring system capable of determining the acoustic pressure is that it is almost impossible to install a pressure sensor in primary pressure boundary.

A non-invasive pressure sensor has been designed and manufactured formed by a ring of strain gages welded to a thin metal band. The ring is not welded to the pipe surface, so it can be easily mounted and removed, thereby minimizing personnel dose during installation.

Figure 3 Photograph of an actual pressure measurement ring installed on a main steam line, before covering it with thermal insulation (right) and after installing the reflective thermal insulation over it (right).

ACOUSTIC RESONANCES MITIGATION DEVICE

A device capable of eliminating resonances without the need for costly modifications to the geometry of the main steam system itself, thereby dramatically reducing the cost and dose associated with the implementation of the modification. The three critical requirements stated at the start of the mitigation device development project are stated below:

- **Requirement 1**: No need to perform any modifications to the primary pressure boundary
- **Requirement 2:** Reversible. Easy to return to original configuration
- **Requirement 3:** Significant improvement over other OEMS mitigation devices

Figure 4 Scaled mitigation device prototype designed

The effectiveness of the proposed mitigation device was tested using the same scale model test facility built for the development and testing of the monitoring system described.

CAPABILITIES OF THE GPU-BASED DYNAMIC MONTE CARLO CODE GUARDYAN

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Project summary

Targeting ultimate fidelity coupled reactor physics and thermal-hydraulics calculations has recently entered the forefront of reactor safety analysis research enabled by the vast forward leap of High-Performance Computing (HPC). Our project has achieved a breakthrough by introducing Graphics Processing Units (GPUs) to the prodigiously progressive Dynamic Monte Carlo (DMC) method, where time dependence is handled explicitly rather than by a series of static calculations, achieving simulations very faithful to nature. In 2016 the **GUARDYAN** (GPU Assisted Reactor Dynamic Analysis) code development started and recently reached the capabilities to accomplish full core VVER-440/V213 calculations with meaningful detector reading simulation results.

Validation with BME Training Reactor measurement

An experiment was conducted at the BME TR at zero power by shooting a Cd foil rolled up to form a cylinder (0.5 mm thick, 4 cm high, 9 mm in diameter, with weight of 4.3 g) into the core using a pneumatic rabbit system. The sample arrives approximately to the middle of the core, is left there for 1.5s and then is quickly withdrawn. Total power time evolution was modelled by GUARDYAN.

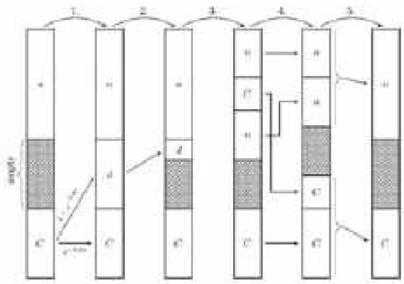


Figure 1: Neutron population maintenance scheme

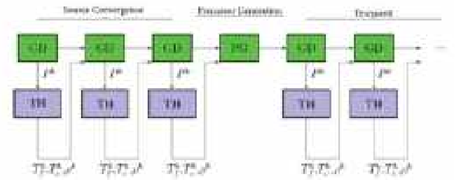


Figure 2: Thermal-Hydraulics coupling scheme

GUARDYAN main features

- GPU-based Monte Carlo engine, NVIDIA CUDA 11.6 environment
- Constructive solid geometry for material composition and geometry
- ENDF/B-VII.1 in ACE format, continuous energy handling
- Constant-sized population with frequent statistical combing, including delayed neutrons (see **Fig**. 1)
- Advanced variance reduction techniques with adjont based population combing
- Coupled to SUBCHANFLOW, a subchannel thermal-hydraulic solver (see **Fig**. 2)
- Extensive verification process with comparison to MCNP, Serpent-2 and TRIPOLI

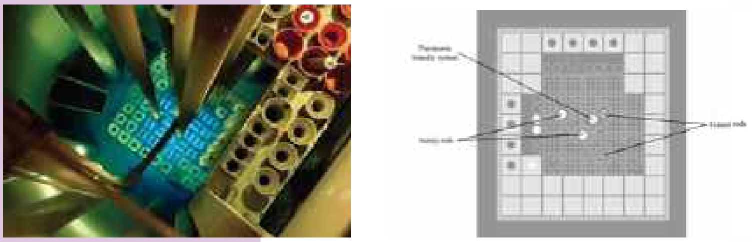


Figure 3: BME TR geometrical structures, transversal cross section (right) and a photo of the same core (left) during operation. Cd sample is shot in the core by a pneumatic transfer system.

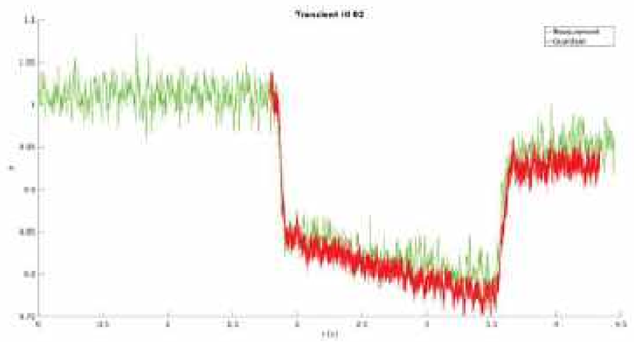


Figure 4: BME TR total power time evolution measured and modelled with GUARDYAN

Validation with a full VVER-440 core with burnup of Paks NPP, Unit 4

A recent (2019) asymmetric rod-drop experiment was modelled with GUARDYAN and the Paks NPP in-house diffusion code VERETINA. 3 ex-core detector readings were reproduced accurately. Pin-wise core modelling included a detailed burnup map.

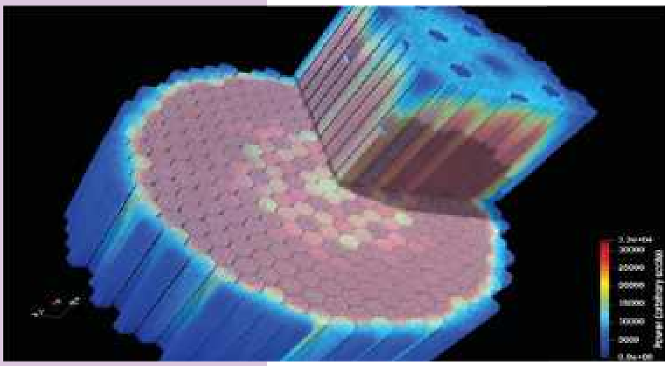


Figure 6: Paks NPP Power distribution at the beginning of the transient, simulation results of GUARDYAN

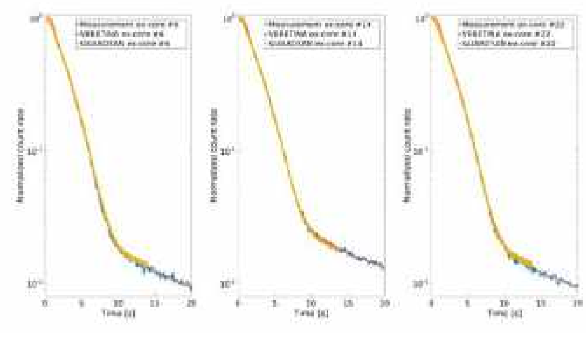


Figure 5: Paks NPP Ex-core detector signals modelled: calculations fit measurements excellently

Conclusions

The code GUARDYAN fused existing and novel Monte Carlo techniques with GPU-based high-performance computing advocating DMC to be the gold standard of reactor physics, a calculation tool devoid of obscure approximations. A high-fidelity simulation tool enables more optimal use of design safety margins and creates room for efficiency improvement of power plants.

Passive decay heat removal function for the LDR-50 low-temperature nuclear reactor

FISA 2022

VTT

Ville Tulkki, Jaakko Leppänen (presenting), Ville Hovi, Joona Kurki, Ville Valtavirta, Seppo Hillberg and Rebekka Komu

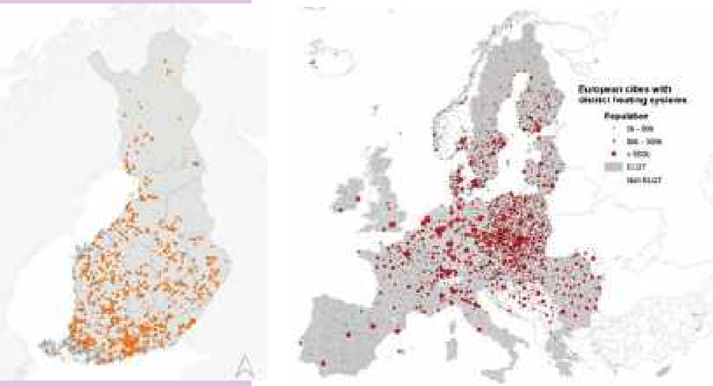
VTT Technical Research Centre of Finland Ltd

Challenge: de-carbonization of the energy sector

- IPCC scenarios: Global CO2 emissions must be reduced to zero by 2055.
- Meeting the climate goals requires a comprehensive energy transition, and liberating entire industries from fossil fuels.
- In many countries climate actions have so far been focused on electricity production.
- Heating is another major source of CO2 emissions, especially in countries with cold winter climate.
- Heat, unlike electricity, cannot be transported cost-effectively over large distances.

Case Finland:

- Almost 50% of Finnish houses, residential and commercial buildings are connected to a local district heating network.
- More than 80% of domestic electricity production is covered by low-carbon technologies, but fossil fuels are still used for co-generation of heat and power.
- Goverment-issued phase-out for coal by 2029.
- Similar challenges in several European countries.
- War in Ukraine has brought serious concerns on the security of supply.

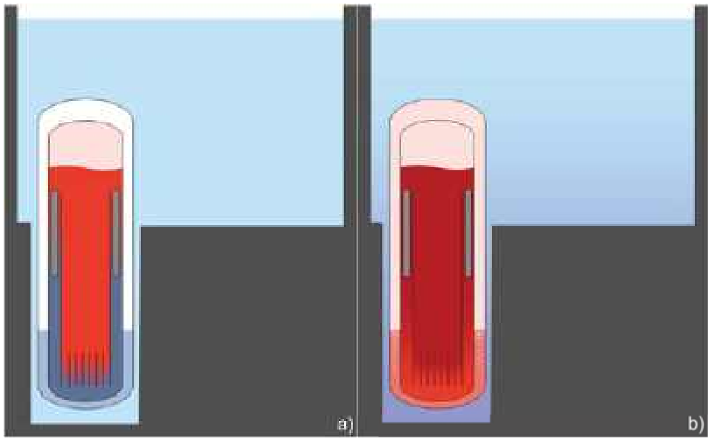


What about nuclear energy?

- District heating networks operate at around 65-120 °C temperatures.
- The operating regime can be easily reached with any nuclear reactor technology.
- Low-temperature district heating reactors were extensively studied and developed in the Nordic countries in the 1970's and 1980's.
- Renewed interest in recent years, following the challenges related to the decarbonization of the heating sector.
- Since the market is divided into a large number of independent networks, most conventional SMRs are too large to meet the demand.

VTT's district heating reactor project:

- LDR: "Low temperature district heating and desalination reactor".
- The project was launched in March 2020.
- Aim is to develop a low-temperature SMR for the Finnish and European heat market.
- Combination of conventional LWR technology and innovative passive safety design.
- Primary circulation by natural convection, connection to district heating network via secondary circuit and heat exchangers.
- Simplified design, taking advantage of low operating temperature and pressure (< 150 °C / < 1 Mpa).
- Modular technology – the heating plant may be comprised of one or several 50 MW LDR-50 units.
- Designed primarily for district heating, but the same technology can be applied to desalination.



The innovation:

- The low operating temperature of the LDR-50 reactor enables passive decay heat removal without any mechanical moving parts.
- The reactor units are submerged in a pool of water, and comprised of an inner reactor vessel and outer containment.
- The containment space is partially filled with water.
- In normal operation (a), temperature at the lower part of the reactor vessel remain below 100 °C.
- When heat transfer through primary heat exchanges is compromised (b), temperature at the bottom begins to rise.
- Water in the containment space begins to boil, forming an efficient heat transfer route into the pool.
- Patent for the invention granted in 2021.

Questions?

Email: Jaakko.Leppanen@vtt.fi

FISA PhD PRIZES

EURADWASTE'22

30 May - 3 June 2022
Lyon, France

Model Based System Engineering

An industrialization path for decommissioning projects

assystem

Speaker: Mihaela RACAPE

Process Technical Leader

10th European Commission Conference on EURATOM Research and Training in Radioactive Waste Management
30 May - 3 June 2022 | Lyon, France

Complexity and risks of decommissioning projects

Challenges for the Owner

How to conciliate **conditions of work** and **skills' availability** when D&D operations start?

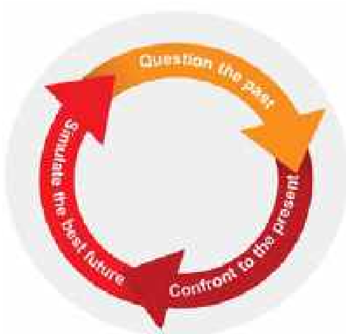
How to **lower cost** & **risks** of **uncertainties: radiological, physical and regulatory**

What kind of **technical development** to **industrialize dismantling operations** – large range of technologies, different radioactivity level?

Reduce the level of risk :

- Good **competencies pre-requisite** : necessary but not sufficient
- Work on **DATA & REQUIREMENTS**

Rebuilding the decision making process thanks to **System engineering**



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Assystem's methodology and key assets

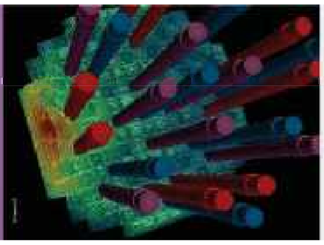
❶System Engineering and developpement of Model Based System Engineering

- Rationalize the needs with the project owner
- Identify data and requirements throughout the life of the project. In design phase, the management of the requirements is placed at the heart of the design and used to guide its development, assess its progress and progressively validate it.
- Adapt the architecture of the solution
- And manage its optimization through a quick and self-coherent follow-up of modifications.

❷ Digitalization In addition to the system engineering method based on requirements, one of the key is to manage and work around data at the different stages of the project, not only for design but also at the operator levels => implementation of digital tool to operate the project

Client’s benefits

- **Streamline requirements** with the project owner,
- **Identify data and needs** throughout the life of the project,
- **Adapting the solution architecture** and define the building blocks of the decommissioning installation,
- **Manage its optimisation through rapid and self-consistent monitoring of changes,**
- **Contribute to operational excellence** in the preparation, supervision and monitoring of the institution's operations,
- **Improve the traceability/quality/reliability** of the data acquired on the site, its exploitation and its dissemination,
- **Bring together all the players** (owner, industrial operators) around a shared collaborative space with access to data acquired on site,
- **Increase productivity.**



FISA 2022

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PARUPM: A SIMULATION CODE FOR PASSIVE AUTOCATALYTIC RECOMBINERS

Araceli Domínguez-Bugarín[1], Miguel A. Jiménez[2], Ernst-Arndt Reinecke[3] and Gonzalo Jiménez[1]

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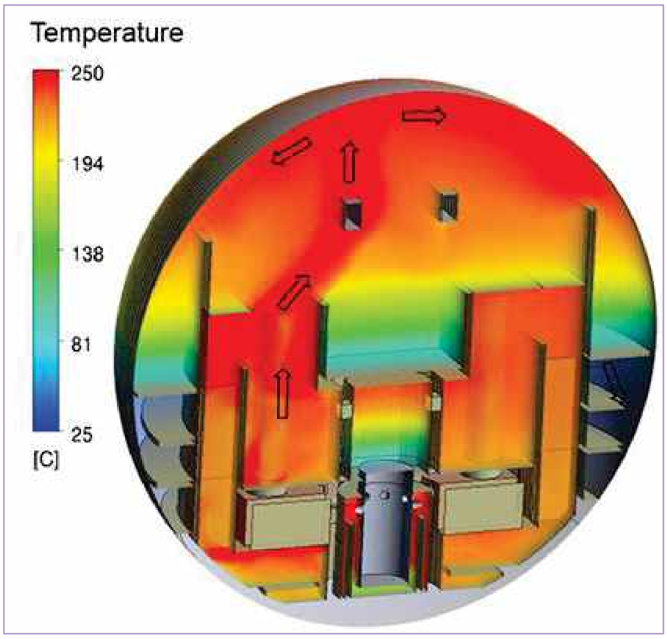
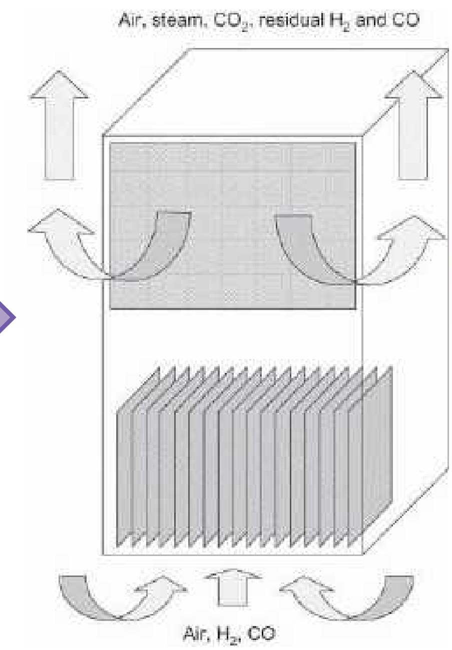
BACKGROUND AND AMHYCO PROJECT

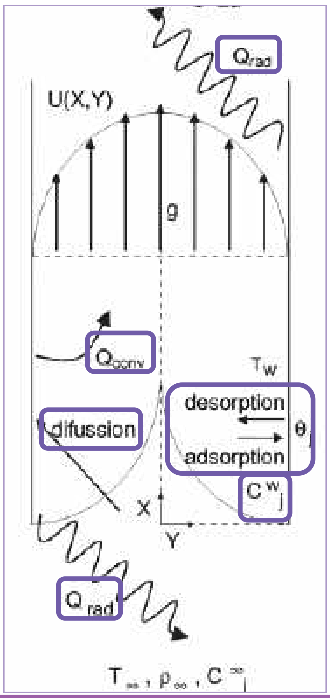




PARUPM: A RECOMBINER SIMULATION CODE

Deutschmann combustion model for methane catalyzed with Pt

1a	$H_2 + 2\ Pt(s) \rightarrow 2H(s)$	7a	$CO + Pt(s) \rightarrow CO(s)$
1d	$2H(s) \rightarrow H_2 + 2Pt(s)$	7d	$CO(s) \rightarrow CO + Pt(s)$
2a	$O_2 + 2\ Pt(s) \rightarrow 2O(s)$	8d	$CO_2(s) \rightarrow CO_2 + Pt(s)$
2d	$2O(s) \rightarrow O_2 + 2Pt(s)$	9	$CO(s) + O(s) \rightarrow CO_2(s) + Pt(s)$
3a	$H_2O + Pt(s) \rightarrow H_2O(s)$	10	$CH_4 + 2\ Pt(s) \rightarrow CH_3(s) + H(s)$
3d	$H_2O(s) \rightarrow H_2O + Pt(s)$	11	$CH_3(s) + Pt(s) \rightarrow CH_2(s) + H(s)$
IV	$OH + Pt(s) \rightarrow OH(s)$	12	$CH_2(s) + Pt(s) \rightarrow CH(s) + H(s)$
4	$H(s) + O(s) \rightarrow OH(s) + Pt(s)$	13	$CH(s) + Pt(s) \rightarrow C(s) + H(s)$
5	$H(s) + OH(s) \rightarrow H_2O + Pt(s)$	14+	$C(s) + O(s) \rightarrow CO(s) + Pt(s)$
6	$OH(s) + OH(s) \rightarrow H_2O + O(s)$	14-	$CO(s) + Pt(s) \rightarrow C(s) + O(s)$



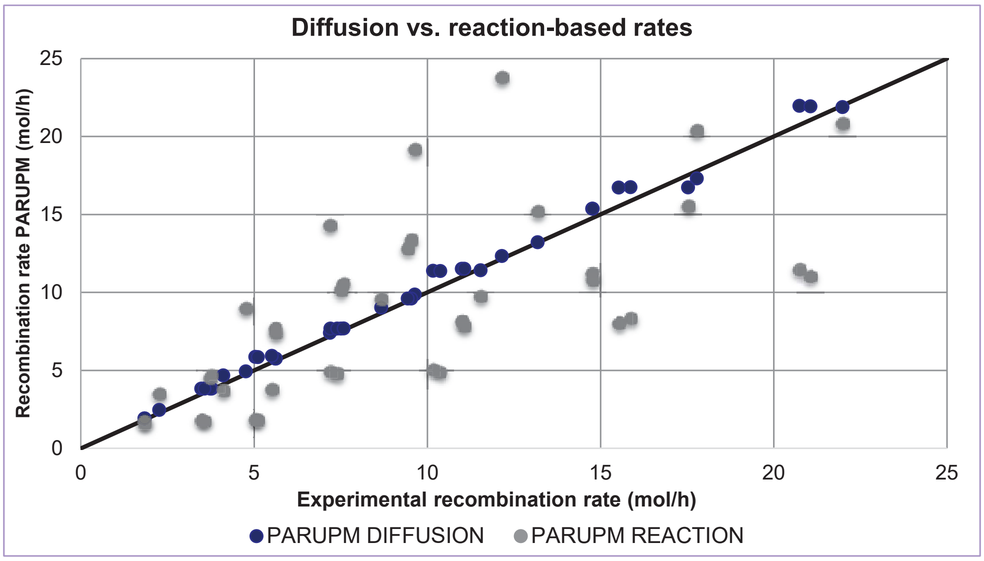
PARUPM: MODEL AND ENHACEMENTS

SURFACE REACTION MODEL

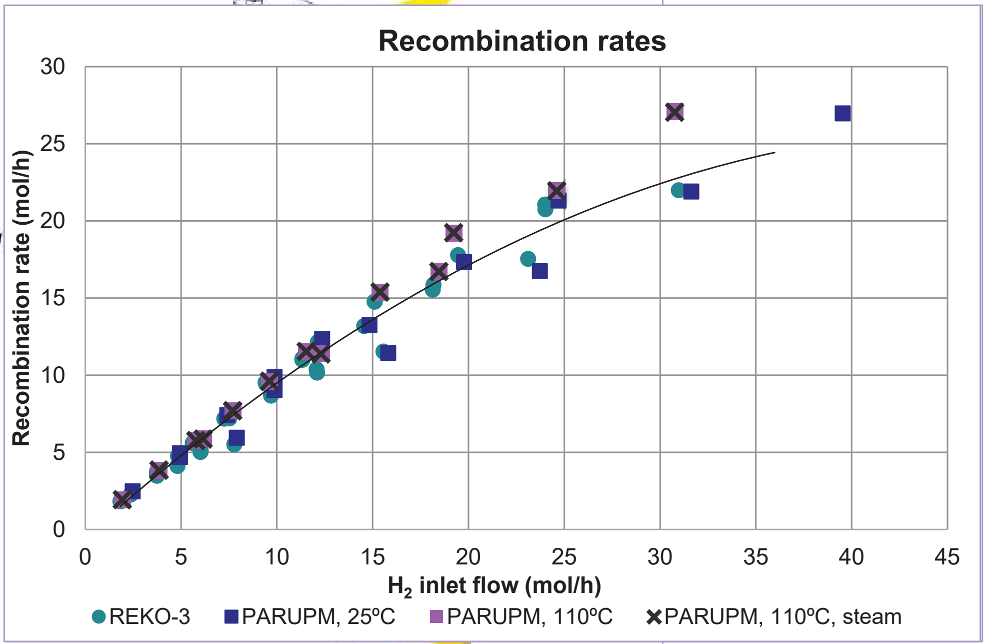
$$Rate_{H_2} = \omega_1 \Gamma(2Lh) M_{H_2}$$

MASS TRANSFER MODEL

$$Rate_{H_2,dif} = \frac{Sh_{H_2} D_{dif}}{D_h}\left(\frac{p_{H_2}}{RT}\right)$$



CODE VALIDATION AGAINST REKO-3 DATA



3 main cases

- Gas temperature 25ºC and steam 0%
- Gas temperature 110ºC and steam 0%
- Gas temperature 110ºC and steam 20%

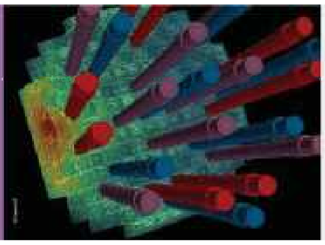
3 inlet velocities:

0.25 m/s , 0.5 m/s, 0.8 m/s

Results and conclusions

- **Good predictions of the recombination rate** are achieved with the **diffusion model**, independently of the velocity of the inlet gas flow.
  - With the reaction-based rates, the recombination rate was overpredicted at lower velocities by an average ≈40% and was underpredicted for higher velocities by an average ≈40% as well.
  - The biggest deviation appears for low H_2 inlet concentrations, higher inlet temperatures, and higher velocities, though the average deviation is ≈5%.
- **PARUPM will be coupled** to thermohydraulic codes for SA analysis with PARs operation.

THANK YOU FOR YOUR ATTENTION!



FISA 2022

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An Innovative Supercritical Carbon Dioxide Cycle for Decay Heat Removal in Existing and Future Nuclear Power Plants

Markus Hofer, Frieder Hecker, Michael Buck, Jörg Starflinger, Albannie Cagnac

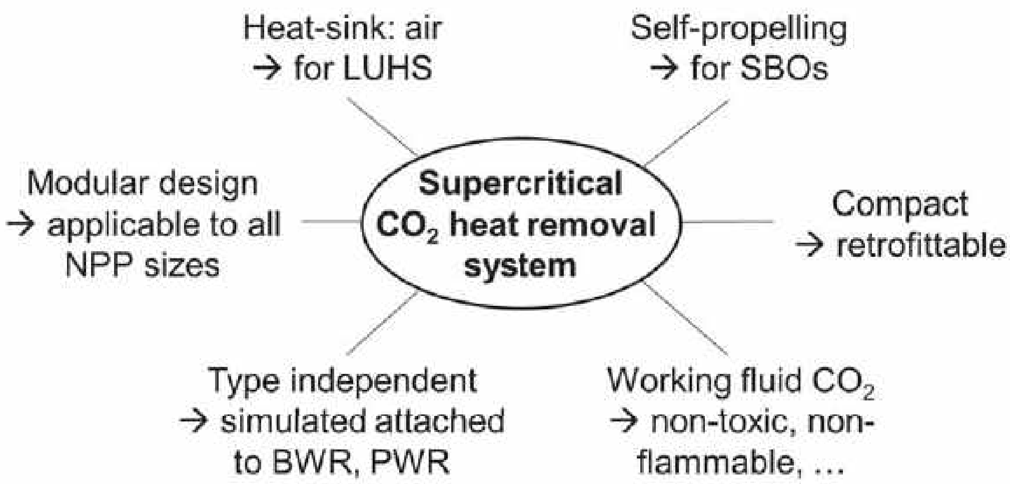
sCO_2-4-NPP

University of Stuttgart
Germany

IKE

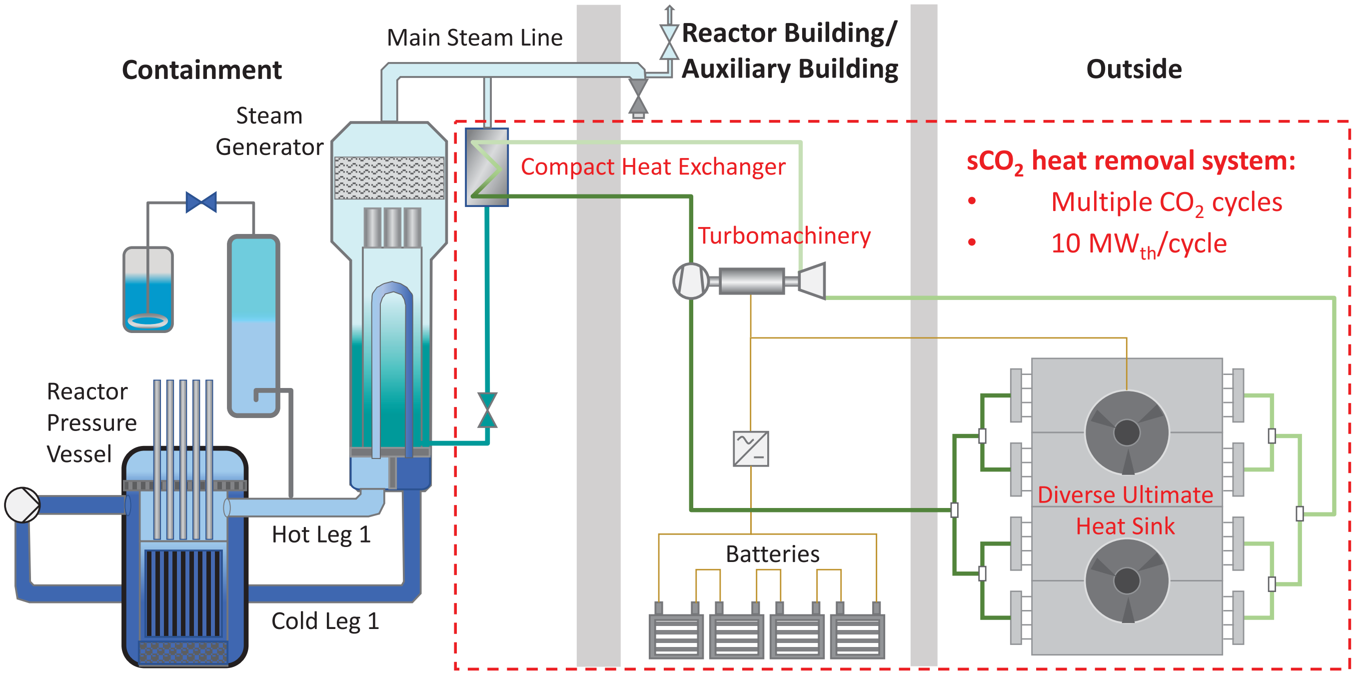
Motivation, Objective, Approach

Fukushima: **Station black-out** and **loss of the ultimate heat sink**



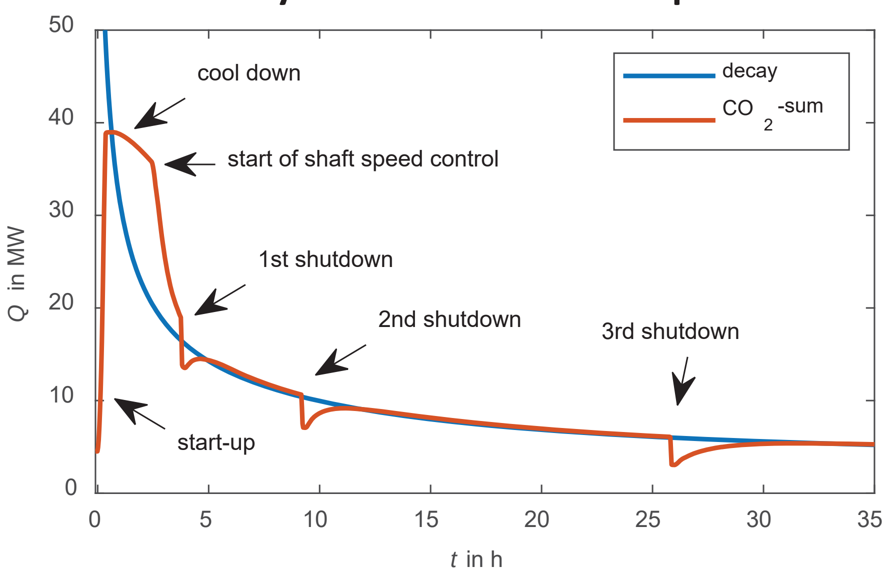
Model, simulate and evaluate this system in interaction with NPPs with ATHLET

sCO_2 Heat Removal System Attached to a PWR



4 CO_2 Cycles with a Decay Heat Adaption Strategy

Decay vs. removed thermal power



- Generic Konvoi PWR (3800 MW_{th})
- Combined SBO and LUHS scenario

Removed thermal power adapted to decay heat curve by **shaft speed control** and **successive shutdown** of single CO_2 cycles

→ A sCO_2 heat removal system with 4 CO_2 cycles (total: 40 MW_{th}) safely removes the decay heat for more than 72 h

Thank You

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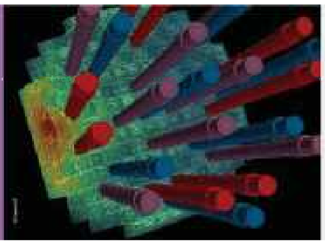

FISA 2022

30 May - 3 June 2022
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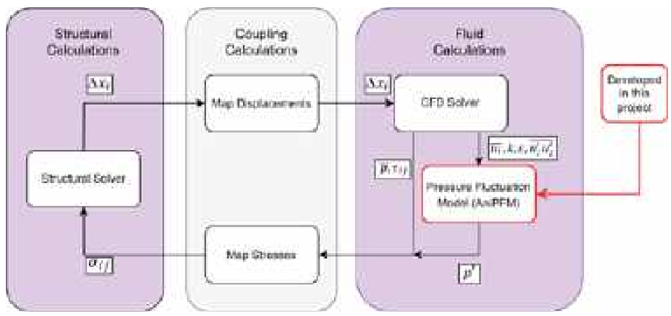
Turbulence Induced Vibration Prediction

Through Use of an Anisotropic Pressure Fluctuation Model

Motivation & Objective

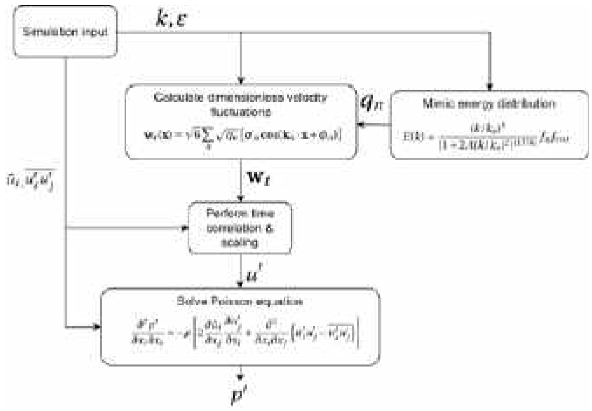
- Nuclear fuel rods in axial flow can experience vibrations induced by pressure fluctuations.
- Vibrations can cause material fatigue and fretting wear.
- Can be modelled with FSI + model for pressure fluctuations



Objective:
To develop a new anisotropic pressure fluctuation model (AniPFM), to improve the prediction of pressure fluctuations with respect to the existing PFM.

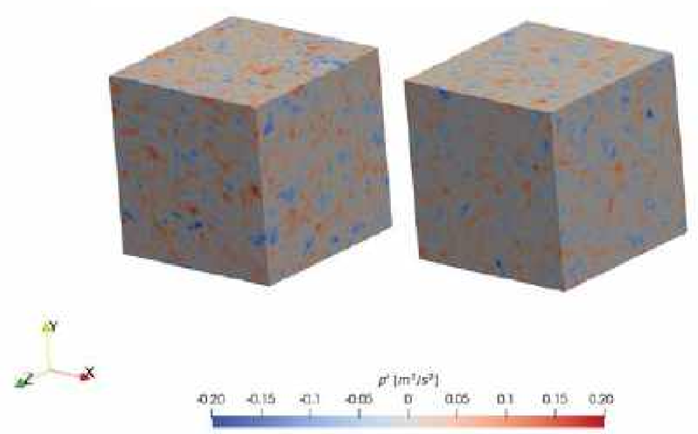
Methodology

- Pressure fluctuations are defined by a Poisson equation.
- Velocity fluctuations are modelled by a Fourier series.
- Energy distribution is modelled after real life turbulence.
- Convection and decorrelation approximates the transport phenomena found from Navier-Stokes.



Results

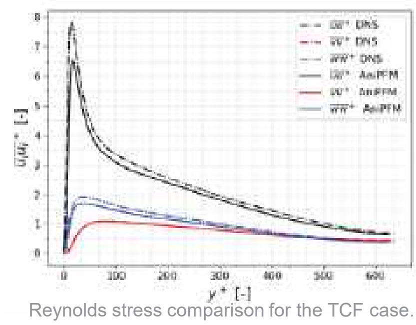
- Performed simulation of Homogeneous Isotropic Turbulence.
- Qualitatively close results to high-fidelity methods.
- ~1% error in RMS pressure fluctuations w.r.t. DNS data.



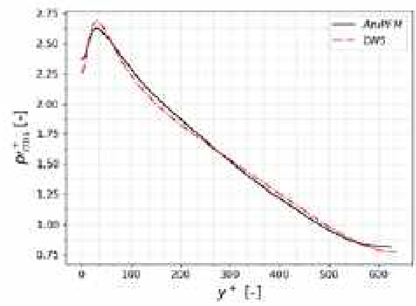
Pressure fluctuation comparison for the HIT case.

Results

- Performed simulation of Turbulent Channel Flow.
- AniPFM shows ~5% error in p'_{rms} at the wall, w.r.t. DNS data.
- Steep improvement, previous PFM showed ~47% underestimation.



Reynolds stress comparison for the TCF case.



RMS pressure fluctuation comparison for the TCF case.

Conclusion & Further work

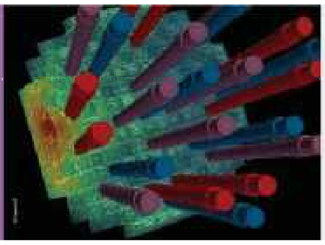
- The proposed model shows good correlation w.r.t. higher-fidelity methods.
- Both for isotropic and anisotropic turbulence.

Further Work

- Validation of the AniPFM in combination with FSI simulations.
- In particular, evaluate the prediction of vibrations of nuclear fuel rods in axial flow.

Contact info:

Nout van den Bos, noutvdbos@gmail.com



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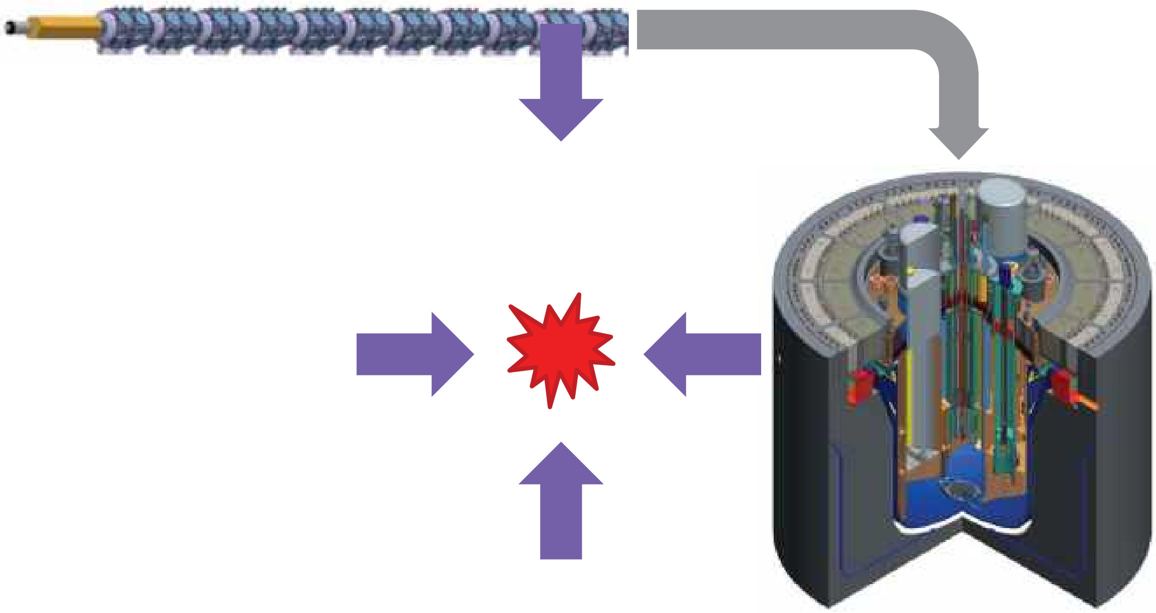
Investigation of a Hypothetical Core Disruptive Accident Scenario in Multipurpose hYbrid Research Reactor for High-tech Applications (MYRRHA)

Đorđe Petrović
Belgian Nuclear Research Centre (SCK•CEN)

Multipurpose hYbrid Research Reactor for High-tech Applications



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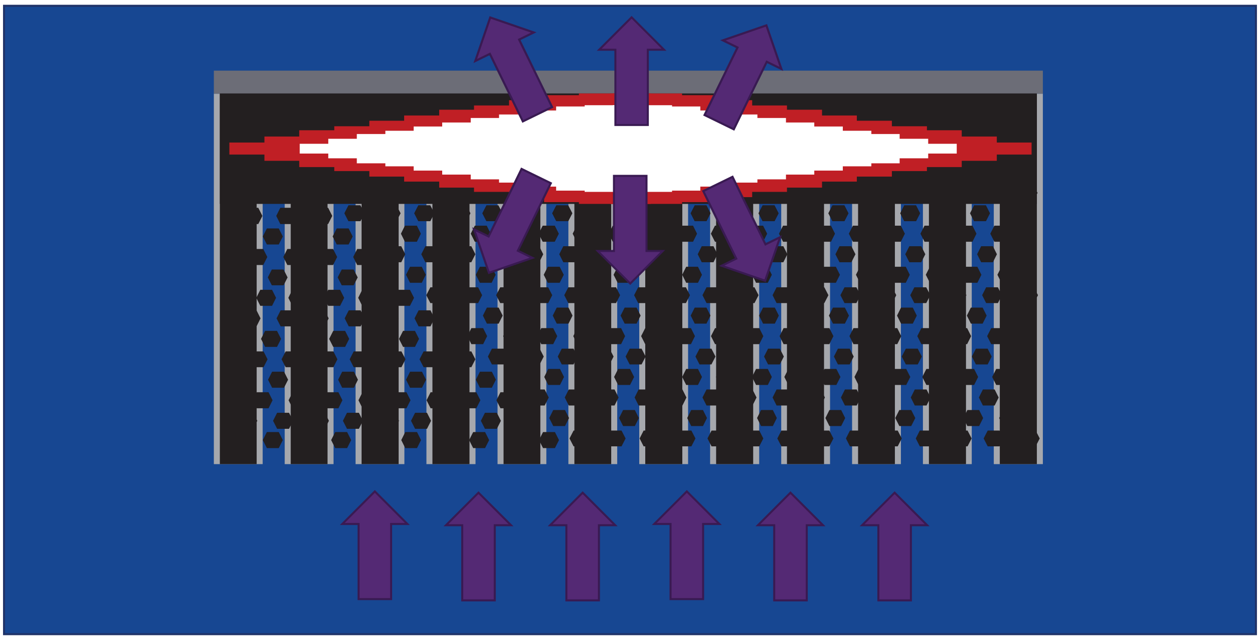
Hypothetical Core Disruptive Accident



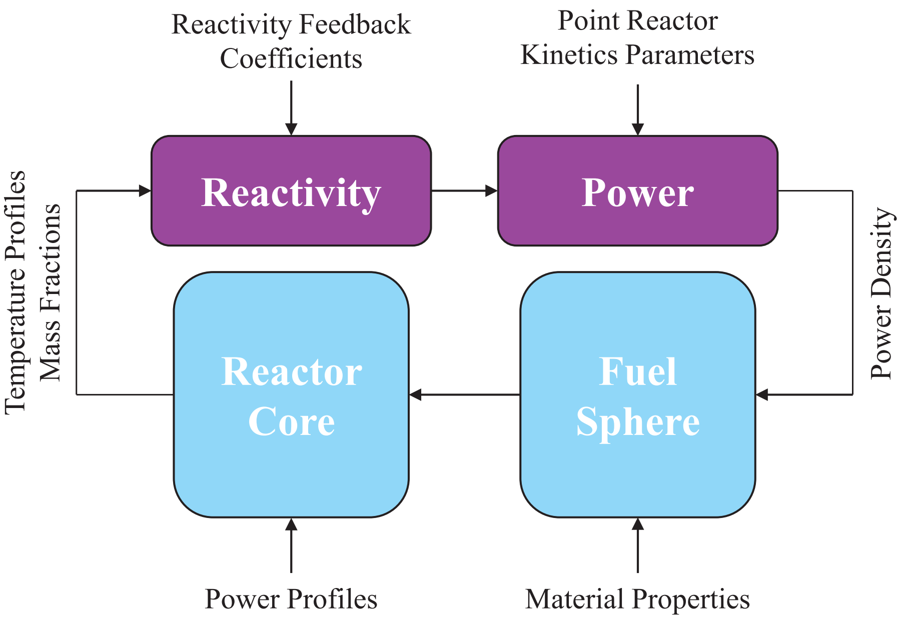
Methods

Phases of the accident

- Core compaction
- Power buildup
- Fuel dispersion

Employed codes

- SIMMER-III
- ‘Fundamental physics’ code



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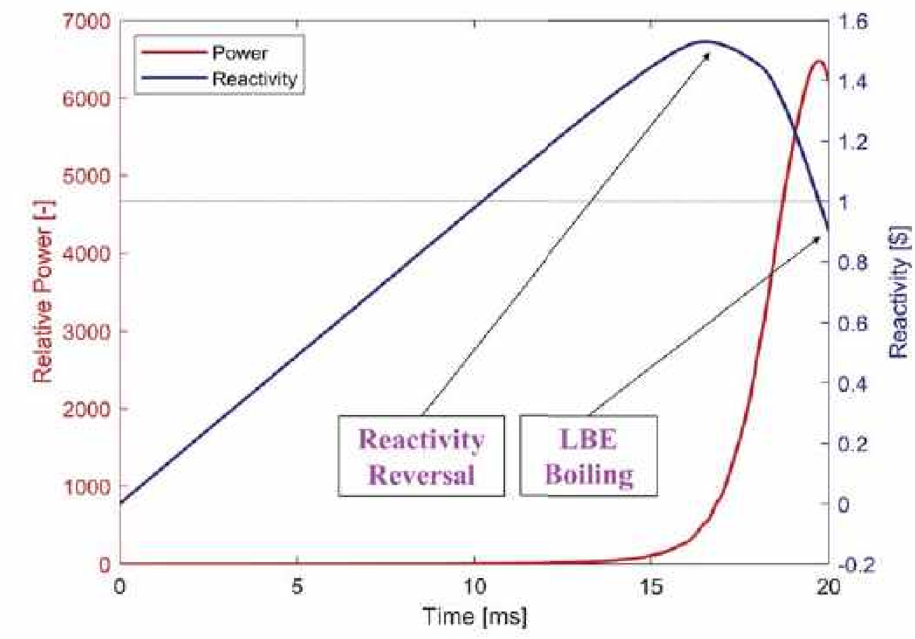
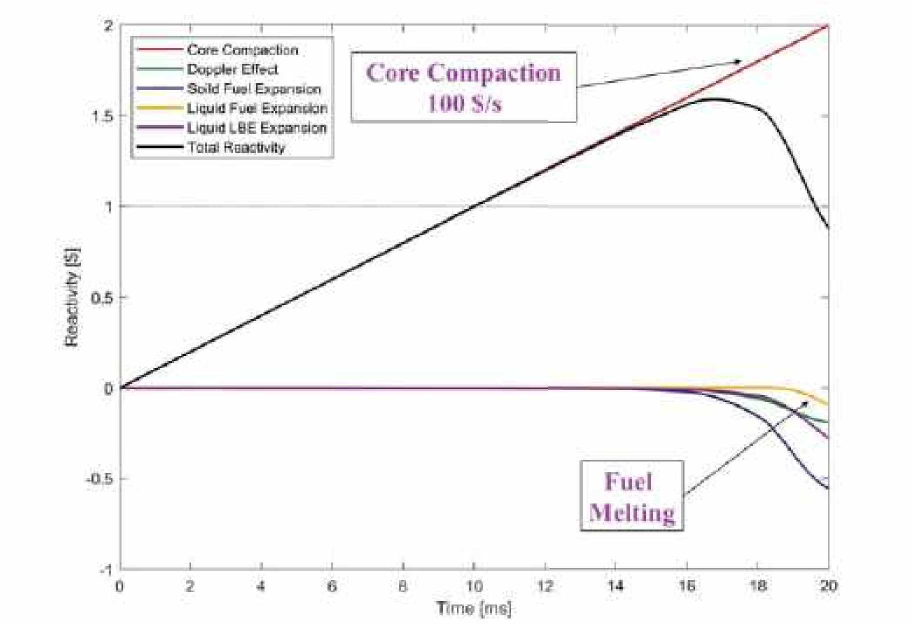
Core Power Evolution



Core Reactivity Evolution



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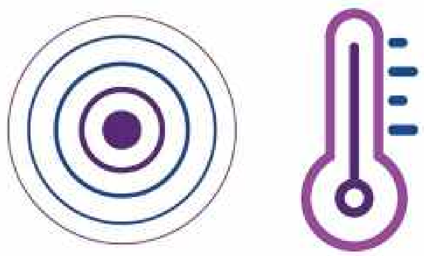
Conclusions



Reactivity reversal is caused by the combination of **Doppler effect** and **thermal expansion** of the core materials.

Fuel melting rapidly drives the reactor core reactivity **below prompt supercritical level**.

FISA R&D PRIZES

FISA 2022

Reactor Safety Analysis Toolbox RESA-TX

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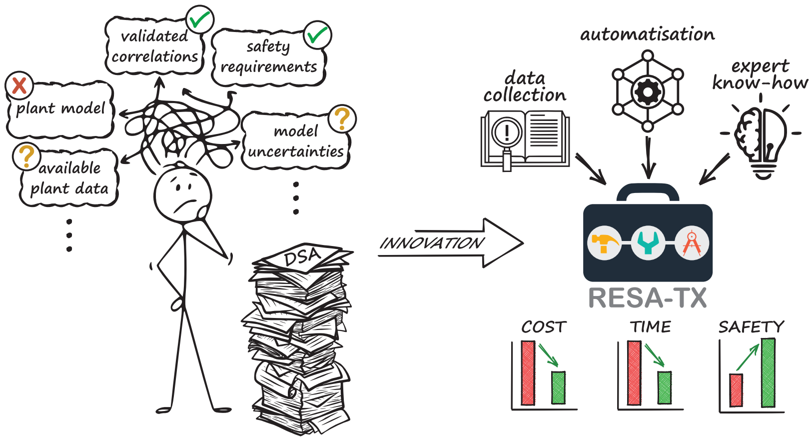
Department of Safety Analysis
Alejandra.Cuesta@grs.de, Simone.Palazzo@grs.de, Stefan.Wenzel@grs.de

Background and motivation

Background: issues associated with DSA

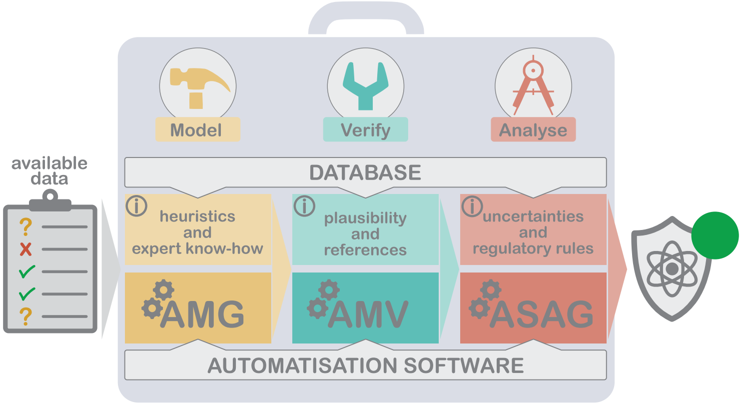
- Requires extensive plant data that is not always available.
- The quality of the analysis is strongly dependent on the quality of the model.
- Model developers must be experienced in TH modelling and the TH code.
- Time consuming and error prone.
- The finalised model requires verification.



Motivation:

- In our Safety Analysis department at GRS, we have been successfully working on both the modularisation of input data sets to enable automatic input generation and on the automation of data set verification processes for quality assurance.
- Project results have shown that these methods are both feasible and applicable, and that they lead to an increase in work efficiency and quality of results.

▪ The idea: A "toolbox" for Reactor Safety Analysis



- The proposed "Reactor Safety Analysis Toolbox RESA-TX" is a software and data package that allows the automation of all established methods for deterministic safety analysis (DSA) with the integration of expert know-how and a large collection of information about plant properties, plant behavior and model development.
- How: using an automated and standardised procedure, supported with a large database of plant design characteristics, plant behaviour and DSA expert knowledge. This database is incorporated within the tools using algorithms based on heuristics methods.

Main objective, benefits and applications

- Main objective: allow the end user to automatically generate and verify an input deck, as well as conduct design basis accident (DBA) calculations for a certain design with highly reduced manual intervention.
- Main benefits:
  - The automation increases both the efficiency of the analysis and the quality of the results by reducing the complexity, the repetitiveness as well as user induced errors.
  - This is supported by the large integrated database enhancing data availability and expert know-how.
  - In consequence, RESA-TX will allow for a DSA to be conducted more frequently and reliably in situations where time or budget were a constraint before, hereby **contributing to an increase in reactor safety.**
- Main applications
  - Reactor design assessment with a quick by technically grounded safety analysis, be it either in detail for confirmatory analysis purposes, or coarser to support an assessment that needs to be made with time constraints, for example by nuclear regulators.
  - From the generation of a safety case for licensees up to the continuous (re)running of certain transients for after plant design enhancements with minimal effort and throughout the lifetime of the plant.
  - Code validation and verification process: given its automated and modular nature, the tool would translate in significant time saving for code developers.

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DIPSICOF for Diagrid Integrated Passive System LImiting COre Flow bypass in accidental condition for advance FBR reactor

Florian VAIANA, Framatome DTI

Antony WOAYE HUNE, Framatome DTI

Lyon, 01/06/2022

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CONTENT

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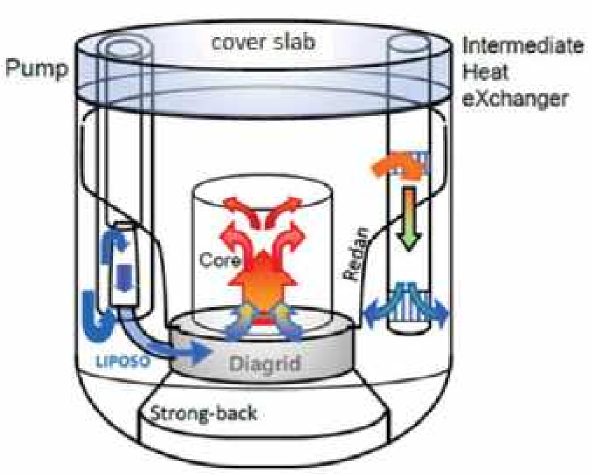
Context of the innovation

- Safety improvement on GEN IV advanced reactors using liquid metallic coolant like sodium, lead or lead-bismuth
- Need to limit the core flow bypass in case of accidental loss of coolant due to one primary pump seizure.
  - The safety device is passive: no action to be taken ;
  - One pump seizure is an “acceptable” risk in terms of safety, because it is passively solved.
- The innovation aims at:
  - Installing a passive device inside the structure supporting the core ;
  - Improving the safety by limiting the core flow bypass in the case of a loss of coolant due to a primary pump seizure.



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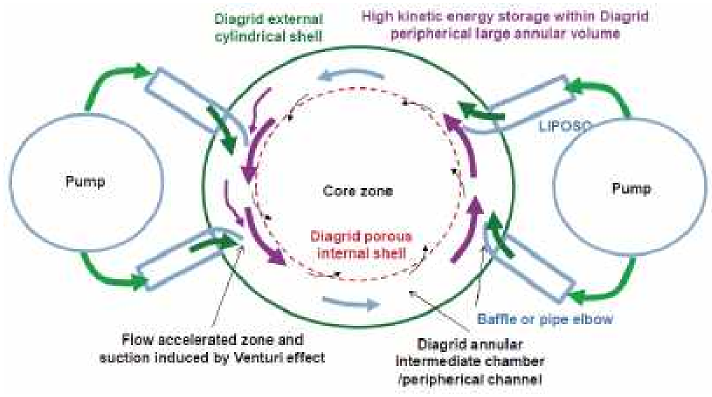
Approach and innovation description

- The innovative idea consists in:
  - An extra annular intermediate chamber set-up at the periphery of the diagrid, with coolant circulating inside tangentially.
  - Each LIPOSO pipe is extended with a pipe elbow to feed the annular volume tangentially and ***not radially as usually organized in past FBR concept***
  - ***First-of-a-kind, distinguishable*** and ***original*** arrangement.
  - Use of the Bernoulli principle and Venturi effect



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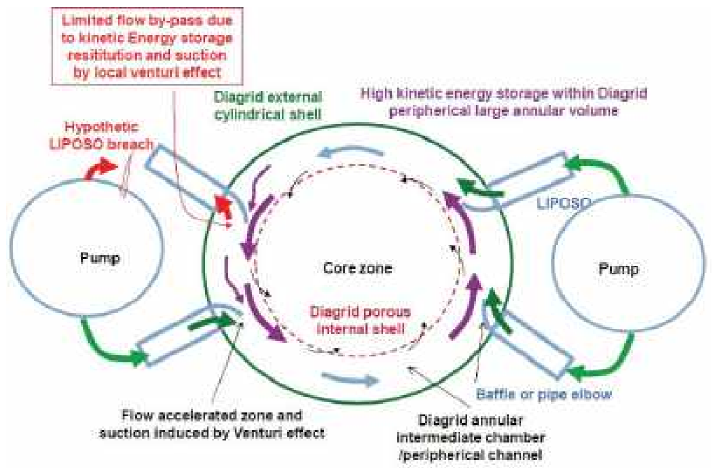
Interest of the innovation

- Benefits:
  - Full manufacturing allowed in factory if the vessel size is below the transportation size limit
  - A minimum amount of additional material to be implemented (reduction of total cost)
  - Only full passive and static device implementation
  - In case of a pump or LIPOSO seizure, equilibrium between:
    - The incident kinetic energy delivered by coolant mass flowrate at LIPOSO exit
    - And the pressure drop due to flow friction within the annular chamber



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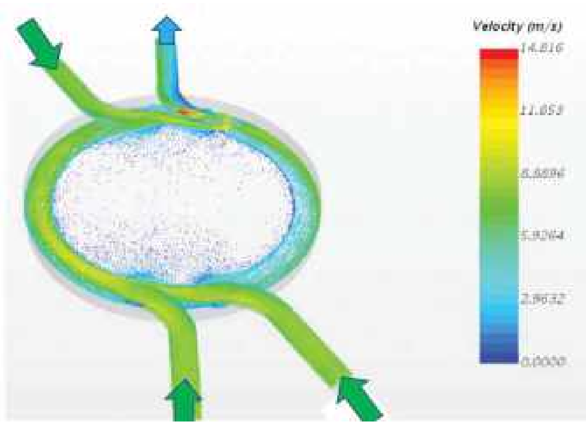
Prospect



- DIPSICOF passive concept feasibility analysis initiated ➔ promising behavior and results.
- Optimization remains to be performed. Further investigations related to core behavior, safety analyses, design and qualification program.

The "DIPSICOF" innovation is increasing reactors safety, it is simple, fully passive and implementable onto many reactor types options. It enables significant economy. It will contribute to ease the public acceptance and realistic nuclear reactors deployment.

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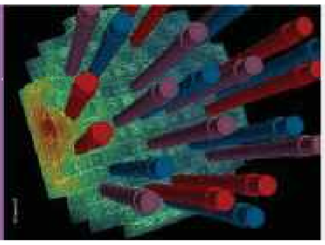
EURATOM PROJECT



FISA 2022

30 May - 3 June 2022
Lyon, France

HEALTH EFFECTS OF CARDIAC FLUOROSCOPY AND MODERN RADIOTHERAPY IN PAEDIATRICS (HARMONIC)

Isabelle THIERRY-CHEF

[1]Barcelona Institute of Global Health (ISGlobal), [2]University Pompeu Fabra,[3]CIBER Epidemiologia y Salud Pública, Spain

HARMONIC

In **therapeutic use** of ionising radiation, benefits to the patient largely outweigh the risk

However, late effects of exposure are important to understand in children with increased survival

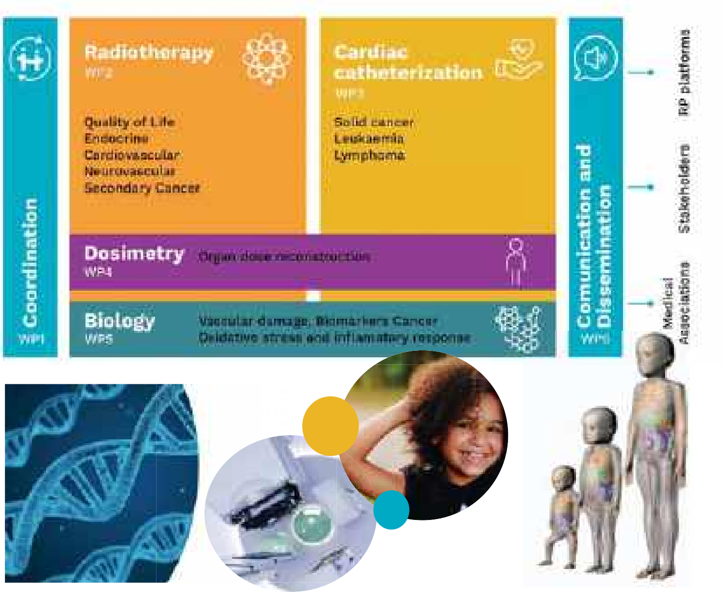
Objectives

Better understand the long-term health effects of medical exposure to ionising radiation in children:

- Cancer patients treated with modern radiotherapy modalities
- Cardiac patients treated with X-ray guided imaging procedures

HARMONIC

Organisation



Cohorts

Radiotherapy

CENTER	RETROSPECTIVE INCLUSION TIME PERIOD	RETROSPECTIVE INCLUSION No. PATIENTS	PROSPECTIVE INCLUSION TIME PERIOD	PROSPECTIVE INCLUSION No. PATIENTS	TOTAL
KU Louven	2008-2020	320	2021-2023	90	410
Aarhus	na	0	2021-2023	**18**/90	90
Buckesse	na	0	2021-2023	90	90
G. Roussy	2013-2020	380	2021-2023	180	560
UK Essen	2013-2020	**330**/1140	2021-2023	**16**/360	1500
OVERALL		1840		810	2660

In blue, are centers including photon therapy patients

In bold, are numbers of patients already included (as of April 5th 2022)

Cardiology

COUNTRY	AGE (YEARS)	START OF ACCRUAL & FOLLOW-UP	NUMBER OF HOSPITALS	END OF ACCRUAL	END OF FOLLOW-UP	ALREADY IN	EXPECTED COHORT SIZE
BELGIUM	0-18	2004	3	2020	2020	1341	6,000
FRANCE	0-16	2000	15	2013	2016	18600	19,000
GERMANY	0-18	2004	2	2020	2020		4,000
	0-18	2004	health care database	2020	2018		30,000
ITALY	0-18	2017	2	2021	2022	384	1,000
NORWAY	0-18	1975	1 (Oslo)	2022	2022	4817	6,000
SPAIN	0-21	1995	1 to 2	2021	2020		5,000
UK	0-22	1991	6	2020	2020	20464	30,000
						~45600	**~100,000**

Thank you for your attention !

On behalf of the Consortia:


FISA 2022
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ANNEX 3 – FISA 2022 POSTERS

SUPPORTING ACCESS TO KEY PAN-EUROPEAN RESEARCH INFRASTRUCTURES AND INTERNATIONAL COOPERATION

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GABRIEL PAVEL, *ENEN, Rue d'Egmont 11, 1000 Brussels Belgium, Tel. +32 483240330, gabriel.pavel@enen.eu*
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Large research infrastructures, especially nuclear ones, are extremely expensive to build and operate. Therefore, to develop expertise and competences in nuclear research is more efficient to have a limited number of complementary specialized large nuclear research infrastructures, shared by European researchers from different countries.

Since 2002, JRC has been providing access to its installations through two projects ACTUSLAB (research infrastructures in the field of physics and chemistry of actinides) and EUFRAT (Facilities for Nuclear Reaction and Decay Data Measurements). In 2019 JRC and the Commission DG RTD started a project to provide financial support to the users of the JRC's nuclear research infrastructures. The agreement allowed also enhancing the accessible JRC's infrastructures, opening for external users, additionally, the hot-cells and materials properties laboratories.

The TOURR project is the first well-coordinated action among European Research Reactors (RRs) operators aiming at a strategy for the optimal use of the European RR fleet. The goal is to evaluate the current and future need for neutron sources in Europe along 5 science and technology axes: education and training; basic and fundamental research and its instruments; medical applications, including radioisotope R&D and beam applications; material testing, including fuel, structural material and its instrumentation; core physics testing for reactors in "zero power" installations. Based on this thorough evaluation a strategy for maintaining and upgrading existing RRs and building new ones shall be proposed for the benefit of the European Research Area.

One of the future key infras in Europe will be Jules Horowitz Materials Testing Reactor (JHR). JHR will be a reference high power research Reactor to perform R&D program on innovative nuclear fuels and materials for enhancing safety and competitivity of existing and future power plants as well as providing even up to 50% of the radioisotopes for medical applications for European needs. The consortium is gathering today 15 partners (one of them being the European Commission) and each consortium member has acquired Access Rights giving access to the JHR experimental capacity for the whole life of operation of the reactor. Such Access Rights could be used either for proprietary projects (bilateral contract) or for joint research and development projects. In particular, these joint R&D projects will be open to non-members of the JHR consortium for the benefit of all European Member States and of the international community.

As Euratom owns 6% of access right to the reactor capacity, it is of utmost importance that these access rights are used effectively. The EU-JHOP2040 project is developing the first roadmaps for JHR's operations to cover the first 15 years of operation.

KEY EUROPEAN RESEARCH INFRASTRUCTURES AT YOUR SERVICE NOW AND IN FUTURE

PETRI KINNUNEN[1], GILLES BIGNAN[2], GABRIEL PAVEL[3], VICTOR ESTEBAN-GRAN[4]

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[2]JHR project bâtiment 1222 CE Cadarache 13108 St Paul lez Durance France: Tel: +33 4 42254816, gilles.bignan@cea.fr.
[3]ENEN, Rue d'Egmont 11, 1000 Brussels Belgium, Tel. +32 483240330, gabriel.pavel@enen.eu
[4]European Commission, CDMA 05/181, B-1049 Brussels, Belgium. Tel +32 229 95070. victor.esteban-gran@ec.europa.eu

OASIS

Open access to EC Joint Research Center infrastructure

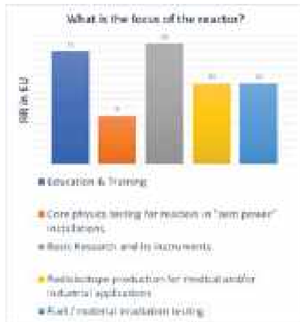
- Duration 2020 – 2024
- Free access to JRC nuclear infrastructure for granted projects
- Financial support to the user's stay possible
- Special scheme for young scientist
- Fair and transparent selection method

TOURR

Towards Optimized Use of Research Reactors in Europe

- Duration 2020 – 2023
- 9 partners out of which 6 Research Reactors (RR) operators
- Response to the challenge of coordinating the optimization of the exploitation of available research reactors in Europe
- The primary objective is to develop a strategy for RRs in Europe and prepare the ground for its implementation

A **survey** was conducted among European research reactors



JHOP2040 and JHR's Access Rights

Jules Horowitz Reactor operation planning and ways to access the capacity

- JHOP2040 duration 2020 – 2023
- Strategic research roadmaps for the first 15 years of operation operation of the JHR covering especially the first 4-year programme in detail.
- The outcome will be financial and programme models for Euratom taking into account also the governance and cost breakdown of the programmes.
- EC (Euratom-JRC) 6 % of guaranteed Access Rights to JHR experimental capability for the whole life of operation of the reactor and 6 % of voting rights in the JHR Consortium.

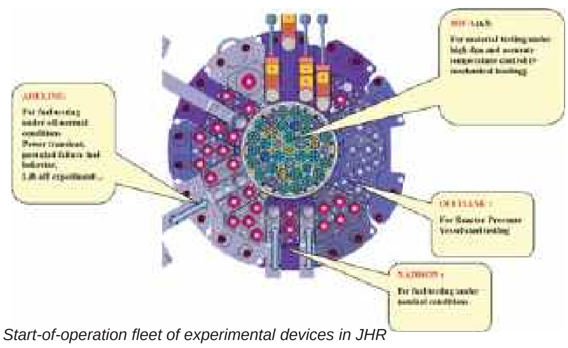
EC's 6 % of Access Rights represents about 79 Access Units per year giving access annually to e.g., 7 to 8 ramps type experiments using the ADELINE device or 6 fuel loop irradiation type experiments using the MADISON device

Example of loading plan
A.U. = Access Units

Type of experiment	Associated Access Unit per experiment and per cycle	Number of JHR locations for the type of experiment considered	Cumulated number of Access Unit per year (on the basis of 7 cycles per year)
Fuel ramps studies (ADELINE)	10	3	210
Fuel loop steady-state studies (MADISON)	12	2	168

Start-of-operation phase fuel experiments

Fuel test device (first fleet)	T0	Year N (T0+1)	Year N+1	Year N+2	Year N+3	Year N+4
ADELINE		Tests for validation of the performance	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
MADISON		Tests for validation of the performance	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]



Start-of-operation fleet of experimental devices in JHR

NUCLEAR COGENERATION WITH HIGH TEMPERATURE REACTORS

Josef SOBOLEWSKI

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JOHN LILLINGTON, *Jacobs, UK*
WOJCIECH BRUDEK, *Energoprojekt - Warszawa SA, Poland*

The Nuclear Cogeneration Industrial Initiative (NC2I), one of the three pillars of the (European) Sustainable Nuclear Energy Technology Platform (SNETP), emphasizes that non-electric energy needs (industry, transport, district heating, etc) represent a large fraction of energy needs in industrialized countries. Almost entirely produced by fossil fuels today, they cause the largest part of the emission of CO_2 and other noxious gases. NC2I partners were therefore working together in the GEMINI+ project co-funded by Euratom towards nuclear CO_2-lean solutions in non-electric applications. The result is a conceptual design and safety approach for a High Temperature Gas-cooled Reactor (HTGR) for industrial cogeneration.
The Polish government has declared its interest in replacing coal and gas with nuclear energy in industry offering an opportunity for near-term demonstration of nuclear industrial high temperature cogeneration with an HTGR. In the frame of national strategy program GOSPOSTRATEG, the National Centre for Research and Development was granted about €4M (2019 – 2022) for preparation of law, organization and technical instruments to deploy the HTGR.
GEMINI+ focused on the support of such a demonstration, aligning the characteristics of the proposed design to the needs of Polish industry where the priority is to replace fossil-fired boilers. The system is flexible to adapt in many industrial sites, which implies having components compact enough to be transportable to the site by road and to shorten works at construction site, and to adapt without design change to various fractions of process steam and electricity. Flexibility is also required in accommodating load variations on a local industrial site.
In 2021, the Polish Ministry of Education and Science signed with NCBJ the contract for further design work towards a research and demonstration HTGR. The conditions for preparing construction of this reactor within three years will be created and most of the basic design will be accomplished. The reactor will be a prismatic type HTGR using TRISO fuel producing approximately 30-40 MWth at an outlet temperature of 750^{o}C. The 3 year contract value is €14M.
For the new Euratom Programme, NC2I partners submitted the GEMINI 4.0 project proposal. GEMINI 4.0 is to clear the way towards demonstration and subsequent

deployment of high temperature industrial nuclear cogeneration with the system developed in GEMINI+, by addressing open questions regarding system safety demonstration and confirmation of its licensing readiness, the capacity of polygeneration of process heat, hydrogen and electricity with this system and feasibility of a consistent fuel cycle.

FISA 2022

GEMINI+

The versatile and zero-emission cogeneration system with small and modular nuclear HTGR

NC2I Nuclear Cogeneration Industrial Initiative

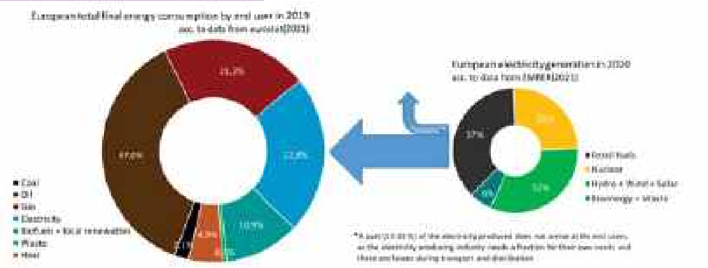
Józef Sobolewski[1], Eleonora Skrzypek[1], Janusz Malesa[1], Dominik Muszyński[1], Maciej Skrzypek[1], Michael A. Fütterer[2], Dominique Hittner[3], Christoph Pohl[4], John Lillington[5] and Wojciech Brudek[6]

[1]National Centre for Nuclear Research, Poland, [2]European Commission, DG Joint Research Centre, The Netherlands, [3]Hit Tech Relay, France, [4]Jülich Centre for Nuclear Waste Disposal mbH (JEN), Germany, [5]Jacobs, UK, [6]Energoprojekt - Warszawa SA, Poland

GEMINI+ selected for funding in the frame of the 2016 call of H2020

- ❑ 3.5 years project, 4 M€.
- ❑ Started in September 2017, completed in February 2021.
- ❑ Initiated by the (European) Nuclear Cogeneration Industrial Initiative (NC2I) for implementing its strategy meant.

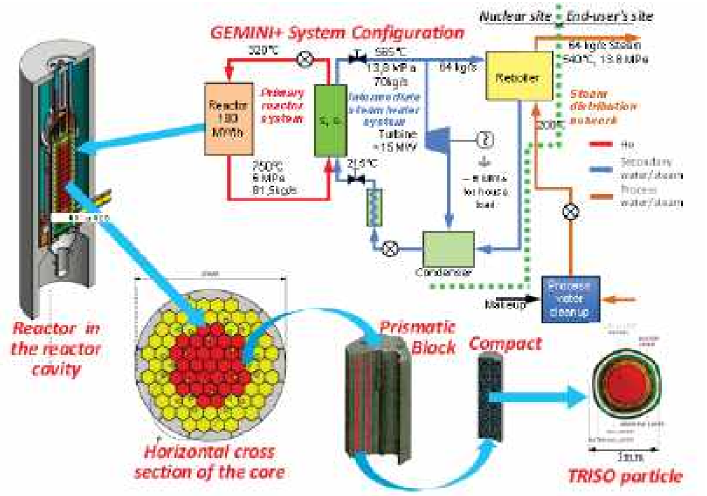
Project provided a **conceptual design of a high temperature nuclear cogeneration system** to supply process steam to industry, a licensing framework for this system and a business plan for a full scale demonstration.



Green Deal – how relevant is nuclear cogeneration?

- ❑ Reduction of Greenhouse Gases (GHG) emissions – COP21.
- ❑ Decarbonization by use of nuclear power.
- ❑ Emission reduction in electricity production sector insufficient to achieve the goal.
  - ❑ Significant GHG emissions in industry and transport.

Parameter	GEMINI+
Thermal power	180 MW
Power density	5.8 MW/m³
Block type	FSV/SC-HTGR (NBG-17)
RPV inlet / outlet temperature	325ºC / 750ºC
Coolant pressure	6 MPa
Coolant flow	79 kg/s
Bypass flow	9.1%
Number of fuel columns	31
Core height	8.8 m (11 fuel blocks in a column)
Equivalent core diameter	2.12 m
RPV outer diameter	4.488 m (SA 508)
Fuel	HALEU, UO_2
Burnup	60 MWd/kgHM
Refueling time	every 1.5 years
Steam output to End-User	540ºC / 13.8 MPa / 64 kg/s

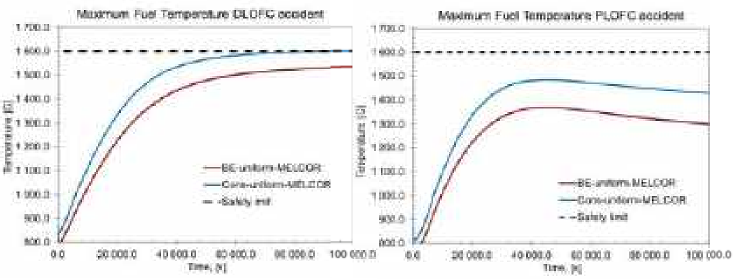


HTGR: High Temperature Gas-cooled Reactor

- ❑ Modular design and construction of SMR power scale.
- ❑ Coolant – helium, moderator – graphite.
- ❑ Fuel based on TRISO particles dispersed in a graphite matrix.
- ❑ Outlet temperature up to 750˚C (qualified existing industrial materials), 900-1000˚C (with advanced materials).

HTGR safety

- ❑ Safety features: huge inertia, refractory materials, leak tight fuel.
- ❑ Inherently safe physical properties of the reactor and purely passive behavior.
- ❑ No physical possibility of core melting and of significant radioactive release – below 1600˚C limit for fuel.
- ❑ No exclusion zone around the nuclear plant: possibility to locate the nuclear plant close to the industrial site.
- ❑ Suppression of many redundant active safety systems existing in present reactors: an asset for competitiveness.



Main achievements of GEMINI Plus project

The project has been designed to support an early demonstration of industrial nuclear cogeneration of electricity and steam in Poland using an inherently safe HTR. Project main results:

- ❑ A flexible standard design that can address versatile steam industry needs.
- ❑ A safety approach meeting present highest safety standards.
- ❑ An identification of residual technology gaps.
- ❑ A better understanding of industrial application needs: Importance of hydrogen for industrial applications.
- ❑ An understanding of the integration of high temperature nuclear cogeneration systems in global or local energy systems.

Follow us on NC2I page **www.snetp.eu/nc2i/**

GEMINI+ website: **www.gemini-initiative.com**

Contact us: contact@gemini-initiative.eu

Follow us on Twitter! **@Gemini_Plus**

For ZERO Emission

GEMINI+ project will be continued **GEMINI 4.0 received funding from HORIZON Euratom 2021 programme**

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement n°755478. The content of this presentation reflects only the author's view. The European Commission is not responsible for any use that may be made of the information it contains.

EDUCATION, TRAINING AND MOBILITY, KNOWLEDGE MANAGEMENT: TOWARDS A COMMON EFFORT TO ENSURE A FUTURE WORKFORCE IN EUROPE AND ABROAD

Gabriel Lazaro PAVEL

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The European Commission through its Euratom Program continuously supports the initiatives in the nuclear field through both collaborative projects (Indirect Actions) or via direct research activities implemented by the European Commission Joint Research Centre, JRC (so-called Direct Actions). Both types of actions support research contributing to increased knowledge and competences for nuclear safety and safeguards. A dedicated line of recent collaborative projects addresses the specific needs in the sector such as lack of personnel (ENENplus) and provide state-of-the-art approaches and in-depth knowledge when it comes to reactor physics (GRE@T-PIONEeR) or nuclear radiochemistry (A-CINCH). A highly skilled nuclear engineer must undoubtedly undergo experimental work to better observe theoretical principles at work. Following the ENEEP initiative, a network of research reactors is made available for performing such activities. Another issue found is that results of Euratom funded research activities are spread across multiple platforms and websites making it difficult to find relevant information within a reasonable timeframe. To cope with this situation, the PIKNUS project aims to define a concept of a knowledge management (KM) method and tool to improve the sharing and availability of Euratom research results.
As methodologies to tackle the lack of personnel and to substantially contribute to the revival of the interest of young generations to the nuclear sector, several actions are

undertaken under the ENENplus project to attract, retain and sustain the nuclear talents throughout their entire E&T career. Under both A-CINCH and GRE@T-PIONEeR projects, state-of-the-art tools and methodologies are proposed for enhancing knowledge retention, such as: active learning, flipped classes, video materials, interactive live sessions, computer simulators and computer-based modeling, 3D virtual reality, “learn through play” – lessons gamification, virtual robo-laboratory, NucWiki, MOOCs, etc. Within the ENEEP consortium, a dedicated platform is created and shared with the community to provide both access to nuclear facilities but also a pre-defined set of actions in regard to hands-on training. Within the PIKNUS project, the developed information system will provide a single platform to access the aggregated knowledge of both Direct and Indirect Actions of Euratom programmes.

Education, Training and Mobility, Knowledge Management: Towards a Common Effort to Ensure a Future Workforce in Europe and Abroad

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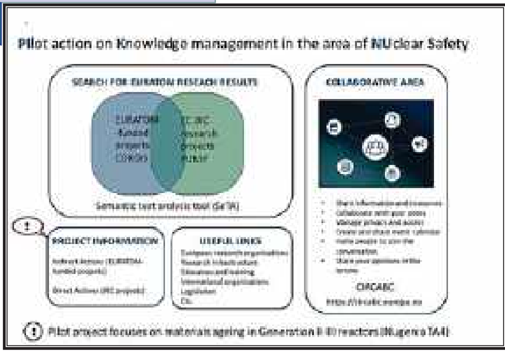
Abstract

Continuous and future-oriented education and training as well as knowledge management for young talents are required for the safe and reliable operation of nuclear reactors and nuclear facilities in Europe. A dedicated line of collaborative projects addresses the specific needs, such as lack of personnel (project **ENEN+**: "Attract, Retain and Develop New Nuclear Talents Beyond Academic Curricula"). State-of-the-art approaches and in-depth knowledge are provided when it comes to reactor physics (project **GRE@T-PIONEeR**: "Graduate Education Alliance for Teaching the Physics and Safety of Nuclear Reactors") or nuclear radiochemistry (project **A-CINCH**: "Augmented Cooperation in Education and Training in Nuclear and Radiochemistry"). A highly skilled nuclear engineer must undergo experimental work to better observe theoretical principles at work. Following the **ENEEP** (European Nuclear Experimental Educational Platform) initiative, a network of research reactors and special laboratories is made available for performing such activities. The **PIKNUS** project aims to define a concept of a knowledge management method and tool to improve the sharing and availability of Euratom research results. All projects successfully demonstrate that European collaboration could address certain needs to attract, develop and retain young talents in future-oriented nuclear fields.

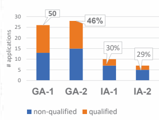
PIKNUS



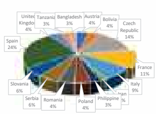
ENEEP

An essential element in the implementation and safe operation of nuclear facilities is a knowledgeable and skilled workforce. The nuclear specific skills and experience of workforce cannot be built without an experimental hands-on nuclear E&T. To address these challenges the European Nuclear Experimental Educational Platform is established.

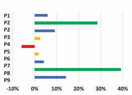
ENEEP brings experimental E&T closer to everyone. ENEEP E&T activities are based on experiments utilizing research reactors and laboratories of nuclear physics, material science and radiation protection. So far 4 demonstration courses were carried out (2 group, 2 individual) with 71 applications received.



Success rate of applicants



Country of applicants



Evolution of the knowledge of participants

In 2022 new courses are planned:

- *"Train the trainers" – 3days – 10 trainers*
- *"Train the lecturers" – 3x3 days – 10 lecturers*
- *"Train the students" – 3 days – 10 students*

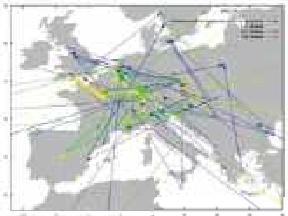
For more information about the courses, please follow us:

www.eneep.org

ENEN+

To support the revival of the interest of young generations in careers in nuclear sector we used five objectives on four educational topics:

The project had an important impact on the nuclear community and beyond. Figure below contains data about more than 600 "mobilities" that have been granted, demonstrating the European dimension for nuclear E&T of the project.

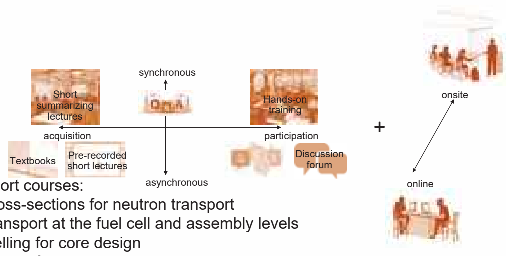


Although the ENEN+ project ended, the consortium decided to continue the initiative and we are providing a more complex support program for the whole nuclear community.
https://plus.enen.eu/
https://enen.eu/

GRE@T-PIONEeR

Developing and offering specialized education and training resources for nuclear engineers, graduate and post-graduate students, and researchers in nuclear reactor physics, modelling, and safety.

Use of innovative pedagogical methods promoting learning and relying on flipped classrooms, with the interactive sessions proposed onsite and online.



6 thematic short courses:

- Nuclear cross-sections for neutron transport
- Neutron transport at the fuel cell and assembly levels
- Core modelling for core design
- Core modelling for transients
- Reactor transients, nuclear safety and uncertainty and sensitivity analysis
- Radiation protection in nuclear environment

Interactive sessions heavily relying on computer-based modelling and simulations, and on hands-on exercises at training reactors.

More info at: https://great-pioneer.eu

A-CINCH

Augmented **C**ooperation in education and training **I**n **N**uclear and radio**CH**emistry

The **A-CINCH** project augments **CINCH teaching tools** developed in the three previous projects – CINCH, CINCH II and MEET-CINCH – with the state of the art three-dimensional (3D) virtual reality (VR) environment to complete the existing **toolbox for radiochemistry education**.

Acknowledgements & references

ENENplus project is funded under H2020 EURATOM Grant Agreement no. 755576/ NFRP-2016-2017-1

The **ENEEP** project received funding from the EURATOM Research and Training programme under the grant agreement no. 847555

GRE@T-PIONEeR project is supported by the European Union's Euratom research and training programme 2019-2020 under the Grant Agreement n°890675.

A-CINCH project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945301

HEALTH EFFECTS OF CARDIAC FLUOROSCOPY AND MODERN RADIOTHERAPY IN PAEDIATRICS (HARMONIC)

Isabelle THIERRY-CHEF

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The use of ionising radiation (IR) for medical diagnosis and treatment procedures has had a major impact on the survival of paediatric patients. Although the benefits of these techniques largely outweigh the risks, the evidence to date suggests that children are more sensitive than adults to the carcinogenic effects of IR. Therefore, there is a need to better understand the long-term health effects of such exposures in order to optimise treatment in these young patients and reduce the risk of late toxicities.
HARMONIC aims to improve our understanding of the health effects of exposure to medical IR in children, specifically cancer patients treated with modern radiotherapy techniques, and cardiac patients treated with cardiac fluoroscopy procedures (CFP). HARMONIC also develops dosimetric data collection software tools to allow dose reconstruction in both CFP and radiotherapy.
The project builds on a multi-disciplinary collaboration to investigate long-term outcomes (endocrine dysfunction, cardiovascular and neurovascular damage, quality of life (QoL) and social impacts, and secondary cancers) of paediatric cancer patients after the application of modern radiotherapy modalities. Instruments for harmonised demographic, clinical and dosimetric data collection were defined serving as a pilot phase for a future pan-European registry.
The cardiac component of HARMONIC builds a pooled cohort of approximately 100,000 patients who underwent CFP in 7 countries, while aged under 22 years. The cohort, based on data collection from hospital records and/or insurance claims data, will be followed-up using national registries and insurance records to determine vital status and cancer incidence. Where available, information on organ transplantation (a major risk factor for cancer development in this patient group) and/or other conditions predisposing to cancer will be obtained from national or local registries and health insurance data. The relationship between estimated radiation dose and cancer risk will be investigated using regression modelling.
With its prospective design and the creation of a biobank for the collection of biological samples, HARMONIC also aims at providing a mechanistic understanding of radiation-induced adverse health effects and identify potential biomarkers indicative of vascular

adverse effects and secondary cancer. These biomarkers could ultimately contribute to early diagnosis, treatment and prevention of adverse effects.

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May – 3 June 2022 | Lyon, France

FISA 2022

Health effects of cArdiac fluoRoscopy & MOderN RadIotherapy in PaediatriCs

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No. 847707

HARMONIC

I.Thierry-Chef, B.Timmermann, N. Journy, M.-O. Bernier, R. McNally, J.Dabin, L. Brualla S. Haghdoost, A. Sarukhan, K. Haustermans, I. De Wit, S. Isebaert, Y. Lassen, L. Tram Henriksen, M. Høyer, L.Toussaint, G. Boissonnat, J. Thariat, C. Demoor-goldschmidt, C. Vidaud, N. Haddy, S. Bolle, B. Fresneau, S. Dreger, H. Zeeb, M. G. Andreassi, E.Picano, A. Jahnen, C.Ronckers, J. Maduro, K. Kjaerheim, G. Døhlen, H. M. Olerud, U. Salini Thevathas, U. Schneider, L. Walsh, V. Chumak, A Dumas, A. Jackson, M. De Saint-Hubert, C. Bäumer, T. Steinmeier, M. Wette, R Ortiz

The use of ionising radiation (IR) with advanced technology in medicine represents a tremendous benefit for the diagnosis and treatment of pathologies in paediatric populations. While benefits to the patient largely outweigh the risk, the late effects of exposure to IR are particularly important to understand in populations of young patients who nowadays survive the disease for decades.

HARMONIC aims at better understanding the health effects of exposure to medical IR in paediatric cancer patients treated with modern radiotherapy techniques, and in paediatric cardiac patients treated with x-ray guided imaging procedures.

METHODS AND MATERIALS

The project builds on a multi-disciplinary collaboration to provide the medical and scientific communities with instruments to

- investigate cancer and non-cancer outcomes,
- evaluate Quality of Life (QoL) and social impacts,
- generate advanced patient-specific dose reconstruction,
- provide a mechanistic understanding of radiation-induced cellular responses

RADIOTHERAPY & CARDIOLOGY

- Setting up the structure of the databases for inclusion of patients in both cohorts, developping the SOPs and starting data collection.

DOSIMETRY

- Currenlty developing simulation models for dose reconstruction and implementing measurement sessions for validation of these models.

BIOLOGY

- Pilot testing methodology and framework for analysis of biomarkers in both blood and saliva.

IMPACTS

BUILD EUROPEAN COHORTS AND REGISTRIES OF PAEDIATRIC PATIENTS TO ESTABLISH & INVESTIGATE:

- Late health effects of ionising radiation in children
- Cancer and non-cancer outcomes
- Tools for long-term follow-up of children exposed
- Radiation doses to specific organs
- Possible biological mechanisms
- Recommendations to optimise techniques and reduce radiation doses

Our ultimate goal is to improve the quality of life of children treated with medical radiation

PRELIMINARY RESULTS

RADIOTHERAPY

- Database ready at the end of 2020.
- SOP finalized and data collection started in 2021.

CENTER	RETROSPECTIVE INCLUSION Time period	No. patients	PROSPECTIVE INCLUSION Time period	No. patients	TOTAL
KU Leuven	2008-2020	320	2021-2023	90	410
Aarhus	na	0	2021-2023	**18**/90	90
[illegible]	na	0	2021-2023	90	90
G. Roussy	2013-2020	380	2021-2023	180	500
UK Essen	2013-2020	**330**/1140	2021-2023	**16**/360	1500
OVERALL		1840		[illegible]	[illegible]

In blue, are centers including photon therapy patients
In bold, are numbers of patients already included (as of April 5th 2022)

- This is the first international registry of paediatric cancer patients treated with modern radiotherapy techniques.
- To study neuro & cardiovascular effects, endocrine dysfunction, second cancer and QoL
- Analytical and Monte Carlo-based **dosimetric** tools aiming at estimating far-from-the-field dose distribution for conventional and proton therapy are developed.

CARDIOLOGY

- Pooling of data on already 45,000 paediatric patients who underwent cardiac catheterization in Europe (out of 100,000 expected) to study the relationship between IR exposure early in life, and subsequent cancer in children treated for cardiac birth defect.
- The **dosimetric** tool relies on table of precomputed dose coefficients to allow rapid dose estimates.

COUNTRY	AGE (YEARS)	START OF ACCRUAL & FOLLOW-UP	NUMBER OF HOSPITALS	END OF ACCRUAL	END OF FOLLOW-UP	ALREADY IN	EXPECTED COHORT SIZE
BELGIUM	0-18	2004	3	2020	2020	1341	6,000
FRANCE	0-16	2000	15	2013	2016	18600	19,000
GERMANY	0-18	2004	2	2020	2020		4,000
	0-18	2004	health care database	2020	2018		30,000
ITALY	0-18	2017	2	2021	2022	784	1,000
NORWAY	0-18	1975	1 (Oslo)	2022	2022	4817	6,000
SPAIN	0-21	1995	1 to 2	2021	2020		5,000
UK	0-22	1991	6	2020	2020	20464	30,000
						~45600	~100,000

BIOLOGY

- Two pilot studies to test the quality of saliva samples. Collection of fresh saliva in tubes (no preservative and storing at -20°C) is adequate for obtaining a good quality of DNA .
- A third pilot study to test the quantity and quality of lymphocytes for reverse phase protein array (RPPA) assay using 2 different protocols.

REFERENCES

- Harbron RW, Thierry-Chef I, Pearce MS, Bernier MO, Dreuil S, Rage E, et al. The HARMONIC project: Study design for assessment of cancer risks following cardiac fluoroscopy in childhood. J. Radiol. Prot. 2020;40:1074-90
- Toussaint L, Peters S, Mikkelsen R, Karabegovic S, Bäumer C, Muren LP, et al. Delineation atlas of the Circle of Willis and the large intracranial arteries for evaluation of doses to neurovascular structures in paediatric brain tumor patients treated with radiation therapy. Acta Oncol. 2021;60(11):1392-8.
- Hermida-López M, Sánchez-Artuñedo D, Rodríguez M, Brualla L. Monte Carlo simulation of conical collimators for stereotactic radiosurgery with a 6 MV flattening-filter-free photon beam. Med Phys. 2021;48(6):3160-71.
- Sempau J, Kazantsev P, Izewska J, Brualla L. Monte Carlo verification of the holder correction factors for the radiophotoluminescent glass dosimeter used by the IAEA in international dosimetry audits. Phys Med. 2021;86:1-5.
- Verbeek N, Wulff J, Janson M, Bäumer C, Zahid S, Timmermann B, et al. Experiments and Monte Carlo simulations on multiple Coulomb scattering of protons. Med Phys. 2021;48(6):3186-99.
- Verbeek N, Wulff J, Bäumer C, Smyczek S, Timmermann B, Brualla L. Single pencil beam benchmark of a module for Monte Carlo simulation of proton transport in the PENELOPE code. Med Phys. 2021;48(1):456-76.
- Zaragoza FJ, Eichmann M, Flühs D, Timmermann B, Brualla L. Monte Carlo Computation of Dose-Volume Histograms in Structures at Risk of an Eye Irradiated with Heterogeneous Ruthenium-106 Plaques. Ocul Oncol Pathol. 2020;6(5):353-9

PARTNERS

For more information, visit: **www.harmonicproject.eu** **#harmonicproject**

EURAMED ROCC-N-ROLL: DEVELOPING A EUROPEAN STRATEGIC RESEARCH AGENDA AND A CORRESPONDING ROADMAP FOR MEDICAL APPLICATIONS OF IONIZING RADIATION

Christoph HOESCHEN

CHRISTOPH HOESCHEN[1], GUY FRIJA[2], MONIKA HIERATH[3], JOHN DAMILAKIS[4], KATRINE RIKLUND[5], ALAN H. TKACZYK[6], MARC KONIJNENBERG[7], GRACIANO PAULO[8], ON BEHALF OF THE EURAMED ROCC-N-ROLL CONSORTIUM

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Radiation protection in medicine is well established throughout Europe, however still facing challenges like large differences in procedures between countries, but also within a country and even within a hospital. Novel promising approaches and technologies for medical applications of ionising radiation such as personalized medicine and artificial intelligence are developing and need further research including new medical radiation protection issues. Acknowledging the importance of medical applications as the largest man-made source of exposure and the great possibilities of applying ionizing radiation in medicine, the EURATOM programme has launched a call for a coordination and support action to develop a strategic research agenda (SRA) on medical applications of ionizing radiation also identifying the potential to improve links to other research programmes in the fields of health and digitalization.
A consortium called “EURAMED rocc-n-roll” has been put together to develop such an

SRA, partially based on the existing EURAMED SRA on medical radiation protection. In addition, it will also develop a roadmap describing how this research agenda can be implemented. An interlink document showing the potential contributions of the different European research programmes to such defined approaches will also be developed. All these documents need to be derived based on a broad consensus of all stakeholders including especially the patients' perspective. Therefore, EURAMED rocc-n-roll is based on a series of workshops and consultation panels. The workshops allow contributions by interested stakeholders in person or through members of the consortium. EURAMED rocc-n-roll is committed to developing the SRA and the roadmap with a strong focus on the patient perspective and highlighting the potential for individualized radiation-based medicine for combating cancer and other diseases.
This poster will provide an overview of the activities of EURAMED rocc-n-roll. It will show the current status including the achieved consensus on a structure for the SRA to be developed. It will summarize the results of the first (online) workshops and highlight the possibilities to contribute to the documents to be developed, i.e., the SRA, the roadmap and the interlink document.

FISA 2022

EURAMED rocc-n-roll: Developing a European Strategic Research Agenda and Corresponding Roadmap for Medical Applications of Ionizing Radiation

EURAMED ROCC-N-ROLL

Chistoph Hoeschen[1], Guy Frija[2], Monika Hierath[3], John Damilakis[4], Katrine Riklund[5], Alan H. Tkaczyk[6], Marc Konijnenberg[7], Graciano Paulo[8], Jing Ma[1] and Katharina Krischak[3] on behalf of the EURAMED Rocc-n-Roll consortium

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Background

Radiation protection in medicine is well established throughout Europe but still faces challenges like large differences in procedures between countries and also within countries and even within a hospital.
Novel promising approaches and technologies for medical applications of ionising radiation such as personalized medicine and artificial intelligence are developing and need further research, including new medical radiation protection issues.

Acknowledging the importance of medical applications as the largest man-made source of exposure and the great possibilities of applying ionizing radiation in medicine, the EURATOM programme has launched a call for a coordination and support action to develop a strategic research agenda (SRA) on medical applications of ionizing radiation with the potential to improve links to other research programmes in the fields of health and digitalization.

Introducing the Consortium

The EURAMED rocc-n-roll consortium has been assembled to develop such an SRA, partially based on the existing EURAMED SRA on medical radiation protection.

In addition, it will also develop a roadmap describing how this research agenda can be implemented. An interlink document showing the potential contributions of the different European research programmes to such defined approaches will also be developed.

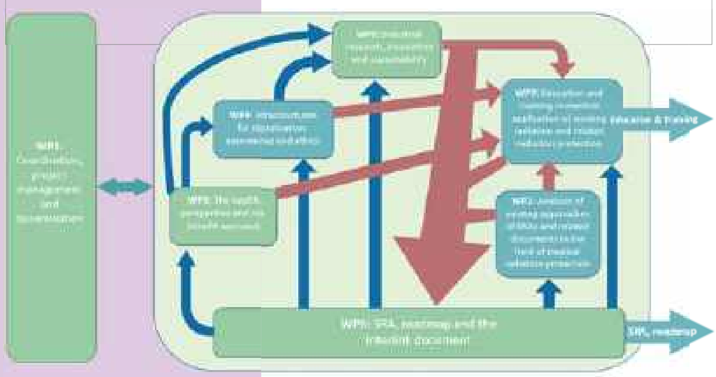
All these documents need to be derived **based on a broad consensus** of all stakeholders, including **especially the patients' perspective**.

Therefore, EURAMED rocc-n-roll running September 2020 until August 2023 is based on a series of workshops and consultation panels. The workshops allow contributions by interested stakeholders in person or through members of the consortium.

EURAMED rocc-n-roll is committed to developing the SRA and roadmap with a strong focus on the patient perspective and **highlighting the potential for individualized radiation-based medicine for combating cancer** and other diseases.

EURAMED rocc-n-roll will also consider the results of the projects MEDIRAD, SINFONIA and HARMONIC in collaboration with the EU radiation protection platforms.

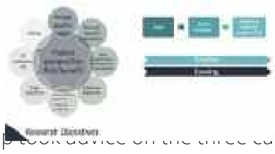
The structure of the project



https://roccnroll.euramed.eu/

The last Workshops

During the European Radiation Protection Week 2021, about 80 participants attended two workshops that presented and discussed the activities of **WP3, health perspective and risk benefit approach,** and **WP6, SRA for medical applications of ionizing radiation**.
The WP3 workshop highlighted the patient perspective and summarized the benefit of medical applications of ionizing radiation for various diseases including cancer The potential possibilities of new and optimized applications were described and necessary research was discussed.



The WP6 workshop took advice on the three categories of SRA objectives The **roadmap** was also addressed as a programme for the implementation of SRA research topics.

The structure of the SRA

Abstract
Keywords
Introduction

1.Medical challenge and corresponding research needs
Introduction
1.1 Patient centered perspective
1.2 Oncological aspects – needs and opportunities
1.3 Neurovascular aspects – needs and opportunities
1.4 Cardiovascular aspects – needs and opportunities
1.5 Identifying radiation application and radiation protection needs and opportunities in other relevant clinical scenario
1.6 Addressing common interests and identifying synergies
Summary of chapter 1

2.The corresponding Radiation Protection approaches
Introduction
2.1 Radiation biology perspectives
2.2 Dosimetry perspectives
2.3 Social science and humanity perspectives
2.4 Emergency preparedness and radioecology perspectives
2.5 The concepts of the existing EURAMED SRA including correlations to chapters 2.1 to 2.4
2.6 Regulatory interests
Summary of chapter 2

3. Organisational requirements and corresponding research introduction
3.1 Networks and Excellence centers
3.2. Sustainable resources and new applications
3.3 Digitalisation and corresponding ethical issues
3.4 Education and training (including the corresponding part of the former EURAMED SRA)
3.5 Transfer and translation
Summary of chapter 3

Conclusion
Summary list of proposed research topics and measures
References

This project has received funding from the Euratom research and training programme2019-2020 under grant agreement No 899995..

IMPROVING SCIENCE AND CLINICAL PRACTICE OF MEDICAL RADIATION PROTECTION - RESULTS AND RECOMMENDATIONS OF THE MEDIRAD PROJECT

Elisabeth CARDIS

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The MEDIRAD project aims to enhance the scientific bases and clinical practice of radiation protection in the medical field and addresses the need to better understand and evaluate the health effects of low-dose ionising radiation exposure from diagnostic and therapeutic imaging and from off-target effects in radiotherapy.

A multi-disciplinary consortium involving research groups focusing on radiology, nuclear medicine, radiotherapy, dosimetry, radiobiology, computer science, epidemiology, radiation protection and public health worked together to develop innovative tools to increase the efficiency of future radiation protection research activities and to support good clinical practice, as well as to improve the understanding of low-dose ionising radiation risks associated with major medical radiation procedures. Key results include (1) image quality assessment tool, organ dosimetry calculation tool, imaging and dose repositories and guidance for dose evaluation and optimization in CT, fluoroscopy-guided procedures and nuclear medicine; (2)

standardised quantitative I-131I imaging for dosimetry in thyroid cancer patients, freeware dosimetry tools for molecular therapy and recommendations for a large-scale epidemiological study; (3) development and validation of a prediction model to assess the risk of acute coronary events after RT in individual breast cancer patients based on 3D cardiac dose distributions (BRACE Study); identification and validation of the most important cardiac imaging and circulating biomarkers of radiation-induced cardiovascular changes after breast RT; development of preclinical models as well as different modelling approaches; (4) extended follow-up of major cohorts from the EPI-CT study of paediatric CT patients, implementation of a nested case-control study of brain and haematological malignancies and identification of potential biomarkers of susceptibility to low dose radiation induced cancer.

Based on MEDIRAD's research findings, a set of consensus recommendations has been developed in collaboration with a broad range of stakeholders to address the scientific and clinical communities as well as policy makers, encourage professional/regulatory guidance, follow-up research activities as well as to ensure that the research findings and tools developed under MEDIRAD find their uptake in clinical practice and thus benefit Europe's patients.

The main results and recommendations of the project will be highlighted in the poster, together with plans for their dissemination and exploitation.

IMPROVING SCIENCE AND CLINICAL PRACTICE OF MEDICAL RADIATION PROTECTION - RESULTS AND RECOMMENDATIONS OF THE MEDIRAD PROJECT

FISA 2022

MEDIRAD
Implications of Medical Low Dose Radiation Exposure

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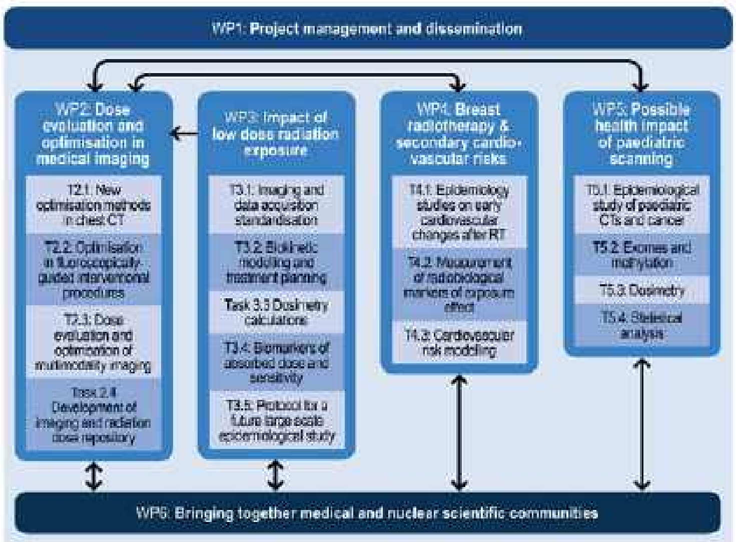
Introduction:

The evolution of medical science and growing pace of innovation and deployment of medical technology have led to a situation where most of the artificial ionising radiation exposure of the European population is due to medical procedures. Though most results in low to moderate doses in most tissues, there is a need to evaluate their health effects and optimise dose reduction practices and dose evaluation tools.

MEDIRAD aimed to enhance the scientific bases and clinical practice of radiation protection (RP) in the medical field by bringing together scientists and clinicians in a joint collaborative effort to conduct research to enhance protection of patients and medical professionals to:

- Develop innovative tools to increase efficiency of future RP research activities and support good clinical practice.
- Improve understanding of low-dose ionising radiation risks associated with major medical radiation procedures.
- Develop recommendations based on the scientific evidence emerging from MEDIRAD research results and establish procedures and information exchange infrastructures to facilitate professional consensus.

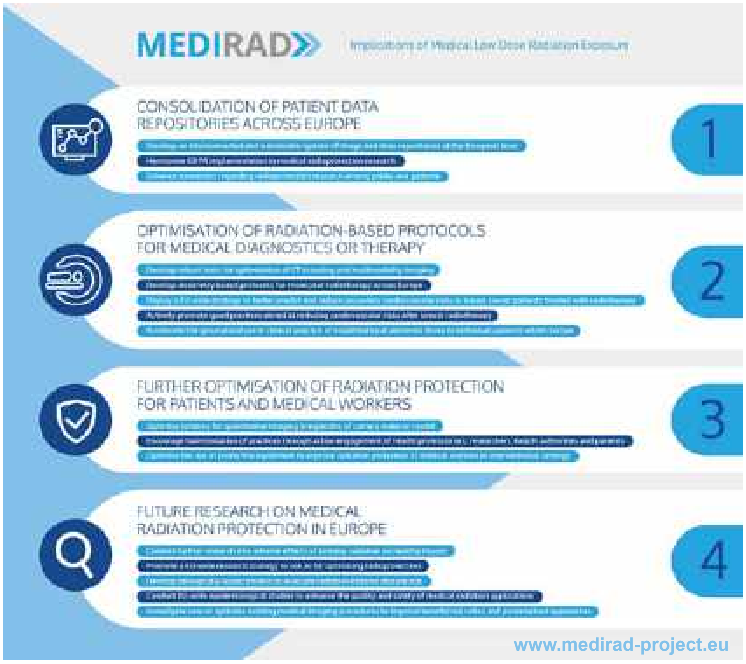
MEDIRAD Work Plan



MEDIRAD key scientific results:

- Tool to determine image quality to maximise optimisation of RP in medical imaging;
- First European imaging and dose repository;
- Standardised quantitative I-131I imaging for dosimetry;
- Dose calculation tools for CT scanning and molecular radiotherapy;
- Prediction model to assess risk of acute coronary events after RT in individual breast cancer patients based on 3D cardiac dose distributions;
- Identification of important cardiac imaging and circulating biomarkers of radiation-induced cardiovascular changes after breast RT;
- Identification of potential biomarkers of susceptibility to low dose radiation induced cancer;
- New multinational cohorts of breast cancer patients:
  - To investigate cardiac changes arising in the first 2 years after RT
  - To investigate long term cardiac complications of RT
- Extended follow-up of key EPI-CT cohorts of patients with paediatric CT scanning;

The MEDIRAD Recommendations



MEDIRAD (June 2017 – February 2022) brought together 34 partner institutions from 14 European countries. The multi-disciplinary consortium included clinical experts, scientists and policy makers in the fields of medical, radiation protection and nuclear research from hospitals, universities and major research centres across Europe:

EIBIR Gemeinnützige GmbH zur Förderung der Erforschung der Biomedizinischen Bildgebung (AT), Fundación Privada Instituto de Salud Global Barcelona (ES), Université de Paris (Université Paris Descartes) (FR), Panepistimio Kritis (GR), The Royal Marsden National Health Service Trust (UK), University Medical Center Groningen (NL), Institut de Radioprotection et de Sûreté Nucléaire (FR), Otto-Von-Guericke-Universität Magdeburg (DE), Instituto Politécnico de Coimbra (PT), Vastra Gotalands Lans Landsting (SE), Universitat Politécnica de Catalunya (ES), Instytut Medycyny Pracy Imienia Prof. Dra med. Jerzego Nofera w Lodzi (PL), B-COM (FR), Universitätsmedizin der Johannes Gutenberg-Universität Mainz (DE), Université de Genève (CH), Helmholtz Zentrum München Deutsches Forschungszentrum für Gesundheit und Umwelt GmbH (DE), Studiecentrum voor Kernenergie/Centre d'étude de l'Energie Nucléaire (BE), Universiteit Gent (BE), Universitätsklinikum Würzburg - Klinikum der Bayerischen Julius-Maximilians-Universität (DE), Philipps Universität Marburg (DE), Institut National de la Santé et de la Recherche Médicale (FR), Associação para Investigação e Desenvolvimento da Faculdade de Medicina (PT), Klinikum rechts der Isar der Technischen Universität München (DE), Universita degli Studi di Roma La Sapienza (IT), Vereniging voor Christelijk Hoger Onderwijs Wetenschappelijk Onderzoek en Patientenzorg (NL), University of Newcastle upon Tyne (UK), Stichting het Nederlands Kanker Instituut-Antoni van Leeuwenhoek Ziekenhuis (NL), Universitat Autònoma de Barcelona (ES), Istituto Superiore di Sanità (IT), University College Dublin, National University of Ireland, Dublin (IE), Institut Claudius Regaud (FR), Institut Català d'Oncologia (ES), Imperial College London (UK), Brandenburg Medical School (DE).

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 755523.

RADIATION RISK APPRAISAL FOR DETRIMENTAL EFFECTS FROM MEDICAL EXPOSURE DURING MANAGEMENT OF PATIENTS WITH LYMPHOMA OR BRAIN TUMOUR: THE SINFONIA PROJECT

John DAMILAKIS

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The main objective of the SINFONIA (Radiation risk appraisal for detrimental effects from medical exposure during management of patients with lymphoma or brain tumour) project is to develop novel methodologies and tools that will provide a comprehensive risk appraisal for detrimental effects of radiation exposure on patients, workers, carers and comforters, the public and the environment during the management of patients suspected or diagnosed with lymphoma and brain tumours. Personalised dosimetry methods and AI-assisted tools to estimate the radiation burden to patients undergoing imaging and radiation therapy procedures for diagnosis, staging, treatment response and follow-up are currently being developed. A computational system for real time dose assessment of nuclear medicine staff is under development. The impact on human and biota from the release of radiopharmaceuticals by hospitals is being assessed by developing appropriate transport models. Research work is in progress to determine the degree of intra-, and inter-individual variability for the risk of developing second malignant neoplasms (SMN) after radiotherapy and to validate functional and genetic biomarkers of susceptibility to SMN. Data will be collected in a shared depository. A training programme is currently being developed to train young clinicians, medical physicists, radiobiologists and other healthcare professionals as a team.

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RADIATION RISK APPRAISAL FOR DETRIMENTAL EFFECTS FROM MEDICAL EXPOSURE DURING MANAGEMENT OF PATIENTS WITH LYMPHOMA OR BRAIN TUMOURS: THE SINFONIA PROJECT

SINFONIA

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The main objective of the **SINFONIA** (Radiation risk appraisal for detrimental effects from medical exposure during management of patients with lymphoma or brain tumour) project is to develop novel methodologies and tools that will provide comprehensive risk appraisal for detrimental effects from radiation exposure to patients, workers, carers and comforters, the public and the environment during the management of patients suspected or diagnosed with lymphoma and brain tumours. Personalised dosimetry methods and AI-assisted tools to estimate the radiation burden to patients undergoing imaging and radiation therapy procedures for diagnosis, staging, treatment response and follow-up are currently being developed. A computational system for real-time dose assessment of nuclear medicine staff is under development. The impact on human and biota from the release of radiopharmaceuticals by hospitals is being assessed by developing appropriate transport models. Research work is in progress to determine the degree of intra- and inter-individual variability for the risk of developing second malignant neoplasms (SMNs) after radiotherapy and validate functional and genetic biomarkers of susceptibility to SMNs. Data will be collected in a shared depository. A training programme is currently being developed to train young clinicians, medical physicists, radiobiologists and other healthcare professionals as a team.

A novel tool based on personalised dosimetry and advanced artificial intelligence algorithms is under development for a) accurate and quick estimation of patient organ doses from CT and radiography examinations performed on those with suspected or diagnosed lymphomas and benign and malignant brain tumours and b) estimation of the radiogenic risk associated with these examinations.

Research on PET–CT has been focused on the development of tools for patient-specific internal radiation dosimetry calculations using deep-learning techniques. This includes the development of fully automated segmentation techniques from PET images to enable calculation of the radiation dose to malignant lesions using conventional MIRD-based approaches.

SINFONIA is currently performing measurements and simulations to develop a tool to determine 3D dose distributions within the patient and estimate organ doses from imaging in radiation therapy. Relevant imaging procedures include treatment planning CT, pre-treatment kV-CBCT for patient positioning, and retractable orthogonal planar X ray imaging (IGRT).

A physics-based analytical method for stray-dose calculations from megavoltage radiation therapy has been identified and is under implementation. The model is amenable to an individualised approach to determine organ and tissue doses that may subsequently be used to evaluate associated risks of SMNs. Measurements have been performed to characterise the neutron doses from proton fields.

A multicentre measurement campaign has begun with a harmonised protocol that will be used in each participating hospital to monitor the occupational doses of nuclear medicine staff. Dose measurements to the extremities, eye lens and whole body are performed for ^{68}Ga, ^{177}Lu and ^{131}I. This will yield new data on staff exposure for these increasingly used radionuclides in theranostics.

A computational system for real-time dose assessment of nuclear medicine staff is under development, involving tracking of personnel and relevant source objects and combined with Monte Carlo simulations and machine learning for dose calculations. A computational approach is also under development to determine the external dose rates from nuclear medicine patients in close-contact scenarios with staff, family members or members of the public. Another category of workers for which more staff exposure data will be generated is personnel working in proton therapy centres. The first achievement was the application of a field survey on staff dosimetry practice in these centres across Europe. From the 24 centres contacted, around 75% responded to the survey. Also, the impact on human and biota from the release of radiopharmaceuticals by hospitals is being assessed by developing appropriate transport models.

Research work is in progress to determine the degree of intra- and inter-individual variability for the risk of developing SMNs after radiotherapy for lymphoma and brain cancer and validate functional and genetic biomarkers of susceptibility to SMNs. To this end blood samples are being collected from patients with primary cancer and SMNs, and the in vitro radiosensitivity of lymphocytes is under analysis. The results will contribute to individualisation of radiation protection and cancer treatment.

Data from imaging and non-imaging examinations and radiation therapy sessions, histologic results and demographic information related to individual patients with lymphoma and brain tumours will be collected and pooled in a shared repository. A prototype has already been released to provide **SINFONIA** partners with a usable data-sharing tool and, at the same time, a mechanism to identify needs and issues.

A training programme is currently being developed to train young clinicians, medical physicists, radiobiologists and other healthcare professionals as a team, which will stimulate the exchange of skills and knowledge within Europe. Interactive multidisciplinary massive open online courses on clinical dosimetry and radiation risks will also be created, taking into consideration the specific gaps identified by a survey.

SINFONIA tools and methodologies will produce new knowledge on parameters affecting radiation detriment. This, in the era of personalised medicine, will help clinicians to properly balance risks and benefits of ionising radiation procedures and practitioners and medical physicists to develop dose optimisation strategies.

PROJECT PARTNERS: EIBIR Gemeinnützige GmbH zur Förderung der Erforschung der Biomedizinischen Bildgebung (AT), Panepistimio Kritis (GR), SCK CEN Studiecentrum voor Kernenergie / Centre d'etude de L'energie Nucleaire (BE), Stockholms Universitet (SE), CESGA Fundación Pública Gallega Centro Tecnológico de Supercomputación de Galicia (SP), Universiteit Gent (BE), SKANDION Kommunalförbundet Avancerad Strålbehandling (SE), Jan Kochanowski University (PL), QAELUM NV (BE), SERGAS Servizo Galego de Saude, Universite de Geneve (CH), Swietokrzyskie Centrum Onkologii (PL), Otto-von-Guericke-Universität Magdeburg (DE), Narodowe Centrum Badan Jadrowych (PL).

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THE MUSA PROJECT – MANAGEMENT AND UNCERTAINTIES OF SEVERE ACCIDENTS

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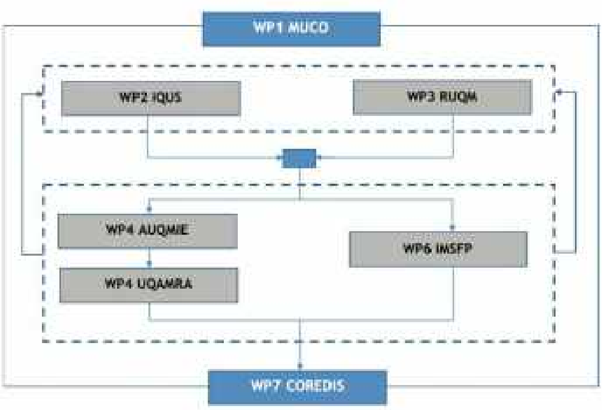
Management and Uncertainties Of Severe Accidents (MUSA) project was founded in HORIZON 2020 EURATOM NFRP-2018 call on "Safety assessments to improve Accident Management strategies for Generation II and III reactors". Coordinated by CIEMAT (Spain) and participated by 28 Organizations from 16 countries, MUSA overall budget is 5.768,452.50 €, more than 55% of which is contributed by the EU. The project started on June 1st, 2019 for a duration of 48 months. On July 7th, 2018, MUSA project received the NUGENIA label recognizing the excellence of the project proposal.

MUSA was devised to build a harmonized approach for the analysis of uncertainties and sensitivities associated with Severe Accidents (SA) and, particularly, with the Source Term to the environment. In this regard, MUSA plans to go beyond the current state-of-the-art regarding the predictive capability of SA analysis codes by assessing/developing methodologies for their use in combination with the best available Uncertainty Quantification (UQ) tools. In order to meet such a purpose a solid work structure has been put in place in the form of technical working packages (WP) properly coordinated.



As shown in the Figure, MUSA consists of 7 WPs: WP1, MUSA COordination and project management (MUCO) led by CIEMAT; WP2, Identification and Quantification of Uncertainty Sources (IQUS) led by GRS; WP3, Review of Uncertainty Quantification Methodologies (RUQM) led by KIT; WP4, Application of UQ

Methods against Integral Experiments (AUQMIE) led by ENEA; WP5, Uncertainty Quantification in Analysis and Management of Reactor Accidents (UQAMRA) led by JRC; WP6, Innovative Management of SFP Accidents (IMSFP) led by IRSN; and WP7, COmmunication and Results DISsemination (COREDIS) led by UNIPI.

After more than two years, major steps have been given in the identification and quantification of uncertainty sources and the familiarization with uncertainty and sensitivity analytical tools (WP2 and WP3, respectively), and the project is fully immersed in the phase of application both in reactor (WP5) and spent fuel pools (WP6). Preceding those applications, partners have used the PHEBUS-FPT1 scenario to test their approaches for the BEPU analyses of SA (WP4) and a number of useful insights have been gained for the WP5 and WP6 applications. It is worth noting that the experiences gained in the “practical WPs” will feedback WP2 and WP3 to eventually formulate recommendations. Specific aspects of the progress made so far will be summarized in this paper.

FISA 2022

The MUSA Project
Management and Uncertainties of Severe Accidents

MUSA

Luis E. Herranz[1] and Sandro Paci[2]

[1]Unit of Nuclear Safety Research, CIEMAT Madrid (Spain)

[2]University of Pisa – Department of Civil and Industrial Engineering DICI (Italy)

SNETP Sustainable Nuclear Energy Technology Platform

NUGENIA

MUSA Consortium

28 Organizations (25% non EU)

4 years duration from June 2019

630 person months

MUSA overall costs € 5,768,452.50

This project has received funding from Euratom research and training programme 2014-2018 under grant agreement No 847441

7 WP leaders

Ciemat

GRS

KIT

ENEA

IRSN

Università di Pisa

Project management Office

LGI

Project Coordinator
Prof. Luis E. Herranz
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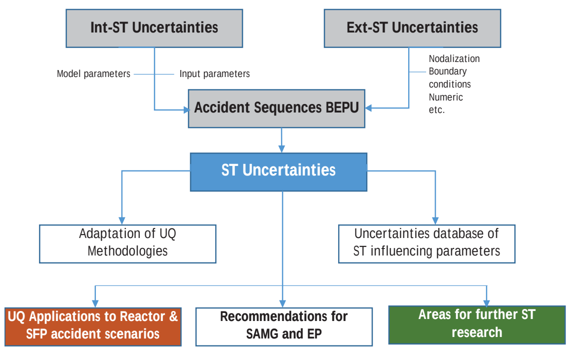
Objectives

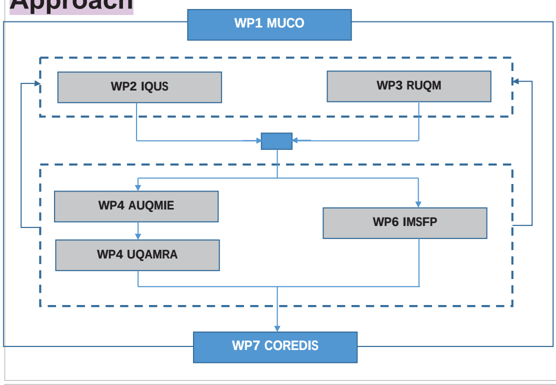
In a so complex field as Severe Accidents (SA), knowing uncertainties of safety analyses would provide a better assessment of safety margins, insights to optimize SA management, and help to identify key areas on which research might yield significant safety enhancement.

MUSA aims to consolidate a harmonized approach for the application of Uncertainty and Sensitivity Analyses (UaSA) in SA modeling, with specific focus on Source Term (ST) Figure of Merits (FOM). By doing so, not only the prediction of timing for the failure of safety barriers and of the radiological ST will be possible, but also the quantification of the uncertainty bands of the selected FOMs.

Both Gen. II and III reactors and Spent Fuel Pools (SFP) accident scenarios are being addressed.



Approach



WP1 MUSA COordination (MUCO), by CIEMAT

WP2 Uncertainty Sources (IQUS), coordinated by GRS

WP3 Uncertainty Methods (RUQM), coordinated by KIT

WP4 Modelling uncertainties in IETs (AUQMIE), by ENEA

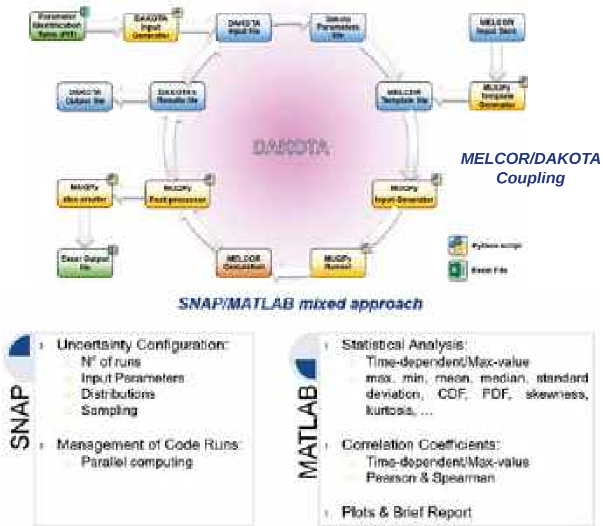
WP5 Analysis and Management of Reactor Accidents (UQAMRA), by JRC

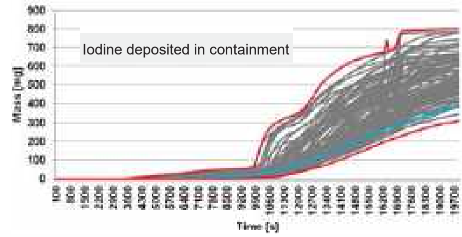
WP6 Uncertainty Quantification and Innovative Management of SFP Accidents (IMSFP), by IRSN

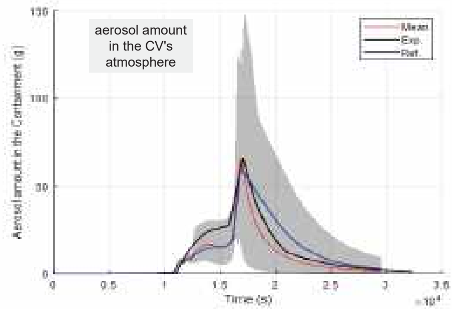
WP7 COmmunication & REsults DISsemination (COREDIS), coordinated by UNIPI & LGI

Current Status

- A large, though still incomplete, database of the uncertainties in input variables built in WP2 (LB, UB and PDFs).
- Uncertainty quantification methodologies reviewed and adapted to SA in WP3.
- UaSA training in WP4 on PHEBUS-FPT1 test highlighted challenges and provided insights to identify and solve some of the issues found (SA/Uncertainty Tools coupling, post processing, code crashes, etc.).







- UaSA in WP5 and WP6 is presently ongoing for reactor and SFP accidents.

Perspectives

- MUSA is meaning a better exploitation of the research previously performed within the EU framework.
- MUSA gathers experienced SA modelers to face challenges and ease spreading harmonized UaSA in SA.
- In addition, MUSA encourages cooperation in research, innovation, and young generation's formation.

https://musa-h2020.eu/ **www.linkedin.com/company/musa-h2020-project/**

POST-TEST ANALYSIS OF THE HYMERES-2 H2P5 SERIES ON THE SPRAY SAFETY SYSTEM USING GOTHIC8.3 (QA)

Carlos VAZQUEZ-RODRIGUEZ

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HYMERES-2 was a 4-years OECD/NEA Project dedicated, among other topics, to extending the experimental database on hydrogen behaviour in a large vessel. Specifically, the H2P5 Series studied the cooling effect and the mixing ability of a spray system when actuated in a pre-stratified gas mixture with three gases: air, steam, and helium. The H2P5 Series consisted of two tests with different configurations of the spray system, one using a single nozzle and the other, for the first time in PANDA, a spray ring with several nozzles. After a dedicated assessment of the experimental measurements, the two experiments of the H2P5 series were modelled using GOTHIC 8.3(QA) with a 3D model of approximately 47000 cells. The analysis was separated into a thermal part (cooling effect of the spray) and a dynamic part (mixing ability of the droplets). The main differences between the two experiments were the faster cooling and mixing in the single nozzle case, both qualitatively captured by the simulations. However, from a quantitative perspective, the pressure of the vessel and the gases concentrations evolution of the reference simulations were improvable. The deviations between the experimental measurements and the simulations were addressed by a comprehensive parametric variation of the variables affecting the most important phenomena, i.e., the liquid re-evaporation and the steam condensation onto droplets for the thermal part, and the momentum transfer from the disperse droplet phase to the continuous gas phase for the dynamic part. Especially for the thermal part, there were no defensible hypotheses that could justify the faster pressure decrease obtained in all the simulations. The only approach that reproduced the pressure decay rates was an unrealistic decrease of the spray flow rate, which indicated that the steam condensation onto droplets might be overestimated when using the actual flow rate.

POST-TEST ANALYSIS OF THE HYMERES-2 H2P5 EXPERIMENTS ON THE SPRAY SAFETY SYSTEM USING GOTHIC8.3(QA)

FISA 2022

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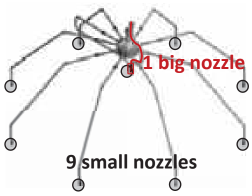
1. HYMERES-2 and the Spray Safety System

This poster presents the investigations on the spray system performed during the OECD/NEA HYMERES-2 Project. Specifically, two experiments (data still confidential) actuated the spray in a pre-stratified mixture of three gases: air, steam, and helium. The objectives are two-fold:

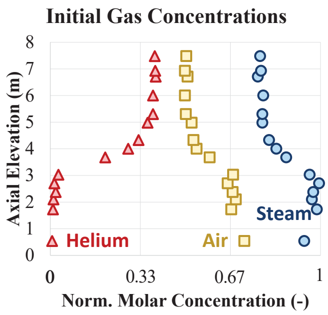
- To evaluate the difference between the two experiments, which used either a single nozzle or a spray ring to represent the spray system
- To validate the code GOTHIC8.3(QA) for reproducing the cooling effect and the mixing ability of the spray system actuation

2. The Experiments: Single-Nozzle (1N) vs Spray Ring (9N)

For the first time in PANDA, one experiment used a **spray ring**. It was compared with a "conventional" **single nozzle** configuration.

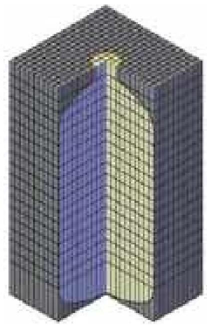


Main measurements:
≈340 Thermocouples
7 Points Mass Spectrometer



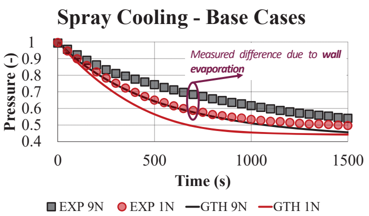
3. GOTHIC 3D Model

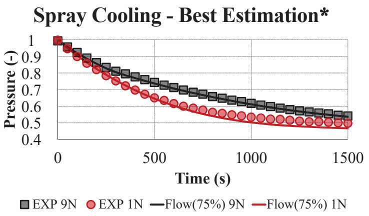
Thermal-hydraulic multi-phase code mainly used for containment applications (Lumped and 3D models)



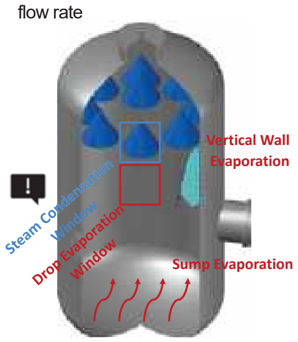
- Conservation equations for *vapor continuous liquid* and *droplets*
- Mono-disperse droplet population
- Euler-Euler phases interaction
- Turbulence: k-ε STD
- Friction and heat transfer solved by bulk correlations
- Cartesian mesh
- Fluid & Solid in the same cell
- 67 000 cells

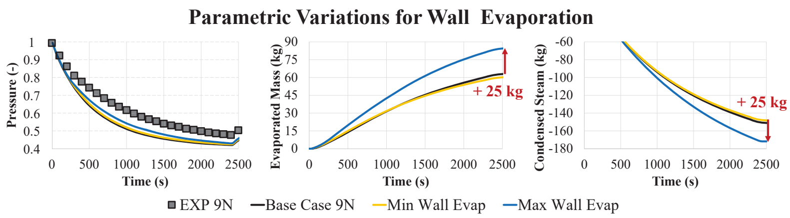
4. Normalized results for the cooling effect

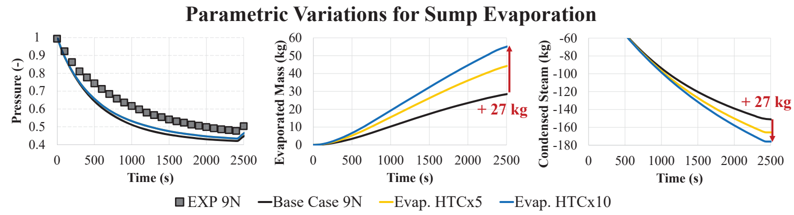




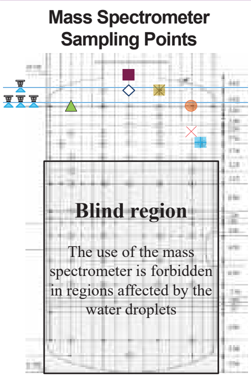
*After more than 50 parametric cases, the experimental pressure was reproduced only by using a 75% of the actual spray mass flow rate



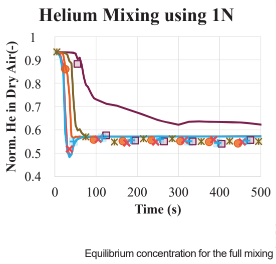


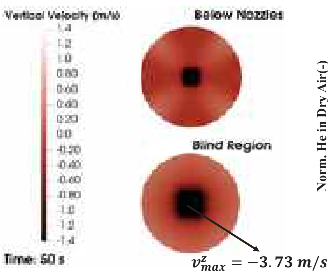


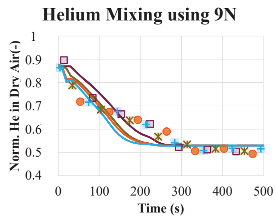
5. Normalized results for the helium mixing

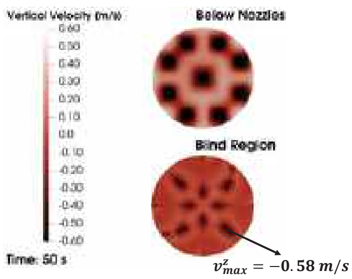


The recordings of the mass spectrometer indicated a much faster mixing when using a single nozzle. The concentration of droplets in a single location induced larger velocities in the vapor field (reproduced by GOTHIC)









6. Conclusions

- GOTHIC can reproduce qualitatively the faster cooling and mixing measured in the single nozzle experiment
- The parametric analysis for the spray cooling indicates that GOTHIC may overestimate the role of the steam condensation on droplets
- The helium mixing is accelerated when the *droplet/vapor* interfacial area is concentrated (single nozzle) or increased (smaller droplets)

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
30 May – 3 June 2022 | Lyon, France

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IMPACT OF GEOMETRICAL MODIFICATIONS ON CONTAINMENT THERMAL HYDRAULICS AND COMPUTATIONAL COST USING GOTHIC 8.3(QA)

Sofía ARFINENGO-DEL-CARPIO

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Three-dimensional computational codes have become a useful tool regarding containment analysis due to their capacity to simulate phenomena in detail. The GOTHIC 3D capacities are achieved through the porous media approach, which implies that fluid and solid phases are allowed to coexist inside the same computational cell. Having that characteristic causes some numerical cells with particularly problematic configurations (low free volume or transversal area compared with the surrounding cells) to appear, which lead to numerical instabilities when simulating large mass and energy releases, causing an important increase in computational costs. To avoid the appearance of these problematic cells, the Universidad Politécnica de Madrid (UPM) has developed what has been called “preventive methodology”. It consists of modifying the original geometry to adapt it to the GOTHIC Cartesian mesh. Aiming to reduce its computational cost, the preventive methodology is applied to optimize the Almaraz NPP full containment model. In order to assess whether the geometric modifications have a significant impact on the model capacities for accurately representing the containment phenomenology during an eventual accident, a comparative study against previous models without such geometric modifications is conducted. The agreement between both models is adequate. It is possible as the combination of the porous media approach with the built-in correlations for friction and heat transfer allows maintaining the model thermal hydraulics by keeping the same free volume, transversal areas, and heat transfer surfaces. Finally, it must be pointed out that the computational cost for the preventive methodology model is one order of magnitude lower than the previously developed model. As the model accurately represents the containment thermal hydraulics, it can be concluded that the preventive methodology has proven to be a powerful tool for model optimization with the GOTHIC code.

Impact of geometrical modifications on containment thermal hydraulics and computational cost using GOTHIC 8.3(QA)

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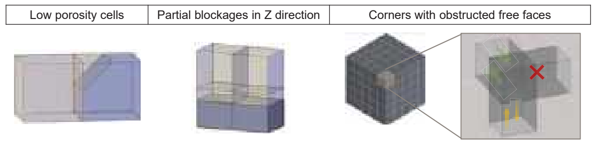
Background

- CAD software became the main working environment for model development, for gathering and tracing all the information.
- Model development process:
  1. Detailed CAD geometry from plant layouts.
  2. Simplified CAD geometry, which suits GOTHIC's modelling and domain discretization particularities.
  3. Model geometry in GOTHIC.

Motivation

- GOTHIC's porous media approach causes problematic cells to appear.



- In this work, the simplified CAD geometry avoids the appearance of the problematic cells, by adapting the geometry of a three loop PWR (Almaraz NPP) to GOTHIC's Cartesian mesh.

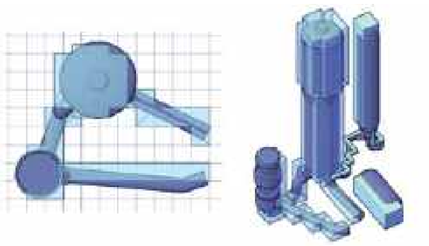
Model development

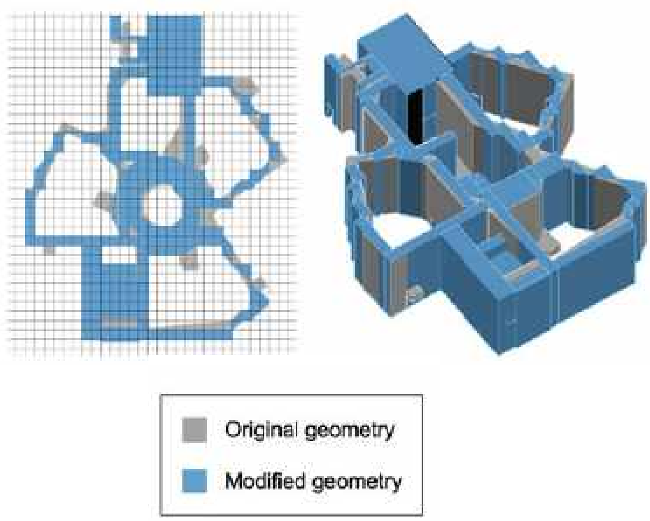
Modelling decisions

- Integral model (single control volume)
- Cubic 1-meter-wide homogeneous mesh

Simplified geometry

- All the structures (compartment walls, floors, equipment…) are adapted to the Cartesian mesh
- Z direction blockages are avoided
- Free volume of each cell is at least 50%
- The relative error for the free volume and upper areas of all the compartments, in relation to the original geometry, is maintained below 3%.



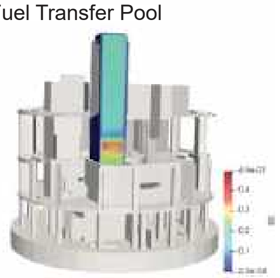


Model robustness

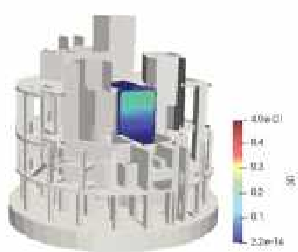
Airtightness tests

An hydrogen source is added to check the coherence of the possible hydraulic paths after the implementation of the simplified geometry. Tests:

- Steam Generator compartments
- Pressurizer compartment
- Fuel Transfer Pool



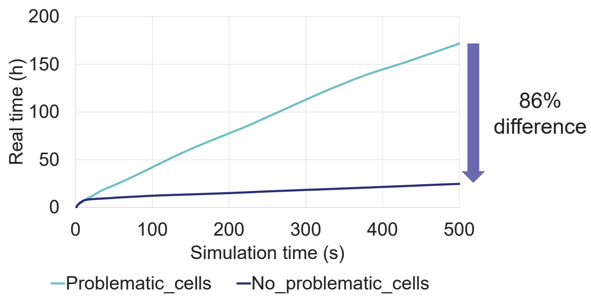
PZR Compartment



Fuel Transfer Pool

Computational time

By using this methodology, the computational times are significantly reduced. A model with no methodology run 500 seconds of a transient in 171 hours, while the same model without problematic cells needed 24 hours to run the same transient.



Conclusions

- The methodology can be applied to a full containment geometry with no major impact on the geometrical aspects (free volume, free areas between spaces, etc.).
- The methodology allowed the use of an homogeneous mesh, which reduces the numerical instabilities during the simulations.

MODEL BASED SYSTEM ENGINEERING, AN INDUSTRIALIZATION PATH FOR DECOMMISSIONING PROJECTS BY ASSYSTEM

Brice ROFFINO

PAULINE SUCHET – *Senior Project Manager – psuchet@assystem.com*
BRICE ROFFINO – *Project Manager – broffino@assystem.com*

Conventional engineering development cycle are too long to accommodate the uncertainties inherent to the decommissioning and waste retrieval and conditioning projects, leading to costly hazard detection. Dismantling projects will last between 10 and 50 years and will generate a significant volume of data. How to make the decision with an important part of unknown, how to drive project and monitor the risk, How to standardize the dismantling industrialization and in what extent the standardization can reduce the cost and how far can we go without all the keys data. All these questions are key for project owners, and engineering must provide solutions, to lead project to success. To meet the challenges of uncertainties such as industrialization, the use of digital solutions is seen as a performance lever for projects with a very strong impact, especially in the engineering phases, for which the development process are, for decades, to linear to manage uncertainties.
Industrialization of the engineering of dismantling should offer the sufficient confidence of the initial state of the installation to state the dismantling scenarios while offering data flexibility and continuity through the project lifetime, notably regarding evolution of regulatory constraints and waste management path while reducing time and costs to reengineer scenarios.Thanks to its mastery of model based system engineering, Assystem has developed a digital suit: « DEMologist » which, coupled with a number of dedicated digital tools, act as a co-designed platform between the project owner and the prime contractor. That digital suit include an asset hub information combine with all the applications connected between them: digital tool combine with AI to read, understand and structure disparate and scattered data in technical achieves GDI; digital tool to simulate the impact of dismantling scenario (ADS/DEM, DEM+, …) : waste, schedule, costs, … ; realization of digital twin coupled with the BIM of the installation for the real time feedback of the installation ; artificial intelligence for default prediction ; virtual reality to simulate dismantling scenario, training the operators and increase the safety and human factor engineering and digital tool for technical inspection FIELD STUDIO (waste, safety, security, schedule, …).

Model Based System Engineering,
an industrialization path for decommissioning projects

SUCHET Pauline[1] and ROFFINO Brice[2]
[1]Principal Project Manager
[2]Project Manager

Complexity and risks of decommissioning projects

Decommissioning is the stage in the life of a nuclear facility that aims to return the site on which the plant was built to "civilian life".

Making decisions with a significant unknown, managing the project and monitoring the risk, standardising the industrialisation of commercial reactor dismantling to reduce costs and consolidating the REX accumulated over the years to improve the performance of specific dismantling cycle installations.

Decommissioning a facility often comes with significant challenges, in direct relation with their ages:

- inadequate storage facilities,
- large but uncertain inventories,
- uncertain material conditions, both originally and current,
- conditions of work in locations range from difficult to extremely challenging,
- extended time for hazard reduction,
- current legacy-related challenges.

In addition, many decommissioning projects are delayed for several years due to the lack of an adequate planning and management infrastructure, which inevitably leads to increased costs.

These questions are essential for project owners, and engineering provides solutions that enable to make progress in the management of risks and, where possible, to achieve economies of scale through industrialization.

Assystem's methodology and key assets

With its broader knowledge of digital and its expertise in dismantling requirements, ASSYSTEM has developed a model based system engineering approach combining artificial intelligence and modeling of installations allowing:

- operators, subcontractors and safety authorities to understand the installation in all its dimensions and to co-design in real time the dismantling scenarios,
- to simulate intervention scenarios before entering the area, thus making it possible to derisks operations.

Assystem's teams are developping the DEMOLOGIST digital suite based on :

- **the implementation of the model-based system engineering method**
- **the development of numerical software to recover, analyse and make reliable the data on the whole project.**

In our experience, decommissioning and waste management relies on three factors

- **the synthesis of complex input data** distributed in documents, their compilation and follow-up during the project,
- **the definition of a structured, mapped and ordered requirements repository** to facilitate safety and compliance demonstrations,
- **the identification of all plant functions**, and in particular interfaces and flows, to optimise the layout of the plant housing the process.

Client's benefits

As a leading nuclear engineering company, Assystem always implements MBSE methodology starting from processes, needs and practices in order to:

- **Streamline requirements** with the project owner,
- **Identify data and needs** throughout the life of the project,
- **Adapting the solution architecture** and define the building blocks of the decommissioning installation,
- **Manage its optimisation through rapid and self-consistent monitoring of changes,**
- **Contribute to operational excellence** in the preparation, supervision and monitoring of the institution's operations,
- **Improve the traceability/quality/reliability** of the data acquired on the site, its exploitation and its dissemination,
- **Bring together all the players** (owner, industrial operators) around a shared collaborative space with access to data acquired on site,
- **Increase productivity**.

A COMBINED LIDAR CAMERA AND COMPTON CAMERA SYSTEM FOR VISUALIZATION AND LOCALIZATION OF HOTSPOTS

Mattias SIMONS

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WOUTER SCHROEYERS, *UHasselt – Hasselt University, CMK, NuTeC, Nuclear Technology- Faculty of Engineering Technology, Agoralaan H, 3590 Diepenbeek, Belgium;*

The localisation, characterisation and remediation of hotspots during a nuclear decommissioning project is an important activity to avoid unneeded dose-uptake for operators. The current practise for identifying hotspots is by performing manual radiological measurements. However, due to the high dose rate of the hotspots at some locations, special measures are necessary to protect workers and the available time to perform mapping and characterisation steps is limited. This not only introduces the risk of missing sources or performing inaccurate measurements and other specific ALARA related challenges, but it is a time consuming and inefficient way of mapping. In the ARCHER project, an (semi) autonomous robotic platform was developed. Using this robot can limit the need for human intervention and therefore also minimises human dose uptake during these measurements. However, this platform currently still uses this inefficient and time-consuming way of mapping. During this research, a Compton camera was developed and combined with a 3D camera as an alternative to the more common scanning based spectrometric approach for radiological mapping. The Compton camera was identified as being more advantageous as sources can be localised without performing many time-consuming robot manipulator manoeuvres. Furthermore, the measurements with the Compton camera are performed relatively far away from the source, thus limiting the chance of contaminating the robot platform. A measurement was made where a 137Cs source was located in front from the detector setup. A direct back projection algorithm was used for the Compton camera to retrieve the direction of the source. This radiological data was then combined with a point cloud of a Realsense L515 lidar 3D camera to visualise the measurements. After a correction was applied for the physical distance between the two detectors, the measurement of

the Compton camera was superimposed with the point cloud to visualise the hotspot. The source location was accurately found and visualised in 3D.

Combined lidar Compton camera system for visualization and localization of hotspots

Mattias Simons[1], Lowie Brabants[1], David De Schepper[2], Eric Demeester[2] and Wouter Schroeyers[1]

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Introduction

To reduce the dose uptake of workers in a nuclear environment, robots or gamma cameras are often used to **localise hotspots and sources**. A semi-autonomous robotic platform was developed during a previous research project called ARCHER. This robot limits the need for human intervention. But still uses the time-consuming way of measuring point by point.

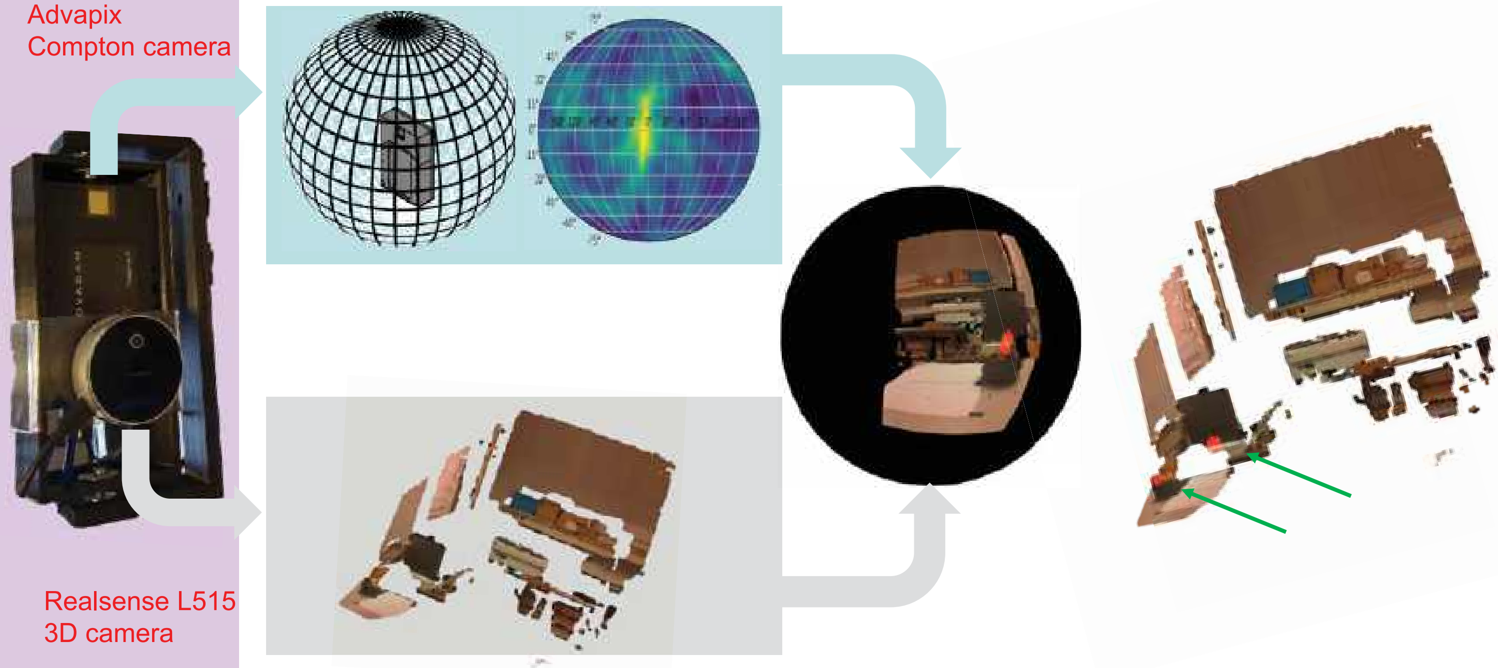
Gamma cameras can measure from relatively **far away** and therefore **reduce the chance of contamination.** This study **combined** a **single layer Compton Camera** with a **3D camera** to better **visualise** the source and estimate the **source-to-detector distance**. Preliminary tests were performed with a ^{137}Cs source.

Experimental setup

- Advapix TPX3 1mm CdTe
- Intel Realsense L515
- ^{137}Cs source (±230 kBq)
- Source placed at 50 cm

Methods

- **Measurement Compton camera:** 3D reconstruction applied on the advapix detector => a single layer Compton camera.
- **Back-projection:** Direct back-projection algorithm in spherical coordinates. Values lower than 99% of the maximum are hidden.
- **Transformation of point cloud:** A point cloud from the 3D camera was corrected for the offset between the two sensors.
- **Superimposition of hotspot with point cloud:** The angular information (coming from the Compton camera) was superimposed with the corrected point cloud



Conclusions

- ^{137}Cs source found near 0 degrees elevation and 5 degrees azimuthal angle.
- Combined with 3D camera data => accurate depth and location estimation
- False hotspot found behind real source => eliminate with second measurement from side

Future works will focus on eliminating the false-positive estimation of a source and increasing the field of view by rotating the setup and optimising the efficiency of the Compton camera.

Mattias Simons

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Radiological mapping and localisation via lightweight Compton imaging system supported by thin shielding and collimation Materials

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Acknowledgements

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The ARCHER project is carried out by UHasselt and KU Leuven in collaboration with Equans (Engie) and Magics instruments. This project is funded by the energy transition fund of the FOD economy (federal government of Belgium).

FROM THE PLANT LAYOUTS TO AN OPTIMIZED 3D PWR-KWU CONTAINMENT MODEL WITH GOTHIC 8.3 (QA)

Luis SERRA

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Containment geometry characteristics play a key role in many accident and severe-accident phenomena, such as flammable gas distribution, accumulation and deflagration dynamics. The containment buildings of nuclear power plants have complex geometries and extracting the data required to build detailed computational models from plant layouts is a demanding task. Using Computational Aided Design (CAD) software as a cornerstone of the modelling process serves as a bridge between the containment layouts and the thermal-hydraulic models. This work will describe all the steps of the methodology used to build a 3D PWR-KWU containment model in GOTHIC from its detailed CAD model. Firstly, an intermediate model with several geometric simplifications will be developed in the CAD environment. These simplifications are intended to avoid problematic configurations when adapting the actual geometry to the porous cartesian mesh of GOTHIC, avoiding numerical instabilities and resulting in shorter simulation times. The simplified geometry is imported into GOTHIC, and it is tested by simulating a Large Loss of Coolant Accident (LB-LOCA) in one of the cold legs. This is the most convenient scenario to check the specific numerical instabilities within the porous cartesian space discretization of GOTHIC, which mainly arise from the massive release of mass and energy during the blowdown. Although the initial containment model did perform adequately in the initial phases of the LOCA, a detailed assessment of the numerical stability revealed several points for improvement in further stages of the simulation. Namely, the accumulation of liquid in sump-type regions with low-porosity problematic cells, hampered the simulation at specific periods of time. Then, the final modifications of the geometry achieved a reduction of the computational costs up to one order of magnitude. Part of this work is included within the AMHYCO project (Euratom 2019-2020, GA No 945057) which main objective is to improve experimental knowledge and simulation capabilities for the H_2/CO combustion risk management in nuclear power plant containments during severe accidents (SAs).

From the plant layouts to an optimized 3D PWR-KWU containment model with GOTHIC 8.3 (QA)

FISA 2022

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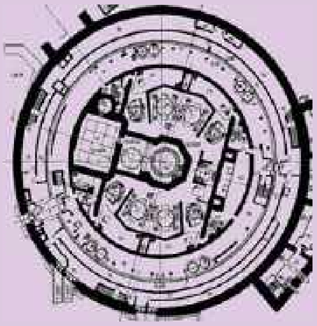
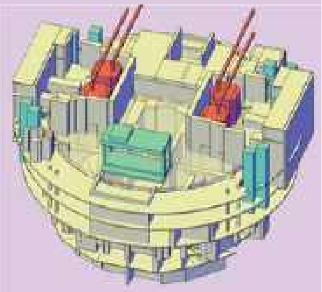
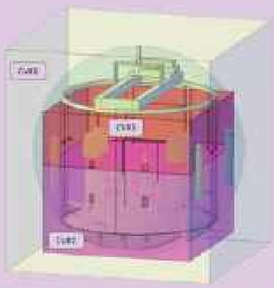
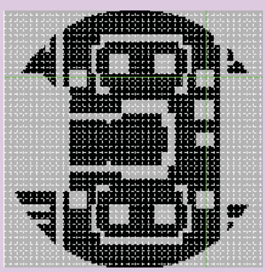


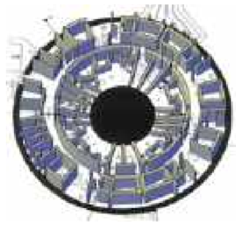


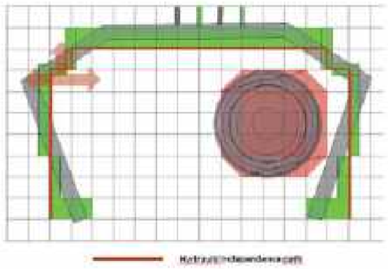




1. Detailed CAD 3D model

Using Computational Aided Design (CAD) software as a cornerstone of the modelling process serves as a bridge between the containment layouts and the thermal-hydraulic models. Detailed 3D CAD models permit a thorough evaluation of free volumes, heat transfer surfaces, flow paths position and **nodalization strategies**, in a data-traceable environment. This containment model is built with extreme attention to detail, regarding both main and secondary structures and components, aiming for an **enhanced representation of containment phenomena** throughout the numerous compartments.



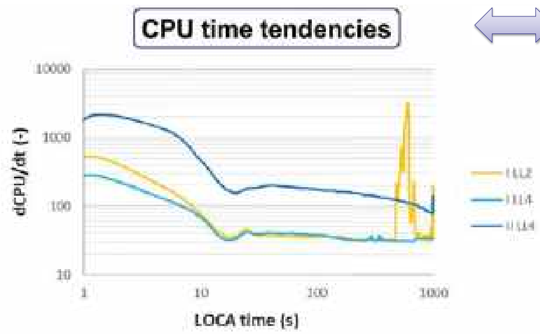


2. Simplified CAD model

To *a priori* avoid some problematic geometrical configurations when exporting the model to GOTHIC, an intermediate model is built. The adaptation is done with simple blocks, fitted in homogeneous orthogonal meshes, and assuring the **hydraulic independence** between rooms. Also, surfaces and free volumes are kept with a maximum error of 3%. These simplifications follow in the footsteps of previous methodological efforts to **avoid numerical instabilities** and enhance the robustness of the models.

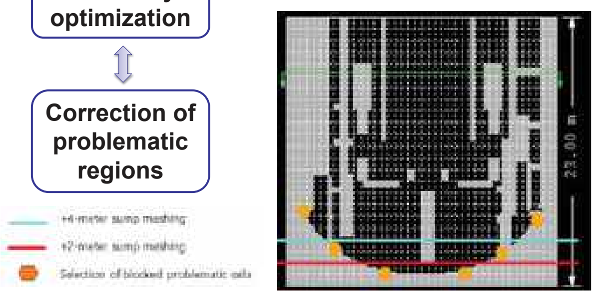
3. Air-tightness test and definition of model strategies

Several tests are performed in crucial compartments to check if the model implementation in GOTHIC is successful. These are done by simulating hydrogen releases and tracking the gas behavior to **detect geometrical incongruities**. Moreover, the geometry is verified for different mesh sizes (1 m^3 to 8 m^3 orthogonal cells), to assure its **robustness** in scenarios where coarser or finer refinements in each control volume may be needed. Then, three models are created, ranging from 12000 to 85000 computational cells.



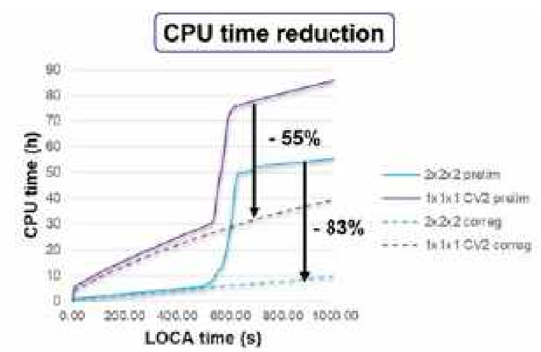
Geometry optimization

Correction of problematic regions



4. Assessment of model stability and optimization of computational cost

To search for possible numerical instabilities, a fast cold-leg LB-LOCA release is simulated. The idea is to **detect and correct local problematic configurations**, to boost model performance. By studying the CPU time tendencies, a period of high computational effort was seen at the middle of the transient, due to the accumulation of water in the sump region. Also, during the first seconds of the blowdown stage, some configurations that were not avoided in the simplification process were detected. Then, the coarsening of the sump area and the blocking of some cells resulted in the **reduction of CPU effort in one order of magnitude**. Moreover, it was seen that the direction of the injection of mass and energy releases can increase simulation times, as was the case for the models with the highest steam flow velocities.



Conclusions

- The creation of adapted models from detailed ones produces robust 3D models subdued to lower simulation efforts, thus allowing to perform more sensitivities with them.
- Model construction and pre-processing can be balanced by the implementation of preventive methodologies and the analysis of local computational instabilities.
- The thorough analysis of synergies between geometry and limiting phenomena can furtherly reduce computational times in at least one order of magnitude.

PARUPM: A SIMULATION CODE FOR PASSIVE AUTOCATALYTIC RECOMBINERS.

Araceli DOMINGUEZ-BUGARIN

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In the event of a severe accident with core damage in a water-cooled nuclear reactor, combustible gases (H_2 and possibly CO) get release into the containment atmosphere. An uncontrolled combustion of a large cloud with a high concentration of combustible gases could lead to a threat to the containment integrity if concentrations within their flammability limits are reached. To mitigate this containment failure risk, many countries have proceeded to install passive auto-catalytic recombiners (PARs) inside containment buildings. These devices represent a passive strategy for controlling combustible gases, since they are capable of converting H_2 and CO into H_2O and CO_2, respectively. In this work, the code PARUPM developed by the Department of Energy Engineering at the UPM is described. This work is part of the AMHYCO project (Euratom 2014-2018, GA No 945057) aiming at improving experimental knowledge and simulation capabilities for the H_2/CO combustion risk management in severe accidents (SAs). Thus, enhancing the available knowledge related to PAR operational performance is one key point of the project. The PARUPM code includes a physical-chemical model developed for the study of surface chemistry, and heat and species mass transfer between the H_2/CO/air/steam/CO_2 mixture and the catalytic plates in a PAR channel. This model is based on a simplified Deutschmann reaction scheme for surface combustion of methane, and the Elenbaas analysis for buoyancy-induced heat transfer between parallel plates. Mass transfer is considered using the heat and mass transfer analogy. PARUPM is capable of simulating the recombination reactions of H_2 and CO inside the catalytic section of the PAR. In addition, this model allows studying the effect of CO in the mixture, allowing to explore the effect of this compound on transients related to accidents that advance towards the ex-vessel phase. Finally, a thorough analysis of the code capabilities executed by comparing the numerical results with experimental data obtained from the REKO-3 facility. This analysis allows to establish the ranges in which the code is validated and to further expand the capabilities of the simulation code which will lead to its coupling with thermal-hydraulic codes in future steps of the project.

PARUPM: A SIMULATION CODE FOR PASSIVE AUTOCATALYTIC RECOMBINERS

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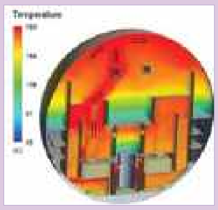
BACKGROUND

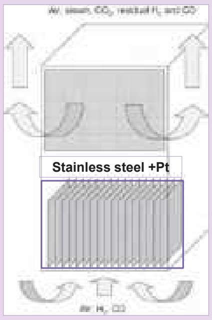
- In severe accidents (SAs) large amounts of combustible gases may get released into the containment atmosphere, generating a risk of combustion.
- To mitigate this hazard, PARs have been installed inside containment buildings.
- These devices can convert H_2 and CO into H_2O and CO_2, reducing the risk of combustion.

AMHYCO PROJECT

- The AMHYCO project aims to improve the knowledge and simulation capabilities for the H_2/CO combustion risk management in SAs.
- The enhancement of the available knowledge related to PAR operational performance is one key point of the project.

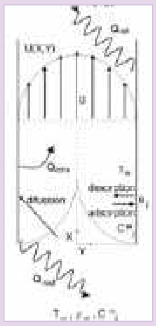


PARUPM MODEL



- Numerical code capable of simulating the behaviour of a PAR device through a physical-chemical approach.
- This code will be implemented into containment analysis codes to study the effect of recombiners in SAs scenarios.

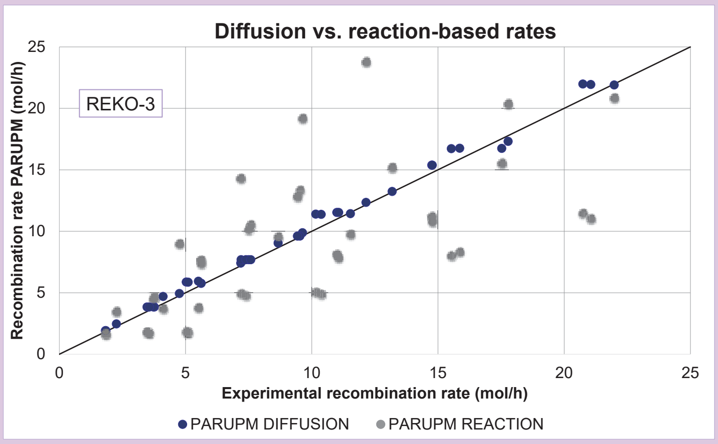
- Relevant phenomena considered in the recombination model:
  - Mass transfer
  - Adsorption/desorption of species
  - Surface chemical reactions and heat release
  - Convective and radiative heat exchange.



MODEL ENHANCEMENT: DIFFUSION RATE

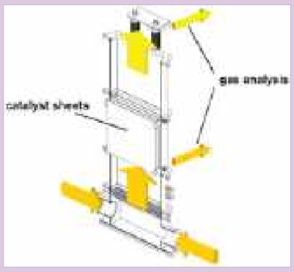
- Heterogenous catalytic reactions involve both surface and transport phenomena. Initially, the recombination rate inside PARUPM was determined by the surface reactions of the species over the catalytic plates.
- A mass transfer model has been added to the code to consider the diffusion through the boundary layer and to study the effect of this phenomenon on the recombination rate.

$$Rate_{H_2,dif} = \frac{Sh_{H_2}\, D_{dif}}{D_h}\left(\frac{p_{H_2}}{RT}\right)$$



CODE VALIDATION AGAINST REKO-3 DATA

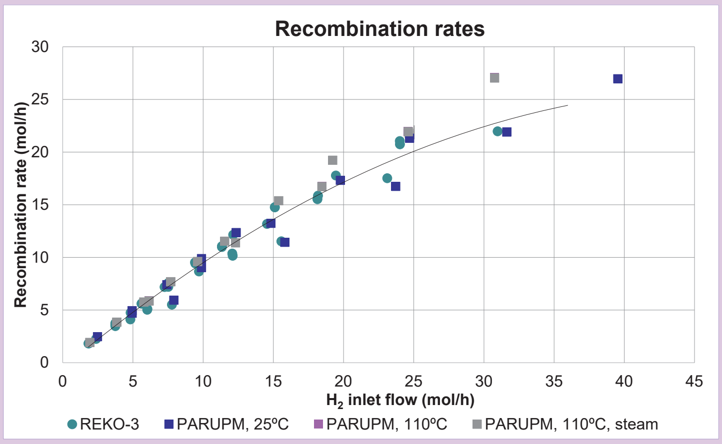
- Analysis of the code capabilities comparing the numerical results with experimental data obtained from the REKO-3 experimental facility.



3 main cases

- Gas temperature 25ºC and steam 0%
- Gas temperature 110ºC and steam 0%
- Gas temperature 110ºC and steam 20%

3 inlet velocities: 0.25 m/s , 0.5 m/s, 0.8 m/s



CONCLUSIONS

- The introduction of the diffusion model significantly improves the results, independently of the velocity of the inlet gas. With the reaction-based rates, the recombination rate was overpredicted at lower velocities by an average ≈40% and was underpredicted for higher velocities by an average ≈40% as well.
- Good predictions of the recombination rate are achieved with the diffusion model. The biggest deviation appears for low H_2 inlet concentrations, higher inlet temperatures, and higher velocities, though the average deviation is ≈5%.
- After the completion of the model development process, PARUPM will be coupled to thermohydraulic codes for SA analysis with PARs presence.

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VALIDATION OF ATHLET-CODE FOR SIMULATING PASSIVE RESIDUAL HEAT REMOVAL VIA LOW-PRESSURE LOOP THERMOSYPHONS

Nelson Felipe RINCON-SOTO

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Inherent reactor safety and advanced passive technologies (APT) are common design features in emerging Small Modular Reactors (SMRs). Among APTs, passive residual heat removal systems (PRHRS) are responsible for the removal of residual core-generated heat after plant shutdown. PRHRS rely on naturally-driven forces to transfer the residual heat to an intermediate containment-adjacent heat sink (Emergency cooling tank - ECT). PRHRS lose their cooling capability once the ECT-water is depleted, hence, the residual heat must be transferred via a secondary loop to an ultimate heat sink (Surroundings or an air-cooling tower – ACT) to extend the grace period of ECTs. Loop thermosiphons (LTS) are considered suitable secondary loops, as the inner natural circulation can be achieved by the temperature gradient and height between ECT and ACT. LTS are usually operated at sub-atmospheric pressures to guarantee a two-phase operation and ensure a sufficient temperature gradient between the ECT-water and the working fluid of the LTS. Datasets from a scale-appropriate LTS-experimental facility operating at sub-atmospheric pressure were used to assess and validate the performance of LTS-models developed with the ATHLET-code. The facility is equipped with an independent hot water circuit which serves as the heat source and an air-cooling tower as the heat sink. A total of 27 stationary states were studied, featuring variations in the filling ratio, heat input i.e. hot water inlet temperature, and air velocity in the cooling tower. Prediction of heat transfer coefficients (HTC), working fluid mass flows, fluid and wall-temperature profiles, along with pressure losses (PL) in inclined condensation sections is studied in detail. A solid agreement between simulated and experimental outputs regarding wall temperatures and hot water pool temperature profiles was achieved. Moreover, a proper prediction of loop instabilities for the two-phase operation was reached. Even though slight overestimations of the working fluid's pressure drop in the inclined condensation sections were evidenced, ATHLET seems suitable for simulating low pressure LTS-facilities. Further empirical correlations for HTC- and PL-computing for two/phase narrow channels could be integrated in ATHLET to enhance its thermohydraulic prediction and close the gap between simulated and experimental data.

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VALIDATION OF ATHLET-CODE FOR SIMULATING PASSIVE RESIDUAL HEAT REMOVAL VIA LOW-PRESSURE LOOP THERMOSYPHONS

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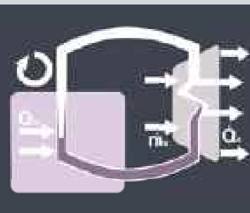
Motivation

Assessment of passive residual heat removal technologies in Small Modular Reactors (SMRs)

Residual heat removal in SMRs

In case of Beyond-Design Accident: Transport of residual core heat to ultimate heat sink. Additional loop needed



Two-phase Loop Thermosyphons (LTS)

Natural-circulation Thermosyphons operated at low pressures to mantain water inventory in emergency tanks[1]

1-Dimensional Code development

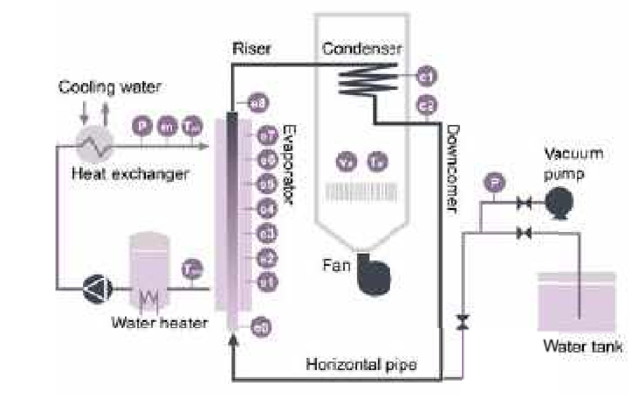
Enhancement of themo-hydraulic system code (ATHLET) via incorporation of proper pressure drop and heat transfer correlations.

Approach

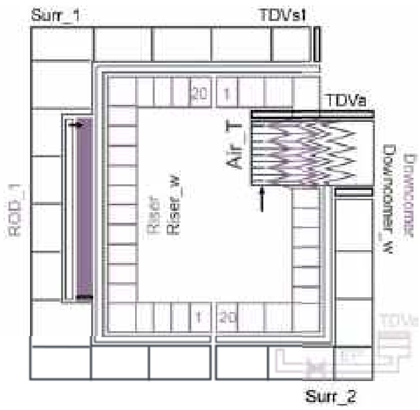
ATHLET-Modelling and validation of a LTS scale-appropriate facility

Studied parameters and boundary conditions: Filling ratio, inlet water temperature, Air velocity

Parametric study: 24 studied stationary states simulated with ATHLET



Experimental Facility- developed by [2]



ATHLET Model nodalization - TFO: Thermofluid Object

Experimental Matrix (2x3x4)

Filling ratios: 14.8% and 27.1% (%v/v of evaporator)
Air velocity: 0.5, 1.5 and 2.5 m/s (In cooling tower)
Water inlet temperature: 50°C, 70°C, 80°C, 90°C (evaporator)

Model features

Closed loop circuit with TFOs. Interaction with environment
Initial conditions in main loop: Pressure and water inventory
Multicomponent property models for air-related TFOs

In-code implementation of two-phase pressure drop and air-related heat transfer correlations

Heat transfer

Already implemente correlations

Baehr and Stephan
Natural convection around cylinders, air properties

Isachenko et al.
Forced convection around cylinders, air channels

Integrated in ATHLET under: Heat Transfer Level II, Mode 29. Heating, superheated fluid

Pressure drop

Studied correlations

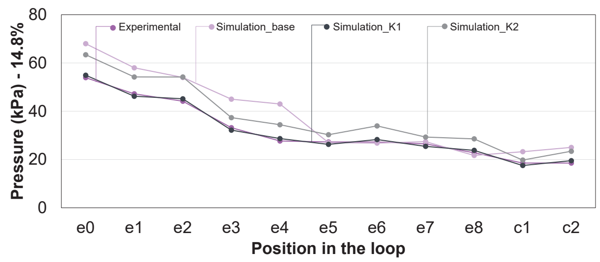
Souza and Pimenta (K1)
Two phase pressure drop in narrow circular pipes

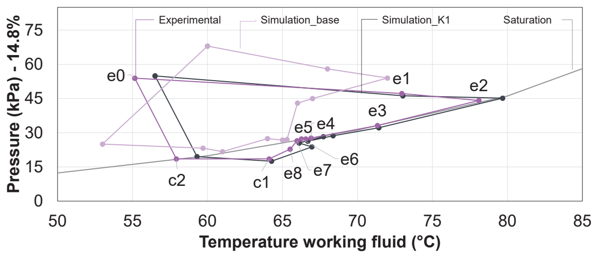
Friedel (K2)
Two-phase pressure drop in inclined pipes

Integrated in ATHLET as ITPM0 – User defined. Pseudo key word: PW FRICTION

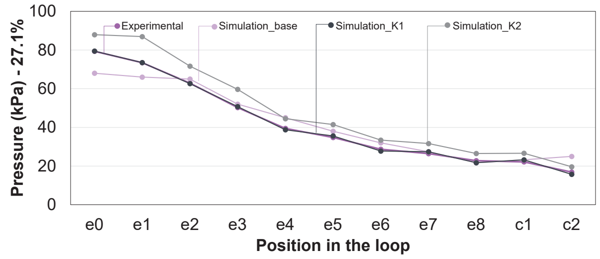
Results

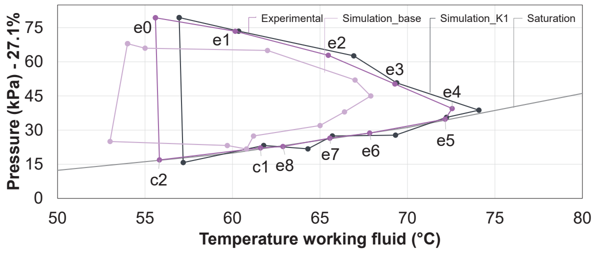
14.8% Filling ratio (FR)
80°C water inlet
1.5 m/s air velocity





27.1% Filling ratio (FR)
80°C water inlet
1.5 m/s air velocity





Model-experimental agreement enhanced when Souza and Pimenta is used

Key results

ATHLET is able to simulate two-phase low-pressure natural circulation loops after proper correlations (Souza and Pimenta) are integrated in its source code.

Outlook: Integration of thermosyphon models in full reactor simulations. Assessment the overall response in case of Beyond Design Accidents.

Framed on the project: VASiL

References

[1] Min, Byung-Yeon; Park, Hyun-Sik; Shin, Yong-Chul; Yi, Sung-Jae, „Experimental verification on the integrity and performance of the passive residual heat removal system for a SMART design with VISTA-ITL". Annals of Nuclear Energy 71 (2014) 118-124.
[2] Xiong, Zhenqin; Ye, Cheng; Wang, Minglu; Gu, Hanyang, "Experimental study on the sub-atmospheric loop heat pipe passive cooling system for spent fuel pool", Progress in Nuclear Energy 29 (2015) 40-47.
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Acknowledgements

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AN INNOVATIVE SUPERCRITICAL CARBON DIOXIDE CYCLE FOR DECAY HEAT REMOVAL IN EXISTING AND FUTURE NUCLEAR POWER PLANTS

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The supercritical carbon dioxide (sCO_2) heat removal system is an innovative, self-propelling and modular decay heat removal system for existing and future nuclear power plants which is based on a simple closed Brayton cycle with sCO_2 as the working fluid. In PWRs, the system could be attached to the steam generator in the secondary loop providing a continuous decay heat removal from the core to a diverse ultimate heat sink, the ambient air, and simultaneously generating electricity which might be useful in the case of station blackout. The conceptual design, layout and control of this compact modular system were developed in the European project sCO2-4-NPP. One sCO_2 cycle module provides a heat removal capacity of 10 MW_{th} and consists of a compact heat exchanger, an air cooler and a compressor and a turbine. By changing the number of sCO_2 modules, the heat removal capacity can be adapted to different plant sizes and types (like EPR, KONVOI, VVER).
To analyze the performance and the interaction of the system with nuclear power plants, the thermal-hydraulic system code ATHLET was extended with the ability to simulate sCO_2 cycles. A scenario with long-term station blackout and loss of ultimate heat sink was simulated for a generic KONVOI PWR with a thermal power of 3840 MW_{th} equipped with four sCO_2 cycles. After the ramp-up, the system runs at its design heat removal capacity to minimize the inventory loss in the PWR. With decreasing decay heat over time, the sCO_2 cycles are moving from nominal to part-load conditions. In this phase, controlling the turbine inlet temperature to 260 °C via the turbomachinery shaft speed and subsequent shutdown of 3 of the 4 cycles balance the heat produced by the decay and the heat removed by the sCO_2 cycles quite perfectly, enabling a very stable operation. Moreover, keeping the design compressor inlet temperature constant at 55 °C by controlling the air cooler fan speed is a viable strategy at any ambient or steam-side boundary condition.
Further analyses consider the failure of single sCO_2 cycles, valves or control systems to provide a deeper insight into the dynamic behaviour of the system.

The ATHLET simulations demonstrated that this very innovative compact heat removal system applied to a nuclear power plant of the KONVOI type with four sCO_2 cycles attached to the steam generators will safely remove the decay heat for more than 72 h.

AN INNOVATIVE SUPERCRITICAL CARBON DIOXIDE CYCLE FOR DECAY HEAT REMOVAL IN EXISTING AND FUTURE NUCLEAR POWER PLANTS

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Scenario:
- Station blackout and loss of the ultimate heat sink

Mitigation:
- Supercritical CO_2 heat removal system

Nuclear Power Plant:
- Generic Konvoi PWR with a thermal power of 3840 MW

Simulation code:
- Thermal-hydraulic system code ATHLET (extended for CO_2 applications)

Boundary conditions:
- Conservatively high decay heat curve

↕

- Ambient temperatures from −45 °C to +45 °C

↕

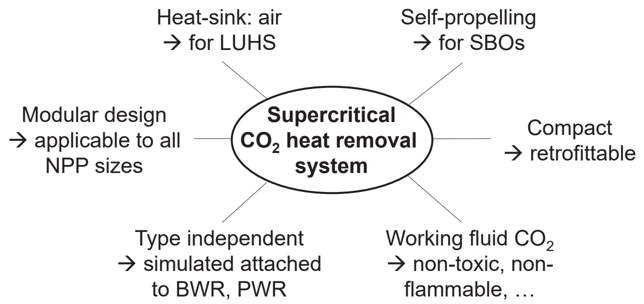
- Conservatively low decay heat curve

Key result:
- Reliable decay heat removal for more than 72 h

Motivation and Objective

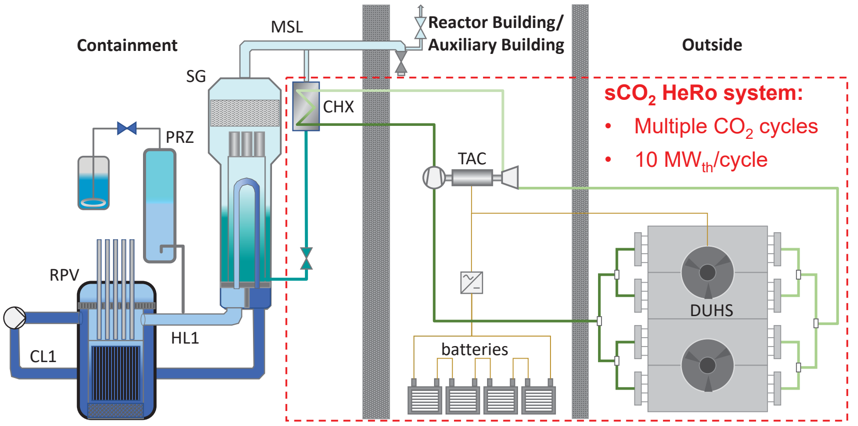
- Fukushima: SBO and LUHS
- Need for additional decay heat removal systems for existing and future NPPs
- sCO_2 systems (compact → retrofittable)

→ **Model, simulate and evaluate the sCO_2 heat removal system attached to a PWR with ATHLET**



Approach

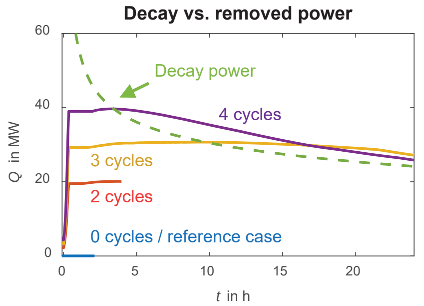
sCO_2 HeRo system attached to a PWR (only one loop shown)

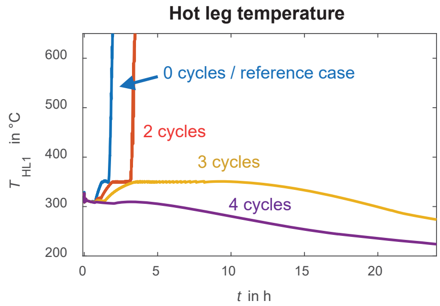


ATHLET extensions:
- Fast calculation of sCO_2 properties with splines
- Real-gas performance map based turbomachinery model
- Improved heat exchanger modelling (e.g. finned air-side of DUHS)

Results

Variation of the number of CO_2 cycles without a strategy to adapt to the declining decay heat:

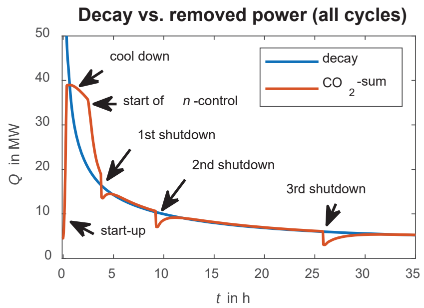


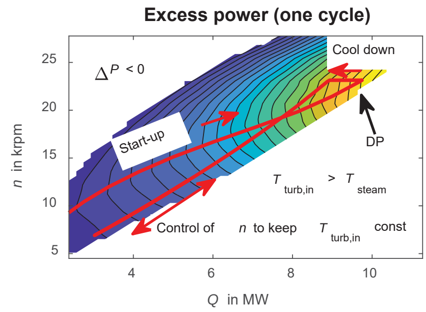


Short-term:
- 4 CO_2 cycles: Sufficient heat removal
- 3 CO_2 cycles: Core is almost uncovered

Long-term (without adaption strategy):
- $Q_{CO2} > Q_{decay}$ → Cooldown
- Control required

Four CO_2 cycles with a strategy to adapt to the declining decay heat:





- CO_2 **turbine** inlet temperature control (via turbomachinery speed) and successive shutdown adapts operation to decay heat curve
- CO_2 **compressor** inlet temperature control (via fan speed) enables operation at any ambient temperature
- Self-propelling decay heat removal achieved (excess power available)

Further simulations: System start-up from operational readiness state, failure analysis (cycles, control systems, fans)

→ A sCO_2 heat removal system with 4 CO_2 cycles safely removes the decay heat for more than 72 h

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847606. This text reflects only the author's views and the Commission is not liable for any use that may be made of the information contained therein.

EVALUATION AND VALIDATION OF ATHLET-CODE FOR BAYONET HEAT EXCHANGERS

Sinem CEVIKALP USTA

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Many SMRs take advantage of the use of innovative heat exchangers as steam generators or within heat removal systems. Because of their compact design and ability to operate as part of passive systems, bayonet heat exchangers have particularly received interest. In parallel to the introduction of new technologies also the thermal-hydraulic tools, that are a common and widely accepted approach to the design, operation, licensing, and safety assessment of nuclear power plants, should be updated to simulate reliably such systems. The objective of the Ph.D. work is to extend the capabilities of the thermal hydraulic system code ATHLET (Analysis of Thermal-Hydraulics of Leaks and Transients, developed by GRS) with modelling methodologies for the bayonet heat exchangers, in addition to U-tube or straight tube steam generators, which are commonly used in present light water reactors. The approach to reach this goal is to apply existing models to bayonet heat exchangers, to identify needs for improvements, to develop and implement suitable approaches and finally to validate the modelling by comparison with experimental data. In the present study, this is exemplarily shown for the application of the ATHLET code to HERO-2 experiments. The modelling of the test facility within the ATHLET simulation is presented and the choice and reasoning for assumptions, which are necessary due to some experimental uncertainties, are discussed. By comparisons of experimental results with the ATHLET predictions especially the capabilities to correctly predict two-phase heat transfer and pressure losses are evaluated, which are crucial for correctly simulating the natural convection in passive systems. The modelling of pressure losses in relatively narrow tubes/ducts, which are typical for the annular design of bayonet heat exchangers, was identified as a potential for model improvement and additional empirical laws from literature were implemented in ATHLET. The model extensions are assessed against the previous status and against experimental data. Conclusions on the validation status are presented. For further work, especially systematic uncertainty analyses are proposed which consider both uncertainties in experimental data and modelling approaches.

EVALUATION AND VALIDATION OF ATHLET-CODE FOR BAYONET HEAT EXCHANGERS

Sinem Cevikalp Usta[1], Michael Buck[2], Jörg Starflinger[3]
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IKE University of Stuttgart Germany

Scenario:
- Station blackout
- Loss-of-coolant accident

Mitigation:
- Residual heat removal with bayonet heat exchangers (BHXs)

Nuclear Power Plant:
- LWR based SMR →SCOR

Simulation code:
- Thermal-hydraulic system code ATHLET extended by 6 alternative correlations for friction loss in a BHX

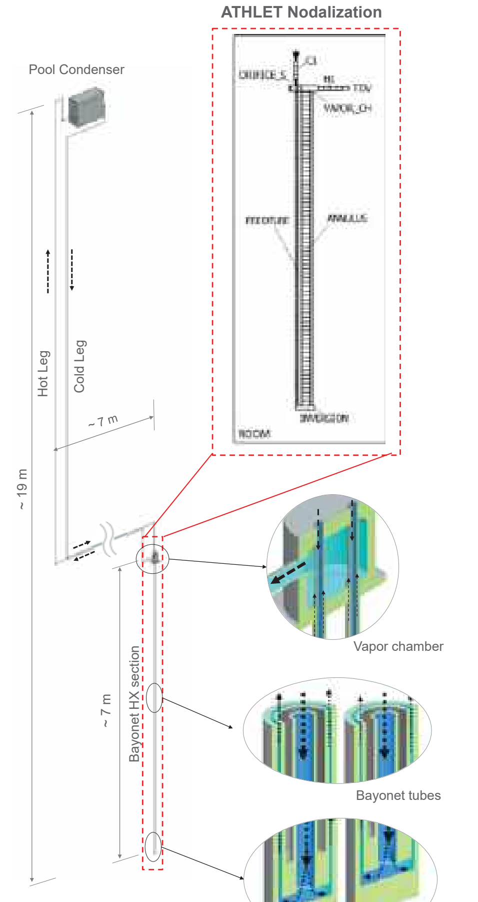
Frictional pressure drop model:
- Better agreement with Chisholm correlation at higher operating pressure and Tran correlation at lower operating pressure

Key result:
- ATHLET prediction of the key thermal-hydraulic phenomena of BHX with good accuracy for the selected test cases

Motivation and Objective

- Small Modular Reactor
- Need for passive heat removal systems in SMRs
- BHXs (compact and operate as part of passive systems)
- System code development & validation needs

→Extend and validate the capabilities of thermal hydraulic system code ATHLET with modelling methodologies for the BHXs



HERO-2 Test Facility at SIET lab in Italy*

Approach

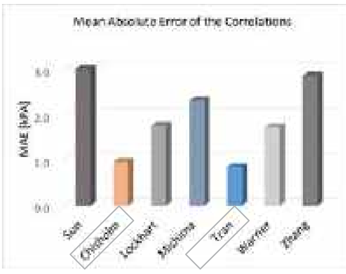
- Validation of the modelling approaches with a series of two-phase experiments based on natural circulation

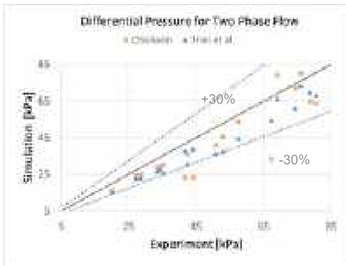
Summary of boundary conditions for all test conditions

Parameter	Range
Mass flow rate	0.02-0.04 kg/s
Inlet fluid temperature	134-262 °C
Outlet pressure	0.4 -6.8 MPa
Electrical Power	9.23- 51.77 kW
Ambient Temperature	25 °C

Two-phase Frictional Pressure Drop Characteristic

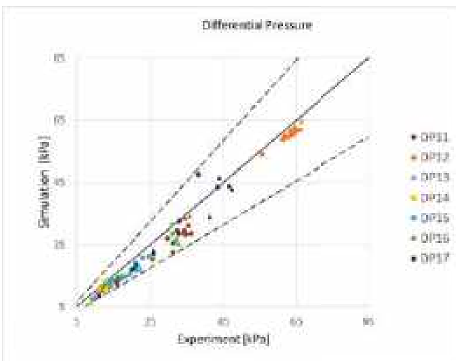
- Comparison and analysis of the newly implemented six correlations and the in-code existing Chisholm correlation for the frictional pressure drop of two-phase flow in the annulus





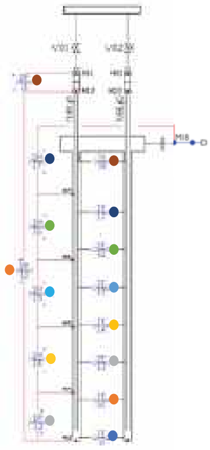
Results

- Results of the simulations calculated with Tran correlation at low operating pressure and Chisholm correlation at high operating pressure

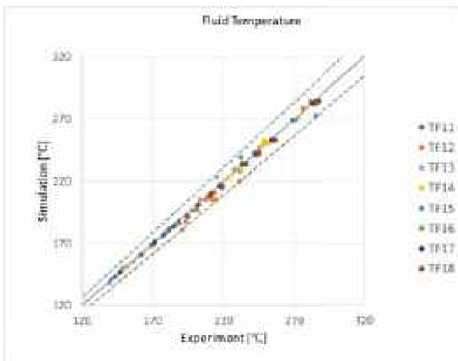


△Tran et al. ○Chisholm

- all within 30% error range



Locations of the Sensors



△Tran et al. ○Chisholm

- all within 5% error range

→ **ATHLET is able to simulate the validation experiments of the bayonet heat exchangers with good accuracy. Model improvements were performed by implementing Tran correlation for deviations at low operating pressure.**

Framed on the project: VASiL

*The data of the HERO-2 experiments were provided by ENEA within the framework of PASTELS project.

This work has received funding from the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection under project no. 1501607C and from the Euratom research and training programme 2014-2018 under grant agreement No 945275. This text reflects only the author's view, and the Commission is not liable for any use that may be made of the information contained therein.

POSITIVE CAMPAIGNING OF NUCLEAR TOPICS

Sophie ZIENKIEWICZ

Imagine the enormous impact you, as a single individual, has in the climate change conversation. Your voice is powerful, and when directed in the right places, highly impactful. And now imagine what would happen if we compounded all our efforts, sharing the same message across the globe, to communicate to leaders and decision makers that 'enough is enough: we need action now'. It would be immense. Global climate activism describes a growing movement of young people across the globe taking action to halt the devastating effects of climate change. We are determined to reach net zero before 2050, and firmly believe that following the science and being technology inclusive is the best way to achieve this. Nuclear energy working alongside other clean energy technologies is essential to reaching these goals. Using the ‘I, us, we’ principles of climate activism, this interactive, thought-provoking workshop will equip you with the necessary tools to communicate nuclear energy to friends, family, strangers, and everyone in between. This two-hour session will explore how trust, people and action lie at the heart of a successful climate campaign and how we can use the principles of compound interest to prepare for COP27. It will also give attendees the opportunity to explore their personal voice and contributions to the climate conversation, especially how to become bold, vocal climate champions. We will draw on the experience and learnings of the hugely successful #NetZeroNeedsNuclear COP26 campaign, and workshop how we can build upon these achievements for November’s COP27 conference. With just five months until COP27, it is imperative we coordinate a global effort to continue the successes of the global youth activist movement. Join the Nuclear for Climate team as they guide you through this engaging, action-focused workshop. Open to all backgrounds, viewpoints, experiences. #Togetherisbetter #NetZeroNeedsNuclear

Positive Campaigning of Nuclear Topics

FISA 2022

Sophie Zienkiewicz
[1]Nuclear for Climate Volunteer, Young Generation Volunteer

Nuclear for CLIMATE

Imagine the enormous impact you, **as a single individual**, has in the climate change conversation.

Your voice is powerful, and when directed in the right places, highly impactful. And now imagine what would happen if we compounded all our efforts, sharing the same message across the globe, to communicate to leaders and decision makers that 'enough is enough: we need action now'. It would be immense.

What is nuclear activism?

Nuclear activism describes a growing movement of young people across the globe taking action to halt the devastating effects of climate change.

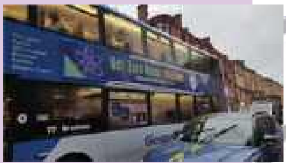
We are determined to reach net zero before 2050, and firmly believe that following the science and being technology inclusive is the best way to achieve this.

Nuclear energy working alongside other clean energy technologies is essential to reaching these goals and so young people are working tirelessly to make this a reality.

Why is nuclear activism important?

It is essential to work together as an international community to create a reliable, clean, technology-neutral energy mix. By taking responsibility for their future, young nuclear professionals are creating positive change and helping to shape the pathway to net zero.

Furthermore, being a catalyst for tangible, action-focused decision making is vital. Taking opportunities to engage with all types of stakeholders helps to inspire others to become nuclear activists.



A #NetZeroNeedsNuclear bus campaign operating during COP26 – this created a campaign presence and generated media interest

Nuclear Institute Young Generation Network's flash mob at COP26, Glasgow

What tools can we use to be effective nuclear activists?

- Use social media to create international support for your campaign
- Creative, unique stunts which gets the interest of general public – it is a great way of generating media attention and appealing to a range of audiences
- Take action to influence legislation and policy – the COP26 position paper and petition was invaluable when engaging decision makers and provided validity
- Map out your stakeholders to understand their motivations, drivers, concerns and any opportunities
- Evidence your campaign with science-based arguments and prepare for the most common questions
- Ensure there is a call to action in each piece of content used to engage your audience

What makes a good nuclear activist?

Nuclear activists and campaigners have formed a strong, global community. It comprises of individuals and organizations from within the industry and outside it, with support from across the clean energy sector.

Uniting characteristics of nuclear activists include:

- Enthusiasm
- Collaboration
- Creativity
- Boldness

However, there is also a certain need for bravery. Misconceptions shroud the nuclear industry and it can be difficult to dispel those in a measured and balanced way. It takes courage to speak up but by uniting as a global community seeking a clean, reliable energy supply nuclear activists are changing the narrative.

Volunteers demonstrating in the blue zone at COP26

Having an online presence was hugely beneficial at driving traffic towards one central location https://www.ygn.netzeroneedsnuclear.com/

#NetZeroNeedsNuclear at COP26

Nuclear energy's representation at COP26 was unique. Nuclear Energy volunteers were able to catalyse the conversation around nuclear and empower others to become nuclear energy activists.

The campaign was bold, inclusive and reached out to new, untapped audiences.

Particular successes included:

- Bella the Giant Gummy Bear – using an alternative way of communicating energy density was effective at sparking conversation with new audiences
- Featuring in numerous forms of media from podcasts, to webinars, to live television interviews

What will COP27 be like?

The young generation of nuclear professionals is already building upon the numerous achievements of the COP26 volunteers to ensure that the clean energy, nuclear message is strongly felt at November's COP27 conference.

With just five months to go, it is imperative that a global, coordinated effort is realised which draws on the creativity and boldness of the industry.

#NetZeroNeedsNuclear #Togetherisbetter

With thanks to the Nuclear Institute Young Generation Network; Nuclear for Climate; The European Nuclear Society; industry organisations; and all the countless young, passionate volunteers who are campaigning tirelessly for nuclear energy's inclusion in the energy mix.

NEW PROGRESS IN PROBABILISTIC SAFETY ASSESSMENT OF NPPS AGAINST CASCADE AND COMBINED NATURAL HAZARDS

Evelyne FOERSTER

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LUKA ŠTRUBELJ, [6]*GEN energija d.o.o., Krško, Slovenia*

The H2020-NARSIS project (2017-2022) aimed at proposing improvements regarding the Probabilistic Safety Assessment (PSA) procedures for nuclear plants in case of external natural hazards.

One of the key objectives in NARSIS was to provide a Multi-Hazard (MH) framework, in order to quantify and assess primary and secondary hazards including cascading effects as well as uncertainty, allowing to study the consequences of combinations of potential well-characterised physical threats due to different external hazards and scenarios. Many natural hazards, most being identified as priorities by the PSA End-Users community in ASAMPSA_E were addressed: earthquakes, flooding, tsunamis, extreme weather (lightening, high winds, rainfall, heat waves, ice, hail) and volcanoes (tephra). Some improvements were explored regarding the existing Probabilistic Hazard Assessment methodologies for tsunamis, flooding and extreme weather, as well as the re-evaluation of the screening criteria for main critical plant systems, structures & components (SSC), so to keep only relevant parameters for each hazard in the final framework. An open-access tool is available, which enables developing plant-specific scenarios for Design Basis Events, proposing datasets collected from various EU decommission sites.

NARSIS was also to develop refined fragility derivation methods in order to increase the estimation accuracy of SSC failure rates, thanks to current advances in quantitative hazard modelling and computational capacities. Hence, the benefits of using vector-valued Intensity Measures for fragility assessment of SSC against single (earthquake) and multiple hazards (earthquake & flood), were investigated. For MH scenarios, the approach relies on the combination of failure modes due to single hazard loadings and on the assessment of cumulative hazard effects on the studied systems, provided the required hazard-specific physical models are available.

Finally, NARSIS was to propose improvements in the risk integration combined with a suitable uncertainty treatment and constraining (also for expert-based information), to support the risk-informed decision making and a risk metrics comparison within extended PSA. Hence, various approaches (Bayesian Network (BN) and Extended Best Estimate Plus Uncertainty (E-BEPU)) were implemented, identifying their advantages and limits. A BN-based multi-risk integration framework was developed, where the vector-based fragility assessment methodology and a novel BN-based method for Human Error Probability were used. The contribution of the E-BEPU methodology was demonstrated through its application on the NARSIS standard design plant model, for evaluation of Defence-in-Depth, Design Extension Conditions and Severe Accident Management Guidelines.

The project has delivered some recommendations regarding the proposed improvements, together with further research needs.

FISA 2022

NARSIS Project
New progress in probabilistic safety assessment of NPPs against cascade & combined natural hazards

New Approach to Reactor Safety ImprovementS
www.narsis.eu

Evelyne Foerster[1], Giuseppe Rastiello[1], James Daniell[2], Pierre Gehl[3], Behrooz Bazargan-Sabet[3], Phil Vardon[4], Varenya K. D. Mohan[4], Luka Štrubelj[5]

[1]CEA - Université Paris-Saclay, Gif sur Yvette, France; [2]KIT, Karlsruhe, Germany; [3]BRGM, Orléans, France; [4]TU DELFT, Delft, Netherlands; [5]GEN energija d.o.o., Krško, Slovenia

Main Achievements

- ✓ **Improvement of the existing Probabilistic Hazard Assessment methodologies** (tsunami, flood, extreme weather)
- ✓ A **Multi-Hazard (MH) framework**
- ✓ **Improved fragility assessment** of main NPPs critical elements
- ✓ **Improved risk integration** dedicated to Probabilistic Safety Assessment (**PSA**)
- ✓ **Suitable treatment/constraining of uncertainty** (e.g., expert elicitation)

The NARSIS Multi-Hazard Explorer (MHE) :

- ✓ **Natural hazards:** earthquakes, flooding, tsunamis, extreme weather (lightening, tornado, low water), volcano (tephra)
- ✓ **Available datasets** collected from various EU decommission sites
- ✓ **Plant-specific scenarios** for Design Basis Events
- ✓ **Quantification + assessment of primary/secondary hazards** (combined/cascading effects) + **uncertainty**
- ✓ Consequences related to main critical SSC: **screening criteria re-examined**, keeping only relevant parameters for each hazard
- ✓ A **5-Level methodology** (Fig. 1 & 2): **(0)** Single hazard assessment; **(1)** MH assessment scoping through potential site specific hazards; **(2)** MH interaction matrix and scoring; **(3)** Modellability matrix; **(4)** Quantitative analysis of multiple hazard probabilities

Open-source, open-access NARSIS Multi Hazard Explorer
https://github.com/a-schaefer/NARSIS-MHE/releases/tag/v1.0

The Multi-Risk Integration Framework for Safety Analysis:

- ✓ **Bayesian Networks (BN) as a suitable framework for:**
  - Integration of technical, human & organisational aspects (Fig. 4);
  - Vector-based fragility modelling;
  - Interactions with multiple external hazards and consequences.
- ✓ **Postulating an accident scenario** (loss of offsite power leading possibly to station blackout) for performance evaluation and comparison between BN & MH PSA analyses based on fault trees
- ✓ **Proposing new approaches:**
  - Common cause failure modelling in BN
  - BN-SLIM coupled with expert judgement elicitation for Human Error Probability estimation on operator actions during accident progression (Fig. 5)
  - BN used for surrogate modelling for reliability assessment, reduce the computational effort

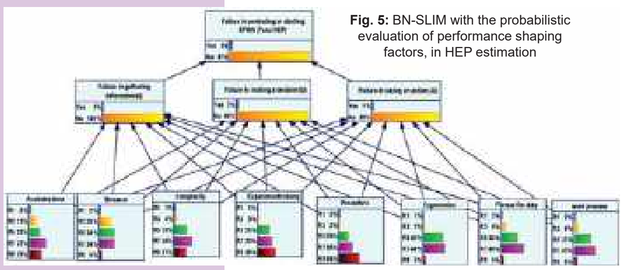


Fig. 5: BN-SLIM with the probabilistic evaluation of performance shaping factors, in HEP estimation

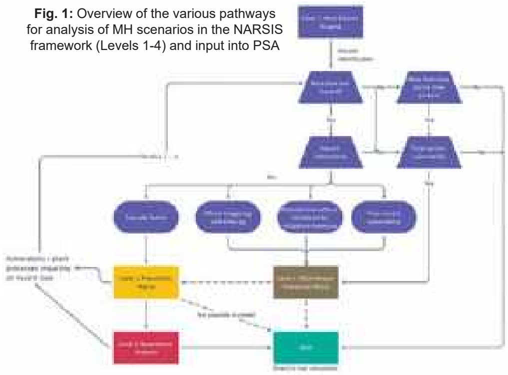


Fig. 1: Overview of the various pathways for analysis of MH scenarios in the NARSIS framework (Levels 1-4) and input into PSA

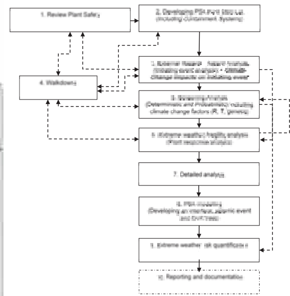
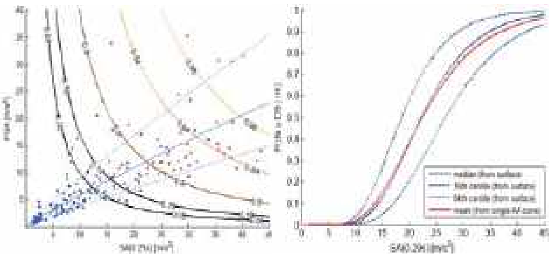


Fig. 2: Extended PSA Flow chart with the proposed incorporation of the NARSIS MH framework inputs (Steps 3 and 5)

Fragility Assessment in a MH Context:

- ✓ **Screening & selecting the most critical SSC**: safety significance based on risk-informed criteria with quantitative importance measures (e.g., the Fussell-Vesely)
- ✓ **Accounting for possible cumulative effects:** succession of events (e.g., thermal fatigue + earthquake), ageing pathologies (corrosion, creeping), soil-structure interactions (earthquake)
- ✓ **Vector-valued Intensity Measures** (IMs) either for single hazard (e.g., earthquake) or MH scenarios → **less dispersion** (i.e., aleatory uncertainty) compared to the standard scalar-IM fragility curves (Fig. 3).

Fig. 3: Seismic fragility surface (left) & equivalent fragility curves (right) - solid blue line : median distribution; dashed blue lines: 16-84% confidence intervals.



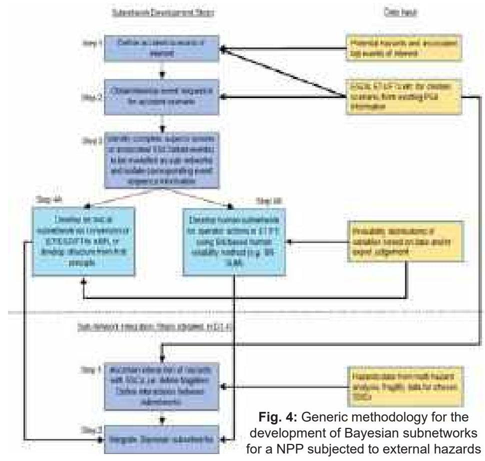


Fig. 4: Generic methodology for the development of Bayesian subnetworks for a NPP subjected to external hazards

Constraining uncertainties:

- ✓ **BN modelling** → A new robust "Boosted Beta Regression" approach to reduce uncertainty on the Conditional Probability Model parameters
- ✓ **SSC fragility** → Bayesian updating with ANN + adaptive training algorithm + amplification-factor-based construction of the likelihood function
- ✓ **Expert judgment** → applying new uncertainty theories for expert knowledge modelling (expert-like reasoning based on fuzzy expert systems) and evaluation of expert-based information to complement the classical model of Cooke, looking for robustness & performance forecast

REVIEW OF IN-SERVICE INSPECTION METHODS OF REACTOR INTERNAL BAFFLE-TO-FORMER BOLTS

Levente Cs. SZEKELY

LEVENTE CS. SZEKELY, *TTSA Engineering Ltd., 193. Szabadság way, BUDAÖRS, 2040, Hungary*

One of the internals of a typical pressurised water reactor is the core barrel. The purpose of the core barrel is to support and orient the fuel assemblies, create way to the control rods as well as drive the coolant through the core. This equipment comprises of three main parts. The outer cylindrical shell, which forms the wall of the barrel, the core baffle, that is a set of vertical plates surrounding the outer rim of the fuel assemblies and the vertical former plates, that make up the structure connecting the baffle plates to the inside surface of the cylindrical shell. The baffle plates are connected to the former plates through hundreds of so-called baffle-to-former bolts. These fastening bolts are subjected to neutron irradiation and mechanical stresses during reactor operation. Operational experience in many nuclear power plants shows that after a certain operating time, radiation-assisted stress corrosion cracking of the bolts may occur, which in some cases causes bolt fracture and loss of integrity of the equipment. Thus, a degradation mechanism considering all effects is proposed. In recent years, the detection of bolt damage through identifying cracks has been a major focus of nuclear power plant service life extension projects. This is illustrated by a statistical analysis of bolt test results. Historical data and the evolution of international recommendations for mitigation are also reviewed. Visual and ultrasonic non-destructive testing methods of bolts are presented and evaluated. Since the equipment is highly radiated, to eliminate doses the inspection is performed using remote controlled manipulators. The different techniques, both mast and diving robot, are described and a comparison is made with respect to the technical specifications of each technique, the performance of the tests and their integrability in periodic in-service inspections. These results essentially contributed to meeting the relevant requirement in the service life extension decisions of Hungary's four operating units.

Review of In-Service Inspection of Reactor Internal Baffle-to-Former Bolts

FISA 2022

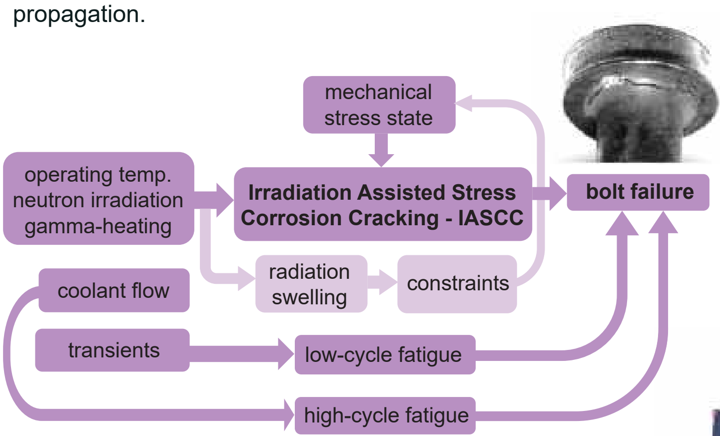
Levente C. SZEKELY
TTSA Engineering Ltd., Budaörs, HUNGARY

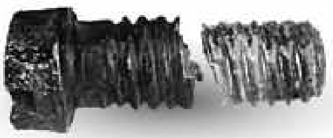
Core Barrel and Baffle-to-Former Bolts

The purpose of the core barrel is to support and orient the fuel assemblies, create way to the control rods as well as drive the coolant through the core. This equipment comprises of three main parts. The outer cylindrical shell, which forms the wall of the barrel, the core baffle, that is a set of vertical plates surrounding the outer rim of the fuel assemblies and the vertical former plates that make up the structure connecting the baffle plates to the inside surface of the cylindrical shell. The baffle plates are connected to the former plates through hundreds of so-called **baffle-to-former bolts** (BFB).

Degradation Mechanism Model

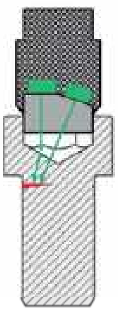
It was shown that the cause of damage is **Irradiation Assisted Stress Corrosion Cracking** (IASCC). This is superposed by **low-cycle fatigue** caused by cooling and heating. In some cases, bolts in the vicinity of the damaged bolt will also be subjected to **flow-induced high-cycle fatigue** stress. In Long Term Operation (LTO), the effect of **radiation swelling** can occur, inducing compressive stresses (due to constraints), which are manifested as tensile stresses on the bolt surface. These also contribute to stress corrosion crack initiation and promotes crack propagation.





Bolts tend to crack at the head-to-shank transitions. Constraints can cause failure at the shank.

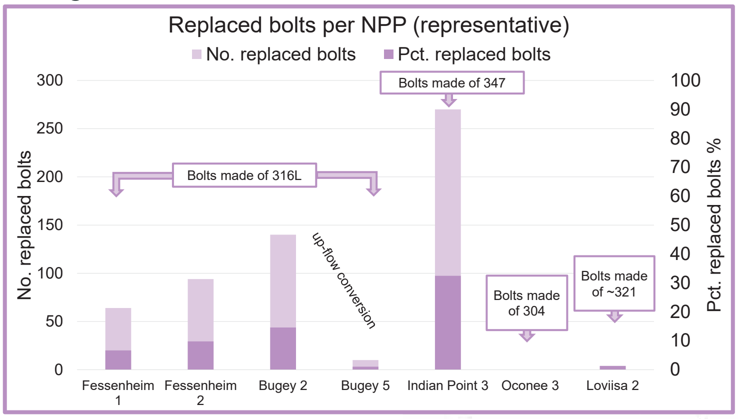
Ultrasonic Transducers for Different Bolt Geometries



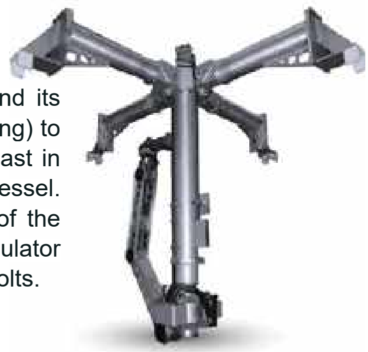
Vendor designs use different type of bolts such as hexagonal or square sockets, flat head bolts. Ultrasound path calculations consider the dimensions of the bolt to avoid non-relevant reflections due to the geometry, thus improving the performance of the test. The shape of the vibrating elements can be circular, elliptical, square, hexagonal, etc. By using a combination of several sizes and shapes, the coupling surface can be maximized, and the test can be prepared for a wide variety of shaped bolt heads. Phased-array technique is also considered.

Operational Experience

The first BFB failures occurred in NPPs commissioned in France, and were discovered during the first in-service inspection interval. Failure is understood as the displacement, or in extreme cases, the breaking and falling off of the bolt head. Following the failures French operators started a comprehensive **Non-Destructive Testing** of bolts.



Central Mast Manipulator

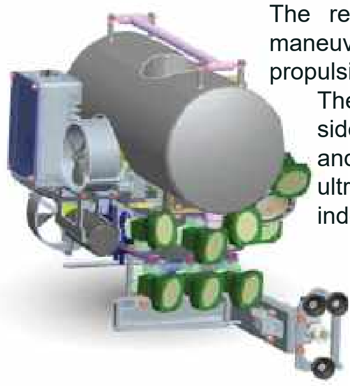


It transports the manipulator carrying the ultrasonic transducer and its associated equipment (camera, lighting) to the inspection site by means of a mast in the longitudinal axis of the reactor vessel. The device is centered on the rim of the reactor. The telescopic manipulator extends from the mast to reach the bolts.

Pros:
- highly consistent results
- vast operating experience

Cons:
- requires crane to position

Remotely Operated Underwater Vehicle



The remotely operated vehicle (ROV) is maneuvered underwater by propeller-driven propulsion powered by an electric motor. The ROV can move back and forth, sideways, turn on its vertical axis, dive and rise. The manipulator holding the ultrasonic probes can be moved independently.

Pros:
- easy to install
- more than one can be operated at once

Cons:
- difficult to position and lock

Results

As a part of a comprehensive investigation of bolt failure and mitigation, these results essentially contributed to meeting the relevant regulatory requirement in the **service life extension decisions of Hungary's four operating units.**

Image courtesy of Westinghouse Electric Company, WesDyne International, Ulla E. et al „Investigations on core basket bolts from a VVER 440 power plant", Engineering Failure Analysis 33 pp. 55-65, 2013.

PASSIVE HEAT REMOVAL FUNCTION FOR A DISTRICT HEATING REACTOR

Jaakko LEPPÄNEN

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Development of a low-temperature nuclear reactor for district heating purposes was launched at VTT in 2020. The design goes under the name LDR-50, and features a 50 MW reactor module, capable supplying heat at 65-120ºC temperature. The aim of the project is to enable transition from fossil fuels to low-carbon technologies within the heating sector, which is a major source of CO_2 emissions in Finland and other countries with cold winter climate. Since alternative near-term solutions are based on bioenergy and natural gas, the nuclear option can also be seen as an effective means to reduce the reliance on imported fuels. One of the major challenges for district heating reactors is that heat, unlike electricity, cannot be transported cost-effectively over long distances. Production has to be located near consumption, which in turn creates new challenges for licensing and public acceptance. High level of safety and reliability can be accomplished by inherent passive safety features, taking advantage of low operating temperature and pressure. The invention presented here is related to the passive heat removal function of the LDR-50 reactor module. The reactor vessel is enclosed inside a larger containment vessel, with the intermediate space partially filled with water. The reactor module is submerged into a large pool, which acts as the final heat sink. In normal operating mode heat is removed from the reactor vessel via the primary heat exchangers. Temperature in the intermediate space remains under the boiling point of water, and the reactor is thermally insulated from the environment. When the primary heat removal route is compromised, the reactor falls back to the passive cooling mode. Temperature inside the reactor vessel begins to rise, which initiates boiling in the intermediate space between the two vessels. The upper part of the containment vessel is filled with steam, which condenses on the cool outer wall and transfers heat into the reactor pool. The passive cooling mode is actuated without any mechanical moving parts, and it does not involve breaching any defence-in-depth release barriers. The feasibility of the concept has been demonstrated by computational analyses, and the invention has been granted a patent in November 2021.

Passive decay heat removal function for the LDR-50 low-temperature nuclear reactor

FISA 2022

Ville Tulkki, Jaakko Leppänen (presenting), Ville Hovi, Joona Kurki, Ville Valtavirta, Seppo Hillberg and Rebekka Komu

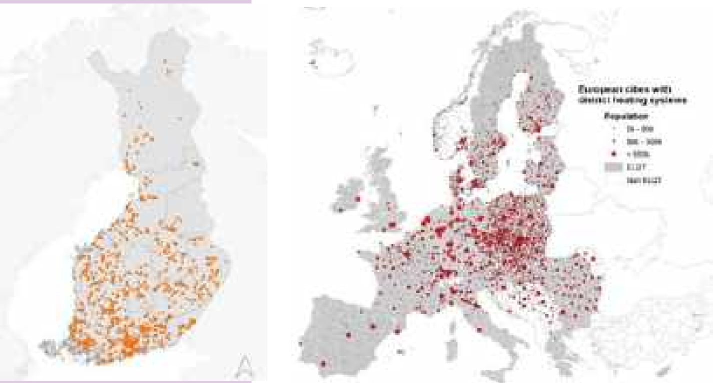
VTT Technical Research Centre of Finland Ltd

Challenge: de-carbonization of the energy sector

- IPCC scenarios: Global CO2 emissions must be reduced to zero by 2055.
- Meeting the climate goals requires a comprehensive energy transition, and liberating entire industries from fossil fuels.
- In many countries climate actions have so far been focused on electricity production.
- Heating is another major source of CO2 emissions, especially in countries with cold winter climate.
- Heat, unlike electricity, cannot be transported cost-effectively over large distances.

Case Finland:

- Almost 50% of Finnish houses, residential and commercial buildings are connected to a local district heating network.
- More than 80% of domestic electricity production is covered by low-carbon technologies, but fossil fuels are still used for co-generation of heat and power.
- Goverment-issued phase-out for coal by 2029.
- Similar challenges in several European countries.
- War in Ukraine has brought serious concerns on the security of supply.

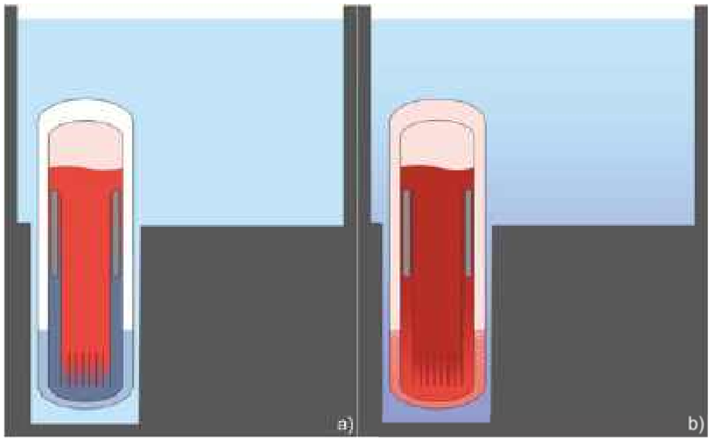


What about nuclear energy?

- District heating networks operate at around 65-120 °C temperatures.
- The operating regime can be easily reached with any nuclear reactor technology.
- Low-temperature district heating reactors were extensively studied and developed in the Nordic countries in the 1970's and 1980's.
- Renewed interest in recent years, following the challenges related to the decarbonization of the heating sector.
- Since the market is divided into a large number of independent networks, most conventional SMRs are too large to meet the demand.

VTT's district heating reactor project:

- LDR: "Low temperature district heating and desalination reactor".
- The project was launched in March 2020.
- Aim is to develop a low-temperature SMR for the Finnish and European heat market.
- Combination of conventional LWR technology and innovative passive safety design.
- Primary circulation by natural convection, connection to district heating network via secondary circuit and heat exchangers.
- Simplified design, taking advantage of low operating temperature and pressure (< 150 °C / < 1 Mpa).
- Modular technology – the heating plant may be comprised of one or several 50 MW LDR-50 units.
- Designed primarily for district heating, but the same technology can be applied to desalination.



The innovation:

- The low operating temperature of the LDR-50 reactor enables passive decay heat removal without any mechanical moving parts.
- The reactor units are submerged in a pool of water, and comprised of an inner reactor vessel and outer containment.
- The containment space is partially filled with water.
- In normal operation (a), temperature at the lower part of the reactor vessel remain below 100 °C.
- When heat transfer through primary heat exchanges is compromised (b), temperature at the bottom begins to rise.
- Water in the containment space begins to boil, forming an efficient heat transfer route into the pool.
- Patent for the invention granted in 2021.

Questions?

Email: Jaakko.Leppanen@vtt.fi

H2020 MCSAFER: HIGH-PERFORMANCE ADVANCED METHODS AND EXPERIMENTAL INVESTIGATIONS FOR THE SAFETY EVALUATION OF GENERIC SMALL MODULAR REACTORS

Victor Hugo SANCHEZ-ESPINOZA

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The High-performance advanced methods and experimental investigations for the safety evaluation of generic Small Modular Reactors (McSAFER) project is a research and innovation project funded by the Horizon 2020 research program of the European Commission. McSAFER started in September 2020 and will last until August 2023. Thirteen partners from nine countries form the Consortium. The main objective of

McSAFER is to provide new experimental data gained in three different facilities (KIT, KTH, and LUT) under conditions relevant for light-water cooled Small Modular Reactor (SMR)-concepts. Moreover, the purpose of the project is to compare different safety analysis methodologies (industry-like standard methods, advanced and high-fidelity numerical tools) to analyse the behaviour of the core, the Reactor Pressure Vessel (RPV) and the integral plant under selected transient conditions. The safety evaluations focus on four SMR-concepts: the French boron free F-SMR, the Argentinian CAREM system based on natural circulation and hexagonal core, the US NuScale design, and the Korean SMART reactor. The advanced numerical tools selected for the safety investigations are based on multi-scale (RPV and plant) and multi-physics (core) methods developed partly in former European projects, such as NURESAFE, HPCM and McSAFE. Beyond the involvement of industry (PEL, JACOBS, TRACTEBEL) and research centres (VTT, CEA, HZDR, UJV, CNEA), universities (KIT, KTH, LUT, UPM) are also engaged. The universities foster the education, training (master and doctoral students), and dissemination activities of the knowledge generated inside the project. The McSAFER project is structured around four technical Work Packages and one devoted to dissemination, exploitation and communication.

H2020 McSAFER Project: High-Performance Advanced Methods and Experimental Investigations for the Safety Evaluation of Generic Small Modular Reactors

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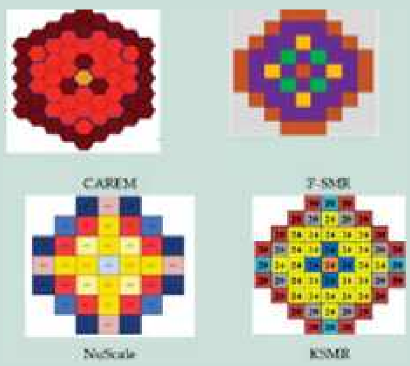
[1]KIT, [2]LUT, [3]VTT, [4]UJV, [5]HZDR, [6]UPM, [7]CEA, [8]JACOBS, [9]JRC Ka, [10]PEL, [11]TRACTEBEL, [12]KTH, [13]CNEA

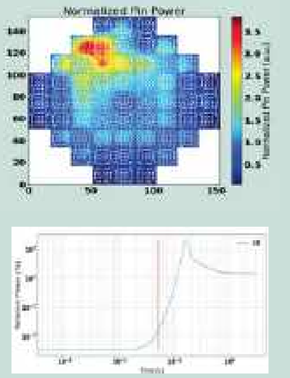
Main goals:

- Advance the safety research for water cooled SMR
  - Perform key experiments relevant for SMR-safety (core, helical HX) at EU-facilities (COSMOS-H, MOTEL, HWAT)
  - Develop, improve, validate simulation tools for safety evaluations of SMRs
  - Demonstrate advantages of advanced (multiphysics /multiscale) tools compared to legacy ones
- Apply advanced simulation tools to analyse accidents of four designs (F-SMR, CAREM, NuScale, SMART)

Multiphysics Core Analysis:



McSAFER: SMR-Core Designs



CAREM: Cold Water Injection

SMR Experimental Investigations:

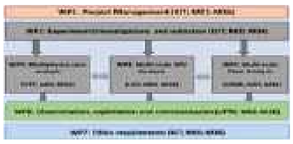
COSMOS-H (KIT) MOTEL (LUT) HWAT (KTH)

McSAFER: Key-Experimental Facilities

Multiscale Thermal Hydraulics:

NuScale: Multiscale Thermal Hydraulics

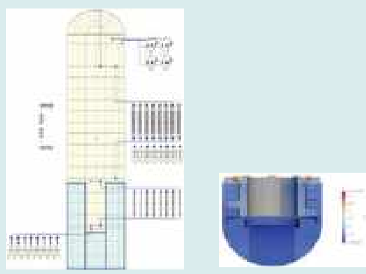
McSAFER: Consortium



Budget:
- Total: 4 045 133.75 €
- EC-contribution: 95 %
- In-Kind: 5 %

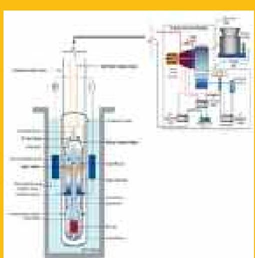
Partners: 13
- R&D: CEA, VTT, HZDR, UJV, JRC KA, CNEA
- Universities: LUT, UPM, KIT, KTH
- Industry: Jacobs, TRACTEBEL, PEL

Multiscale Thermal Hydraulics:

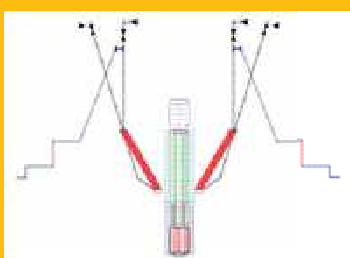


SMART: Multiscale Thermal Hydraulics

Multiscale / Multiphysics Analysis of SMRs:

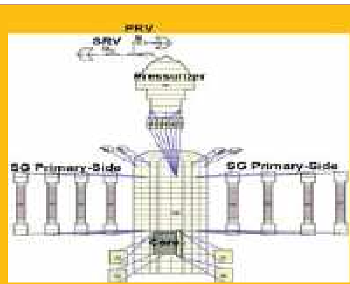


NuScale Plant



NuScale: ATHLET Model

SMART Plant



SMART: TRACE Model

For more information, visit:
www.McSafer-h2020.eu

- Coordinator: Dr. V. Sanchez – Espinoza, Karlsruhe Institute of Technology (KIT)
- Contact: Victor.sanchez@kit.edu

INNOVATION AND CHALLENGES FOR SEISMIC SAFETY ASSESSMENTS ADRESSED BY EURATOM METIS

Irmela ZENTNER

IRMELA ZENTNER, *EDF R&D Lab Paris-Saclay, 7 bvd Gaspard Monge, 91120 Palaiseau, France*

EURATOM METIS (Methods and Tools Innovation for Seismic Safety Assessments https://metis-h2020.eu/) has started in September 2020 under the EURATOM Horizon 2020 program and is running until 2024. It addresses the three ingredients of seismic safety assessment in an overall approach: seismic hazard; structural and equipment fragility analyses and integration in the full Probabilistic Safety Assessment (PSA) framework to determine plant failure probabilities.

The overall framework for probabilistic safety assessment is well established but the partitioning into disciplines prevents from integration of common approaches, for example for uncertainty propagation.

In the recent years, there have been significant advances in the scientific and engineering community to develop statistical and numerical approaches for “bestestimate” and site specific assessments. METIS follows these paths and further develops methods to improve the predictability of beyond design analyses. The project further develops the use of databases, numerical simulations and uncertainty propagation to improve fidelity and accuracy of the engineering models.

In this context, one major technical objective of METIS is to develop, improve, and disseminate open-source tools for seismic hazard, fragility and risk assessment. Open-source tools for Probabilistic Seismic Hazard Assessment (PSHA) and structural analyses are getting more and more commonly used both by the scientific and engineering communities and allow for numerous collaborations. One of the high-level objectives of METIS is the development and dissemination of an open-source tool for PSA computations.

This contribution presents the challenges and first results obtained by the METIS consortium.

EURATOM METIS: Innovations for seismic risk assessment

Irmela ZENTNER[1]
[1]EDF R&D Lab Paris Saclay

METIS - MEthodologies and Tools Innovation for Seismic risk assessment

Duration: 4 years
September 2020 - 2024

Contribute to European consensus on best practice for seismic risk assessment analysis chain

High level objectives

- Develop, improve, disseminate open-source tools for seismic hazard, fragility and risk assessment to address the whole analysis chain
- Testing model performance by comparison to data and model updating
- Uncertainty quantification, propagation and communication
- Improve state of the art in seismic risk assessment and disseminate best practice to engineering

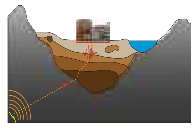
Innovation/concept

Integrated simulation-based approach from the seismic source to floor response

- Avoid double-counting of uncertainty
- Avoid conservative assumptions at interfaces
- Physical models and scenarios rather than envelopes

Ground motion for engineering and site response

- Physical models to develop time histories for transient SSCs response simulation
- Site specific scenarios and ground motion rather than empirical approaches



Achievements

			
Seismic source and ground motion	Site response	SSCs response and fragility	Risk quantification
• Efficient sampling plans for uncertainty propagation • Stochastic ground motion simulation model • Main and aftershock seismicity models • V&V procedure (« PSHA Testing »)	• Numerical simulation of wave propagation including geometry and spatial variability of soil properties • Ground motion selection procedures adequate for SSCs response	• V&V procedure including Bayesian model updating by comparison to observations	• New open-source tool for seismic risk assessment (SCRAM coupled to Andromeda) and data management tool to facilitate uncertainty propagation and parametric analysis

Project partners

EURATOM Fission 2019 NFRP-03 Safety margins determinations for design-exceeding external hazards

TURBULENCE-INDUCED VIBRATIONS PREDICTION: THROUGH USE OF AN ANISOTROPIC PRESSURE FLUCTUATION MODEL

Nout VAN DEN BOS

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Due to the complicated design of nuclear reactors, many complex phenomena can cause points of failure. In the case of nuclear fuel rods, the axial flow that cools the rods can induce vibrations due to the turbulent nature of the flow. Turbulence-induced pressure fluctuations create small but significant vibration amplitudes, which in turn can cause structural effects such as material fatigue and fretting wear. For this reason, turbulence-induced vibrations have been the subject of many studies, with a recent focus on the development of computational methods, so called Fluid-Structure Interaction (FSI) simulations. While scale-resolving methods can predict pressure fluctuations directly, they are typically too expensive for industrial nuclear applications in FSI. Instead, an Unsteady Reynolds-Averaged Navier-Stokes (URANS) approach coupled with a pressure fluctuation model can be used, to reduce the computational cost. While showing promising results, this approach generally underestimated the vibration amplitudes. For this reason, an improved pressure fluctuation model, called AniPFM (Anisotropic Pressure Fluctuation Model), was developed. It models velocity fluctuations based on existing methods for synthetic turbulence. In turn, these velocity fluctuations are used to obtain the pressure fluctuations. AniPFM improves the prediction of the pressure fluctuations in three ways. First, whereas previous iterations could only represent the turbulence as isotropic, in the current model anisotropic Reynolds stresses can be embodied. Second, only the scales that can be resolved on the grid are represented by the velocity fluctuations, causing a more realistic distribution of energy along the different wavelengths. Finally, time correlation is introduced based on the transport and decorrelation of turbulence. From simulating decaying homogeneous isotropic turbulence, we find that this time correlation method gives a significant improvement over previous methods. From turbulent channel flow simulations, our results show that for anisotropic turbulence, the pressure fluctuations are overestimated, but they are still within a reasonable range of 10% compared to high-resolution data. AniPFM doubles the cost of simulation, compared to a URANS

simulation. Even though that is a steep increase, the cost is still much lower than scale-resolving methods. While further validation is ongoing, the AniPFM has demonstrated its potential for cheaper simulations of turbulence-induced vibrations in industrial nuclear applications.

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Turbulence Induced Vibration Prediction: Through Use of an Anisotropic Pressure Fluctuation Model

NRG Nuclear. For life.

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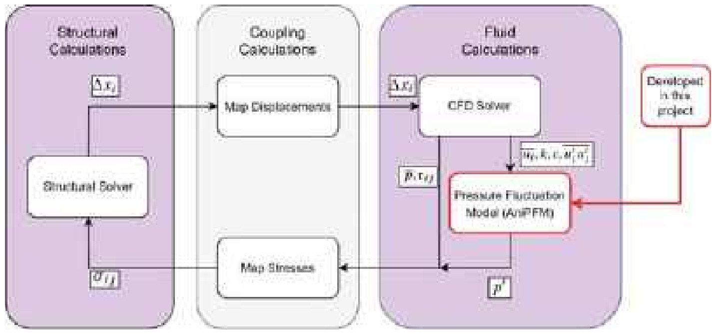
[2]Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 1, 2629 HS Delft, The Netherlands

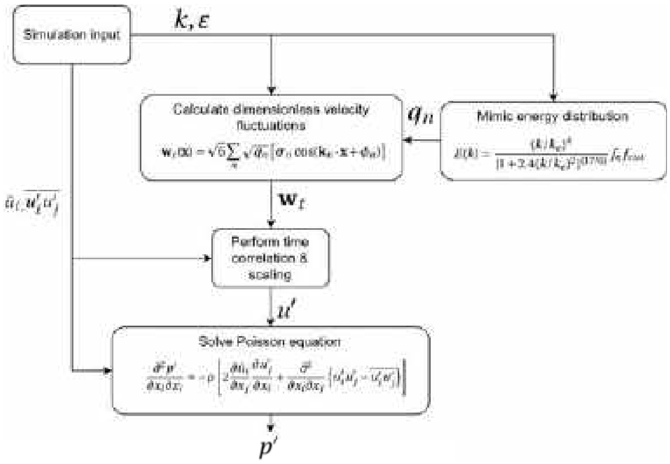
Motivation & Objective

- Nuclear fuel rods are subjected to axial flow for cooling, which can induce vibrations due to pressure fluctuations in the flow.
- This can cause structural effects, such as material fatigue and fretting wear.
- The phenomenon can be modelled by using Fluid-Structure Interaction (FSI) simulations, combined with a model for pressure fluctuations.
- The objective of the current project was to develop a new anisotropic pressure fluctuation model (AniPFM), to improve the prediction of pressure fluctuations with respect to the existing PFM.



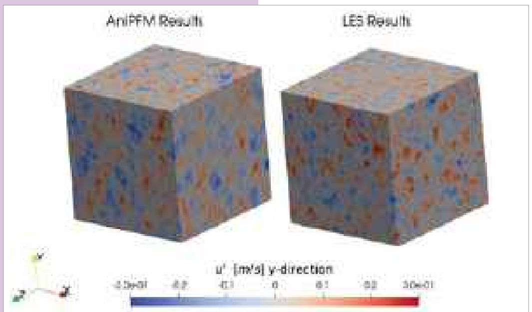
Methodology

- The pressure fluctuations are defined by a Poisson equation, in order to solve this equation, the velocity fluctuations must first be modelled.
- The velocity fluctuations are modelled as a Fourier series, which mimic real velocity fluctuations in terms of the distribution of kinetic energy in the wavenumber domain.
- The velocity fluctuations are convected and correlated in time, in order to model the transport phenomena of the Navier-Stokes equations.
- Boundary conditions are implemented that approximate the behavior of pressure fluctuations at the domain boundaries.

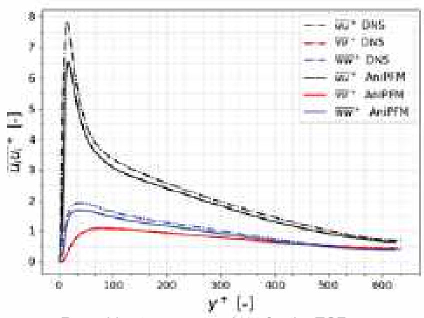


Results

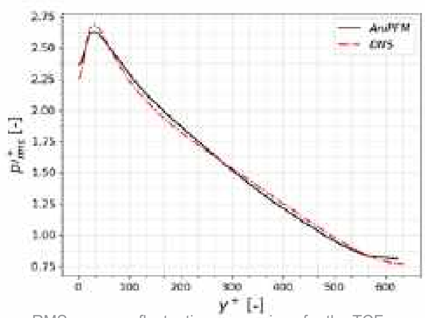
- Both Homogeneous Isotropic Turbulence (HIT) as well as a Turbulent Channel Flow (TCF) are simulated.
- The AniPFM shows close qualitative results w.r.t. large-eddy simulations of HIT in terms of velocity and pressure fluctuations, as well as the distribution of the kinetic energy.
- The AniPFM predicts the RMS pressure fluctuations of homogeneous isotropic turbulence with a ~1% error with respect to DNS data, while using a mesh that is 64 times as coarse.
- For turbulent channel flow, the mean flow quantities are taken from a reference Direct Numerical Simulation (DNS) as input.
- A small underestimation is shown for the Reynolds stresses, due to the fact that the mesh can not fully resolve the kinetic energy close to the wall.
- Nevertheless, the AniPFM shows only a ~5% difference in the RMS pressure fluctuations at the wall, with respect to DNS data.
- In comparison, the existing PFM shows a 47% underestimation, standard URANS can not physically predict pressure fluctuations.



Velocity fluctuation comparison for the HIT case.



Reynolds stress comparison for the TCF case.



RMS pressure fluctuation comparison for the TCF case.

Conclusion & Further Work

- The AniPFM shows good correlation with respect to higher-fidelity methods, both for isotropic and anisotropic turbulence.
- In further research, the use of the AniPFM in fluid-structure interaction simulations has to be validated. In particular, it is of interest to see if the current FSI framework can accurately predict the vibration amplitude of nuclear fuel rods subjected to axial flow.

TRAINING AND TUTORING FOR THE NUCLEAR SAFETY EXPERTS OF COUNTRIES OUTSIDE THE EU

Gerard COGNET

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Keywords: Training and tutoring, nuclear safety, radiation protection, Nuclear Regulatory Authorities, Technical Support Organizations

Safe utilization of nuclear energy requires competent, independent, and adequately financed National Nuclear Regulatory Authorities (NRAs) and Technical Support Organizations (TSOs). Because of the high demands on technical competence, the continuous availability of new information (development of new reactor types, new safety mechanisms or new assessment methodologies), the recruitment of new staff, there is always a need for general, in-depth and specific training for the experts of NRAs and TSOs to build and maintain their necessary knowledge and skills. The European Union (EU) supports the achievement of the above in countries outside the EU through the Instrument for Nuclear Safety Cooperation (INSC) and has initiated several actions to provide training for countries in need of technical assistance.

Training & Tutoring initiative to support competence building worldwide is part of the INSC's efforts towards making the EU a global reference in matters of nuclear safety and radiation protection, emergency preparedness and regulatory framework.

Phase 5 of the European Commission's INSC project has been launched in January 2022. It is implemented by a Consortium led by EK (Hungary), having members of NucAdvisor (France), N.IN.E. S.r.l. (Italy), VUJE, a. s. (Slovakia), Uni-Energy Ltd. (Hungary) and ENEN (Belgium). Throughout the nearly three years of the project, several courses – both in the form of trainings and several weeks tutoring – and assistance will be provided for the experts of non-European countries' NRA(s) and TSO(s) to strengthen their capabilities with regard to their tasks and responsibilities related to radiation protection and nuclear safety. Developing such expertise is more than a matter of education, as it involves not only the transfer of technical knowledge, experiences, and best practices, but also helps promoting the European nuclear safety culture.

The programme of the current project will be presented as well as the lessons learned from the previous phases.

Training and Tutoring for the Experts of Nuclear Regulatory Authorities of Countries Outside the EU

FISA 2022

Funded by the European Union

Tamás PÁZMÁNDI[1], Giovanni BRUNA[2], Csilla PESZNYÁK[3], Gérard COGNET[2]*, Alessandro PETRUZZI[4], Gabriel PAVEL[3], Márton BENKE[5], Branislav HATALA[6], Alain VAN DEN BRANDE[7], Dorottya JAKAB[1]

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[7]European Commission – EC, Brussels, Belgium

Introduction

The European Union (EU) supports the promotion of the effective nuclear safety and radiation protection culture and implementation of its highest standards in non-EU countries through the European Instrument for International Nuclear Safety Cooperation (INSC). INSC includes a Training & Tutoring (T&T) initiative that involves transferring practical knowledge for countries in need of technical assistance in the field of nuclear safety. The initiative aims at assisting the National Nuclear Regulatory Authorities (NRAs) and Technical Support Organisations (TSOs) of non-EU countries in strengthening their capabilities in relation to their regulatory responsibilities and tasks.

The 5th project of the EU-financed INSC T&T initiative („*Training and tutoring for experts of the NRAs and their TSOs for developing or strengthening their regulatory and technical capabilities - MC3.01/20*"), that follows up the previous project phases, has been launched in January 2022.

Objectives of the project

The project supports the enhancement of capacities of NRAs and TSOs in INSC Partner Countries through provision of training and tutoring to develop and maintain competences and skill related to the different areas of regulatory responsibilities and functions and to provide the underlying technical knowledge necessary for the effective nuclear safety regulation.

The training and tutoring courses transfer knowledge with reference to EU directives and international safety standards, illustration of the practicalities, such as application and implementation of the best EU regulatory approach, with particular attention to addressing the local needs and specificities of the countries concerned.

The project promotes and contributes to strengthening global and regional cooperation on nuclear safety.

INSC Partner Countries benefitting from the T&T initiative

Algeria	Armenia	Belarus	Bosnia and Herzegovina
Botswana	Brazil	Egypt	Georgia
Ghana	Indonesia	Iran	Iraq
Jordan	Malaysia	Mexico	Moldova
Mongolia	Morocco	Nigeria	Philippines
Serbia	South Africa	Tajikistan	Tanzania
Thailand	Turkey	Ukraine	Vietnam

The programme is open to countries interested in joining.

Implementing Consortium

EK is a TSO of the Hungarian Atomic Energy Authority, having several years of experience in training professionals in developing countries, and being a collaborating centre of the IAEA.

NucAdvisor is a nuclear consulting company established by a group of senior executives from across the European nuclear industry, providing, among others, advisory services, technical assistance and training to clients across the nuclear sector.

NINE is a private nuclear engineering company having extensive experience in nuclear reactor safety assessment and licensing, offering multi-level training courses and participating in IAEA SAET programme.

VUJE is an engineering company providing services and regulatory support in the energy sector, with a special focus on NPPs, and having a training centre to prepare specialised personnel for the NPP operation.

Uni-Energy Ltd, wholly-owned subsidiary of the University of Miskolc, has an important role in the further development of higher education and training in nuclear technology and energy in Hungary.

ENEN is an international nuclear education network with the main purpose of the preservation and the further development of expertise in the nuclear fields by higher education and training in Europe.

Training & Tutoring activities

A T&T Programme is designed and implemented to best serve the competence development needs related to the regulatory functions of the Beneficiary/Partner Countries of INSC. It aims to ensure that trained experts from NRAs/TSOs maximize the use of the knowledge they acquire in their day-to-day work.

Throughout the nearly three years of the project, several 1-2-week training courses will be held

- in the EU and
- specific regions (Latin America, South-East Asia, Eastern Europe-Central Asia, South-East Africa, North Africa and Arabic Countries).

In addition, 1-2 month tutoring courses (on-the-job-trainings) will be held in EU NRAs/TSOs.

Topics covered include

- regulation, licensing and enforcement
- site and constructing inspection
- inspection of equipment manufacturing, safety systems and structure
- emergency preparedness and response
- regulation of radiation protection in medical and industrial applications
- management of spent fuel and radioactive waste
- safety assessment for existing nuclear installations
- public information and crisis communication

Enhanced cooperation on nuclear safety regulation

A dedicated platform is established to facilitate networking, discussing common challenges and opportunities, providing guidance and creating opportunities for cooperation and partnerships on nuclear safety regulation at regional or global level.

Contact Information

Website: https://training.ek-cer.hu/ **Email:** info@training.ek-cer.hu Read more on https://nuclear.jrc.ec.europa.eu/tipins/europeaid-safety-training

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APPLICATION OF THE TRANSPOSITION METHOD INVOLVING EDF NUCLEAR PLANTS MEASUREMENTS: CASE OF REACTIVITY.

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Key words: nuclear data, sensitivities, uncertainties, covariance matrices, representativity, assimilation, transposition, industrial measurements.

Usually, comparisons to experimental data are performed to validate a calculation code in a specific domain (called the validity domain). However, the lack of experimental data of new reactor concepts (EPRs, SMRs, …) has made the transposition method becoming more widely used for domains which have insufficient experimental data. The use of this method is discussed by the French Safety Authority (ASN) in its “guide 28”, related to first barrier safety. It has been in use for several years now in the field of experimental research reactors (by the CEA in France for example) and has given satisfactory results, especially for designing new critical mock-up experimental programs. Therefore, the main concern of this paper is to study its application to an industrial concept (such as an EPR) with experimental data coming both from mock-up and power plant measurements, the later making the approach quite innovative. The goal is to improve predictability of industrial codes. One observable is studied: the reactivity. First order Standard Perturbation Theory (SPT) is used to compute the nuclear data sensitivities, whose uncertainties are propagated to the outputs through the “Sandwich rule”. The covariance matrices are those of the CEA (COMAC), based on JEFF-3.1.1. The transposition formulas are used to compute the posterior outputs and uncertainties. At this time, only an intermediate scale (several assemblies at various burn-up steps) has been treated to set up the process and analyse the 8 group COMAC consistency, freshly constructed for our needs and not yet validated. The results showed that transposition leads to biases and uncertainties reduction (up to 40%). Some unexpected behaviour of the given 8 group COMAC (inconsistent propagated uncertainties on supposed known nuclear data) has been bypassed by using the

validated 36 group COMAC and conserving the uncertainty information during its condensation to new 8 group matrices. The paper details the used methodology. We also point out the robustness of the sensitivity calculation versus the calculation scheme degradation. We expect that the inclusion of industrial measurements in the transposition process, using industrial calculation codes, will increase their predictability (same target value with reduced uncertainty).

APPLICATION OF THE TRANSPOSITION METHOD INVOLVING EDF NUCLEAR PLANTS MEASUREMENTS: CASE OF REACTIVITY.

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CONTEXT

The emergence of new generations nuclear concepts (EPRs, SMRs, MSFRs, …) and the inaccessibility to the measurement of some operating domains of existing NPPs have increased the need of developing strong methodologies to improve the predictability of the scientific calculation codes and extend their domain of validity to a domain where sufficient data are not available. One of these methodologies is the transposition method [1] that consists in transferring experimental information from one or more experiments to an application in order to reduce the output biases and related uncertainties linked to the considered input data (such as nuclear data). This method has been in use in the field of experimental research reactors for several years now (by the CEA for example) and has given satisfactory results especially for designing new optimized experiments [2]. The interest of this paper is to extend the application of this method to an industrial frame with its specificities. Two observables were chosen for this purpose: the reactivity and the power distribution of an EPR core.

NUCLEAR DATA SENSITIVITIES AND UNCERTAINTY PROPAGATION

Various sources are involved in the overall uncertainty of any output of a scientific calculation code. In the neutronics field, those sources are mainly:

- The technological uncertainties;
- The numerical biases (physical models, simplifications, …);
- The nuclear data uncertainties.

These latter are the main sources and constitute an important lever for reducing uncertainties. In our study, they are propagated through the “Sandwich rule” given by the expression:

$$\varepsilon = \sqrt{S^t \,\underline{\boldsymbol{D}}\, S} \qquad (1)$$

$\underline{\boldsymbol{D}}$ is the covariance matrix of the nuclear data and S is the sensitivity vector of the output to the nuclear data, obtained using the perturbation theory (standard, generalized or equivalent) [3].

isotopes	réactions	Tripoli 4 (T4) sensitivities	cocagne sensitivities (SP3 - PbP): S1	delta S1 (cocagne - T4)	cocagne sensitivities (diff - Hom): S2	delta S2 (cocagne - T4)
U234	nu	1,36E-04	1,21E-04	-11%	1,21E-04	-11%
	capture	-2,48E-03	-2,32E-03	-6%	-2,30E-03	-7%
U235	nu	9,32E-01	9,32E-01	0%	9,32E-01	0%
	fission	3,71E-01	3,93E-01	6%	4,03E-01	9%
	capture	-1,25E-01	-1,21E-01	-4%	-1,19E-01	-5%
U238	nu	6,83E-02	6,77E-02	-1%	6,77E-02	-1%
	fission	3,89E-02	3,86E-02	-1%	3,86E-02	-1%
	capture	-1,88E-01	-2,44E-01	29%	-2,43E-01	29%
H_H20	capture	-3,82E-02	-3,96E-02	4%	-3,95E-02	3%
	scattering	1,29E-01	1,58E-01	22%	1,45E-01	12%

Table 1: reactivity sensitivities of some nuclear data, applied to a UOX 17x17 PWR assembly, with EDF core code COCAGNE compared to TRIPOLI-4 (Monte Carlo).

PbP (pin by pin) and Hom (homogeneous) are the different spatial discretization. SP3 (simplified transport of order 3) and diff (diffusion) are the different neutronic solvers used.

The highest discrepancies observed in this table are linked to the nature of the perturbed data in each code: continuous energy nuclear data in the Monte Carlo code versus mutli-group nuclear data in the deterministic code. The latter hides an **implicit** term which should be added to the **explicit sensitivity** computed by COCAGNE. This implicit sensitivity is due to **resonance self-shielding,** operated prior the **energy collapsing step** in deterministic codes**.** It can have a non negligeable impact to the **total sensitivity** especially for resonance nuclides in the resonance energy groups as shown in the references [4] and [5]. Finally, as it can be seen in Table 1, the sensitivity calculation has a low dependency on the deterministic scheme.

REPRESENTATIVITY, ASSIMILATION AND TRANSPOSITION

Once the uncertainties are propagated, the goal of the assimilation-transposition process is to incorporate the experimental information in order to improve the precision of the code on the application case. Based on assumption of normal distribution of the variables [1], the obtained formulas are the following (with one experiment):

$$\frac{\tilde{C}_{app} - C_{app,0}}{C_{app,0}} = \left(r * \frac{\varepsilon_{app}}{\varepsilon_{exp}} * \frac{1}{1 + \frac{\delta E^2}{\varepsilon_{exp}^2}}\right) * \left(\frac{E - C_{exp,0}}{Cexp,_0}\right) \qquad (2)$$

$$\tilde{\varepsilon}_{app} = \varepsilon_{app} \sqrt{1 - \frac{r^2}{1+\frac{\delta E^2}{\varepsilon_{exp}^2}}} \qquad (3)$$

$C_{x,0}, \varepsilon_x$: prior values of the output and his uncertainty

$\widetilde{C_x}, \widetilde{\varepsilon_x}$: posterior values of the output and his uncertainty

δE: experimental *uncertainty*

E measurement

$r_{axp,app} = \frac{S_{exp}^t . \underline{\boldsymbol{D}} . S_{app}}{\varepsilon_{exp} * \varepsilon_{app}}$ is called the representativity factor and tells how the experiment (exp) and the application (app) are similar. A matrix form of those expressions exists in case of more than one experiments [2].

BRIEF FOCUS ON COVARIANCE MATRICES

The question of covariance matrices is an unavoidable question in any uncertainty analysis. They are specific to every nuclear evaluation file and determine the results. Those of this study are issued from the CEA: **COMAC** [6], based on JEFF-3.1.1. Some unexpected behaviour (inconsistent propagated uncertainties of supposed known data) of the 8 groups matrices, especially produced for our needs, led us to establish a procedure to collapse the validated 36 groups matrices to new 8 groups ones used for our calculation. Based on a total uncertainty conservation principle between the 36 groups matrix and the 8groups result, we obtain the formula:

$$cov\left(\sigma_{x,I}^{j}, \sigma_{x',I'}^{j}\right) = \frac{1}{S_I * S_{I'}} \sum_{\substack{g \in I \\ g' \in I'}} S_g * S_{g'} * cov\left(\sigma_{x,g}^{j}, \sigma_{x',g'}^{j}\right) \qquad (4)$$

where σ is a nuclear data, j is an isotope, x and x' are reactions, S is the sensitivity vector. $\mathrm{g}(\mathrm{g}')$ and $I(I')$ are respectively a group in the 36 groups energetic mesh and the related group in the 8 groups energetic mesh.

Some results before and after the procedure can be found in table 2.

sensitivities	36 groups	8 groups	8 groups
COMAC	36 groups	8 groups	36 groups -> 8
UOX_320	539	1145	540
UOX_420	575	1387	576
UGD_230_12G_GD80U130	546	920	545
UGD_230_8G_GD80U130	533	920	533
UGD_420_12G_GD80U250	579	1350	579

Table 2: Propagated uncertainties of some PWR assemblies at 0 MWd/t BU

Applications are EPR-type assemblies where UOX_XXX denotes UOX assemblies with (XXX/100)% U235 enrichment and UGD_XXX_YG_GD80UZZZ denotes UGD assemblies with Y pins containing 8% gadolinium on a (ZZZ/100)% U235 enrichment support. The other pins are (XXX/100)% U235 enrichment UOX pins.

SOME TRANSPOSITION RESULTS: EXAMPLE OF THE REACTIVITY

Experiment: UH1.4 critical configuration of the CEA EOLE EPICURE mock-up

> 1256 standard PWR UO2 pins + 109 guide tubes in a 95 cm radius and 1 m hight cylindrical core.

Applications: EPR-type assemblies (in infinite medium).

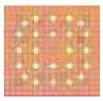

Figure 1: Radial cut of an EPR-type assembly (UGD_420_12G_GD80U250)

With is 24 guide tubes and 12 UGD pins (in gray). The other pins are UO2 pins

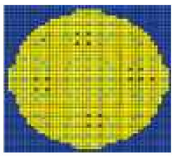

Figure 2: Radial cut of the UH1.4 configuration.

The UO2 pins are in yellow, the guide tubes are in blue (with a cross for safety guide tubes). One fission chamber (in red) is also present and the coolant cool surrounds the fuels pins

assemblies	UOX_420 (0 GWd/t)	UGD_420_GD80U250 (5 GWd/t)	UOX_420 (60 GWd/t)
reactivity	21500	12866	-18116
representativity (vs UH1.4)	0,91	0,86	0,33
prior uncertainty due to nuclear data (pcm)	557	508	556
posterior uncertainty due to nuclear data (pcm)	**340**	**335**	**534**
relative varaition of the uncertainty	-39%	-34%	-4%

Table 3: transposition applied to the reactivity of some assemblies at different burnups

As a first step, we didn’t have access to the nuclear parc data. So, we have considered a mock-up as experience and some assemblies as applications to set up the process and verify the consistency of our results prior to a whole EPR core application. A more complete set of reactions and isotopes could be considered for a complete uncertainty propagation.

CONCLUSION AND PERSPECTIVES

Through an extended representativity and transposition approach mixing integral information from critical facilities and data from the nuclear fleet, an improvement of the predictability of the industrial calculation code is expected. The first step settled the process with first numerical benchmarks of Gen-III assemblies vs preliminary experiments conducted in ZPR. The next step is to perform a whole EPR core analysis for both the reactivity and the power distribution. The power distribution presents the particularity to be **reconstructed from flux maps**. So, the interest would be to study how we take into account this reconstruction during the assimilation in addition to the **size effects** on this local output.

REFERENCES

[1]: J.-M. PALAU, P. TAMAGNO, A. RIZZO, “Advanced information criteria applied to IDA benchmark problems: Reducing the degree of freedom in Bayesian approaches”, in proceedings of ANS M&C 2021, October 2021.

[2]: N. DOS SANTOS, “Optimisation de l'approche de représentativité et de transposition pour la conception neutronique de programmes expérimentaux dans les maquettes critiques”, PhD thesis, Université Grenoble Alpes, 2013.

[3]: L. N. USACHEV, Proceduring International Conference on Peaceful Uses of Nuclear Energy, 1955.

[4]: J. MA, C. HAO, G.LIU, L. KANG, P. LI, Fdla. RENTERIA DEL TORO, “Generalized Perturbation Theory Based Total Sensitivity and Uncertainty Analysis for High-Fidelity Neutronics Calculation”, Frontiers in Energy Research, 9:743642.

[5]: M. R. BALL, D. R. NOVOG, J. C. LUXAT, “Analysis of implicit and explicit lattice sensitivities using DRAGON”, Nuclear Engineering and Design, 265 (2013) 1-12.

[6]: C. DE SAINT JEAN et al, “ Estimation of multi-group cross section covariances”, proceedings of the PHYSOR2012 conference, 2012.

10th European Commission Conference on EURATOM Research and Training in Safety of Reactor Systems
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NEUTRON CONVERTER SAFETY LIMITS DETERMINATION BY MEANS OF CFD ANALYSIS

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In the National Centre for Nuclear Research (NCBJ) in Poland, the so-called H2 experimental facility for BNCT research, as a part of a new laboratory, is being constructed as a part of a new laboratory at one of horizontal neutron beam channels of MARIA reactor. One of the significant technical challenges is to provide a high-quality beam, required for various targets irradiations. Since the primary neutron energy spectrum from the reactor includes both fast neutrons and thermal ones, it is essential to shape the beam accurately. The beam spectrum will be based dependent on two systems: a neutron converter and the beam shaping assembly. The neutron converter is a subcritical system absorbing thermal neutrons to produce fast ones. Its main active parts are small plates containing uranium dioxide. Since the fission reactions occur within the plates, a significant amount of heat is released. That is why the proper cooling of the system has to be ensured. In the paper, the aim of determining the heat transfer and the coolant flow conditions using Computational Fluid Dynamics is shown. In addition, the safe levels of the operational reactor parameters are proposed. The specific objectives are to determine the flow characteristics in the neutron converter installation, to investigate heat transfer from the plates to water, and to model the coolant flow blockage event. The applied initial and boundary conditions in the test cases cover the entire spectrum of neutron converter operating conditions within the reactor core. The results presented in this study were used to determine whether the existing MARIA Research Reactor pool cooling conditions are able to ensure the safe operation of the neutron converter.

FISA 2022

NEUTRON CONVERTER SAFETY LIMITS DETERMINATION BY MEANS OF CFD ANALYSIS.

Narodowe Centrum Badań Jądrowych
National Centre for Nuclear Research
ŚWIERK

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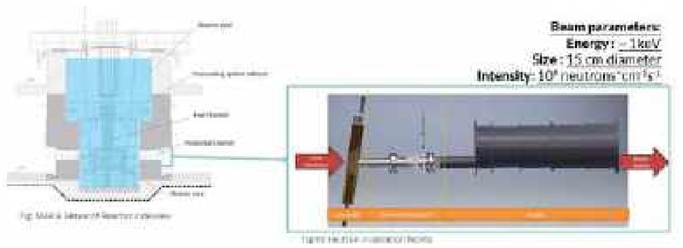
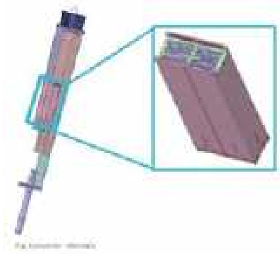
H2 experimental facility @MARIA Research Reactor

MARIA is a multi-purpose reactor of a pool-type with pressurized fuel channels containing concentric fuel tube assemblies. It is a high flux reactor of 30MW nominal power moderated with water and beryllium. MARIA is equipped with vertical channels for irradiation target materials, a rabbit system for short irradiations which are located near fuel channels. Eight horizontal channels enable to lead the neutron beam outside the reactor core. The designed test facility is located at one of the horizontal channels. The core part consists of the converter and the intermediate channel, while the beam shutter is mounted in the concrete reactor pool wall. The aim of the facility is to provide a broad spectrum of neutron energy from fast to the thermal beam for various research purposes.



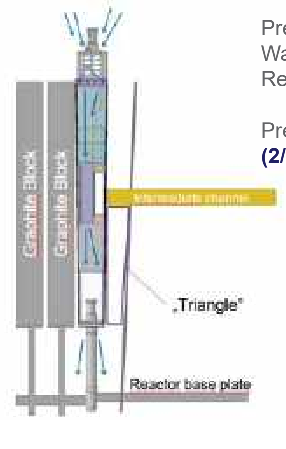
Neutron Converter

The converter is the subcritical uranium plates assembly in which the fission reaction occurs. The reaction is initiated with thermal neutron originating from the reactor core. As one of the fission reaction products, the fast neutrons appear. Another product of the fission reaction is a significant amount of heat so the proper cooling conditions have to be ensured.



Methodology & Boundary conditions

Having considered the location, operating conditions and complexity of the problem i.a. 3D geometry, 9° tilt from vertical, discrete heat generation data, it was decided to use Computational Fluid Dynamics (CFD) code. CFD deals with the numerical analysis of the flow. Firstly, the numerical model of the neutron converter was prepared. This enabled to simulate the specific conditions in the reactor core. Using this model, the broad spectrum of cases was analyzed. This allowed determining operating safety limits for steady-state operation. The capability of the pool cooling system to cool down the converter was concluded from the obtained characteristics. The flow inside the neutron converter was modeled with ANSYS tools. The flow domain (geometry) was prepared using SpaceClaim R17.2, then it was meshed using ANSYS Workbench Mesher 17.2, and the CFD simulation was run with ANSYS Fluent 17.2.



Pressure: 174,090 kPa (atm+7,5m H2O)
Water inlet temperature: **323K**
Reactor water level: 7,05m

Pressure diffrence: **8,829kPa**
(2/ 2.3/ 4 /10/ 13.8 kPa)

Flow characteristics

The IV-B socket at MRR is inclined by almost 9 degrees from the vertical direction thus some impact on the flow distribution both among the slots and within one slot were anticipated. The flow is forced by the pressure difference and nonidentical slot size, flow distribution among slots is nonuniform. The greatest mass flow is observed in the middle (13*th* and 14*th*) slots which have the biggest cross section, while the smallest coolant flow rate occur for the extreme slots, which are the smallest ones. Having considered only regular slot the velocity profile for each set can be compared to a laminar velocity profile encountered in pipes and ducts.

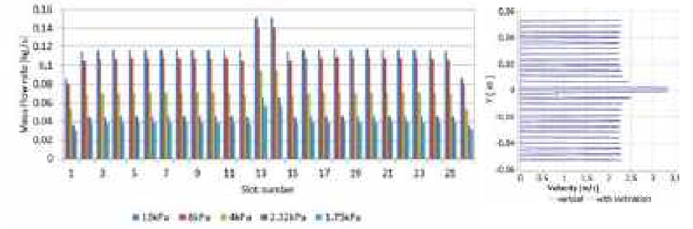


Fig: Left: Coolant mass flow rate in the SbFPs with regard to pressure difference and slots numbering. Right: Velocity profile in the slots.

Heat transfer conditions

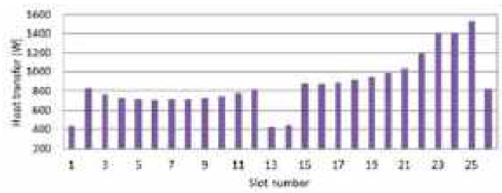


Fig: Heat exchanged by each slot.

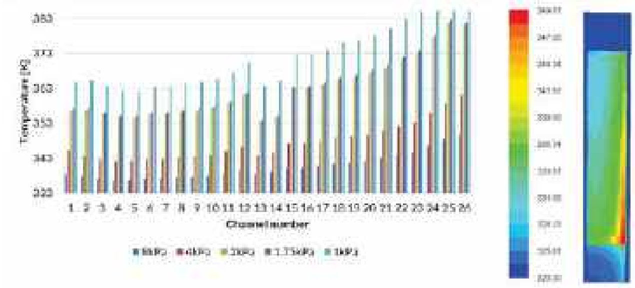


Fig: Left: Maximum wall temperature with regard to pressure difference and slot number. Right: Channel wall temperature contour map.

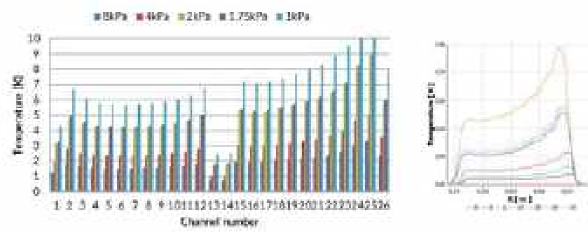


Fig: Left: Temperature difference between slot outlet and inlet. Right: Coolant temperature profile at the channel outlet.

Conclusions

- ✓ The average water velocity in a single slot during normal reactor operation equals **1.6 m/s.**
- ✓ The total mass flow rate for converter: **2.6 kg/s** (<1% of total pool water mass flow rate)
- ✓ Flow blockage at the inlet to the plate zones do not affect the area with uranium.
- ✓ Minimum pressure difference for safe operation of the converter: **2.3 kPa (ONBR = 1.2)**
  Minimum delta P for the reactor start up 13.8 kPa.
- ✓ The coolant mixing within single slot is negligible.

INVESTIGATION OF A HYPOTHETICAL CORE DISRUPTIVE ACCIDENT SCENARIO IN MYRRHA

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Multipurpose hYbrid Research Reactor for High-tech Applications (MYRRHA) is a fast neutron spectrum facility cooled by Lead-Bismuth Eutectic (LBE), currently under development at Belgian Nuclear Research Centre (SCK CEN). The main purpose of MYRRHA is to demonstrate the feasibility of an Accelerator Driven System based on a Lead-cooled Fast Reactor. As an ultimate safety barrier in the case of a severe accident, MYRRHA intends to rely on in-vessel retention of the nuclear fuel material. In order to determine the viability of the in-vessel retention strategy, an enveloping case is postulated: the Hypothetical Core Disruptive Accident (HCDA). In the course of the HCDA, core degradation and subsequent fuel relocation are assumed to happen in a way that will lead to a compaction of fissile material with a maximum increase of core reactivity. This further results in a power excursion that leads to coolant boiling and consequent overpressure in the reactor vessel. Three phases are considered to describe the HCDA: a core compaction phase leading to prompt supercriticality, a power-buildup phase until delayed supercriticality and a fuel-dispersion phase. The focus of this contribution is on the power-buildup phase. Within this phase, mechanism of reactivity reversal and sequence of events that lead to the disassembly are determined. The reactivity evolution in this phase is driven by a reactivity insertion due to the compaction and countered by the negative reactivity feedbacks due to Doppler effect and thermal expansion of core materials. The power-buildup phase is effectively terminated by fuel expansion due to fuel melting. The reference for the phenomena related to the HCDA in MYRRHA was established by employing computer code SIMMER-III. Since the power profile does not change significantly up until the point of LBE boiling, a point kinetics approach can be used to reproduce the reactivity evolution in the power-buildup phase. A simplified approach to analysis of HCDA, based on a coupled neutronic/thermodynamic solver, has been developed at SCK CEN in order to investigate the evolution of reactor core parameters during the power-buildup phase. The core reactivity evolution indicates that the reactivity reversal is caused by the combination of Doppler effect and thermal expansion of the core materials. For large power excursions, further expansion is provided by the fuel melting which rapidly drives the core reactivity to delay supercritical level. Due to thermal inertia, LBE boiling begins during the delay supercritical phase and will result in fuel dispersion, thereby stopping the core compaction. Sensitivity studies indicate that the reactivity reversal mechanism and the sequence of events considered within the power-buildup phase do not depend on the magnitude of the reactivity insertion rate.

Investigation of a Hypothetical Core Disruptive Accident Scenario in Multipurpose hYbrid Research Reactor for High-tech Applications (MYRRHA)

Đorđe Petrović, Matteo Zanetti and Guy Scheveneels
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Introduction

Multipurpose hYbrid Research Reactor for High-tech Applications (**MYRRHA**) is a fast neutron spectrum facility cooled by Lead-Bismuth Eutectic (LBE), currently under development at Belgian Nuclear Research Centre (SCK•CEN). The main purpose of MYRRHA is to demonstrate the feasibility of an Accelerator Driven System based on a Lead-cooled Fast Reactor.

As an ultimate safety barrier in the case of a severe accident, MYRRHA intends to rely on **in-vessel retention of the nuclear fuel material.**

Objective

In order to **determine the viability of the in-vessel retention strategy**, an enveloping severe accident case is postulated: the **Hypothetical Core Disruptive Accident** (HCDA). In the course of the HCDA, core degradation and subsequent fuel relocation are assumed to happen in a way that will lead to a compaction of fissile material with a maximum increase of core reactivity. This further results in a **power excursion** that leads to coolant boiling and consequent **overpressure** in the reactor vessel.

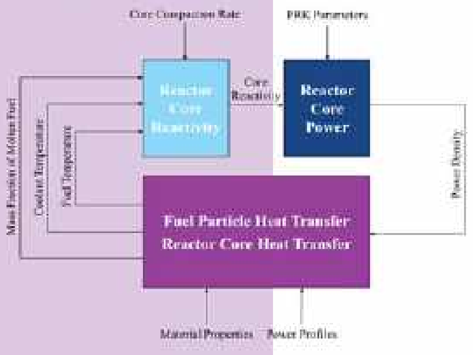
Methods

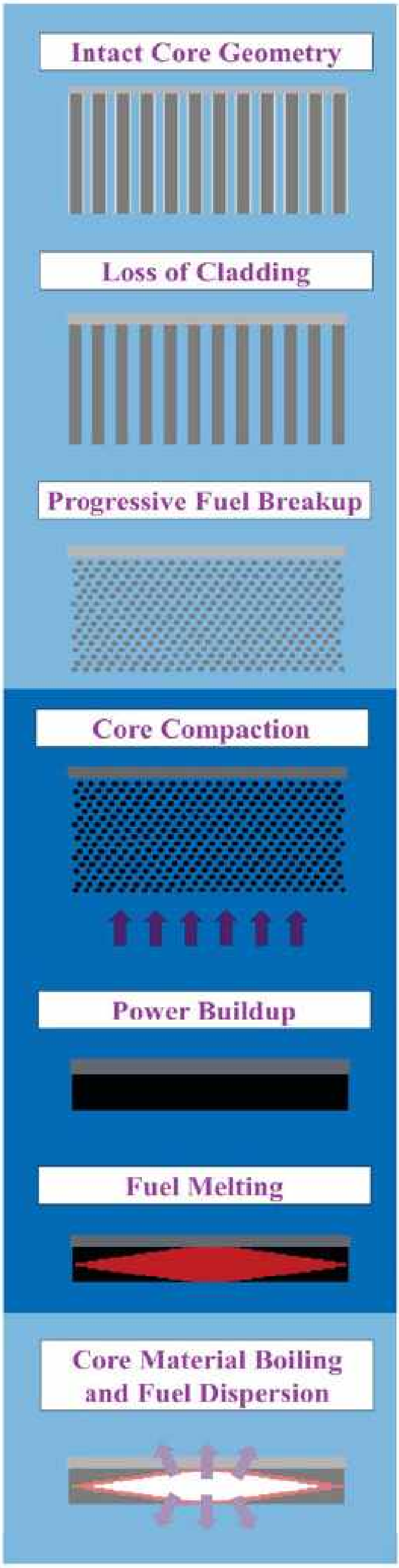
The phenomena related to the HCDA in MYRRHA were first studied by employing the computer code **SIMMER-III**. Three phases are considered to describe the HCDA in MYRRHA:

- **Core compaction phase** leading to the prompt supercriticality
- **Power buildup phase** until delayed supercriticality is reached
- **Fuel dispersion phase**

Since the power profile does not change significantly until the LBE boiling occurs, a **Point Reactor Kinetics** (PRK) approach can be used to determine the core reactivity in the power buildup phase. PRK parameters and reactivity feedback coefficients were obtained by employing Serpent-2 Monte Carlo code. This model is further coupled to a **1D heat transfer model** in order to investigate the dynamics of the power buildup phase.

Coupling of these two models based on the basic principles of neutron physics and heat transfer can **successfully reproduce** SIMMER-III results **until the incipience of the LBE boiling.**



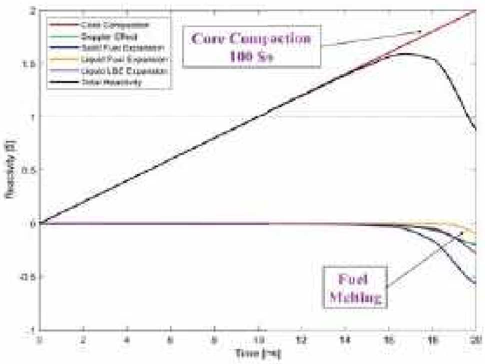


Core Compaction

Among the variety of ways in which the degraded core can be compacted, the hypothetical **compaction** of fuel particles **at the nominal mass flow rate** yields the highest reactivity insertion rate at **~ 170 $/s.**

Power Buildup Phase

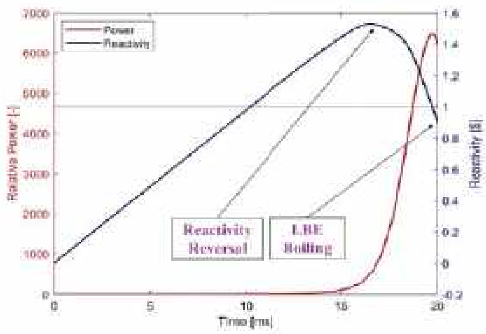
The reactivity evolution in the power buildup phase is determined by reactivity insertion due to the core compaction, which is modeled by ramp reactivity input, and reactivity feedbacks due to **Doppler effect**, **expansion of core materials** due to temperature increase, and **fuel melting**. The power-buildup phase is effectively terminated by fuel expansion due to fuel melting.



Reactivity reversal is caused by the combination of Doppler effect and thermal expansion of the core materials.

Expansion due to **fuel melting** rapidly drives the core reactivity **below prompt supercritical level.**

Sensitivity studies indicate that the reactivity reversal mechanism and the sequence of events within the power buildup phase **do not depend** on the **magnitude of the reactivity insertion rate.**



Due to thermal inertia, **LBE boiling** happens after the prompt supercritical phase and results in fuel dispersion, thereby stopping the core compaction.

Conclusions

Fuel melting rapidly drives the reactor core reactivity **below prompt supercritical level.**

Reactivity reversal is caused by the combination of **Doppler effect** and **thermal expansion** of the core materials.

THE INSPYRE PROJECT: INVESTIGATIONS SUPPORTING MOX FUEL LICENSING IN ESNII PROTOTYPE REACTORS

Marjorie BERTOLUS

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Nuclear fuel constitutes an essential component of the performance and safety of nuclear reactors. It is composed of complex actinide-bearing materials with specific properties and is subjected under irradiation to a large number of diverse but interconnected phenomena. One way of increasing significantly the efficiency in designing and qualifying innovative fuels for the next generation of reactors is to enhance the predictive capability of fuel behaviour simulation by improving the understanding of fuel behaviour in reactor and developing a more physically based description of nuclear fuels.
To this aim, INSPYRE partners used an efficient approach complementing the examination of neutron-irradiated materials by a basic research approach combining separate effect experiments and multiscale modelling. Harnessing basic and applied research, INSPYRE has brought significant advances in the understanding and simulation of uranium-plutonium mixed oxide fuels on four paramount operational issues: margin to fuel melting; atom transport properties and fission gas behaviour; mechanical evolution of fuel pellets and thermochemistry of irradiated fuels. This was supported by the development of numerous set-ups in the project partner hot labs enabling the detailed characterization of Pu and Am bearing oxides. To capitalize the results of INSPYRE investigations, numerous physics-based models were developed to

describe the fuel behaviour under irradiation at the grain and macroscopic scales. These models were implemented in three European fuel performance codes, GERMINAL, MACROS and TRANSURANUS and the improved predictive capabilities of the codes were assessed against a selection of irradiation experiments. Finally, the new versions of the codes were applied to the simulation of the cores of ESNII prototypes.

INSPYRE has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 754329. This project is part of the research activities portfolio of the Joint Programme on Nuclear Materials.

The INSPYRE Project: Investigations Supporting MOX Fuel Licensing in ESNII Prototype Reactors (2017-2022)

Marjorie Bertolus[1], Dragos Staicu[2], Matthias Krack[3], Marie-France Barthe[4], Christine Guéneau[1], Thierry Wiss[2], Lelio Luzzi[5], Alessandro Del Nevo[6], Anna Smith[7]

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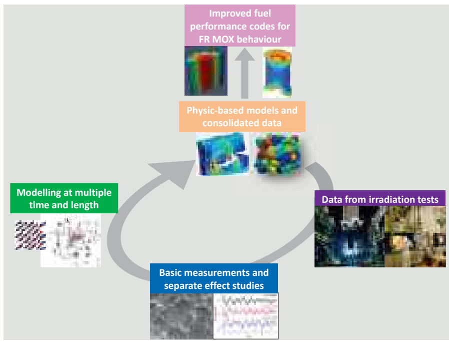
Strategic Objectives and Approach

- Harness basic and applied science to make the motto “Better data in better codes for better predictive performance” a reality
- Make major breakthrough in understanding and describing fast reactor mixed oxide fuel behaviour under irradiation by coupling
  - PIE results on neutron-irradiated fuel from past campaigns
  - Separate effect experiments
  - Multiscale and thermodynamic modelling
- Advance predictive capabilities of fast reactor fuel performance codes by
  - Transferring knowledge acquired from basic and technological research into operational tools
  - Bringing together experts from various areas of expertise
- Apply approach to four important operational issues: margin to fuel melting; atom transport and fission product behaviour; evolution of mechanical properties under irradiation; fuel thermochemistry and interaction with the cladding
- Transfer approach and results of proposal to users, develop training to prepare next generation of researchers and initiate or participate in outreach activities to improve public acceptance of next reactor generation



INSPYRE Partners

- Nuclear organizations: CEA (France), JRC (European Commission), ENEA (Italy), NNL (UK), NRG (The Netherlands), PSI (Switzerland), SCK.CEN (Belgium)
- Industrials: EDF (France)
- Academic organizations: CNRS (France), Aalto (Finland), KTH (Sweden), Polimi (Italy), TU Delft (The Netherlands)
- SME: LGI (France)
- 8 countries + JRC

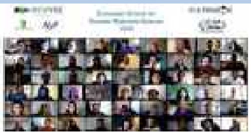
Education & Training activities

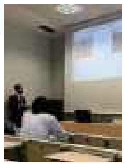
Training through research and implementation of a mobility scheme between project partners for young researchers and allow access to hot laboratories and specific facilities

Co-organisation of summer schools with other European initiatives to disseminate results and approach toward young researchers and train next generation

May 2019: Nuclear fuel cycle, Delft, Netherlands

November 2020: European School on Nuclear Materials Science 2020, online





Advances in the understanding of UO_2 and MOX fuels under irradiation

Foundations

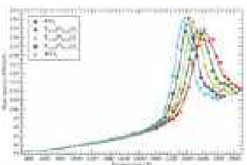
Analysis of available data and models and identification of gaps and prioritization

Development of experimental set-ups in hot labs of several partners enabling detailed characterization of Pu and Am bearing compounds: high temperature Raman spectrometer, laser heating devices, positron annihilation lifetime spectrometer, electrical conductivity device, compression test with oxygen content control, in situ measurement of swelling under ion irradiation

Margin to fuel melting of MOX

Combined experimental and modelling determination of structural and thermodynamic properties of $(U,Pu)O_{2-x}$: thermal expansion, enthalpies, heat capacities, melting temperatures as a function of composition (Pu content, O/M)

Improved thermodynamic model of U-Pu-Am-O system



Atomic transport and fission gas behaviour in fresh & irradiated MOX

Modelling of thermal and irradiation-induced defects in MOX

Multiscale modelling determination of self-diffusion coefficient

Combined modelling and experim-ental determination of fission gas behaviour in UO_2 and MOX

TEM/EBSD characterisation of irradiated MOX

Thermomechanical properties of UO_2 and MOX

Experimental and modelling determination of mechanical properties of fresh UO_2 and MOX fuels

Modelling of impact of primary damage on mechanical properties

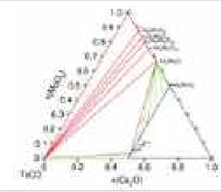
Investigation of thermal and ion irradiation induced creep of UO_2

Thermochemistry of irradiated MOX

Experimental characterization and modelling of fission products compounds

Improved thermodynamic models of (Cs-I-Te-Mo-U-Pu-O) system

Experimental study and thermo-dynamic modelling of MOX/steel interaction at high temperature



Advances in the simulation of MOX fuels under irradiation

Improved correlations and physics-based models for

- Thermal expansion, melting temperature, thermal conductivity of irradiated and Am-bearing MOX vs parameters of interest
- Inert gas behaviour in high burn-up structure and transient conditions

$$\begin{cases} \frac{dN}{dt} = \nu - b_N N \\ \frac{d\bar{n}}{dt} = g_{\bar{n}} c_1 - b_{\bar{n}} \bar{n} \end{cases}$$

- Creep, rupture of MOX fuel in normal and off-normal conditions

Improved and validated version of codes and simulation of ESNII cores

Implementation and validation of data obtained and models developed in FPC

Application on fast-neutron irradiation experiments and representative conditions of ESNII reactor cores:

- Normal ASTRID operation
- Transient in MYRRHA reactor

Dissemination and communication

- 40 peer-reviewed articles published
- 80 communications at conferences
- 13 PhD defended
- 25 public deliverables
- 4 meetings with the User Group
- Co-organisation of 3 workshops: Nufuel-MMSNF 2019, Nufuel 2021, Project final international workshop

- Website online since September 2017 http://www.eera-jpnm.eu/inspyre/ 40 000 views
- 4 newsletters distributed
- Series of posters for general audience on fuels and codes to improve safety
- Video on project’s objectives and results

Conclusions

- Challenging studies on challenging materials
- Common work between many researchers with different areas of expertise
- Significant progress made in the understanding and simulation of MOX fuels
- Further investigation needed on irradiated MOX and cladding, effect of minor actinides and non-linear mechanical properties

Credits

INSPYRE has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 754329.

This project is part of the research activities portfolio of the Joint Programme on Nuclear Materials.

The authors wish to thank Joe Somers for his invaluable help in INSPYRE preparation.

ORIENT-NM: ORGANISATION OF THE EUROPEAN RESEARCH COMMUNITY ON NUCLEAR MATERIALS

Mariano TARANTINO

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ORIENT-NM explores the possibility, and critically assesses the added value, of establishing a Co-Funded European Partnership (CEP) to support a coordinated European research and innovation programme on nuclear materials, thereby positively impacting Europe's competitiveness in the nuclear field at world scale. Accordingly, ORIENT-NM is: (1) Producing a single vision and a corresponding strategic research agenda (SRA) for nuclear materials until 2040 which should be consistent with national programmes and industrial needs, considering supply chain constraints, standardisation issues, and availability of infrastructures, availed by more than 50 European nuclear materials experts; (2) Elaborating an efficient CEP governance and implementation, observant of: decision-making processes; intellectual property issues; promotion of innovation; implementation schemes: quality assurance, SRA updating, knowledge & data management. (3) Developing protocols to interact with other relevant stakeholders: International organisations, Standardisation bodies & Technical safety organisations, research communities, infrastructure managers, industry. To achieve its objectives, ORIENT-NM established a dialogue with the research community, through associations and beneficiaries, with stakeholders at large through specific workshops, and, crucially, with the Member States and the European Commission.

ORIENT-NM

Organisation of the European Research Community on Nuclear Materials

Lorenzo MALERBA[1], Mariano TARANTINO[2], Marjorie BERTOLUS[3], Abderrahim ALMAZOUZI[4], Petri KINNUNEN[5], Wade KARLSEN[5], Angelika BOHNSTEDT[6], María Luisa FERNÁNDEZ VANONI[7]

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OBJECTIVES

ORIENT-NM **explores the possibility, and critically assesses the added value, of establishing a Co-Funded European Partnership (CEP)** to support a **coordinated European research and innovation programme on nuclear materials**, thereby positively impacting Europe's competitiveness in the nuclear field at world scale.

EXPECTED IMPACTS

ORIENT-NM aims at designing a complete plan for a successful CEP on nuclear materials.

Why a Co-Funded European Partnership (CEP) on nuclear materials?
Europe aims to be climate-neutral by 2050. The transition towards an economy with net-zero greenhouse gas emissions relies on a secure and sustainable energy supply. Nuclear energy has an important role to play in this regard, being the single largest source of low-carbon electricity in Europe.
Nuclear materials represent a key element for the safety, efficiency, economy, and sustainability of nuclear energy. **Hence the importance of establishing an ambitious and coordinated research and innovation EU-wide partnership that catalyses EU Member States' national resources towards consensually defined objectives.**

HIGHLIGHTS

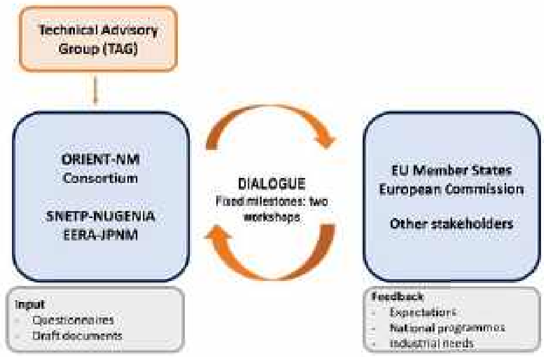
ORIENT-NM is:

Producing a single vision and a corresponding strategic research agenda for nuclear materials until 2040:
- Consistent with national programmes and industrial needs.
- Considering supply chain constraints, standardisation issues, and availability of infrastructures.
- Availed by more than 50 European nuclear materials experts.

Elaborating an efficient CEP governance and implementation, observant of:
- Decision-making processes;
- Intellectual property issues;
- Promotion of innovation;
- Implementation schemes: quality assurance, SRA updating, knowledge & data management.

Developing protocols to interact with other relevant stakeholders:
- International organisations
- Standardisation bodies & technical safety organisations
- Research communities
- Infrastructure managers
- Industry

To achieve its objectives, ORIENT-NM established a dialogue with the research community, through associations and beneficiaries, with stakeholders at large, and, crucially, with the Member States and the European Commission.



PARTNERS

CIEMAT / EERA / SNETP / SCK CEN / VTT / CEA / EDF / KIT / ENEA / NRG / NCBJ / RATEN / KTH / CVR /

DURATION & BUDGET

October 2020 – April 2023 – 30 months

CONTACTS

Project Coordinator: Lorenzo Malerba (CIEMAT)
Email: lorenzo.malerba@ciemat.es

EVENTS

Two main workshops with stake-holders at fixed moments of the project have been at the centre of ORIENT-NM: one was held in Nov. 2021, the second one at the FISA conference on 31st May 2022.

This project has received funding from the Euratom research and training programme 2019/2020 under grant agreement No 899997.

M4F: MULTISCALE MODELLING FOR FUSION AND FISSION MATERIALS

Lorenzo MALERBA

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The M4F project brings together the fusion and fission materials communities working on the prediction of radiation damage production and evolution and its effects on the mechanical behaviour of irradiated ferritic/martensitic (F/M) steels. It is a multidisciplinary project in which several different experimental and computational materials science tools are integrated to understand and model the complex phenomena associated with the formation and evolution of irradiation induced defects and their effects on the macroscopic behaviour of the target materials. In particular the project focuses on two specific aspects: (1) To develop physical understanding and predictive models of the origin and consequences of localised deformation under irradiation in F/M steels; (2) To develop good practices and possibly advance towards the definition of protocols for the use of ion irradiation as a tool to evaluate radiation effects on materials. Nineteen modelling codes across different scales are being used and developed and an experimental validation programme based on the examination of materials irradiated with neutrons and ions is being carried out. The project is now finished. This poster overviews the structure of the project, highlighting its impact for fission and fusion materials science.

M4F: Multiscale Modelling for Fusion and Fission Materials

Lorenzo Malerba

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The project impact concerns:
(1) cross fertilization between fission and fusion
(2) overcome bottlenecks that are limiting developments in fission and fusion.

In connection with cross-fertilization (1), two considerations need to be made:

(a) During the preparation and at the beginning of the project, significant effort was made to clearly distinguish between fission and fusion contribution, so as to guarantee the 50/50 benefit, with two persons in charge for each domain, in representation of the two communities. However, in the course of the project this distinction became completely blurred and was, accordingly, never reflected in the reports. Parallel approaches were followed in the different tasks and WPs, which were more or less successful, but these did not correspond to "fusion" of "fission" approaches, but rather to approaches towards given common goals, in which knowledge and inputs were openly shared, as much as possible. In this respect, therefore, the M4F project was successful in not only motivating cross-fertilization, but in fact in completely merging the two communities, at least in a materials modelling framework, making the contributions from one or the other totally undistinguishable.

(b) The M4F project was heavily affected by the pandemic, yet continuous effort was made to identify and disseminate cross-cutting research activities of equal interest for fission and fusion applications. Thanks to this effort, the spectrum of these commonalities has progressively widened overtime. The pioneering role of the project is proven by the fact that synergies between fission and fusion are currently being sought for also by the IAEA. The outcome of the M4F project in terms of identification of commonalities between the two materials communities will certainly impact the outcome of this IAEA effort.

Concerning the goal of overcoming the bottlenecks that are limiting developments in fission and fusion (2), these should be translated into advancing towards the goals that were set out at the beginning of the project, which are stated in the first section of this report, namely:

(c) To develop physical understanding and predictive models of the origin of localised deformation under irradiation in F/M steels and its consequences on the mechanical behaviour of components. This is meant to set the basis for the future elaboration of physically-motivated, non-over-conservative design rules for this class of steels, of use for both fission and fusion applications.

(d) To develop good practices for the use of ion irradiation as a tool to evaluate radiation effects on materials for modelling and screening purposes, minimising artefacts with respect to neutron irradiation experiments and allowing the evaluation of not only microstructural changes, but also mechanical property changes.

The impact of the project on these two items is discussed in detail in two dedicated presentations that were given at the final workshop by, respectively, Dr. J. Aktaa (KIT) and Dr. C. Kaden (HZDR), the latter together with Prof. M.J. Caturla (UA). They can be found at: http://www.h2020-m4f.eu/events/201-M4F_Final_Workshop.

The conclusions of the first presentation are that:

- "The modeling approach developed within M4F allows adequate simulation of flow localization in F/M steel structures under neutron irradiation taking into account finite strains and ductile damage"
- "The developed model is a powerful tool for the assessment and development of new criteria for immediate plastic flow localization"
- "The developed model can also be used to assess other failure modes caused by ductile damage and to be considered in case of irradiation/loss of ductility, e.g. immediate local fracture due to exhaustion of ductility and its dependence on triaxiality"

The second presentation highlighted that:

- Characteristic bands of defects linked to the dpa and implanted ion profile exist, one of which "safely" resembles the microstructure that is observed under neutron irradiation, provided that the Fe-ion beam energy is ≥ 5 MeV.
- 8 MeV give even better results than 5 MeV in reproducing SRC formation under neutron irradiation, in particular, no significant difference between ion and neutron-irradiated Fe-9Cr-NiSiP (L252, G389) was observed for the same conditions (300°C, 0.1 dpa).
- Three microstructure evolution models have been developed which, combined can provide a complete description of the radiation-induced microstructure under neutron and also ion irradiation, including all the specific features of the latter.
- While for defects such as dislocation loops further calibration work is needed to obtain fully satisfactory predictions, the size, density and composition of SRC is extremely well predicted.

In addition, the publication of the CEN NATEDA Workshop Agreement represents an important precedent for the standardization of nanoindentation testing, as a tool for the characterization of the mechanical behaviour of ion-irradiated specimens.

Thus the project produced results that have clear and undeniable technical impact, even though of course further work is needed for their full extension and exploitation.

URL project's public website:
http://www.h2020-m4f.eu

DOI of main publication:
https://doi.org/10.1016/j.nme.2021.101051

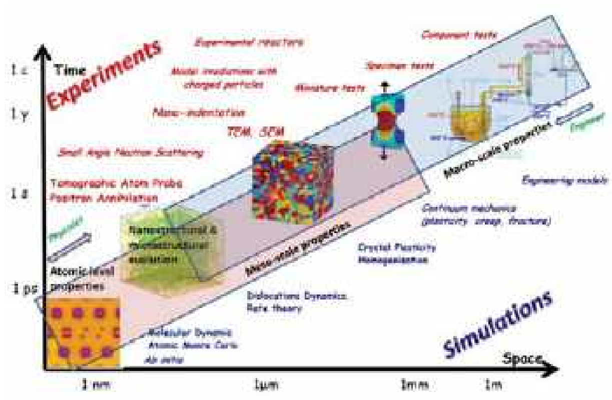
This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 755039

Participants

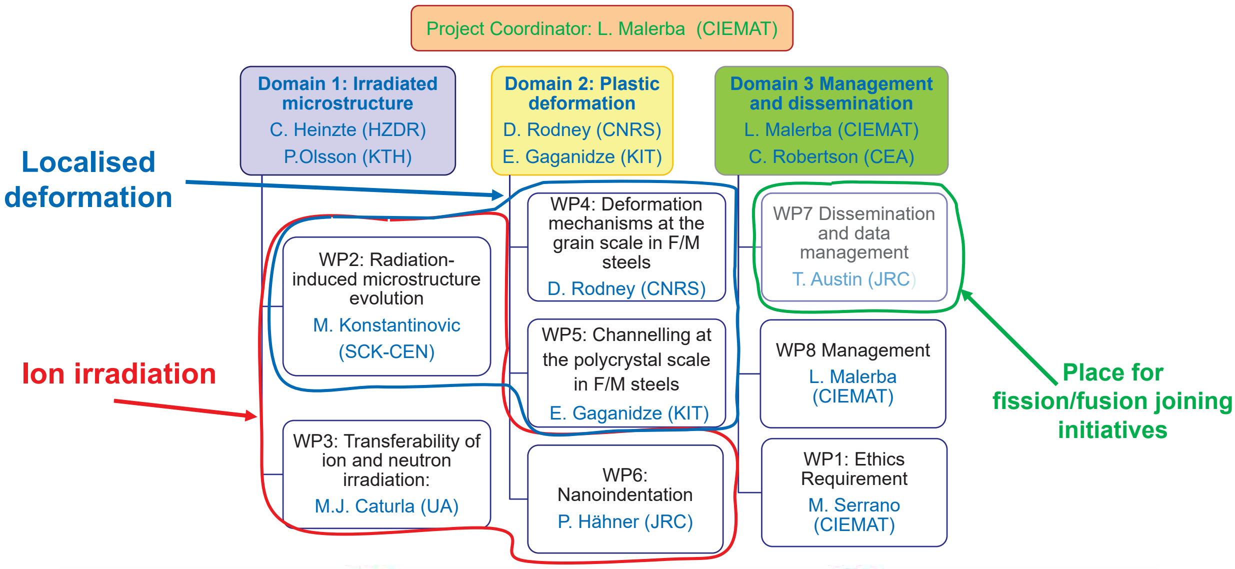
SINTEC S.r.l.

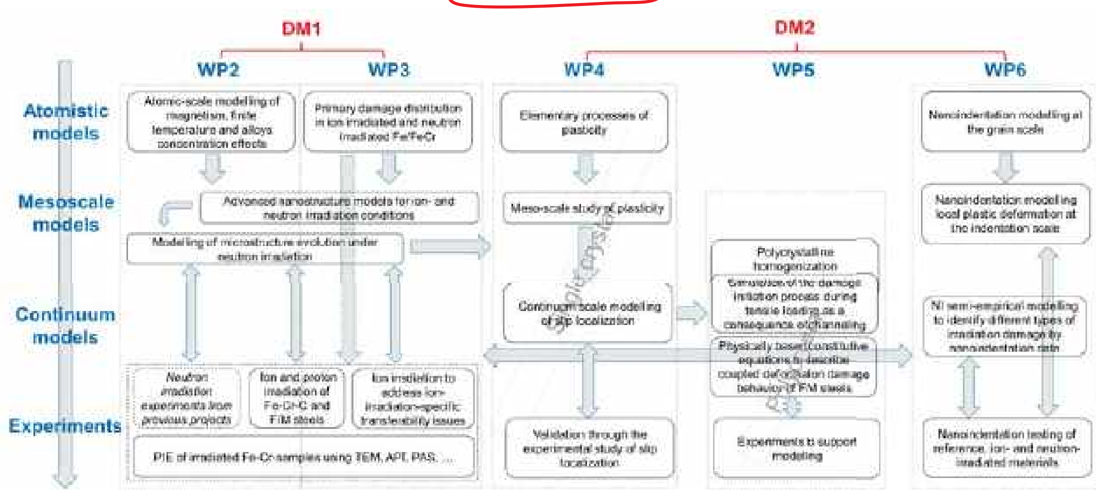
Guiding objectives

Approach: Multiscale Modelling



Structure of the project





AUGMENTED COOPERATION IN EDUCATION AND TRAINING IN NUCLEAR AND RADIOCHEMISTRY – THE A-CINCH PROJECT

Roberta CIRILLO

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A-CINCH CONTRIBUTORS

Expertise in nuclear and radiochemistry (NRC) is of strategic relevance in the nuclear energy sector and in many vital applications. The need for radiochemistry expertise will even increase as the focus shifts from safe nuclear power plant operation to decontamination and decommissioning, waste management and environmental monitoring. The non-energy fields of NRC applications are even much broader ranging from life sciences – radiopharmaceuticals, radiological diagnostics and therapy – through dating in geology and archaeology, (nuclear) forensics and safeguards operations, to radiation protection and radioecology. The A-CINCH project primarily addresses the loss of the young generation's interest for nuclear knowledge by focusing on secondary / high school students and teachers and involving them by the "Learn through Play" concept. This will be achieved by bringing advanced educational techniques such as state-of the art 3D virtual reality NRC laboratory, Massive Open Online Courses, RoboLab distance operated robotic experiments, Interactive Screen Experiments, NucWik database of teaching materials, or Flipped Classroom, into the NRC education. All the new and existing tools wrapped-up around the A-CINCH HUB – a user-friendly and easy-to-navigate single point of access – will contribute increasing the number of students and trainees in the field of nuclear and radiochemistry. Nuclear awareness will be further increased by the High School Teaching Package, Summer Schools for high school students, Teach the Teacher package and many others. A-CINCH project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945301.

AUGMENTED CINCH

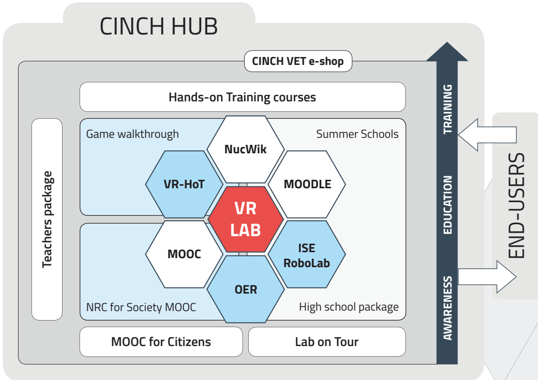
Augmented cooperation in education and training in nuclear and radiochemistry

Expertise in nuclear and radiochemistry (NRC) is of strategic relevance to the whole nuclear energy sector, from safe nuclear installation operations to decontamination and decommissioning, and waste management. The non-energy fields of NRC applications are even broader and range from life sciences – radiopharmaceuticals, radiological diagnostics and therapy – through to dating in geology and archaeology, (nuclear) forensics and safeguards, radiation protection and radioecology.

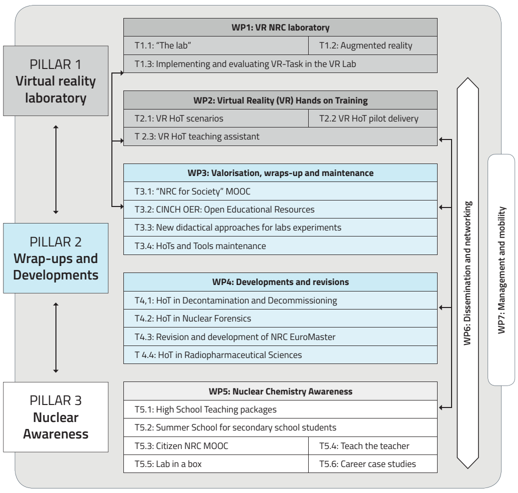
The **A-CINCH** project primarily addresses the young generation's loss of interest for nuclear knowledge by focusing on secondary education, using a "Learn through Play" concept to engage with students and teachers. The **A-CINCH** augments CINCH teaching tools developed in the three previous CINCH projects – CINCH, CINCH II and MEET-CINCH – with the state-of the art three-dimensional (3D) virtual reality (VR) environment to complete the existing toolbox for radiochemistry education. It is our belief that including a sophisticated VR radiochemistry lab and integrating it with traditional teaching, training, and advanced distance-learning methods will make the NRC field more attractive for younger generations and enhance the learning outcome of the very expensive, but indispensable, hands-on training.

CINCH teaching tools

- state-of the art **3D VR NRC laboratory** (VR-LAB)
- **Massive Open Online Courses** (MOOCs)
- **CINCH MOODLE** e-learning platform for Nuclear Chemistry
- **RoboLab** remote operated robotic experiments
- **Interactive Screen Experiments** (ISE)
- **NucWik database** of teaching materials
- **Flipped Classroom concept** providing improved interaction between teachers and students
- **Hands-on-training courses** (HoT) in "real" radiochemistry laboratories across Europe
- **CINCH VET e-shop** offering, presenting and organising all types of NRC courses
- High School Teaching Package, Summer Schools for high school students, Teach the Teacher package, Lab on Tour toolkit



Organisation of the work

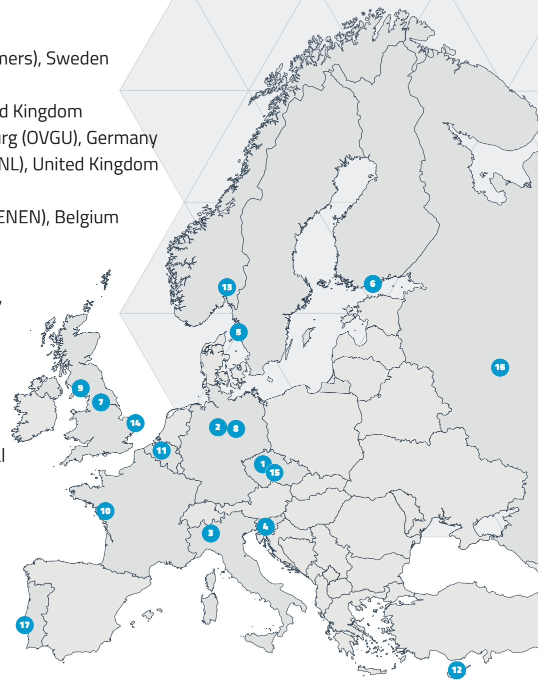


Project duration:

October 2020 – September 2023

List of partners

1 Coordinator: Czech Technical University in Prague (CTU), Czech Republic
2 Gottfried Wilhelm Leibniz University Hannover (LUH), Germany
3 Politecnico di Milano (Polimi), Italy
4 Institut Jozef Stefan (JSI), Slovenia
5 Chalmers Tekniska Hoegskola Ab (Chalmers), Sweden
6 Helsingin Yliopisto (UH), Finland
7 University of Leeds (UNIVLEEDS), United Kingdom
8 Otto-von-Guericke University Magdeburg (OVGU), Germany
9 National Nuclear Laboratory Limited (NNL), United Kingdom
10 Institut Mines-Telecom (IMT), France
11 European Nuclear Education Network (ENEN), Belgium
12 University of Cyprus (UCY), Cyprus
13 Universitetet i Oslo (UiO), Norway
14 The Secretary of State for Environment, Food and Rural Affairs (CEFAS), United Kingdom
15 Evalion s.r.o. (Evalion), Czech Republic
16 M. V. Lomonosov Moscow State University (MSU), Russian Federation
17 Instituto Superior Tecnico (IST), Portugal



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Project linked with European Network on Nuclear and Radiochemistry Education and Training, www.nrc-network.org

This project receives funding from the EURATOM Research and Training programme under grant agreement N° 945301 and from the Norwegian Research Council under grant agreement N° 313053.

www.cinch-project.eu

TOWARDS OPTIMIZED USE OF RESEARCH REACTORS IN EUROPE – THE TOURR PROJECT

Roberta CIRILLO

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Nuclear research reactors (RR) have been constructed in countries implementing nuclear power plants and used in experiments necessary to develop commercial reactors and training programmes. Neutron irradiations techniques have found new applications in the adaption and production of existing and new materials, as well as medical radioisotopes. The latter enabled development of new diagnosis and treatment techniques, for the benefit of millions of people. Europe has a broad and very diverse landscape of RRs, many of them since long time in operation, well maintained and regularly upgraded. Yet financial pressure, caused by combination of declining interest and the absence of a sound financial model, led to closure of many of them and afew others will close soon. This negative scenario calls for a coordinated European action to assess the impact of the decreasing number of RRs, identify future needs (including new neutron sources), draw a roadmap for upgrade of the existing RR fleet, and a model for harmonized resource management. TOURR project is a response to this challenge. Its primary objective is to develop a strategy for RR in Europe and prepare the ground for its implementation. This strategic goal can be divided into specific objectives: assessment of the current status of European RR fleet, including plans for upgrade; evaluation of urgent EU needs; developing tools for optimal use of RR fleet. rising awareness among decision makers on the (future) role of RRs. The ambition of TOURR project is to secure access and availability of RRs as a vital part of the European Research Area and to support stable supply of medical radioisotopes. The TOURR project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945 269.

TOURR | nuclear research reactors

Towards Optimized Use of Research Reactors in Europe

>> STRATEGY

The TOURR project is a response to the challenge of coordinating the optimization of the exploitation of available research reactors in Europe. Therefore, its primary objective is to develop an overall strategy for research reactors in Europe and prepare the ground for its implementation. This strategy is linked with the following processes:

1. **Assessment of the current status of the European research reactors fleet**
2. **Estimation of future needs**
3. **Plan for the upgrade of the research reactor fleet**
4. **Plan to maintain the fleet**
5. **Developing tools for optimal use of the research reactors fleet**
6. **Rising awareness of decision makers and the public on the role of research reactors**

All the above presented objectives, tackle multiple challenges and underline the urgent need of a European strategy for research reactors which represents the main objective of this proposal. We expect that the implementation of the TOURR project will help to contribute to strengthen Europe's competitive advantage over other countries.

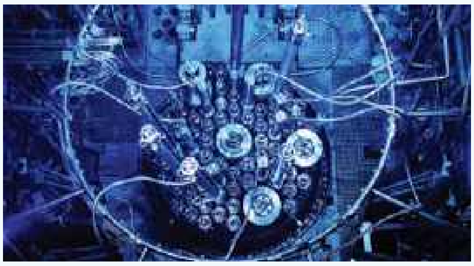
>> APPLICATIONS OF RESEARCH REACTORS

Nuclear research reactors can have an impact on several different domains:

EDUCATION & TRAINING – Research reactors primary use was related to education, training and technological experiments necessary to develop commercial power reactors.

STUDIES ON MATERIALS – Neutron beams extracted from the core soon became a powerful tool to study matter and so high performance research reactors devoted solely to beam experiments have been constructed. Irradiation capability of reactors found more and more applications in producing new materials and changing material properties.

HEALTH – Production of medical radioisotopes enabled development of new diagnosis and treatment techniques. Nowadays, millions of patients each month benefit from nuclear medicine.



BR2 research reactor at SCK CEN, Mol, Belgium
Source: SCK CEN. Used by permission

>> ORGANISATION OF THE WORK

The work plan is structured into five work packages (WPs)

>> **WP1** – Inventory of RR (Research Reactor) fleet – led by JOŽEF STEFAN INSTITUTE, is aimed at collecting and updating the information on the European research reactor fleet and on their plans in the period 2020-2030. Furthermore, it is supposed to perform RR gap analyses in the areas of science & technology, medical matters and education & training.

>> **WP2** – Assessment of needs and opportunities to support supply of medical radioisotopes – led by NARODOWE CENTRUM BADAN JADROWYCH, assesses the needs and opportunities for the contribution of RR to the medical domains including radioisotope production.

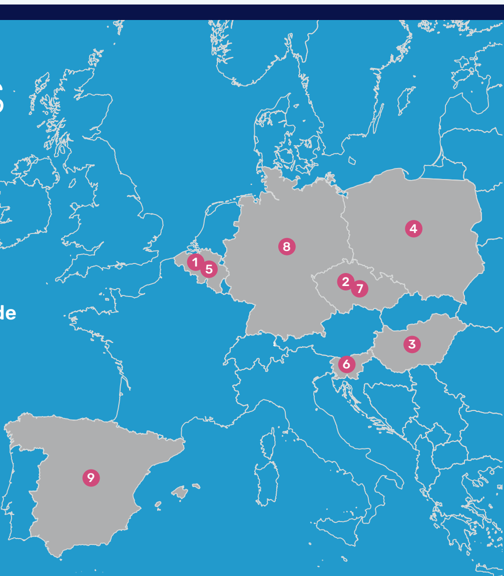
>> **WP3** – Tools for optimized use of European research reactors – led by EUROPEAN NUCLEAR EDUCATION NETWORK, will result in a Strategy for optimized use of European RR and a set of tools supporting the implementation of the strategy.

>> **WP4** – Dissemination and outreach – led by EVALION, will disseminate the project results to various audiences. It is also aimed at networking and raising awareness on the role of RR in research in today's society.

>> **WP5** – Project management – led by EUROPEAN NUCLEAR EDUCATION NETWORK, the consortium leader, deals with coordination and consortium management activities, monitoring the progress of the other WPs, financial management and preparation of reports and reviews.

>> PROJECT PARTNERS

1. **European Nuclear Education Network** (ENEN) Belgium
2. **Centrum Vyzkumu Rez sro** (CVR) Czechia
3. **Energiatudomanyi Kutatokozpont** (EK) Hungary
4. **Narodowe Centrum Badan Jadrowych** (NCBJ) Poland
5. **Studiecentrum Voor Kernenergie / Centre D'etude De L'energie Nucleaire** (SCK CEN) Belgium
6. **Jožef Stefan Institute** (JSI) Slovenia
7. **Evalion sro** (EVALION) Czechia
8. **Universitaet Stuttgart** (USTUTT) Germany
9. **Centro De Investigaciones Energeticas, Medioambientales Y Tecnologicas-Ciemat** (CIEMAT) Spain



>> CONTACT

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PROJECT WEBPAGE
www.tourr.eu

This project has received funding from the Euratom research and training programme 2019–2020 under grant agreement No 945 269.

REACTOR SAFETY ANALYSIS TOOLBOX RESA-TX

Alexjandra CUESTA

ALEJANDRA CUESTA, SIMONE PALAZZO, STEFAN WENZEL, ALEXANDER KERNER
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The Reactor Safety Analysis Toolbox RESA-TX is a software and data package managed by AI powered big data algorithms that combines the automatisation of all established procedures for Deterministic Safety Analysis (DSA), the integration of expert know-how and a large database including most relevant information required for conducting a DSA. In the current state of the art, DSA is a complex and thus error prone process that is highly time consuming and repetitive. The reliability of the result is strongly dependent on the availability of plant data and expert know-how. The idea of RESA-TX arose at GRS out of the necessity to cope with these conditions. The innovative approach proposes an automated and standardised procedure, supported with a large database of plant design characteristics, plant behaviour, regulatory rules and DSA expert knowledge incorporated within the tool. Its application allows the end user to automatically generate and verify an input deck, as well as conduct design basis accident (DBA) calculations for a certain design with highly reduced manual intervention. The databases can be extended depending on available information or other boundary conditions. Enabled by AI powered algorithms, a heuristic approach is integrated in the model generation and verification process, where users often suffer from a lack of information about the facility under consideration. These heuristics can be replaced when higher information quality is available or enhanced over time, which can lead to more reliable results with increasing usage of the tool. As a result, the application of RESA-TX highly increases the efficiency of the DSA process, reducing both repetitiveness as well as user induced errors. This in return will lead to an improvement in quality of the analysis and reliability of the results. In consequence, RESA-TX will allow for a DSA to be conducted more frequently in situations where time or budget were a limitation before, hereby contributing to an increase in reactor safety.

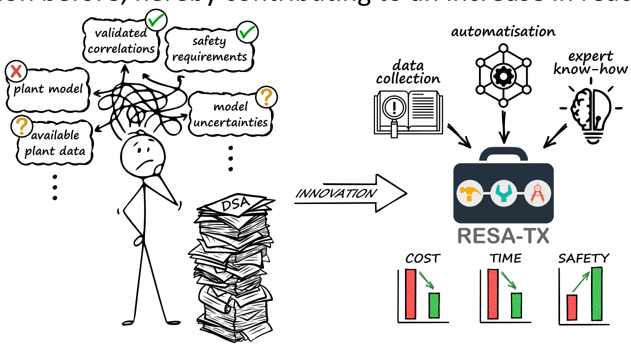


Figure 1State of the art DSA vs. innovative approach of RESA-TX

Reactor Safety Analysis Toolbox

RESA-TX

Alejandra Cuesta, Simone Palazzo, Stefan Wenzel, Alexander Kerner
Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Department of Safety Analysis
Alejandra.Cuesta@grs.de, Simone.Palazzo@grs.de, Stefan.Wenzel@grs.de, Alexander.Kerner@grs.de

Background: Deterministic Safety Analysis (DSA)

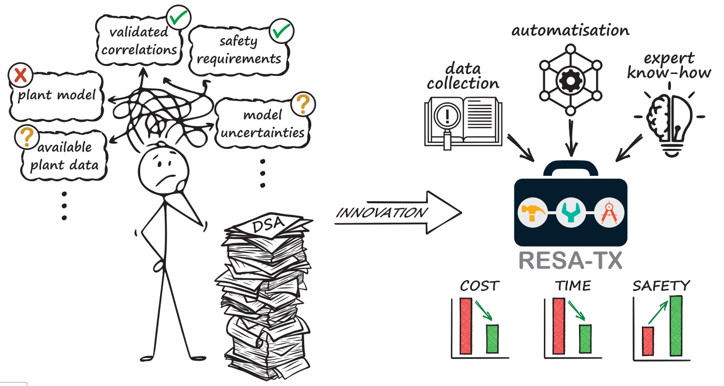
- DSA is mandatory to demonstrate the safety and adequacy of a reactor design within the defence in depth concept.
- The main objective of DSA is to confirm that safety functions can be fulfilled and that the necessary structures, systems and components, in combination with operator actions, are effective in keeping the releases of radioactive material from the plant below acceptable limits.
- Thermal-hydraulic system codes like ATHLET, RELAP, TRACE or CATHARE are used to execute DSA.
- The three main steps to be undertaken for analysing the plant behaviour by applying these system codes are:

1) Model development 2) Model verification 3) Conduction of the analysis

BUT:

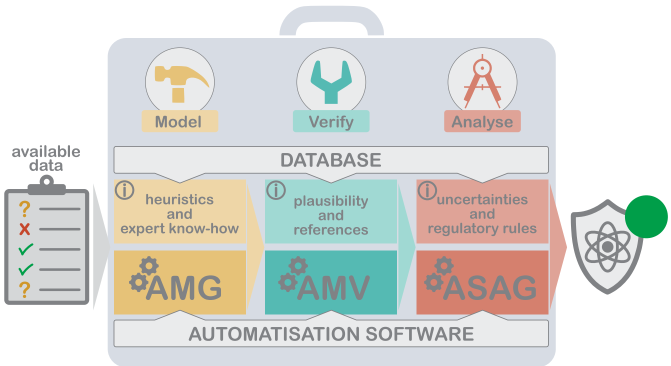
Issues associated with DSA:

- Requires extensive plant data (i.e. geometry of the main components, material properties, valve and pump characteristics, control logic data) that is not always available.
- The quality of the analysis is strongly dependent on the quality of the model.
- Model developers must be experienced in TH modelling and the TH code.
- Processing the large amount of data and translating it into a plant model is a time-consuming task. The process is repetitive and error prone.
- The finalised model requires verification, ideally against plant data if available. Otherwise plausibility checks based on expert judgement.



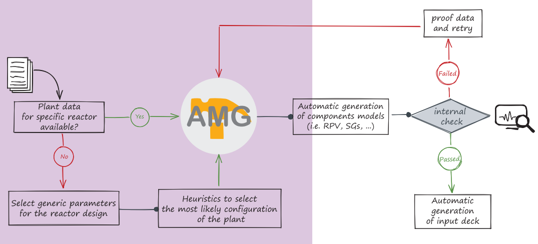
The RESA-TX proposal

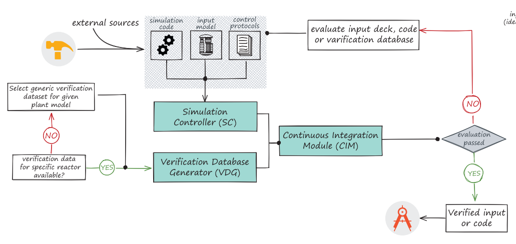
- Main objective: allow the end user to automatically generate and verify an input deck, as well as conduct design basis accident (DBA) calculations for a certain design with highly reduced manual intervention.
- How: using an automated and standardised procedure, supported with a large database of plant design characteristics, plant behaviour and DSA expert knowledge. This database is incorporated within the tool using algorithms based on heuristics methods.
- Main benefits: the automation increases both the efficiency of the analysis and the quality of the results by reducing the complexity, the repetitiveness as well as user induced errors. This is supported by the large integrated database enhancing data availability and expert know-how. In consequence, RESA-TX will allow for a DSA to be conducted more frequently and reliably in situations where time or budget were a constraint before, hereby **contributing to an increase in reactor safety.**

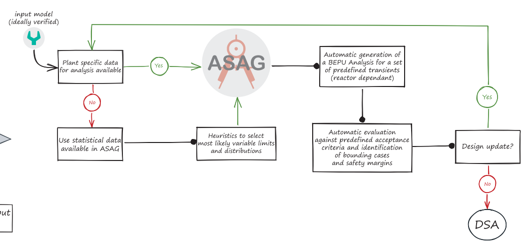


Description of the tool

The REactor Safety Analysis ToolboX (RESA-TX) is a collection of three different tools corresponding to the three main steps of DSA.







1) Module AMG

(Automatic Model Generator)

by the automatic generation of a thermal-hydraulic model of the desired facility in form of an input deck. This is supported by a heuristic network in case of lack of specific plant data.

2) Module AMV

(Automatic Model Verifier)

by the automatic verification process of the input deck to confirm the adequacy of the model based on a qualitative system behaviour evaluation and/or the NPP documentation.

3) Module ASAG

(Automatic Safety Analysis Generator)

by the automatic generation of a safety analysis case (calculation of a basic set of design basis scenarios, e.g. a loss of coolant accident) and subsequent assessment.

Main applications

- reactor design assessment with a quick by technically grounded safety analysis, be it either in detail for confirmatory analysis purposes, or coarser to support an assessment that needs to be made with time constraints, for example by nuclear regulators.
- from the generation of a safety case for licensees up to the continuous (re)running of certain transients for after plant design enhancements with minimal effort and throughout the lifetime of the plant.
- code validation and verification process: given its automated and modular nature, the tool would translate in significant time saving for code developers.

EUROPEAN DATABASE FOR MULTISCALE MODELLING OF RADIATION DAMAGE (ENTENTE)

Marta SERRANO-GARCIA

MARTA SERRANO[1], JULIEN SANAHUJA[2], CHRISTIAN ROBERTSON[3], MATTI LINDROSS[4]
[1] *CIEMAT, Avda de la Complutense 40, 28040 Madrid, SPAIN,*
[2] *EDF R&D, 6 quai Watier, 78401 Chatou Cedex, France*
[3] *Université Paris-Saclay, CEA, 91191, Gif-surYvette, France,*
[4] *VTT Lifecycle Solutions, Tampere 33720, Finland*

This poster summarize the objectives and first results for the ENTENTE "European Database for Multiscale Modelling of Radiation Damage” project Euratom 2019-2020 Grant Agreement number 9000018. ENTENTE aims to design a new European experimental/modelling materials database to collect and store highly-relevant data on radiation damage of Reactor Pressure Vessel (RPV) steels, according to FAIR (Findability, Accessibility, Interoperability, and Reusability) principles. The project can be seen as three interconnected blocks:

DATABASE Design

- Multi-disciplinary teams (materials scientists, engineers, software developers) will define new effective data formats suitable for microstructural and modelling data, and interfaces needed to ensure interoperability.

- Interface the SOTERIA platform with the ENTENTE database so that experimental data and metadata can be retrieved and post processed in order to correctly parametrize modelling tools.

ADVANCED experiments/models

- Microstructural characterisation, linked with appropriate models, by means of advanced (S)TEM techniques, APT, μ-XRD and in-situ TEM for mapping the radiation induced defects and associated strain-stress fields.

- In-depth analysis of segregation and structural, chemical nature and strength of grain boundaries to study hardening and non-hardening embrittlement.

INNOVATIVE data analysis and hybrid models

- Simulation tools that enable the description of radiation damage up to length and time scales that are comparable with those reached in experiments on RPV steels. Accelerated physically informed fracture laws with a reasonable predicting capability on heterogeneous microstructures.

- First application of Integrated Computational Materials Engineering (ICME) approaches to enable virtual studies of alternative neutron embrittlement scenarios
- -Machine learning and artificial neural networks approaches not only to support atomistic modelling but also to predict hardening and/or embrittlement

The exploitation of the ENTENTE data base, including the interface with SOTERIA Platform, will allow the integrity assessment of Reactor Pressure Vessel to be improved both in a Long Term Operation (LTO) perspective and for new Gen III+ reactors.

FISA 2022

European Database for Multiscale Modelling of Radiation Damage (ENTENTE)

ENTENTE
Euratom 2019-2020 Grant agreement No 900018

Marta Serrano[1], Julien Sanahuja[2], Christian Robertson[3], Matti Lindross[4]

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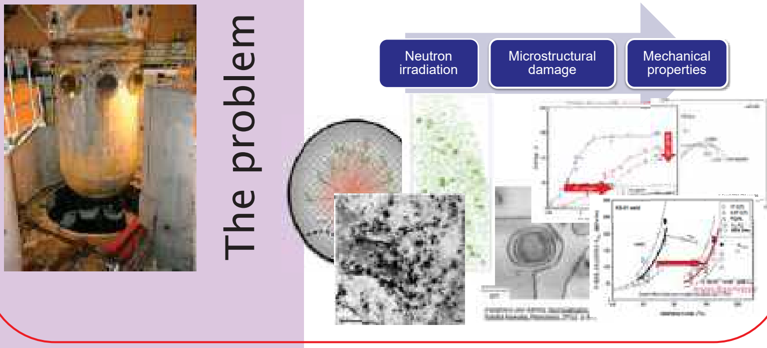
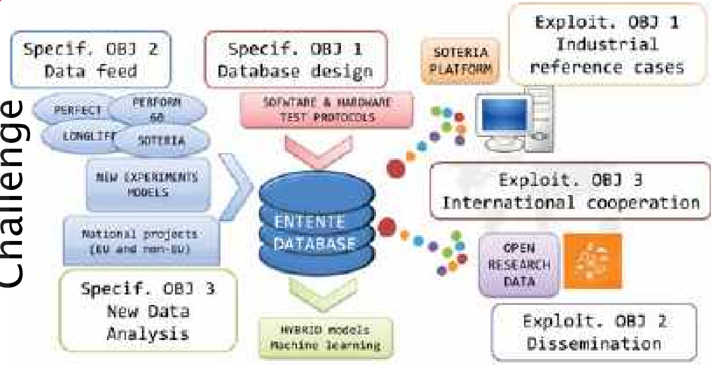
ENTENTE "*European Database for Multiscale Modelling of Radiation Damage*" aims to design a new European experimental/modelling materials database to collect and store highly-relevant data on radiation damage of Reactor Pressure Vessel (RPV) steels, according to FAIR (Findability, Accessibility, Interoperability, and Reusability) principles.

The problem

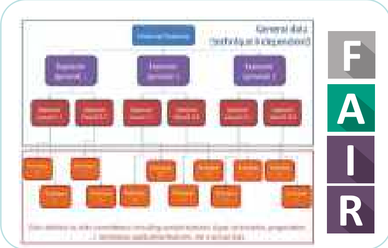
Assessment of the neutron embrittlement of RPV steels

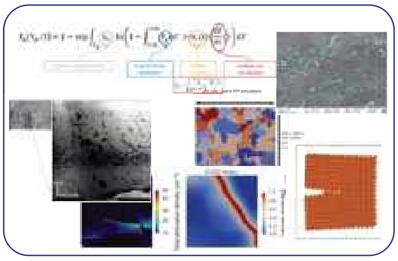


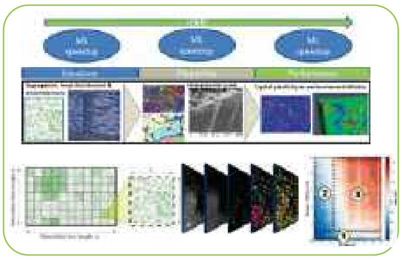
Challenge



Consortium







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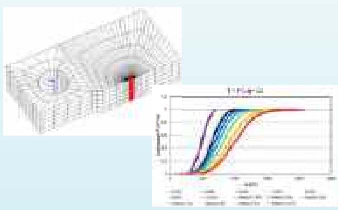
-Machine learning and artificial neural networks approaches not only to support atomistic modelling but also to predict hardening and/or embrittlement

Collaborations

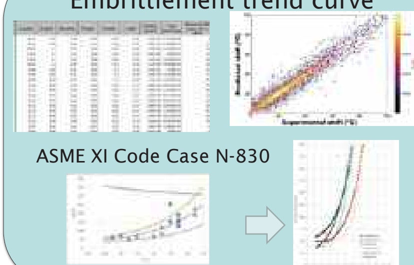
Exploitation Levels

Parametric studies [SOTERIA Platform]

Toughness prediction : local approach to failure



Embrittlement trend curve



* *Figures from ENTENTE contributors*

SAFEG – SAFETY OF GFR THROUGH INNOVATIVE MATERIALS, TECHNOLOGIES AND PROCESSES

Branislav HATALA

The safety of the GFR demonstrator ALLEGRO is to be enhanced with the help of innovative technologies, innovative materials, and unique know-how that has been built both inside and outside Europe over the last 20 years. The most important areas of ALLEGRO safety improvements tackled by SafeG project are:

- To solve remaining open questions in residual heat removal in accident conditions, leading to practical elimination of severe accidents, through innovative design of the reactor core, diversified ways of passive reactor shutdown, passive decay heat removal systems, and instrumentation.
- To strengthen the inherent safety of the key reactor components by review of obsolete material and technologies reference options, selection of innovative options, and designs based on these innovative options.
- Review the GFR reference options in materials and technologies, using experience gained in national research programs, know-how of the consortium and stakeholders, and experience from operation of various research facilities and high-temperature nuclear reactors. The aim is to increase inherent safety of GFRs.
- Adapting GFR safety to changing needs in electricity consumption worldwide with increased and decentralized portion of nuclear electricity by study of various fuel cycles and their suitability from the safety and proliferation resistance points of view.
- Boosting interest in GFR research by wide involvement of universities, promotion of GFR-oriented topics of master theses and dissertations, organizing topical workshops including hands-on training and on-job training connected with staff exchange.
- Deepen collaboration with international non-EU research teams and relevant European and international bodies (GIF, standardization bodies) and partners with experience/interest in GFR.

SAFETY OF GFR THROUGH INNOVATIVE MATERIALS, TECHNOLOGIES AND PROCESSES

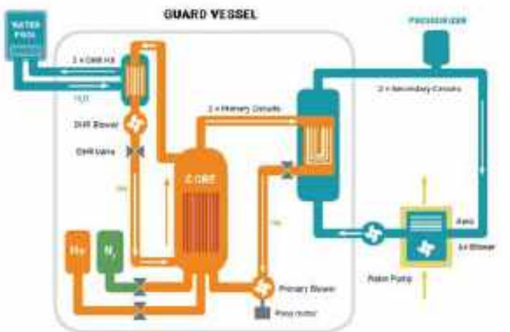
SafeG

Branislav Hatala – Project coordinator

SafeG Project overview

The global objective of the SafeG project is to further develop the gas-cooled
fast reactor (GFR) technology and strengthen its safety. The project shall
support the development of nuclear low-CO_2 electricity and industrial process
heat generation technology through the following main objectives:

- **To strengthen safety of the GFR demonstrator ALLEGRO**
- **To review the GFR reference options in materials and technologies**
- **To adapt GFR safety to changing needs in electricity production worldwide with increased and decentralized portion of nuclear electricity by study of various fuel cycles and their suitability from the safety and proliferation resistance points of view**
- **To bring in students and young professionals, boosting interest in GFR research**
- **To deepen the collaboration with international non-EU research teams, and relevant European and international bodies**



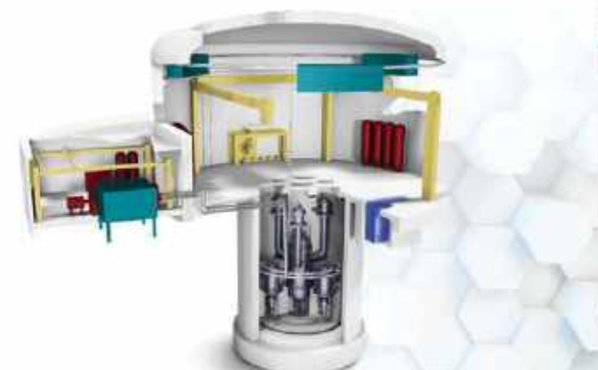
↗ Diagram of ALLEGRO reactor

Ambition of the SafeG project

1) **Completing the ALLEGRO demonstrator safety concept:**
   - core optimization from the neutronic, thermo-hydraulic and thermo-mechanic point of view
   - design of diverse reactor control and reactor shutdown system strategy of passive decay heat removal completed with the design of fully passive systems for the decay heat removal tested on experimental helium loop
2) **Upgrading the ALLEGRO demonstrator design and GFR concept** by innovative materials and technologies such as fuel cladding based on SiC composition, and construction materials capable to withstand extreme temperatures used for the primary system and safety related systems.
3) **Linking the national research activities and creating an integrated platform** aiming to share the knowledge, achieved results, and to coordinate activities, to spread new ideas and findings over the scientific society worldwide.
4) **Deepening the cooperation between Europe and Japan in the GFR research** through sharing the knowledge about advanced high temperature resistant materials for the fuel rod claddings and other primary system´s components.

ALLEGRO – demonstrator of the Generation IV gas cooled fast reactor

The objectives of ALLEGRO are to demonstrate the viability and to qualify specific GFR technologies such as fuel, fuel elements, helium-related technologies and specific safety systems, in particular, the decay heat removal function, together with demonstration that these features can be integrated successfully into a representative system. The ALLEGRO reactor would function not only as a demonstration reactor hosting GFR technological experiments, but also as a test pad of using the high temperature coolant of the reactor in a heat exchanger for generating process heat for industrial applications and a research facility which, thanks to the fast neutron spectrum, makes it attractive for fuel and material development and testing of some special devices or other research works.



↗ Cross-section of ALLEGRO reactor model

Project partners

VUJE, a. s. (Slovakia) – **Coordinator**
ÚJV Řež, a. s. (Czech Republic)
Energiatudományi Kutatóközpont (Hungary)
Narodowe Centrum Badań Jądrowych (Poland)
Centrum výzkumu Řež s.r.o. (Czech Republic)
Commissariat à l'énergie atomique et aux énergies alternatives (France)
Jacobs Clean Energy Ltd. (United Kingdom)
BriVaTech Consulting (Germany)
National University Corporation, Kyoto University (Japan)
České vysoké učení technické v Praze (Czech Republic)
Budapesti Muszaki es Gazdasagtudomanyi Egyetem (Hungary)
Slovenská technická univerzita v Bratislave (Slovakia)
University of Cambridge (United Kingdom)
Nuclear AMRC, University of Sheffield (United Kingdom)
Evalion s.r.o. (Czech Republic)

Duration

October 2020 – September 2024

Budget

4,495,010.00 €

Web

www.safeg.eu

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FROM THE PLANT LAYOUTS TO AN OPTIMIZED 3D PWR-KWU CONTAINMENT MODEL WITH GOTHIC 8.3 (QA)

Luis SERRA-LOPEZ

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Containment geometry characteristics play a key role in many accident and severe-accident phenomena, such as flammable gas distribution, accumulation and deflagration dynamics. The containment buildings of nuclear power plants have complex geometries and extracting the data required to build detailed computational models from plant layouts is a demanding task. Using Computational Aided Design (CAD) software as a cornerstone of the modelling process serves as a bridge between the containment layouts and the thermal-hydraulic models. This work will describe all the steps of the methodology used to build a 3D PWR-KWU containment model in GOTHIC from its detailed CAD model. Firstly, an intermediate model with several geometric simplifications will be developed in the CAD environment. These simplifications are intended to avoid problematic configurations when adapting the actual geometry to the porous cartesian mesh of GOTHIC, avoiding numerical instabilities and resulting in shorter simulation times. The simplified geometry is imported into GOTHIC, and it is tested by simulating a Large Loss of Coolant Accident (LB-LOCA) in one of the cold legs. This is the most convenient scenario to check the specific numerical instabilities within the porous cartesian space discretization of GOTHIC, which mainly arise from the massive release of mass and energy during the blowdown. Although the initial containment model did perform adequately in the initial phases of the LOCA, a detailed assessment of the numerical stability revealed several points for improvement in further stages of the simulation. Namely, the accumulation of liquid in sump-type regions with low-porosity problematic cells, hampered the simulation at specific periods of time. Then, the final modifications of the geometry achieved a reduction of the computational costs up to one order of magnitude. Part of this work is included within the AMHYCO project (Euratom 2019-2020, GA No 945057) which main objective is to improve experimental knowledge and simulation capabilities for the H_2/CO combustion risk management in nuclear power plant containments during severe accidents (SAs).

From the plant layouts to an optimized 3D PWR-KWU containment model with GOTHIC 8.3 (QA)

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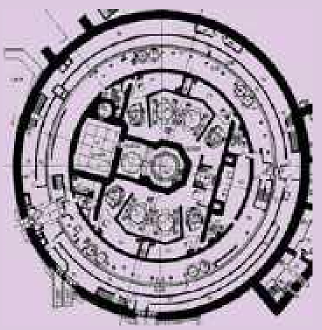
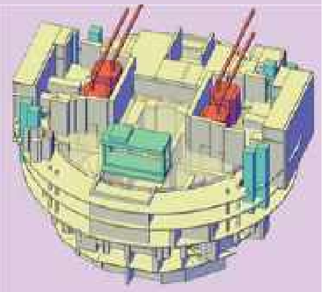
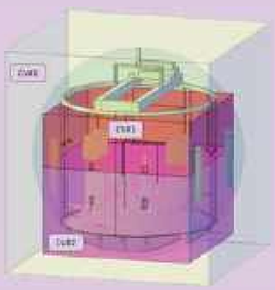
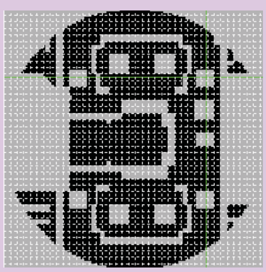


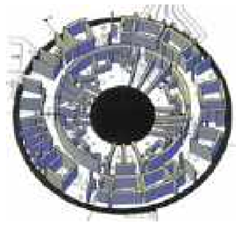


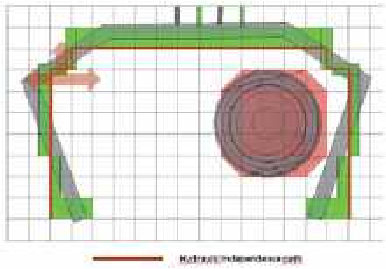




1. Detailed CAD 3D model

Using Computational Aided Design (CAD) software as a cornerstone of the modelling process serves as a bridge between the containment layouts and the thermal-hydraulic models. Detailed 3D CAD models permit a thorough evaluation of free volumes, heat transfer surfaces, flow paths position and **nodalization strategies**, in a data-traceable environment. This containment model is built with extreme attention to detail, regarding both main and secondary structures and components, aiming for an **enhanced representation of containment phenomena** throughout the numerous compartments.



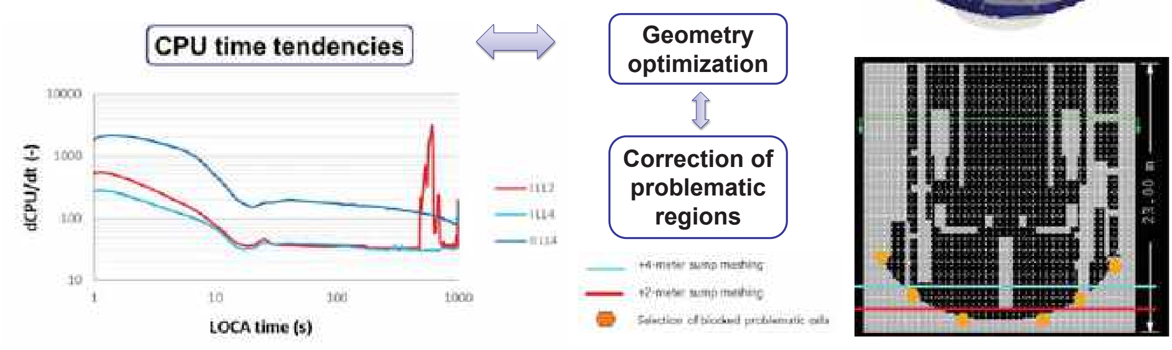


2. Simplified CAD model

To *a priori* avoid some problematic geometrical configurations when exporting the model to GOTHIC, an intermediate model is built. The adaptation is done with simple blocks, fitted in homogeneous orthogonal meshes, and assuring the **hydraulic independence** between rooms. Also, surfaces and free volumes are kept with a maximum error of 3%. These simplifications follow in the footsteps of previous methodological efforts to **avoid numerical instabilities** and enhance the robustness of the models.

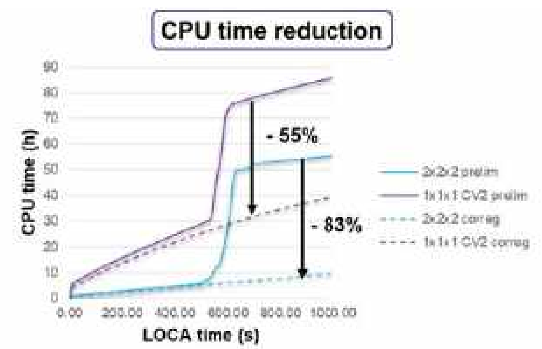
3. Air-tightness test and definition of model strategies

Several tests are performed in crucial compartments to check if the model implementation in GOTHIC is successful. These are done by simulating hydrogen releases and tracking the gas behavior to **detect geometrical incongruities**. Moreover, the geometry is verified for different mesh sizes (1 m^3 to 8 m^3 orthogonal cells), to assure its **robustness** in scenarios where coarser or finer refinements in each control volume may be needed. Then, three models are created, ranging from 12000 to 85000 computational cells.



4. Assessment of model stability and optimization of computational cost

To search for possible numerical instabilities, a fast cold-leg LB-LOCA release is simulated. The idea is to **detect and correct local problematic configurations**, to boost model performance. By studying the CPU time tendencies, a period of high computational effort was seen at the middle of the transient, due to the accumulation of water in the sump region. Also, during the first seconds of the blowdown stage, some configurations that were not avoided in the simplification process were detected. Then, the coarsening of the sump area (LL2 & LL4) and the blocking of some cells resulted in the **reduction of CPU effort in one order of magnitude**. Moreover, it was seen that the direction of the injection of mass and energy releases can increase simulation times, as was the case for the models with the highest steam flow velocities.



Conclusions

- The creation of adapted models from detailed ones produces robust 3D models subdued to lower simulation efforts, thus allowing to perform more sensitivities with them.
- Model construction and pre-processing can be balanced by the implementation of preventive methodologies and the analysis of local computational instabilities.
- The thorough analysis of synergies between geometry and limiting phenomena can furtherly reduce computational times in at least one order of magnitude.

This project has received funding from the Euratom research and training programme 2019-2020 under Grant Agreement nº945057

MULTICOMPONENT NUCLEAR FUEL CLADDING WITH SAFETY AND OPERATIONAL BENEFITS

Martin SEVECEK

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Accident Tolerant or Advanced Technology Fuels (ATF) are one of the hottest research topics in the nuclear engineering research and development area since the Fukushima-Daiichi events with the first concepts inserted into commercial nuclear power plants in 2019. The most advanced ATF cladding concept is Cr-coated Zr-based alloy which was chosen as the near-term ATF solution by fuel vendors operating on the EU nuclear fuel market - Framatome, Westinghouse Electric Company, and TVEL. The research group at CTU in Prague identified several new degradation phenomena linked to this concept such as material interdiffusion, Cr enhanced embrittlement, and Zr-Cr eutectic formation. The optimization of advanced coating techniques and fuel cladding design led the team to develop and qualify innovative multicomponent Cr/CrN coated Zr alloy cladding that limits the degradation effects such as Cr enhanced embrittlement and delays the eutectic reaction to much higher temperature making the cladding more resistant and accident tolerant in comparison with both traditional Zr-based alloys as well as pure Cr coated Zr alloys. This innovative solution was qualified out-of-pile and is now under in-pile investigation in the LVR-15 research reactor. In the next phase, this innovative nuclear fuel cladding will be inserted into a commercial reactor as a non-fueled material, the fabrication process will be qualified for industrial production, and the complete solution will be offered to fuel vendors as an advanced near-term nuclear fuel cladding for the current generation of light water reactors.

INVESTIGATION OF HYDROGEN BEHAVIOUR IN THE TEST FACILITY THAI BY SIMULATION OF SEVERE ACCIDENT CONDITIONS IN THE CONTAINMENT

Veronika KRUSTEVA

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This work presents an analysis of the results received in a simulation of hydrogen deflagration and combustion and flame propagation during experiment HD- 22 in the test facility THAI. The analysis has been performed by the integral computer code ASTEC. For this purpose, modules for processing hydrogen behaviour in the containment have been developed. This work considers the behaviour of the hydrogen during a hypothetical severe accident. Various risk studies have shown that hydrogen combustion is one of the major risk contributors to early containment failure in the case of a severe accident in a nuclear power plant. Therefore, it is very important to properly simulate the processes in the containment. In the past two decades, the different aspects of this issue, namely hydrogen sources, distribution in the containment, combustion behaviour and loads, have been investigated in many research programs, including single effect tests and integral experiments, model and code development and nuclear plant analysis. Hydrogen mitigating and controlling systems like recombiners, igniters have been proposed and developed and their practical implementation is underway. To assess the related risk for hydrogen specificaccident scenarios, and to design and optimize mitigating systems, quantitative hydrogen analysis has to be carried out. Necessary input for such an analysis is the knowledge of the hydrogen release conditions, especially source rates, total mass and time sequence. The hydrogen burns as a diffusion flame and, by rising hot combustion products, increases the mixing of the atmosphere by entangling fresh oxygen and hydrogen rich gas into the flame. Depending on the hydrogen and steam content and the temperature, volumetric combustion can also take place. If these processes occur on the same time scale as the debris dispersal process, they contribute to the peak pressure in the containment. The pressure increase due to hydrogen combustion may be higher than that by other processes. Due to the flammability limits for hydrogen-air- steam mixtures not all available hydrogen will burn. Between 30% and 90% of the available hydrogen has been observed to burn in experiments. The hydrogen burning follows the Shapiro’s diagram i.e. depends also on the oxygen and steam concentration; burning is not possible in steam inerted atmosphere when most of the oxygen has completely reacted. For this reason, oxygen and steam concentrations have been investigated in the present work and compared with the results from test HD-22 performed in THAI facility.

Investigation of hydrogen behaviour in the test facility THAI by simulation of severe accident conditions in the containment

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Abstract

This paper presents a discussion of the results received in a simulation of hydrogen deflagration and flame propagation during experiment HD-22 in the test facility THAI. The analysis has been performed by the integral computer code ASTEC.

One of the factors that can occur at each stage of a severe accident and threatens the final barrier against non-proliferation of radioactivity is the generation, spread and burning of hydrogen. Therefore, it is very important to properly simulate the processes in the containment. For this purpose, modules for processing hydrogen behaviour in the containment have been developed. These modules are introduced into the integral code ASTEC.

Keywords: THAI, ASTEC, Hydrogen deflagration and combustion

Introduction

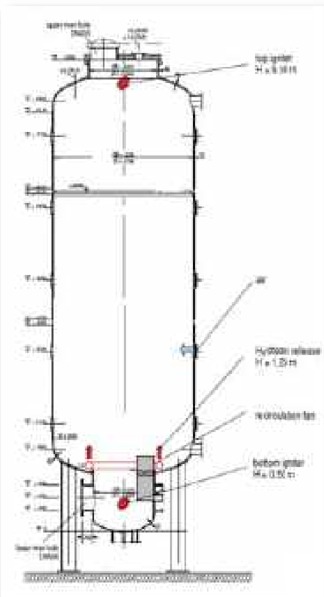
This work considers the behaviour of the hydrogen during a hypothetical severe accident. Various risk studies have shown that hydrogen combustion is one of the major risk contributors to early containment failure in the case of a severe accident in a nuclear power plant.

Objectives of the THAI program research

- ❖ Created and sponsored by the German Federal Ministry of Economics and Technology
- ❖ Related to the thermo-hydration, the behaviour of the hydrogen and the fission products in the containment, as well as the behaviour of iodine with its radiological significance
- ❖ Provides a very important experimental data

Description of the test vessel and the instrumentation of the THAI facility

The THAI is equipped with innovative measuring, sampling and data acquisition systems.



- ❖ The 60 m3 test vessel is made of 22 mm stainless steel
- ❖ Its height being 9.2 m
- ❖ Its diameter 3.2 m
- ❖ It can be operated up to 180 °C and 14 bar

Initial and boundary conditions

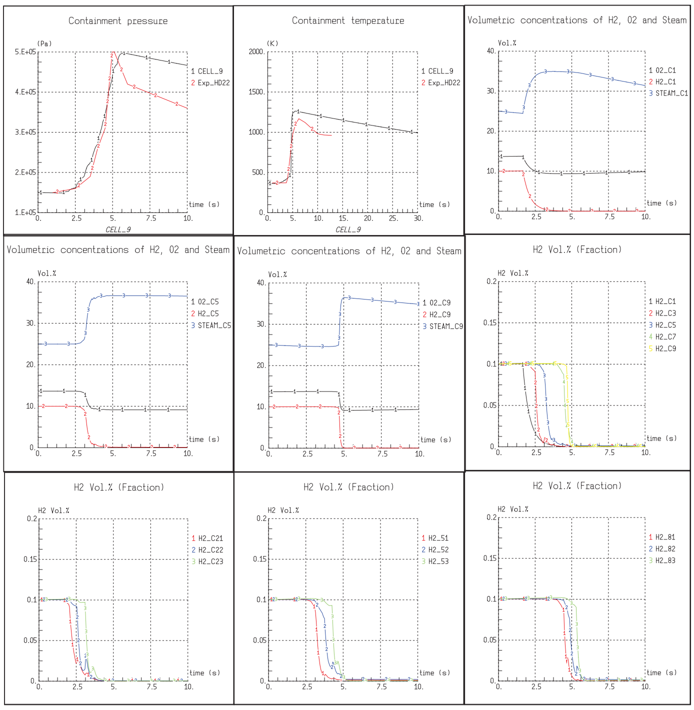
- ✓ Vessel atmosphere contents air, steam and hydrogen
- ✓ Initial pressure - 1.5bar
- ✓ Initial temperature- 90°C
- ✓ Steam concentration- 25vol.%
- ✓ Hydrogen concentration- 10vol.%

Discussion of the model and results

- ❖ The THAI vessel is divided into 23 zones by splitting into 9 axial levels and 3 radial rings, which allows special hydrogen distribution, as well as flame propagation in axial and radial direction.

Elevation for the flame front propagation	Time for 23 zones model [s]	Time for experiment HD- 22 [s]
Propagation from elev. 1 to elev. 2	1.65	1.65
Propagation from elev. 2 to elev. 3	2.04	2.4
Propagation from elev. 3 to elev. 4	2.5	2.7
Propagation from elev. 4 to elev. 5	2.83	3.01
Propagation from elev. 5 to elev. 6	3.18	3.4
Propagation from elev. 6 to elev. 7	3.6	3.7
Propagation from elev. 7 to elev. 8	4.01	4
Propagation from elev. 8 to elev.9	4.45	4.5

- ❖ The table shows that the values for the input model with 23 zones are very close to the experimental values. Therefore, more detailed nodalization allows to obtain more detailed assessment of the parameters and better simulation of the processes.



Summary of results

As shown above in this work, the upward flame propagation was similar to the one observed in the THAI HD-22 experiment. As far as the behaviour of hydrogen in the radial distribution, the burning is from the inside to outside. Hydrogen starts to decrease first in the innermost ring on the second level at 1.61 s, i.e. immediately after the ignition. In the 2.5 s, hydrogen starts to decrease in the next radially distributed area. At last, Hydrogen begins to decrease in the outermost ring in 3.2 seconds. Full burning occurs again in the 5th second when a pressure peak is reached. In the vertical direction the burning of hydrogen starts at cell 1 at 1.61 s and burns completely at cell 9 in the 5-th second when it reaches the maximum pressure. It is exactly the expected behaviour of H_2.

Conclusions

A good match between calculated and experimental data was obtained. Based on the present calculations it could be stated that the hydrogen combustion in upward flame propagation experiment THAI HD-22 is simulated properly with the selected notarization and models in ASTEC. The results support the applicability of the ASTEC code for simulations of hydrogen combustion in actual nuclear power plants.

DIPSICOF, DIAGRID INTEGRATED PASSIVE SYSTEM LIMITING CORE FLOWBYPASS IN ACCIDENTAL CONDITION FOR ADVANCE FBR REACTOR

Florian VAIANA

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Within the Generation IV reactors design exploration framework, Framatome investigates many options to optimize the reactor designs and their costs.
On the today existing sodium fast breeder reactors, including the pool or loop concepts, 3 or 4 primary pumps components are installed within the main vessel. These pumps feed the core by flowing the coolant in a first step through the LIPOSO, and then inside the Diagrid, before feeding the fuel assemblies bundle that constitute the reactor core. In the case of one primary pump malfunction or a severe leakage onto the LIPOSO pipe, the core is partially fed and cooldown by the remaining pumps. But a certain amount of the coolant is rerouted through the failed pump or the damaged LIPOSO breach. To respect the safety criteria in such an accident, at least 3 pumps were installed with 2 LIPOSO per pump, allowing to justify one pump loss in extended Design Basis Accident.
Among the reactor design investigated by Framatome, optimizations related to the safety behavior are a priority. This is performed considering the global cost investment limitation. For that, Framatome Engineering Technical Direction has recently decided to assess a fast breeder Advanced Reactor using only two primary pumps within the primary circuit.
The goal is to avoid worsening the safety behavior specially in the case of the loss of one pump. In accidental conditions, as loss of one of the two pumps, this could be acceptable when accounting a dedicated device that would limit the core flow bypass. To do so, Framatome design team has explored an innovation aiming at enhancing the reactor passive safety in such a case.
The Framatome innovation idea introduced in the present poster consists in implementing a passive dedicated device within the core support structure. It aims at limiting the core coolant reverse flow through the failed pump. This is possible by reorganizing cleverly the dynamic flow distribution within the Diagrid volume. It will enable the minimum core cooling during any hypothetical accident, as for instance one primary pump loss.
Framatome innovation idea is named DIPSICOF for Diagrid Integrated Passive System LImiting Core Flow bypass in accidental condition for advanced FBR reactor.

The "DIPSICOF" innovation proposed by Framatome is increasing reactors safety, it is simple, fully passive, and implementable onto many reactor types options. It enables significant economy. It will contribute to ease the public acceptance and realistic nuclear reactors deployment.
The innovation principle is exposed, preliminary results are showed, the prospects and envisioned next steps to reinforce the justification are emphasized.

DIPSICOF for Diagrid Integrated Passive System LImiting COre Flow bypass in accidental condition for advance FBR reactor

Woaye Hune Antony[1], Vaiana Florian[1], Robin Amauri[1], Dauphin Alexandre[1], Bernard Olivier[1]
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CONTEXT

NEEDS

Need of safety improvement on GEN IV advanced reactors using liquid metallic coolant as sodium, lead or lead-bismuth.
Operational safety is a necessary aspect in a nuclear power plant and the passive safety devices play a leading role :

- No safety action to be made, the pump failure is manageable and therefore "acceptable";
- Cost reduction (smaller vessel, less primary components, less inspections and maintenance…).

APPROACH DESCRIPTION

PRINCIPLE

The innovation aims at:

- Installing a passive device inside the structure supporting the core;
- Improving the safety by limiting the core flow by-pass in the case of a loss of coolant due to a primary pump seizure;
- Improving the economy by limiting the number of primary pumps (2 pumps option could be envisioned).

INTEREST

BENEFITS

This innovation contains several manufacturing benefits:

- Full manufacturing allowed in factory if the vessel size is below the transportation size limit;
- Ease of the reactors cover slab arrangement.

And some economical benefits too:

- A minimum amount of additional material to be implemented (to reduce total cost);
- Only full passive and static device implementation.

FBR GENERAL ARCHITECTURE

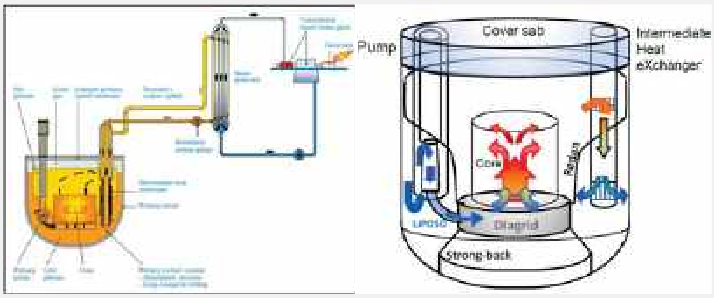

Figure 1 : Typical general arrangement of sodium Fast Breeder Reactor

CALCULATIONS PERFORMED

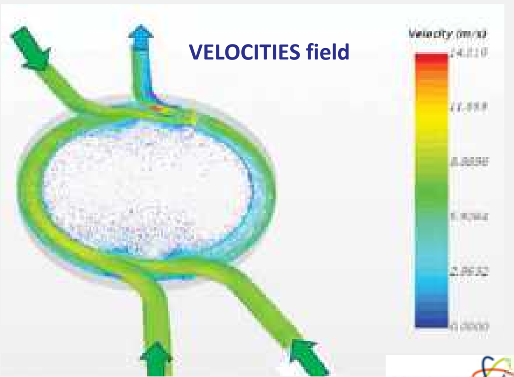

Figure 2: Velocities field inside the calculated domain during accidental conditions

The Computational Fluid Dynamic (CFD) approach has been performed to assess the complex 3D hydraulic behavior (accounting for turbulence, sharp velocity direction changes, in unsteady flow condition). This 3D CFD model complete the first simplified assessment based on analytical Bernoulli equations or Venturi effect approach.
The Reynolds-Averaged-Navier-Stokes numerical model includes:

- The Diagrid center part represented by a simplify equivalent porous domain;
- The Diagrid extra surrounding annular volume;
- 4 LIPOSO pipes connected to the Diagrid with a bended portion entering within the diagrid annular volume.

CFD transient calculation is launched to simulate a conservative instantaneous severe LIPOSO breach.

INNOVATION DESCRIPTION

PHYSICAL PRINCIPLE

The innovative idea consists in:

- An extra annular intermediate chamber set-up at the periphery of the diagrid, free of any structure, and coolant circulates inside tangentially. This chamber is radially bounded by a cylindrical shell on the external side and a porous shell on the internal side. This porous shell enables the coolant flow-in into the Diagrid central part before entering the core.
- Each LIPOSO pipe is extended with a pipe elbow in order to feed the annular volume tangentially (*and not radially as usually organized in past FBR concept*). This is a *first-of-a-kind*, *distinguishable* and *original* arrangement.

The coolant flow is fed inside the annular intermediate chamber and is accelerated tangentially along the circular path. Therefore, it creates an equilibrium between:

- The incident kinetic energy delivered by coolant mass flowrate at LIPOSO exit nozzle (exit nozzle shape or cross section are optimizable in order to increase the velocity and the kinetic energy stored within annular chamber at Diagrid periphery);
- And the pressure drop due to flow friction within the annular chamber.

In case of a hypothetical pump or LIPOSO seizure, the bypass is limited, and the core mass flow is partially maintained and mastered thanks to coolant circulation organization within LIPOSO/Diagrid and thanks to the Bernoulli equations or Venturi effect principle.

THE DIPSICOF

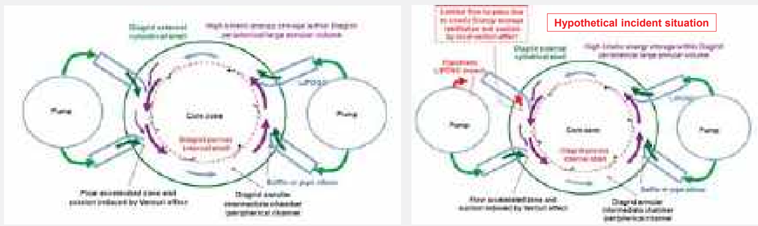

Figure 3: Diagrid peripherical annular volume and bended LIPOSO extensions included within the peripherical volume.

PROSPECTS

Further investigations related to:

- Core behavior and amount of margin available during hypothetical incident;
- Safety analyses, including reliability assessment and passivity arguments;
- Design and manufacturing (mechanical scaling, thermomechanical behavior), but also test demonstration using representative mock-up.

The "DIPSICOF" innovation is increasing reactors safety, it is simple, fully passive and implementable onto many reactor types options. It enables significant economy. It will contribute to ease the public acceptance and realistic nuclear reactors deployment.

This innovation has been filed as a patent application (publication number FR3080704).

POST-TEST THERMAL-HYDRAULIC ANALYSIS OF PKL III I3.1 EXPERIMENT ON LOSS OF RHRS DURING MID-LOOP OPERATION WITH ATHLET

Edgaras SMIGELSKIS

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Every Pressurized Water Reactor (PWR) is periodically brought to Low-Power and Shutdown (LPS) operations, to perform maintenance and refueling. As long as the reactor core is loaded with nuclear fuel, uninterrupted reactor core cooling has to be maintained. During LPS operation modes, the Residual Heat Removal System (RHRS) is used. However, there is 10^{-2} probability of RHRS failure [1], which might lead to the reactor core damage or more severe events. The PKL III i3.1 experiment was conducted in the international framework of the OECD/PKL4 project targeting safety related issues of current and new design PWR plants. In the scope of this project three major areas were emphasized: i) complex heat transfer mechanisms under two-phase flow; ii) boron dilution and precipitation; iii) cooldown procedures [2]. Particularly, this experiment considers the loss of RHRS during low-power and shutdown conditions accident, where a reactor is brought to a reduced coolant inventory state, so called mid-loop operation. The test facility is configured to 3-loop operation mode, the reactor coolant system is assumed to be closed, and a single Steam Generator (SG) is available at the beginning of the transient. In the evolution of the transient, coolant inventory is displaced towards the available SG as a consequence of vapor condensation inside the U-tubes. As the accident progresses the Natural Circulation mode inside the system changes from pure reflux condensation to oscillatory, then to carry-over, and finally to natural circulation mode. Since there is a gap on publicly available studies on such accident sequences performed with best-estimate System Thermal-Hydraulic (SYS-TH) code ATHLET, a dedicated model of the test facility is being built and executed with ATHLET. Such studies serve as code validation and establishment of numerical benchmark to different code cross-comparison. The aim of the present poster is to introduce the sequence of loss of RHRS accident and ongoing post-test analysis of PKL III i3.1 RUN 1 using best-estimate SYS-TH code ATHLET.

[1] S. Schollenberger et al., PKL IIIi3.1: Failure of RHRS during 3/4-Loop Operation and Closed Primary Circuit (3-Loop Operation), Erlangen, 2019

[2] “Nuclear Energy Agency (NEA) - Primary Coolant Loop Test Facility (PKL) Project.” [Online]. Available: https://www.oecd-nea.org/jcms/pl_25236/primary-coolant-loop-test-facility-pkl-project.

Post-test thermal-hydraulic analysis of PKL III i3.1 experiment on Loss of RHRS during mid-loop operation with ATHLET

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MOTIVATION

Background

- PWRs: 440 online / 50 UC / ~100 planned / ~300 proposed
- Refueling every ~2 years
- Low-power shutdown operation (LPSD)
- Probability of Loss of RHRS at mid-loop operation – 10^{-2}
- Higher or similar risk to full power operations

Models done with

- RELAP, MARS, TRACE… but scarce of ATHLET validation

Remaining challenges

- Overspilling
- Fill-and-down phenomena
- Water entrainment
- Mass inventory distribution

EXPERIMENT: Large-Scale Test Facility

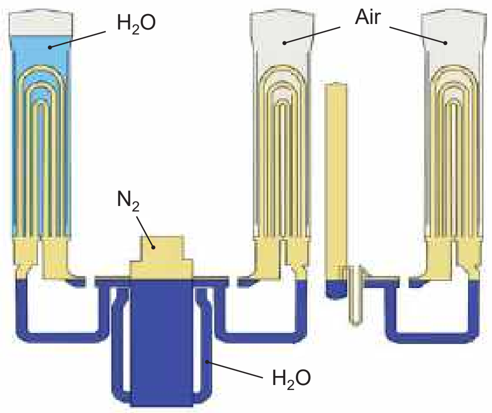


Figure 1. 3-loop PWR configuration at mid-loop

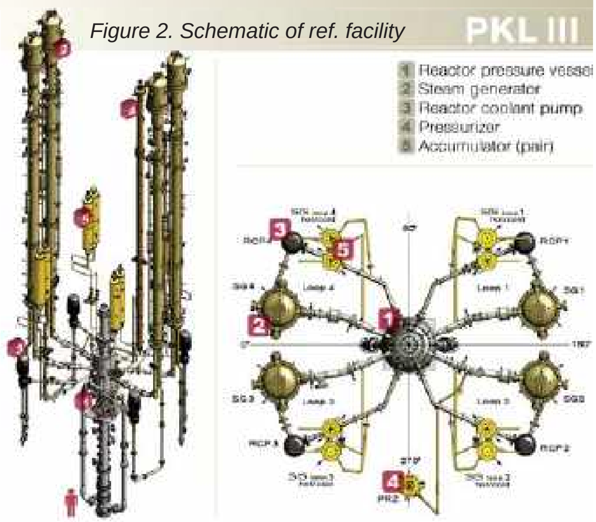
Description

- Vorkonvoi (4-loop, 1300MWe)
- Phillippsburg 2 (ref. NPP)
- Primary side: 45bar
- Secondary side: 60bar

Scaling factor:

- Height 1:1
- Volumes 1:145
- Pressure losses 1:1
- Hydraulic diameter 1:12

Figure 2. Schematic of ref. facility



COMPLEXITY: Accident Evolution

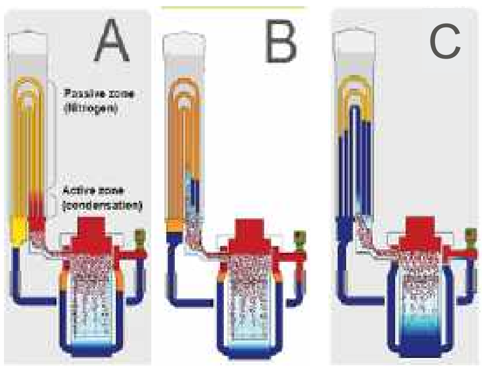


Figure 3. Loss of RHRS accident evolution

Reflux condensation regimes:

A. Film-wise condensation
B. Total reflux condensation (Fill and dump)
C. Complete carry-over (Natural circulation)

ATHLET MODEL & NODALIZATION

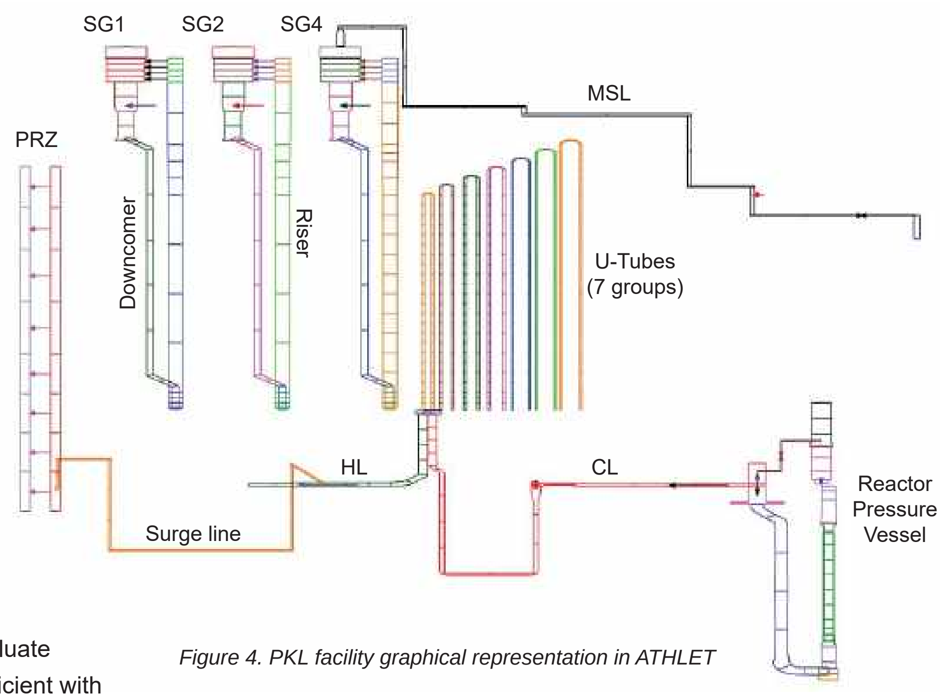


Figure 4. PKL facility graphical representation in ATHLET

FUTURE WORK

- Model validation against experimental data
- Model extension with quasi-3D modelling to evaluate
- Assessment of condensation heat transfer coefficient with presence of non-condensable gas

S. Schollenberger et al., PKL IIIi3.1: Failure of RHRS during 3/4-Loop Operation and Closed Primary Circuit (3-Loop Operation), Erlangen, 2019

J.F. Villanueva et al., RELAP5 Simulation of PKL Facility Experiments under Midloop Conditions, Sci. Technol. Nucl. Install. 2017.

ATOMISTIC SIMULATION TO INVESTIGATE MOX PROPERTIES AND THE IMPACT OF THE IRRADIATION

Giulia PORTO

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Due to the possibility of recycling spent fuel, non-proliferation concerns, and economic considerations, Mixed oxide (MOX) fuel meets the safety requirements of GEN-IV reactors. Thermodynamical properties of MOX fuels are poorly known and several authors in the literature consider the recommendations of MOX to be the same as those for UO_2. Nonetheless, the available recommendations do not rely on updated data and do not reproduce some material behaviours correctly, such as the Bredig transition occurring in superionic materials [1].

The reliability and robustness of Fuel Performance Codes, which simulate the behaviour of the fuel under irradiation in the reactor, depend significantly on the knowledge of the physical and chemical properties of nuclear fuels. This is the reason why a complete investigation of the MOX fuel properties as a function of irradiation and Pu content is strictly required, in particular in hypostoichiometric conditions which represent the initial conditions of the MOX fuel in Fast neutron reactors.

Due to the high radio-toxicity of the Plutonium, the experimental data regarding the MOX fuel are lacking and affected by significant uncertainties, and computer simulations may represent an excellent tool to obtain data, especially in extreme conditions. In particular, as D. Bathellier proved [2], atomistic simulation is a valid means to reproduce the thermodynamic properties of the MOX fuel at high temperatures and in stoichiometric conditions.

To simulate the irradiation in the MOX fuel, fission products, stoichiometry and defects can be involved in classical Molecular Dynamics simulation, providing information concerning irradiated MOX properties.

Employing the Cooper-Rushton-Grimes empirical potential [3], Molecular Dynamics simulations have been carried out for the first time for hypostoichiometric $U_{1-y}Pu_yO_{2-x}$ compounds (with y in the range 0 ÷ 1 and x in the range 0 ÷ 0.08) at high temperatures and the obtained simulation data were used to compute the heat capacity and the linear thermal expansion coefficient. The analytical law of the heat capacity for stoichiometric mixed-oxide fuels $U_{1-y}Pu_yO_2$ developed by D. Bathellier [4] has been modified introducing the deviation from stoichiometry as a variable, and a good agreement is found.

The obtained results show two regions for both thermodynamic quantities: at low temperatures, the trend is independent of the plutonium content, as in the stoichiometric case, whilst at temperatures around 0.8 T_m, where the Bredig transition occurs, a peak appears and its intensity varies with the deviation from stoichiometry.

[1] A.S. Dworkin and M.A. Bredig, J. Phys. Chem. 72 (4) (Avr. 1968) 1277e1281.
[2] D. Bathellier, Calcul des propriétés thermodynamiques et des défauts ponctuels dans les combustibles oxydes mixtes : approche couplée méthodes de structure électronique et potentiels interatomiques empiriques, PhD Thesis, 2021.
[3] M. W. D. Cooper, Atomic Scale Simulation of Irradiated Nuclear Fuel, PhD Thesis, 2015.
[4] D. Bathellier et al, Journal of Nuclear Materials 549 (2021) 152877.

ATOMISTIC SIMULATION TO INVESTIGATE MOX PROPERTIES AND THE IMPACT OF THE IRRADIATION

FISA 2022

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MOLECULAR DYNAMICS simulation

- **Lammps** code
- **CRG** interatomic empirical potential [3]
- Supercel with 2592 atoms (6x6x6 x12)
- 1.92 < O/M ratio < 2.0
- 0% < Pu content < 100%

Stoichiometric conditions

- No Pu effect up to the peak, in opposite to the reference recommendations
- The peak is associated to the Superionic transition
- The transition temperature (temperature related to the highest point) decreases with the increase of the Pu content

Hypostoichiometric conditions: Pu effect

- No Pu effect up to the peak, in opposite to the reference recommendations
- The peak is associated to the Superionic transition
- The transition temperature (temperature related to the highest point) decreases with the increase of Pu content

Hypostoichiometric conditions: stoichiometry effect

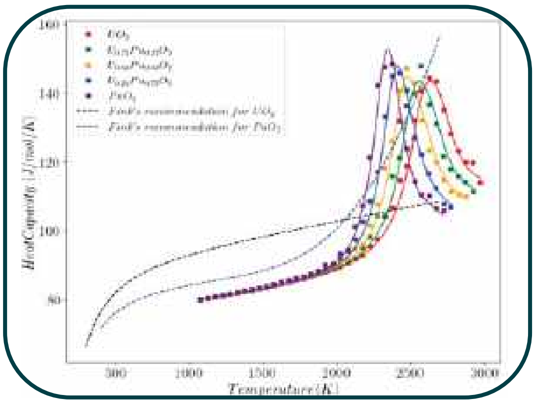
- Strong reduction of the peak intensity with the deviation from stoichiometry
- No stoichiometry effect up to the peak and on the transition starting temperature for the heat capacity
- Stoichiometry effect already before the transition for the thermal expansion coefficient: volume dependence on the number of vacancies

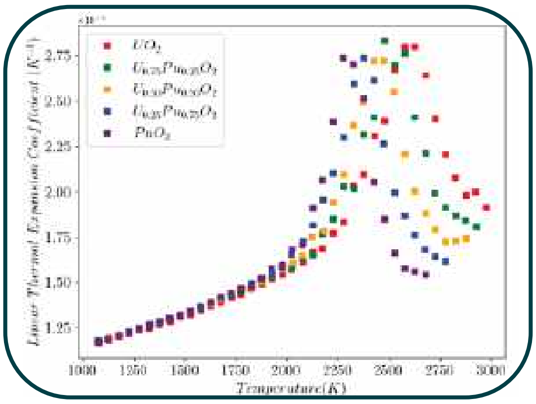
Context

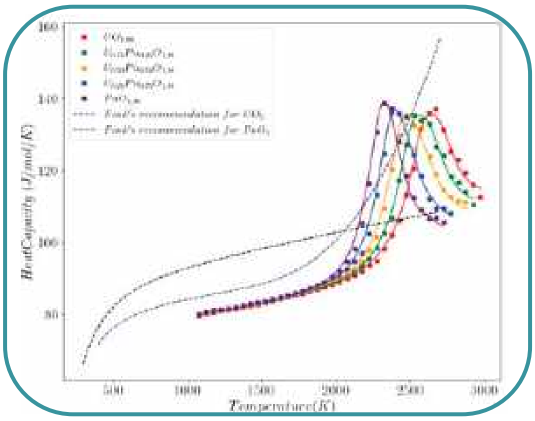
- Mixed oxide (**MOX**) **fuel** meets the safety requirements of **GEN-IV reactors** and have been used in **LWR**
- The available recommendations do not rely on updated data and do not reproduce some material behaviours correctly[1], such as the **Bredig transition** occurring in superionic materials[2]
- MOX properties as a function of irradiation and Pu content to refine **Fuel Performance Code**
- **Atomic-scale simulation** to obtain information regarding irradiated MOX properties in extreme conditions

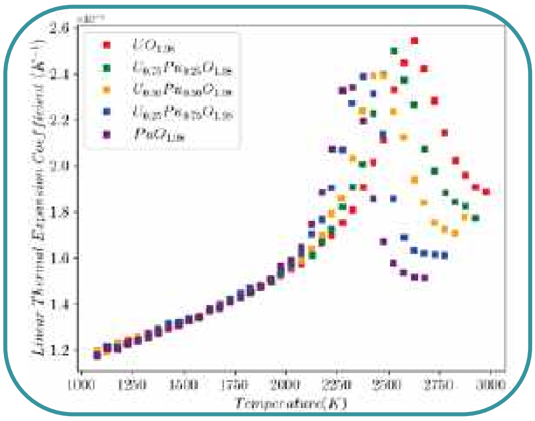
Goals

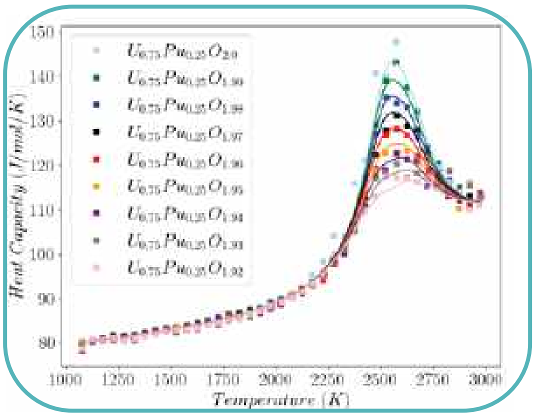
- Investigate **MOX thermodynamic properties**, such as thermal expansion, melting temperature and thermal conductivity, considering the **irradiation-induced defects**(point and extended defects)
- Compare the obtained results with the experimental data
- **Propose thermal laws** to be implemented in Fuel Performance Code
- Contribute to **PuMMA project** to reduce the significant sources of uncertainty in the safety evaluation

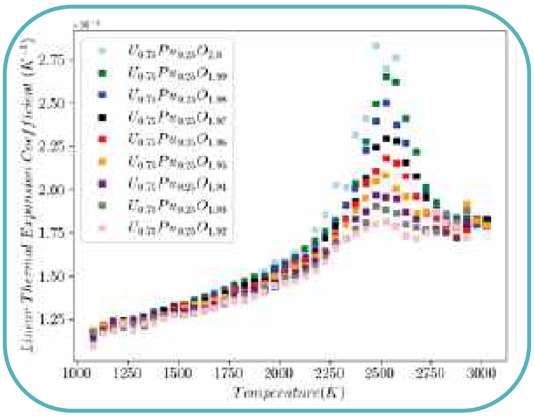












Conclusions and Perspectives

- Molecular dynamics simulation involving oxygen vacancies to reproduce a wide range of hypostoichiometric MOX compounds provided information on heat capacity and thermal expansion coefficient
- Compute other thermodynamic quantities, namely the elastic constants, melting temperature and thermal conductivity, and considering more complex defects (Schottky defects, Frenkel pairs, dislocations, grain boundaries…)

Reference

[1] J.K. Fink, M.G. Chasanov, et al., Thermophysical properties of uranium dioxide, J. Nucl. Mater., 1981

[2] A.S. Dworkin and M.A. Bredig, J. Phys. Chem., 1968

[3] Cooper-Rushton-Grimes potential: M.W.D. Cooper, M.J.D. Rushton, R.W. Grimes, A many-body potential approach to modelling the thermomechanical properties of actinide oxides, J. Phys. Condens. Matter, 2014

INTERATOMIC POTENTIAL INVESTIGATION OF THERMODYNAMIC PROPERTIES OF URANIUM-AMERICIUM MIXED OXIDES

Baptiste LABONNE

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Americium is a chemical element produced by neutron capture in nuclear reactors, whose strong radiotoxicity is a major issue for the management of nuclear waste. One solution envisaged to reduce the amount of americium in the waste is to separate it from the other elements present in the spent fuel, to include it into new fuels such as actinide oxides, and to transform it in reactor into a less radiotoxic element thanks to a transmutation reaction [1]. It is therefore necessary to evaluate the impact of Americium on the behaviour of these fuels, and in particular on their high temperature thermal properties.

One way of increasing significantly the efficiency in qualifying transmutation fuels is to develop a more physically based description of these fuels. Basic research approaches combining multiscale modelling and separate effect experiments can bring significant insight into materials properties and key phenomena involved in the evolution of fuels in reactor.

In particular, atomic scale modelling methods are now essential complements to the experimental characterizations of nuclear fuels. We show in this study the contribution of these methods to the improvement of the knowledge of the Uranium – Plutonium – Americium – Oxygen thermodynamic system, and especially of the (U-Am-O) ternary system for which very little data is available, especially at high temperature [2].

We will first describe the empirical interatomic potential that we developed to study Uranium-Americium mixed oxides. We will then present the structural and thermodynamic properties of $(U,Am)O_2$ as a function of temperature and composition yielded by this potential: thermal expansion, density, enthalpy increment, heat capacity and melting temperature.

[1] Report on sustainable radioactive-waste-management (2012): http://www.cea.fr/english/Documents/corporate-publications/report-sustainable-radioactive-waste-management.pdf

[2] C. Guéneau, A. Chartier, L. Van Brutzel, R. Konings, T. Allen, R. Stoller, S. Yamanaka (Eds.), “Thermodynamic and thermophysical properties of the actinide oxides”, Comprehensive Nuclear Materials (Vol-II), Elsevier, Amsterdam (2012)

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945077.

Interatomic potential investigation of thermodynamic properties of Uranium-Americium mixed oxides

FISA 2022

Baptiste Labonne[1] and Marjorie Bertolus[1]

[1]CEA – DES / IRESNE / DEC

Context: Nuclear waste management

- Americium strong radiotoxicity is a major issue for the management of nuclear waste [1]
- There is a possibility to separate the Americium from the spent nuclear fuel and to include it in mixed oxide fuels in order to transmute it into a less radiotoxic element [1]
- Uranium-Americium mixed oxides thermodynamic and structural properties are poorly known, as well as the U-Am-O phase diagram, especially for high temperatures [2]
- In particular, the melting temperature and heat capacities are required to know the conductivity integral margin to melting, which rules the reactors operating conditions
- Atomic scale calculations can be used to provide more data to CALPHAD modelling and fuel performance codes, especially for conditions that are hard to achieve experimentally

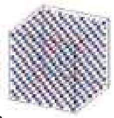
Method: Atomic scale calculations

Cooper-Rushton-Grimes (CRG) formalism for empirical interatomic potentials [3]:

E(CRG) = E(Coulomb) + E(Buckingham) + E(Morse) + E(EAM)

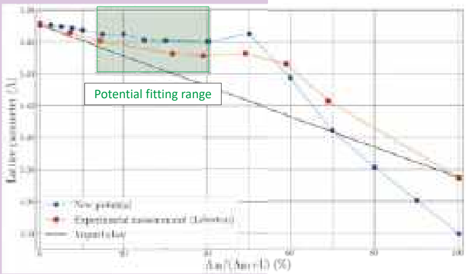
→ Parametrization of a new potential for the study of U-Am mixed oxides < 30% Am content

Molecular Dynamics Method:

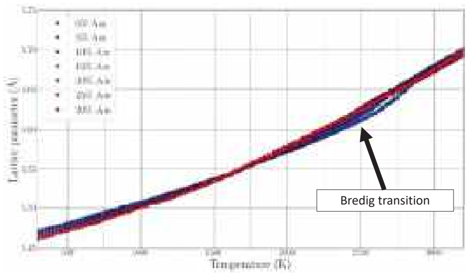


- Simulation of the evolution of the system over time
- Is used to explore the potential energy surface of the system
- Allows one to determine thermodynamic and structural properties of the system

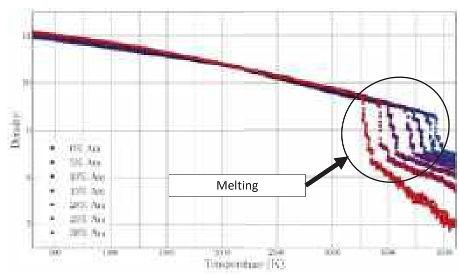
Uranium-Americium mixed oxides structural properties



The lattice parameter is qualitatively reproduced; and quantitatively reproduced for compositions with 60% Americium or less

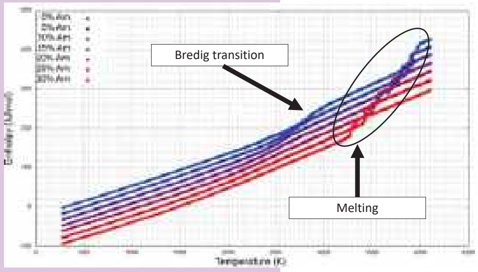


The cell parameter decreases slightly with increasing Am content, except around 2000 K → first hint of superionic Bredig transition

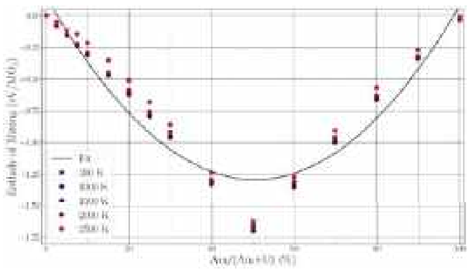


First evaluation of high temperature density, especially for the liquid U-Am mixed oxides; melting is seen in the sudden decrease

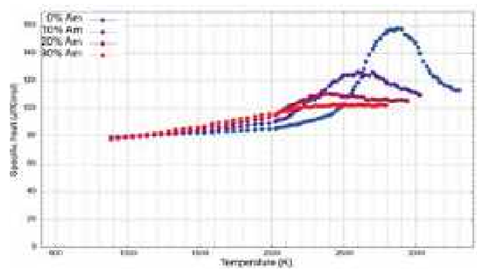
Uranium-Americium mixed oxides thermodynamic properties



The enthalpy increment is linear up to the the Bredig transition and decreases with Am content; melting is seen in the sudden increase in the enthalpy increment → estimate of fusion enthalpy

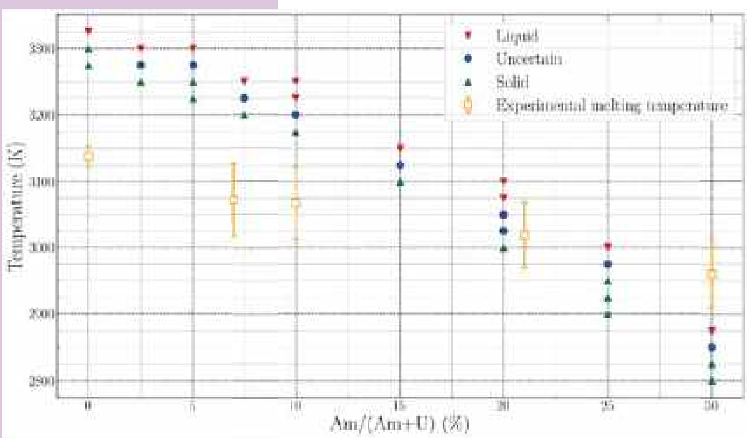


The negative mixing enthalpy indicates the formation of a stable solid solution; temperature has a low impact on ΔH_{mix}



The peak in the heat capacity confirms the superionic Bredig transition and could have an important impact on the behaviour of fuels in power ramps; the intensity of the peak decreases with increasing %Am

Phase of Uranium-Americium mixed oxides as a function of Americium content and temperature



Conclusions

- Various thermodynamic and structural properties determined using atomic scale calculations and our new empirical interatomic potential → good complements to experimental measurements
- Good agreement with experimental measurements for the 0 – 30% Am range
- Prediction of a Bredig transition for low Americium contents, which could have an important impact on the behaviour of fuels in power ramps

Perspectives

- Refinement of the potential to study the whole range of Americium contents
- Performing of electronic structure calculations on a few compositions to validate the potential in areas where no experimental data is available, especially for high temperatures and Americium content
- Study of the non-stoichiometric Uranium-Americium mixed oxides

References

[1] CEA, séparation et transmutation des éléments radioactifs à vie longue, 2012

[2] C. Guéneau et al. "Thermodynamic and thermophysical properties of the actinide oxides", Comprehensive Nuclear Materials (Vol-II), Elsevier, Amsterdam (2012)

[3] M.W.D Cooper *et al.*, J. Phys.: Condens. Matter 26, 105401, 2014

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945077

COLLABORATIVE VIRTUAL ENVIRONMENT FOR SPENT FUEL CASK LOADING

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3D animation has been used in the nuclear industry for many years, producing detailed animated videos to provide a simplified way to inform about future projects or activities.
Due to the complexity of the creation process of these animations, only graphic designers were able to modify, never in real time, these virtual recreations, thus limiting the technical approach provided by end users or developers of the activities that have been animated. Consequently, these animations have been used as a passive tool: once the animation has been developed, final is not able to interact in real time or provide inputs that could be used to redefine the process.

During the spring of 2021 Cofrentes NPP performed the first loading campaign of dry storage fuel casks. Given the importance of this process and its pioneering nature in this plant, the development of a virtual collaborative environment was valued as a great opportunity for the preparation of the work of all the organizations previously involved without the need to access the radiologically impacted areas or traveling from different work centers to the site, a complex fact during the global COVID-19 pandemic.

This project is pioneering for management and planning of processes in Spanish nuclear power plants, paving the way for their use in many other complex activities within the plants, minimizing the exposure time inside radiological areas both in the preparation phase of the task as well as during the execution phase, thus reducing the exposure times of the personnel.

COLLABORATIVE VIRTUAL ENVIRONMENT FOR SPENT FUEL CASK LOADING

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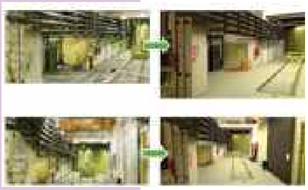
COLLABORATIVE VIRTUAL ENVIRONMENT - AN INTERACTIVE WORLD

Collaborative virtual environment: A virtual space where different users can coexist at the same time and interact with each other and with the media for a common objective. If we extrapolate this concept to an industrial development, the virtual space could be a simulation of an existing real asset such as plant building, and the equipment found there.

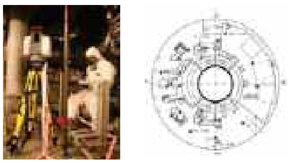
Building a virtual reality 3D model for specific operations or areas brings an added value, planning or training interventions in safe virtual environment, that will be performed lately within the plant, saving time and dose received, especially in critical environments or areas with high radiation levels.

FROM A REAL TO A VIRTUAL WORLD

Spanish NPP were designed throughout the 70´s and constructed during the early 80´s. Consequently, no computer 3D modelling was used for its building, systems, or equipment's design. Thanks to the use of building laser scanning and the 3d modeling technology, full-scale models of the fuel building has been created in virtual reality.



3D Model creation of the Cofrentes fuel building from a point cloud mesh



Laser Scanning inside a Nuclear Power Plant

Cofrentes Fuel Building Collaborative environment

USE OF VIDEO GAMES TECHNOLOGY TO INDUSTRIAL APPLICATIONS

For the video game industry, the use of fictitious virtual worlds where players share with others an interact with the environment is common. Until now, the complexity of programming these environments were the greatest impediment to achieve the needs that an industrial process might require. Thanks to the expansion and development of game engines and the capabilities and facilities they provide, the development of virtual environments becomes simpler, faster, and cheaper, giving to the industry the opportunity to use this technology without making a large investment in its development.

COLLABORATIVE WORK CAPACITY – A MULTIPLAYER ENVIROMENT

16 users within the same virtual reality experience simultaneously they can participate coordinately within the simulator, either as passive spectators or active participators in any of the simulation tasks/functionalities

- Basic interaction, share the same immersive virtual space.
- Simultaneous performance of an activity
- Interaction with same objects:
- Carrying out an activity in a collaborative way

CROSS-PLATFORM APPLICATION

Capable to be executed at any personal computer, an iPad application has been developed to facilitate handling and transport.

ACCESS TO PLANT = TIME CONSUMING = MONEY

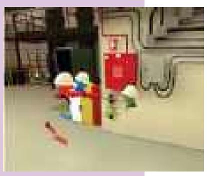
Minimizing the number of accesses and visits to the plant represents a great saving of time especially in activities where many people are involved.

The average time that a worker requires to enter to a radiological building can be around 30 minutes while the times required for access procedures are never less than 2 days plus travelling cost

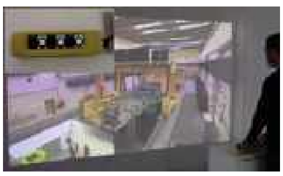
PLANNING AND TRAINING IN A SAFE ENVIRONMENT = MINIMIZING RISK

One of the great possibilities offered using these work tools is that once the virtual environment has been developed, it is possible to implement different tools or capacities for different disciplines. Some examples of possible implementations

Calculation of occupational doses. Implement a simplified module for calculating operational doses



Training in tele-operated equipment: Implement a real interface between equipment controls and virtual environment



Training in preventive maintenance of equipment: virtual training to carry out planned maintenance

RADONORM - TOWARDS EFFECTIVE RADIATION PROTECTION BASED ON IMPROVED SCIENTIFIC EVIDENCE AND SOCIAL CONSIDERATIONS – FOCUS ON RADON AND NORM

Ulrike KULKA

ULRIKE KULKA1*, MANDY Birschwilks1, LAURELINE FEVRIER2, BALAZS Madas3, SISKO Salomaa4, ALES FRONKA5, TANJA PERKO6, ANDRZEJ WOJCIK7, NADJA ŽELEZNIK8

1 BfS Federal Office for Radiation Protection, Ingolstädter Landstraße 1, 85764 Oberschleissheim, Germany
2 IRSN Institut for radiation protection and nuclear security, Saint-Paul-Lez-Durance, Cedex, France
3 EK Centre for Energy Research, Konkoly-Thege Miklós út 29-33, 1121 Budapest, Hungary
4 STUK Radiation and Nuclear Safety Authority, Laippatie 4, 00880 Helsinki, Finland
5 SÚRO National Radiation Protection Institute, Senovážné náměstí 9, Prague 1, Czech Republic
6 SCK_CEN Studiecentrum voor Kernenergie, Boeretang 200, 2400 Mol, Belgium
7 SU Stockholms universitet, Svante Arrhenius väg 20C, 106 91 Stockholm, Sweden
8 EIMV Elektroinstitut Milan Vidmar, Hajdrihova 2, Slovenia

RadoNorm aims at managing risks from radon and NORM exposure situations to assure effective radiation protection based on improved scientific evidence and social considerations.

The project findings and outcomes will have a significant impact on radiation protection in Europe and beyond, thanks to its focus on 1) Initiation, support and implementation of multidisciplinary, innovative, integrated research and technology activities, 2) Integration of education and training in the research and development work of the project and 3) Dissemination of project results through specific actions targeting broad stakeholder community including among others the public, regulators, and policy makers. The project supports European states and the EU Commission in implementing the Basic Safety Standards for protection against ionising radiation hazards at the legislative, executive, and operational levels (Directive 2013/59 / EURATOM) with the aim to significantly reduce uncertainties in all steps of radiation risk management for radon and NORM (naturally occurring radioactive materials). Scientific, societal, and technical aspects of exposure conditions are addressed and clarified, also including exposure from TENORM (technologically enhanced naturally occurring materials). The objectives are achieved through work packages, including scientific research-related topics (exposure, dosimetry, biology, epidemiology, societal aspects), cross-cutting topics (education and training, dissemination, ethics) and project management. The outputs of the project will include guidelines and recommendation at legal, executive

and operational levels. It will enable consolidated, harmonized and sound decision-making in the field of radiation protection considering societal aspects and sustainable knowledge transfer. Thus, RadoNorm contributes in a pioneering way to the implementation of the Basic Safety Standards (BSS), inter alia through knowledge in the field of exposure, dose assessment, effects and risks, as well as countermeasures.
The project also fits seamlessly into the EC's activities to further optimise radiation protection in a consistent and joint manner, as has already been done in previous Commission activities, including the establishment of radiation protection platforms such as MELODI, as well as the promotion of projects such as DoReMi NoE, OPERRA, and partnerships such as CONCERT-EJP and PIANOFORTE. Studies, e.g. addressing exposure, dosimetry and effects and risks of radon and NORM add to knowledge on science underpinning the System of Radiation Protection and may thus impact future international recommendations by the ICRP.
The RadoNorm activities and achievements since the project start are presented.

RadoNorm

Towards effective radiation protection based on improved scientific evidence and social considerations – focus on radon and NORM

Ulrike Kulka[1] on behalf of RadoNorm Consortium

[1]Federal Office for Radiation Protection, Ingolstädter Landstrasse 1, 85764 Oberschleissheim, Germany

Correspondence to radonorm@bfs.de

The RadoNorm project (www.radonorm.eu) has received funding of EUR18 million from the Euratom research and training programme 2019-2020 and includes 57 partners from 22 EU member states and associated countries. It also collaborates with groups in the US and Canada. The multidisciplinary 5-year project began in Autumn 2020 and is being coordinated by Germany's Federal Office for Radiation Protection.

RadoNorm is designed to initiate and perform research and technical development in support of European Union Member States, Associated Countries and the European Commission in their efforts to implement the European radiation protection Basic Safety Standards. The proposed multidisciplinary and inclusive research project will target all relevant steps of the radiation risk management cycle for radon and NORM exposure situations. RadoNorm aims to reduce scientific, technical and societal uncertainties by:

- initiating and performing research and technical developments,
- integrating education and training in all research and development activities, and
- disseminating the project achievements through targeted actions to the public, stakeholders and regulators.

This will strengthen the scientific and technical basis for all key steps of the radiation risk management cycle for radon and NORM. The inclusive character of RadoNorm is given at different levels by :

(i) targeting research and development on all steps of the management cycle,
(ii) combining biomedical and ecological research with mitigation development and social science research,
(iii) integrating researchers from national radiation protection institutions, research centres, universities and small-to-medium enterprises,
(iv) incorporation of E&T activities in all undertakings, and
(v) linking dissemination efforts directly to knowledge achievements and new recommendations.

To achieve its objectives, RadoNorm project is structured in eight work packages (WP) and focused around all steps of the risk management cycle to improving radiation risk knowledge and management for radon and NORM.

WP1

This work package will ensure proper co-ordination across tasks and partners in order to achieve the overall project objectives within time, quality and budget constraints and EC's requirements. Leader is BfS.

WP2

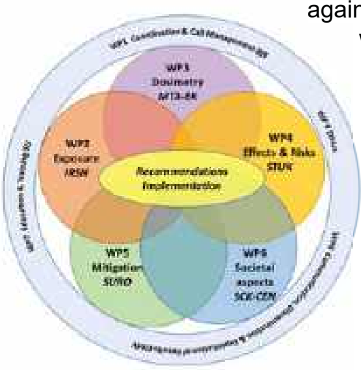
New scientific knowledge, methods and protocols to better characterise the exposure of humans (public and workers) and non-human biota to radon and NORM. Leader is IRSN.

WP3

Doses and dose distributions for epidemiological and experimental studies, and for specific subgroups, and their uncertainties upon exposure to radon and NORM. Leader is EK.

WP4

New knowledge on biological effects and responses after exposure to radon and NORM: implications for risk assessment and radiation protection of humans and the environment. Leader is STUK.



WP5

New mitigation strategies and optimization of existing systems utilizing innovative methods and techniques applied in radiation protection of the general public, workers and the environment against exposure to radon in dwellings and workplaces, and exposures in specific NORM-involving industries and legacy sites. Leader is SURO.

WP6

Development of strategic, innovative, theory- and evidence-based radon and NORM risk communication, as well as contribute to an improved governance of radon and NORM risks in a society. Leader is SCK-CEN

WP7

Educating a team of innovative and enthusiastic young experts in radiation protection research with special focus on radon and NORM. Leader is SU.

WP8

Communication, dissemination activities and exploitation of results to ensure real intake of project results for the wide variety of stakeholders in two-way exchange. Leader is EIMV.

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 900009.

MITIGATION AND REAL TIME MONITORING OF ACOUSTIC RESONANCES IN MAIN STEAM SYSTEMS OF NUCLEAR REACTORS

David GALBALLY

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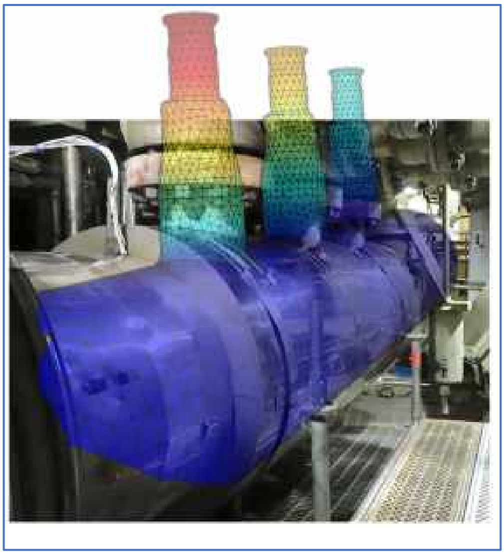
Pozuelo de Alarcón, 28223, Madrid, Cell: +34 677 744 821
Jesus Hernando Perez – Iberdrola Generación Nuclear, *Project Manager, jhernandop@iberdrola.es, C/ Tomas Redondo 1, 28033, Madrid, Cell: +34 617 28 35 36*

In the last two decades, the nuclear fleet worldwide has experienced a relatively high number of events related to damage sustained by different main steam components and reactor internals caused by acoustic resonances. In some cases, this damage has resulted in the malfunction of safety related equipment, such as main steam safety valves and main steam isolation valves in BWRs. Therefore, acoustic resonances have proven capable of causing a deleterious impact on the safety of reactor systems.

The innovation of the work presented in this application is twofold: first has developed a first-of-a-kind sleeve that can be integrated in the nozzle of safety relief valves in order to eliminate resonances without any need for modifying the main steam system. Second, a non-invasive real-time monitoring system has been developed, implemented and tested. This system is capable of determining the amplitude of the pressure waves inside the main steam lines and providing valuable information to the plant operator in order to avoid continued operation in regions where the resonance intensity is capable of damaging the valves or other safety related equipment.



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MITIGATION AND REAL TIME MONITORING OF ACOUSTIC RESONANCES IN MAIN STEAM SYSTEMS OF NUCLEAR REACTORS

IBERDROLA INNOMERICS

David Galbally[1] , Jesus Hernando[2]

[1] Innomerics – Managing Director – Virgilio 25-A 28223 Pozuelo de Alarcon

[2] Iberdrola Nuclear Generation – Project Manager -Tomas Redondo 1 28033 Madrid

THE PROBLEM OF ACOUSTIC RESONANCES

The nuclear fleet worldwide has experienced a relatively high number of events related to damage sustained by different main steam components and reactor internals caused by acoustic resonances. In some cases, this damage has resulted in the malfunction of safety related equipment

Until now, elimination of acoustic resonances required costly modification of the main steam lines, in order to change the geometric dimensions governing the acoustic modes of the system

The innovation of the work presented in this application is twofold: first, the consortium formed by Iberdrola and Innomerics has developed a first-of-a-kind sleeve that can be integrated in the nozzle of safety relief valves in order to eliminate resonances without any need for modifying the main steam system. Second, a non-invasive real-time monitoring system has been developed, implemented and tested

REAL TIME MONITORING SYSTEM

The goal of the monitoring system is to achieve real-time reconstruction of the pressure field inside the main steam system of a nuclear reactor based on a limited number of non-invasive pressure measurements.

This system is capable of determining the amplitude of the pressure waves inside the main steam lines and providing valuable information to the plant operator in order to avoid continued operation in regions where the resonance intensity is capable of damaging the valves or other safety related equipment.

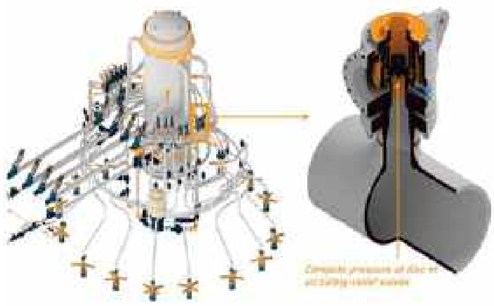


Figure 1. 3D Model of the main steam system of the boiling water reactor where the monitoring system was tested (left) and cross-section of one of the safety relief valves showing the valve disc where acoustic pressure due to resonances reaches its maximum value (right).

THE FOUR INGREDIENTS FOR REAL TIME MONITORING

A high-fidelity aeroacoustic model with over 10^6 degrees of freedom

A reduced order model that enables real-time computation of the outputs of interest

$$\begin{cases} \dot{p}(x,t) = f_r(p(x,t),u(x,t)) \\ y_r(t) = g_r(p(x,t),u(x,t)) \end{cases}$$

Sensor data collected from non-invasive sensors installed at different locations

Inverse problem formulation that allows reconstruction of the pressure field

$$u(x,t) = \arg\min \|g\|_2^2$$

s.t.

$$\dot{p}(x,t) = f_r(p(x,t),u(x,t))$$

where

$$g = p(x_{sensors},t) - p_{measured}(x_{sensors},t)$$

SCALE MODEL VALIDATION

A scale model test facility was built for testing and validating the monitoring system and the mitigation device that were developed during the project. Nondimensional similarity was used extensively in order to develop a test facility capable of replicating the aeroacoustic behavior of the full-scale steam system of a BWR while using air at ambient conditions as the test fluid.

In addition to scale model testing, CFD simulations were also performed in order to develop and validate the design of both the monitoring system and the resonance mitigation device.

Figure 2 Scale model of a complete main steam line; (2) detail of a single SRV branch line and (3) data acquisition system with 80 high-frequency dynamic pressure channels.

THE INSTRUMENTATION CHALLENGE

The main challenge for developing a monitoring system capable of determining the acoustic pressure is that it is almost impossible to install a pressure sensor in primary pressure boundary.

A non-invasive pressure sensor has been designed and manufactured formed by a ring of strain gages welded to a thin metal band. The ring is not welded to the pipe surface, so it can be easily mounted and removed, thereby minimizing personnel dose during installation.

Figure 3 Photograph of an actual pressure measurement ring installed on a main steam line, before covering it with thermal insulation (right) and after installing the reflective thermal insulation over it (right).

ACOUSTIC RESONANCES MITIGATION DEVICE

A device capable of eliminating resonances without the need for costly modifications to the geometry of the main steam system itself, thereby dramatically reducing the cost and dose associated with the implementation of the modification. The three critical requirements stated at the start of the mitigation device development project are stated below:

- **Requirement 1**: No need to perform any modifications to the primary pressure boundary
- **Requirement 2:** Reversible. Easy to return to original configuration
- **Requirement 3:** Significant improvement over other OEMS mitigation devices

Figure 4 Scaled mitigation device prototype designed

The effectiveness of the proposed mitigation device was tested using the same scale model test facility built for the development and testing of the monitoring system described.

Euratom H2020 project

PASTELS - PAssive Systems: Simulating the Thermal-hydraulics with ExperimentaL Studies

Michaël Montout[1] *et al.*[2]
[1]EDF R&D, EDF Lab Chatou, 6 quai Watier, 78401 Chatou
[2]PASTELS consortium

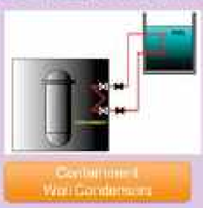
Focus on two specific Passive Safety Systems

- SAfety COndenser (**SACO**)

To cool Steam Generators

- Passive Containment Cooling System (**PCCS**)

To cool the reactor building (LOCA, SLB, severe accident)



Benchmarking of various numerical tools acting at different scales

- **system codes**: AC², CATHARE, RELAP5, TRACE
- **CFD codes**: CFX, Fluent, neptune_cfd
- **severe accident codes**: ASTEC, MELCOR

Main Objectives

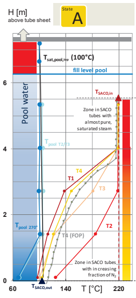
- Advance European players in the nuclear industry on the **design and optimisation of passive systems**
  - Analysis of the **physical behaviour** of passive systems for various scenarios of interest
  - **Validation and benchmarking of numerical tools** used for **design** and safety **demonstration**
- Participate in the emergence of a **methodological guide and a roadmap** to help the introduction of passive systems in the designs of the **reactors of the future**

This project constitutes a valuable way to deal with the technological barriers of the passive systems and evaluate new innovative designs of passive systems up to advanced TRL levels

Project baseline

- Budget: 3.8 M€, ~3M€ funded by Euratom
- 11 partners in Western and Eastern Europe
- Duration: 01/09/20 → 28/02/24 (3.5 years)

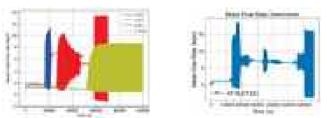
PKL/SACO test facility and first experimental results



HERO-2 test facility and experimental vs numerical comparisons with TRACE (ENEA)

Experimental means at different scales

- Separated effect tests for studying of closed two-phase flow thermosiphon loop
→ existing data from **HERO-2** test facility (SIET, Piacenza, Italy)
- Combined effect tests for studying of passive heat exchanger system in-pool
→ existing data from **PERSEO** test facility (SIET, Piacenza, Italy)
- Integral tests for studying of an open two-phase flow thermosiphon loop design of **PCCS**
→ new data from **PASI** test facility (LUT University, Lappeenranta, Finland)
- Integral tests for studying of an innovative design of **SACO**
→ new data from **PKL** test facility (Framatome GmbH, Erlangen, Germany)



Liquid mass flow rate in for various conditions of pressure and injected steam power in the vessel

PASI test facility and pre-test numerical comparisons (EDF with CATHARE and GRS with ATHLET)

PASTELS official website: https://ww.pastels-h2020.eu

https://www.linkedin.com/company/pastels-h2020

The PASTELS project has received funding from the Euratom research and training programme 2019-2020 under grant agreement N°945275. This text reflects only the author's view and the Commission is not responsible for any use that may be made of the information contained therein

CAPABILITIES OF THE GPU-BASED DYNAMIC MONTE CARLO CODE GUARDYAN

David LEGRADY

D. LEGRADY, G. TOLNAI, M. PUKLER, B. BABCSANY, E. PAZMAN and J. KOPHAZI
Department of Nuclear Techniques, Institute of Nuclear Techniques, Budapest University of Technology and Economics, Műegyetem rkp. 3., H-1111 Budapest, Hungary Department of Nuclear Techniques, Institute of Nuclear Techniques, Budapest University of Technology and Economics, Műegyetem rkp. 3., H-1111 Budapest, Hungary

Targeting ultimate fidelity coupled reactor physics and thermal-hydraulics calculations has recently entered the forefront of reactor safety analysis research enabled by the vast forward leap of High-Performance Computing (HPC). Our project has achieved a breakthrough by introducing Graphics Processing Units (GPUs) to the prodigiously progressive Dynamic Monte Carlo (DMC) method, where time dependence is handled explicitly rather than by a series of static calculations, achieving simulations very faithful to nature. Algorithms were devised to optimally fulfill DMC requirements and adapt to GPU specificities. Moreover, attention was paid to keeping the statistical variance of the population low. In 2016 the GUARDYAN (GPU Assisted Reactor Dynamic Analysis) code development started and recently reached the capabilities to accomplish full core VVER-440/V213 calculations with meaningful detector reading simulation results. This indicates that with the inventions conceived and implemented in GUARDYAN, the DMC method was promoted from proof-of-concept to application to realistic power plants.
The code has been verified and validated against 30 ICSBEP benchmark scenarios by comparison to MCNP6.1 for approximately 440 000 data points; further, by performing experiments using the Budapest University of Technology and Economics (BME) Training Reactor of a Cd sample insertion and rod drop experiments, and even further by replicating a recent safety rod drop experiment results of the Paks Nuclear Power Plant for a VVER-440/V213 unit with realistic burnup values, each comparison was concluded with complete success.
The code GUARDYAN fused existing and novel Monte Carlo techniques with GPU-based high-performance computing advocating DMC to be the gold standard of reactor physics, a calculation tool devoid of obscure approximations. A high-fidelity simulation tool enables more optimal use of design safety margins and creates room for efficiency improvement of power plants.

CAPABILITIES OF THE GPU-BASED DYNAMIC MONTE CARLO CODE GUARDYAN

FISA 2022

D. Legrady, G. Tolnai, T. Hajas, M. Pukler, B. Babcsany, E. Pazman and J. Kophazi
Department of Nuclear Techniques, Institute of Nuclear Techniques, Budapest University of Technology and Economics

Project summary

Targeting ultimate fidelity coupled reactor physics and thermal-hydraulics calculations has recently entered the forefront of reactor safety analysis research enabled by the vast forward leap of High-Performance Computing (HPC). Our project has achieved a breakthrough by introducing Graphics Processing Units (GPUs) to the prodigiously progressive Dynamic Monte Carlo (DMC) method, where time dependence is handled explicitly rather than by a series of static calculations, achieving simulations very faithful to nature. In 2016 the **GUARDYAN** (GPU Assisted Reactor Dynamic Analysis) code development started and recently reached the capabilities to accomplish full core VVER-440/V213 calculations with meaningful detector reading simulation results.

Validation with BME Training Reactor measurement

An experiment was conducted at the BME TR at zero power by shooting a Cd foil rolled up to form a cylinder (0.5 mm thick, 4 cm high, 9 mm in diameter, with weight of 4.3 g) into the core using a pneumatic rabbit system. The sample arrives approximately to the middle of the core, is left there for 1.5s and then is quickly withdrawn. Total power time evolution was modelled by GUARDYAN.

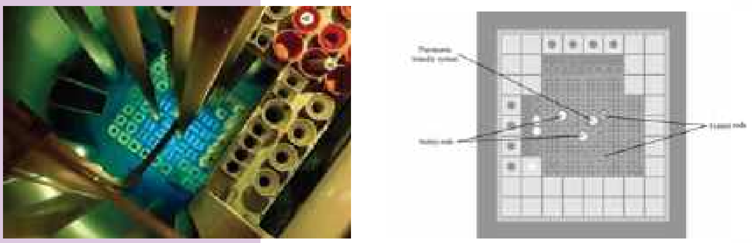


Figure 3: BME TR geometrical structures, transversal cross section (right) and a photo of the same core (left) during operation. Cd sample is shot in the core by a pneumatic transfer system.

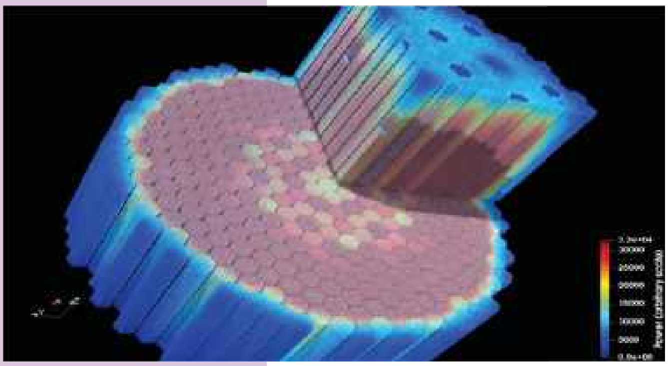


Figure 6: Paks NPP Power distribution at the beginning of the transient, simulation results of GUARDYAN

Conclusions

The code GUARDYAN fused existing and novel Monte Carlo techniques with GPU-based high-performance computing advocating DMC to be the gold standard of reactor physics, a calculation tool devoid of obscure approximations. A high-fidelity simulation tool enables more optimal use of design safety margins and creates room for efficiency improvement of power plants.

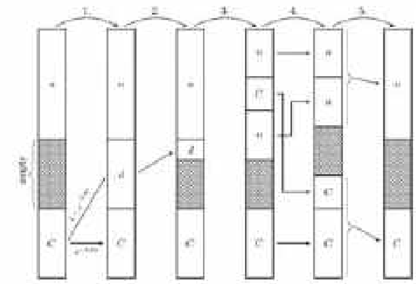


Figure 1: Neutron population maintenance scheme

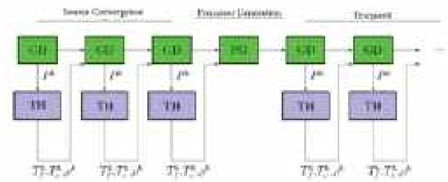


Figure 2: Thermal-Hydraulics coupling scheme

GUARDYAN main features

- GPU-based Monte Carlo engine, NVIDIA CUDA 11.6 environment
- Constructive solid geometry for material composition and geometry
- ENDF/B-VII.1 in ACE format, continuous energy handling
- Constant-sized population with frequent statistical combing, including delayed neutrons (see **Fig**. 1)
- Advanced variance reduction techniques with adjont based population combing
- Coupled to SUBCHANFLOW, a subchannel thermal-hydraulic solver (see **Fig**. 2)
- Extensive verification process with comparison to MCNP, Serpent-2 and TRIPOLI

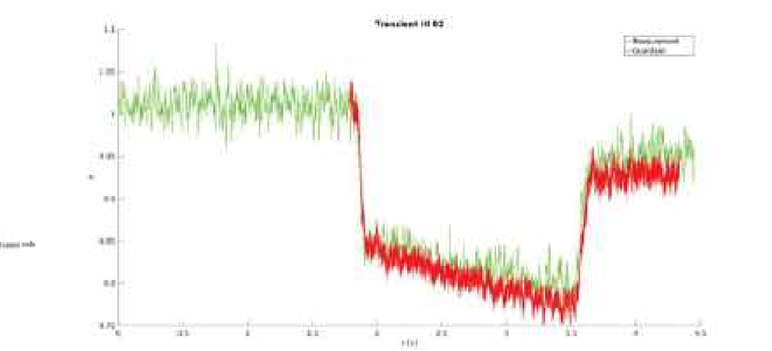


Figure 4: BME TR total power time evolution measured and modelled with GUARDYAN

Validation with a full VVER-440 core with burnup of Paks NPP, Unit 4

A recent (2019) asymmetric rod-drop experiment was modelled with GUARDYAN and the Paks NPP in-house diffusion code VERETINA. 3 ex-core detector readings were reproduced accurately. Pin-wise core modelling included a detailed burnup map.

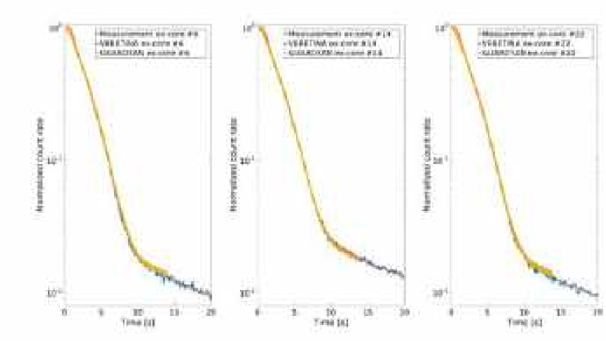


Figure 5: Paks NPP Ex-core detector signals modelled: calculations fit measurements excellently

Fracture mechanics testing of irradiated RPV steels by means of sub-sized specimens (FRACTESUS)

FISA 2022

FRACTESUS

Tomasz Brynk
SCK CEN, Boeretang 200, 2400 Mol, Belgium

General information

Project within EURATOM Work Programme 2019-2020 in the section NFRP-04: Innovation for Generation II and III reactors

- Start date: 01/10/2020
- End date: 30/09/2024

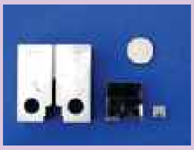
Overall budget: € 4 666 061,25 (EU contribution: € 2 986 814,61)

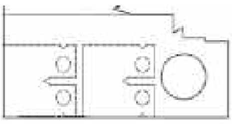
Main aims

- Demonstrate the applicability of miniaturized compact tension specimens (MCT) in fracture toughness testing (master curve approach) of the reactor pressure vessel steels under hot cell conditions
- Prepare of guidelines for MCT usage supported by experimental evidence and numerical modelling

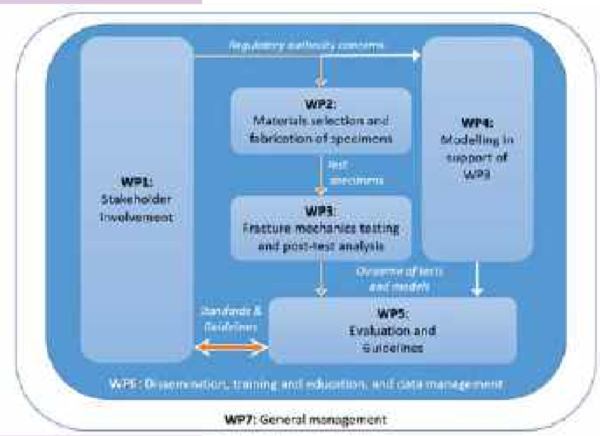
Advantages of miniaturized specimens

- Optimization of surveillance material usage
- Larger number of testing results from the same amount of material
- Possibility to re-use of already tested specimens





Project structural organization



Workflow and progress

Analyze of current standards and stakeholder concerns

Selection of materials

- Results for large specimen available
- Various properties (T0, T41J, upper shelf energy, welds and base materials)
- Availability for testing

Unirradiated round robin

Nr. No.	Material	Orientation	Provider	T0 [°C]	[illegible]	[illegible]	Testing participant 1	2	3	4	5
1	[illegible]	[illegible]	HZDR	[illegible]	[illegible]	[illegible]	SCK CEN	[illegible]	HZDR	VTT	
2	[illegible]	T-L	NRI	[illegible]	[illegible]	[illegible]	NRI	[illegible]	[illegible]	[illegible]	[illegible]
3	[illegible]	T-L	SCK CEN	[illegible]	[illegible]	[illegible]	SCK CEN	CIEMAT	HZDR	VTT	[illegible]
4	[illegible]	[illegible]	CIEMAT	[illegible]	[illegible]	[illegible]	SCK CEN	CIEMAT	[illegible]	NRI	[illegible]
5	[illegible]	T-L	[illegible]	[illegible]	[illegible]	[illegible]	SCK CEN	[illegible]	HZDR	[illegible]	[illegible]
6	[illegible]	T-L	SCK CEN	[illegible]	[illegible]	[illegible]	SCK CEN	[illegible]	[illegible]		

Irradiated round robin

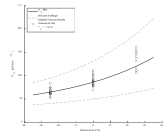
Material	T0 [°C]	Orientation	Fluence [E19 n/cm²]	Number of tests	Testing participant 1	2	3	4	5	6	7
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	SCK CEN	VTT	HZDR	MTA EK	NRI	[illegible]	[illegible]

Arffman, P. (2021). Test matrix of FRACTESUS, Deliverable D2.1

Specimen fabrication

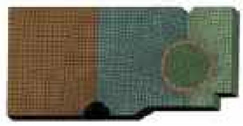
Fracture toughness testing

- Master Curve evaluation according to ASTM E1921 standard



Finite element modeling

- Numerical round robin
- Specific task assigned after preliminary experimental results analyze



Comparison with large specimens

Introduction of corrections (if needed)

Dissemination and guidelines

Current progress

FRACTESUS scope

Approval by the Authorities

Usage by NPP Operators

FRACTESUS ambition

WWW

https://fractesus-h2020.eu/

Facebook

https://www.facebook.com//Fractesus-H2020-100313765184397

LinkedIn

https://www.linkedin.com/company/68850145/admin/

Research Gate

https://www.researchgate.net/project/Fractesus-H2020

Twitter

https://twitter.com/fractesus

Consortium: 21 partners from 14 countries

Project has received funding from the Euratom research and training programme 2020-2024 under grant agreement No 900014.

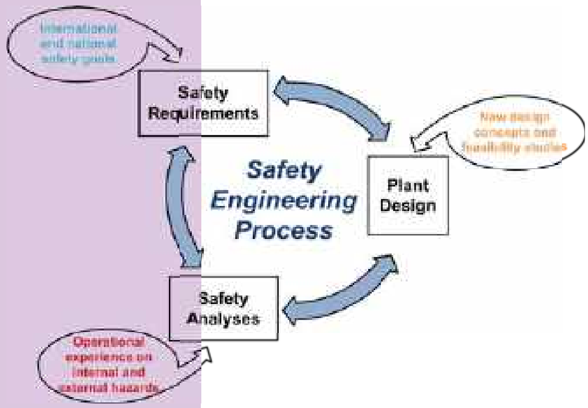
Benchmark Exercise on Safety Engineering Practices (BESEP)

Atte Helminen[1], Essi Immonen[1] and Joonas Linnosmaa[1]
[1]VTT Technical Research Centre of Finland Ltd.

The vision of BESEP is that the nuclear industry utilizes proven, rational and justified Safety Engineering Practices enabling efficient safety margins determination and safety requirement verification, which make licensing processes streamlined and cost-efficient.

Safety engineering process

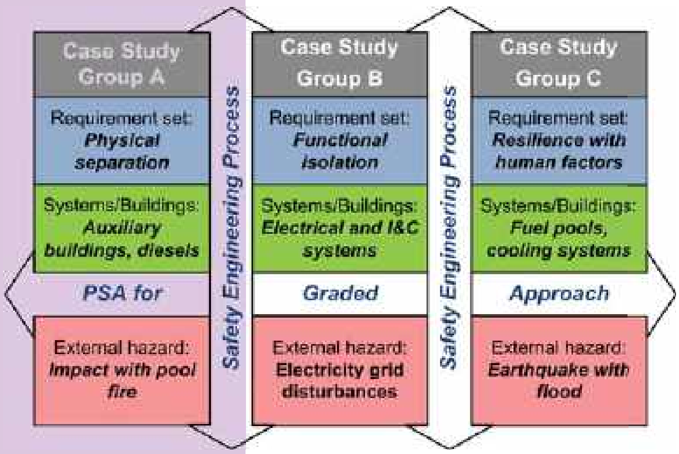
- Safety engineering process connects together the main elements of safety design: safety requirements, safety analyses and plant design.
- In case there is a change in one of the main elements, the change should be reflected in the two other elements.
- With better safety engineering process, modified safety requirements can be implemented to the actual plant design more efficiently.



Methodology

BESEP is a benchmark exercise between project partners:

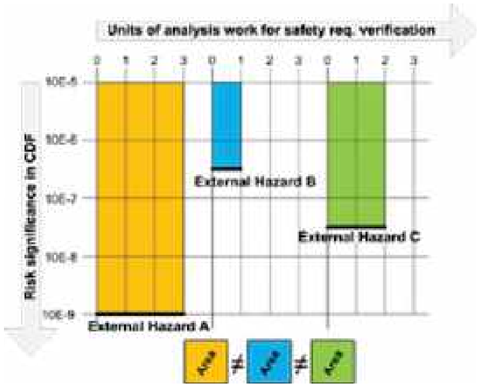
1. Specification of case study requirements and allocation of requirements under specific topics creating a set of requirements.
2. Development of pool of case studies having relevance to external hazards and specification of case study groups.
3. Cross-case comparison within case study groups.
4. Cross-group comparison between case study groups.
5. Best practices and recommendation on closer connection of safety analysis methods.



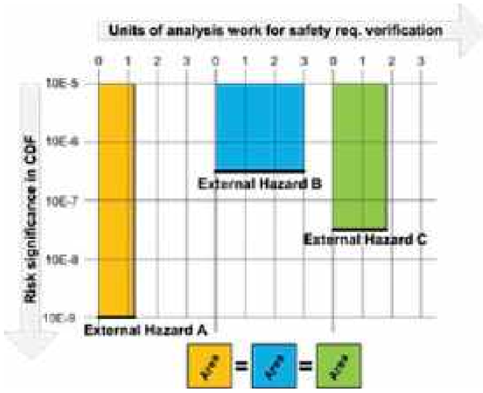
Outcomes

- Best practices for the verification of evolving and stringent safety requirements against external hazards.
- Guidance on the closer connection of deterministic and probabilistic safety analysis and human factors engineering for the determination and realistic quantification of safety margins.
- Guidance on the creation of graded approach for the deployment of more sophisticated safety analysis methods, such as upgrades of simulation tools, while maintaining the plant level risk balance originating from different external hazards.

Situation before BESEP…



… and after BESEP



Areas reflecting the invested analysis work and the risk significance of external hazard will be more balanced with efficient and integrated set of safety engineering practices.

Conclusions:

- **Benchmark on safety engineering practices of project partner countries**
- **Cross-case and cross-group comparisons of case studies**
- **Recommendations on graded approach to safety analyses methods and safety requirement verification**

MULTIMODAL HUMAN-ROBOT INTERFACE FOR HETEROGENEOUS ROBOTIC SYSTEMS CONTROL IN HARSH ENVIRONMENT

Giacomo LUNGHI

GIACOMO LUNGHI, *lunghi.giacomo@gmail.com,* RAUL MARIN PRADES *rmarin@uji.es,* PEDRO J. SANZ *sanzp@uji.es*, MARIO DI CASTRO *mario.di.castro@cern.ch*

The development of robotic solutions is of great interest for modern industries, especially for those hosting facilities potentially hazardous for their personnel, such as nuclear research centers and nuclear plants. Currently available commercial solutions are often not appropriate for the specific organization needs and require additional work upon purchase for providing satisfactory results. More in details, common robotic platforms for tele-intervention in unplanned scenarios, which could be useful, for example, in extraordinary maintenance in hazardous environments, still do not provide a level of usability and flexibility to improve their diffusion. Human-Robot Interfaces play a critical role in this context, as they are the primary interaction tool with the remote agents. The usability of the interface is essential to improve the accessibility to the robots to more operators. The presented work aimed to create a modular interface for the control of heterogeneous robotic systems for remote unplanned interventions in hazardous environments, ensuring safety, usability, and learnability through multiple interaction modalities. The proposed Human-Robot Interface provides a unique and complete system during the entire robotic intervention process, including preparation, training, optimization, data collection and analysis. Furthermore, it implements high- level functionalities and multiple interaction modalities, which assist inexperienced operators in the accomplishment of their goals. Finally, its modularity ensures the adaptability of the interface to heterogeneous hardware and to new functionalities that could be available in future. The proposed interface has been validated through various tests to prove its usability and learnability, as well as its reliability in several scenarios, such as communication limitations and challenging environmental constraints. Moreover, the proposed interface is currently used at CERN, the European Organization for Nuclear Research, in its particle accelerators, and has been validated, at the time of writing, in more than 120 real interventions and 300 hours of operation.

FISA 2022

Multimodal Human-Robot Interface for Heterogeneous Robotic Systems Control in Harsh Environment

Giacomo Lunghi[1, 2], Raul Marin Prades[1], Pedro J. Sanz[1] and Mario Di Castro[2]

[1]Universitat Jaume I, Castellon de la Plana, Spain

[2]CERN, Geneva, Switzerland

Usable
Easy to use
Easy to learn
Easy to remember

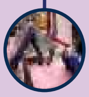
Multi-modal
Multi-sensorial feedback
One-to-many
Many-to-one

Modular
Adapts to robot
Adapts to intervention

Multi-agent
Multi-robot collaboration

Complete
Simulation
Training
Operation
Analysis

Connected
Safe communication
Time-delay handling



Reliable
Safety first
+140 interventions
+300h of operation

The need

Robotic solutions are particularly useful to carry out tasks in those environments that might be hazardous for the personnel. However, robotic systems for teleoperation, in unplanned scenarios, are usually difficult to use, requiring expert operators, and being unable for adapting to unexpected situations and operators' requirements.

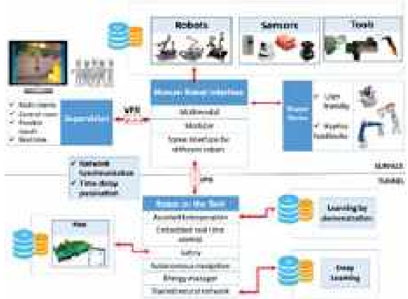
Human-Robot Interaction

Indicates the field of study dedicated to understanding, designing, and evaluating robotic systems for use by or with humans. Remote interaction with mobile manipulators is often addressed as teleoperation or supervisory control, and the human involved in the operation is often addressed as the operator.

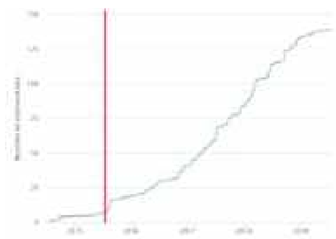
The solution

A unique, multimodal and modular Human-Robot Interface capable to interact with the entire CERN robotic pool.

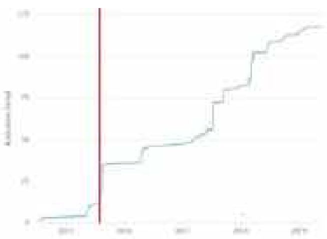
- It integrates with the CERNTAURO framework, a unique framework for remote interventions in hazardous environments.
- It allows operators to control multiple robotic systems simultaneously and in a uniform way, providing complete and non-redundant feedback.
- It uniforms the control strategy among different platforms, to reduce context switch and increase learnability.
- It ensure the reliability of the communication channel over internet protocols, passivating time-delay
- It ensures the safety of the environment and of the robot
- Consistent and safe improvements through continuous integration and deployment software strategies applied to robotic interventions
- It provides a complete system for training, simulation, operation and post-intervention analysis.



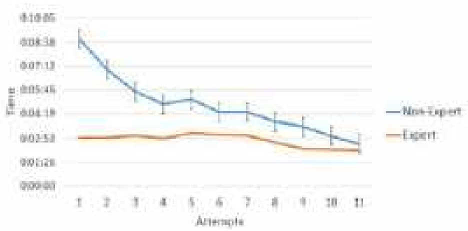
Results



Number of interventions performed

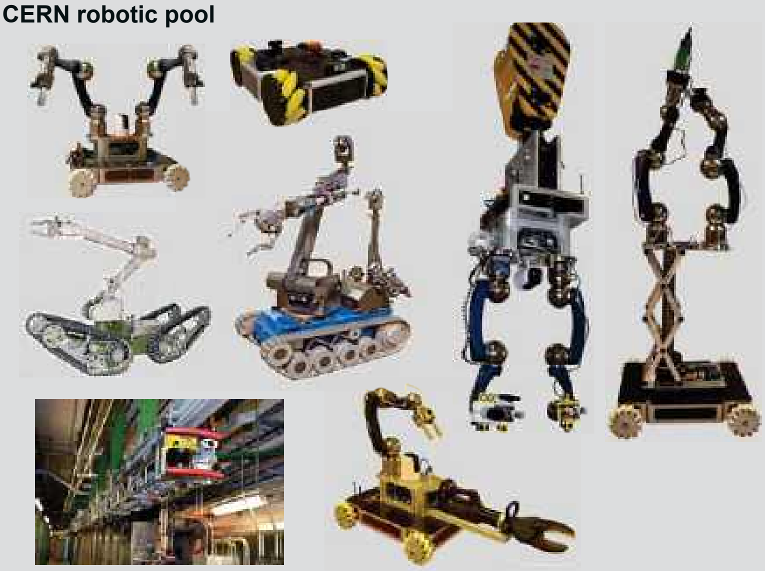


Estimated dose saved



Learnability of the system

CERN robotic pool



Intervention examples

ELSMOR

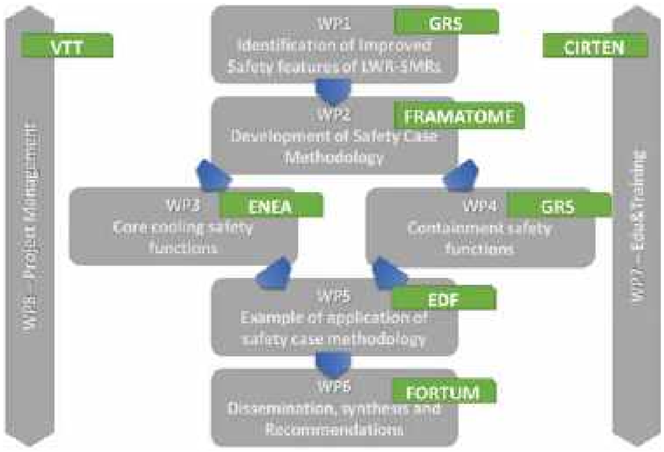
Towards European Licensing of Small Modular Reactors

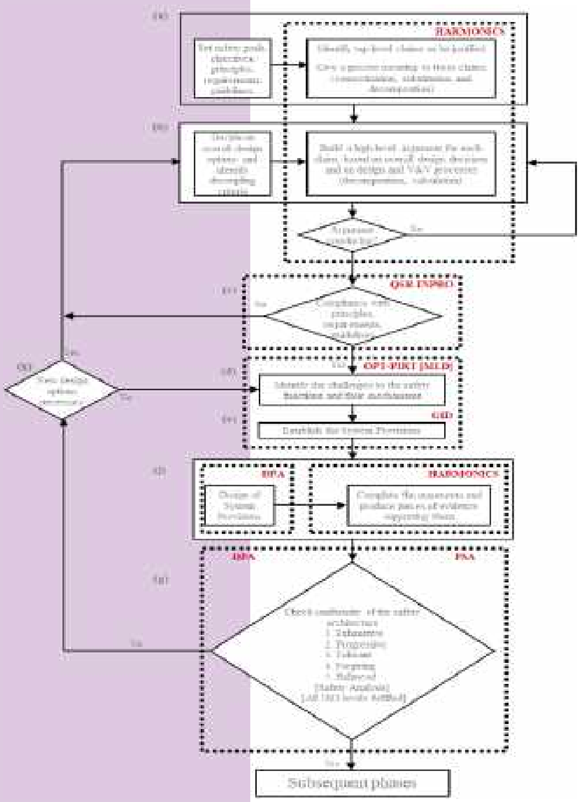
Objectives

The development of Light Water Small Modular Reactors (LW-SMRs) is internationally at the point where various designs are being proposed to be built all around the world. European stakeholders, including the industry, regulators, support organizations and the academia, must be prepared to be able to respond to this change. The ELSMOR project aims to enhance the European capability to assess and develop the innovative SMR concepts and their novel safety features. The work both aims to investigate the safety of the Light Water Small Modular Reactors holistically as well as to drill down in set of topics identified by the consortium to be the most vital in ensuring the compliance of the future SMRs to the safety objectives as established by the amended Directive 2009/71/Euratom.

ELSMOR advances the understanding and technological solutions pertaining to light water SMRs on several fronts: Collection, analysis, and dissemination of the information on the potential and challenges of Small Modular Reactors to various stakeholders, including the public, decision makers and regulators; Development of the high level methods to assess the safety of LW-SMRs; Improvement of the European experimental research infrastructure to assist in the evaluation of the novel safety features of the future LW-SMRs, and; Improvement of the European nuclear safety analysis codes to demonstrate the capability to assess the safety of the future LW-SMRs.

Project consortium





Safety justification scheme based on combination of previous work.
From ELSMOR D2.2: "Overview of safety methodologies for innovative reactor designs, and proposal of a general methodology for LW-SMR"

The project produced a state-of-the-art review of the proposed near term LW-SMRs and their proposed safety features. A methodology for safety analysis wasdeveloped for the innovative LW-SMRs based on the experience in both large reactor analysis methodology as well as the experience in implementing such high-level methodology for Generation IV reactors.

The work on passive safety functions of LW-SMRs in ELSMOR will consist of both experimental and analytical assessments of key safety features. The exact solutions differ between the LW-SMR concepts, but in general the verification of the operation of the passive safety functions and the validation of the analysis codes are vital.

An application of the developed safety case methodologies and models with a chosen reference design will be performed in order to demonstrate their applicability for real cases. The approach will focus on the safety features of the global design, but with special attention and effort on safety systems that differ from large PWRs.

Project website: www.elsmor.eu

This project has received funding from the Euratom H2020 programme 2014-2018 under grant agreement No 847553.

CONTACTS

Technical Project Leader:
Ville Tulkki, VTT Technical Research Centre of Finland ltd
Email: ville.Tulkki@vtt.fi

GEMMA: GEN IV MATERIALS MATURITY

Pietro AGOSTINI

PIETRO AGOSTINI, *ENEA*, ALFONS WEISENBURGER, *KIT*, KAMIL TUCEK, *JRC*, MAYLISE NASTAR, *CEA*, ERICH STERGAR, *SCK-CEN*, MASSIMO ANGIOLINI, *ENEA*, CAMILLO SARTORIO, *ENEA*

GEMMA EU Project addressed materials development and testing for Sodium, Heavy Liquid Metals and High Temperature Helium to be employed in GEN IV reactors.
The main areas addressed are: (1) protective coatings and advanced alumina forming corrosion-resistant austenitic steels for application in heavy-liquid metal-cooled systems; (2) testing of structural steels, protective coatings as well as welds of different type under representative conditions in contact with heavy liquid metals and helium; (3) development of physical models for the prediction of the behaviour of austenitic alloys under long term irradiation.

The poster describes some relevant and interesting new results and observations

FISA 2022

GEMMA: GenIV Materials Maturity

Pietro Agostini[1], Alfons Weisenburger[2] , Kamil Tucek[3], Maylise Nastar[4] , Erich Stergar[5], Massimo Angiolini[1], Camillo Sartorio[1]
1ENEA, 2 KIT, 3 JRC, 4 CEA, 5 SCK-CEN

Management & configuration of GEMMA

Work packages

Technical work packages

WP1: Advanced corrosion mitigation strategies

WP2: Welding development and characterization

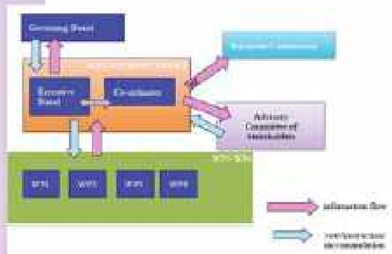
WP3: Irradiation effects: modelling and experiments

WP4: Compatibility with HLM and He coolant

Supporting work packages

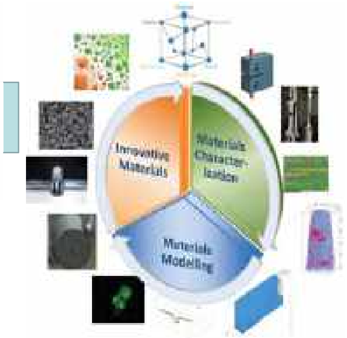
WP5: Consortium management

WP6: Communication, dissemination and exploitation of results



Numbers of GEMMA

Duration in years	4,5
Total number of deliverables to be issued	42
Total cost	6.3 M€
Total EU contribution	4 M€
Number of participants (including KAERI)	23
Number of participating countries	12
Total effort in men-months	699



	Compatibility with coolants	Neutron irradiation effects
Materials Characterization in view of codification	WP4: Compatibility with HLM and He coolant; WP2: Welding development and characterization	
Materials Modelling		WP3: Irradiation effects: modelling and experiments
Innovative Material Solutions	WP1: Advanced corrosion mitigation strategies	

Large amount of experimental data are generated.

Useful rules, for system and component designers, will be deduced.

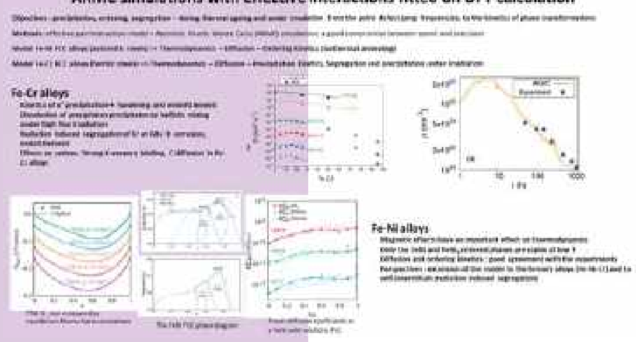
The data are expressed in a suitable way for inclusion in the Design Rules of the RCC-MRx code

The generated data are stored in JRC repository MAT-DB

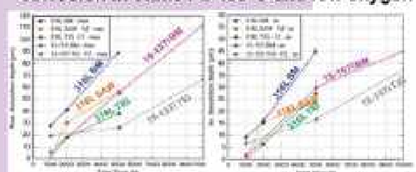
AKMC simulations with effective interactions fitted on DFT calculation

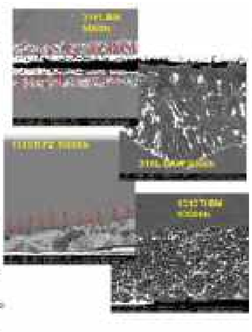
Fe-Cr alloys

Fe-Ni alloys



BASE MATERIAL vs. welded zone corrosion in static Pb 480°C and low oxygen





WELD (FZ) corrosion

- Dissolution corrosion for welds in the FZ (but also in HAZ), with Ni selective leaching and formation of a porous Fe-Cr ferrite layer.
- At short exposure times (1000h and 2000h) some portions of the samples were still unaffected.
- No Cr dissolution in lead, spinodal decomposition of the Cr rich ferrite layer.
- Lower corrosion observed for weld materials (FZ) compared to relative BMs.
- Corrosion in SAW and TIG HAZ's is lower than in BM and higher or comparable to that relative to the FZs.
- Possible effect of δ-ferrite grain boundaries which inhibits diffusion along fast diffusion paths. The effect of the grain size on dissolution has been considered but the large dispersion in the grain size distribution makes hardly possible a numerical correlation.

Interesting observations: Coated steels and AFA are able to mitigate corrosion

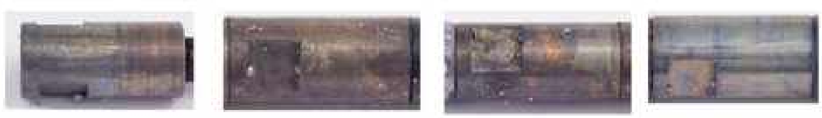
PLD Alumina coating confirmed its superior protective action on 15-15 Ti at 550°C, low oxygen, flowing Pb after 4000 h

AFA 6 and AFA 9 show low corrosion (2-5 um)

Naked 15-15 Ti | Naked 15-15 Ti weld | 15-15 Ti PLD | 316L pack cem. | AFA 6

Interesting observations: negligible corrosion @480°C

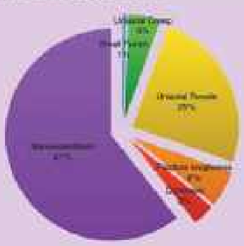
CV-Rez evidenced negligible corrosion of austenitic steels at 480°C,low oxygen, 2 m/s flowing Pb

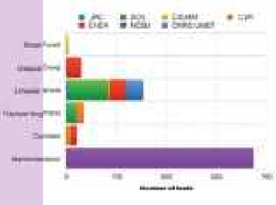


316L 16000 h | TIG 316L 16000 h | SAW 316L 16000 h | 15-15 Ti 16000 h

Repository of GEMMA experimental data

- 1083 validated test results have been entered by partners into the MatDB database https://odin.jrc.ec.europa.eu
- Test results are accompanied by metadata including source information, material pedigree data, specimen information and test conditions.
- All the experimental data coming from GEMMA mechanical testing and corrosion testing will be enabled for citation with DataCite DOIs.





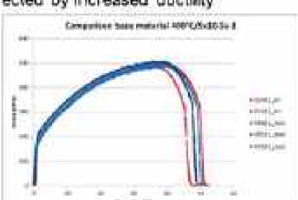
Test	N.
Small Punch	7
Uniaxial Creep	53
Uniaxial Tensile	270
Fracture toughness	60
Corrosion	37
Nanoindentation	656
Tot	1083

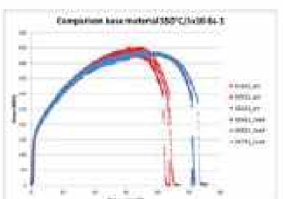
Interesting observations :No embrittling effect due to liquid Pb

The 316L base material doesn't seem to be affected at all by LME (Liquid Metal Embrittlement).

At the temperature of 400°C and with a strain rate of $5x10^{-5}s^{-1}$ the tensile curves achieved in lead almost perfectly superpose to those obtained in air.

Increasing the temperature to 550°C and decreasing the strain rate to $5x10^{-6}$ s^{-1} the steel is even affected by increased ductility





FISA 2022
EURADWASTE'22

ANNEX 4 – TECHNICAL VISITS

Friday 3 June 22	
Day 4 AM-PM	**Technical visits** - JACOMEX - SILEANE - VELAN - CEA Marcoule - ANDRA Cigeo

JACOMEX

https://www.jacomex.com/

Jacomex is leader in the design and manufacturing of:

- inert gas purification units,
- glove boxes for the nuclear, R&D and industrial sectors,
- pharmaceutical isolators,
- customized containment enclosures of all sizes.

The company has a multi-skilled and established 75-years experience and has its main services, as design and production, located at Dagneux, close to Lyon.

Jacomex is worldwide renowned from having permanently focused on technique, strong tightness control and safety. Therefore, the company has developped a varied range of gloveboxes and systems designed for specific applications:

gloveboxes and filtered containment enclosures operating in negative pressure under air or inert gas for the protection of operators and the environment,

gloveboxes in positive pressure working under highly pure inert gas for the protection of air-sensitive products,

standard and custom gloveboxes,

climatic glove boxes,

nuclear purified glove boxes.

The company has also developped specific nuclear ventilation safety equipment, like regulating and safety valves, filter housings and ventilation accessories which have been now in use for decades.

Terms of registration

Departure: 9:00 a.m at Lyon Perrache train station

Expected return: 12:15 p.m at Lyon Perrache train station

30 minutes journey by bus

Required: have your identity papers on the day of the visit.

SILEANE

https://www.sileane.com/en/

Siléane’s men and women have been serving their customers since 2002. They give eyes and hands to “blank” robot arms and endow them with analysis capabilities for many industrial applications (agri-food industry, pharmacy, HPC, environment, plastics industry, micro-technology, automobile, etc.).

Handling, packing, assembling, … sorting waste, deconstructing for recycling, bin picking all kinds of objects, … these are all activities that our technologies serve efficiently for the automation of gestures in random or unknown contexts, where blind robots can no longer operate.

Our teams use all their enthusiasm to innovate in many disciplines (mechanics, mechatronics, robotics, cobotics, vision, artificial intelligence, etc.). So Siléane robots analyse their environment and adapt their gestures and movements in real time to act meticulously, accurately, delicately and speedily. This is what makes them so different!

At the crossroads of digital, optics and automation, Siléane's activity and R&D stimulates the industrial sectors, proof of which is seen in its market-leader products.

Located in Saint-Etienne, Siléane now has nearly 90 members of staff and has a turnover in the order of 11 million Euros.

Terms of registration

Departure at 8:30 a.m at Lyon Perrache train station

Expected return at 6:00 p.m at Lyon Perrache train station

50 minutes journey by bus

Required: have your identity papers on the day of the visit.

VELAN

https://www.velan.com/

Velan France was established in 1974 for supplying the newborn French Nuclear Industry. Located in Lyon (France) in a 20 000 m^2 plant, Velan France is specialized in the design and manufacture of High performance valves for Nuclear, Cryogenic and specific applications (300 people, 70 M€ turnover). With an installed base in 350 nuclear power reactors worldwide and with over 50 years of uninterrupted nuclear experience, Velan is the leading valve supplier for all nuclear reactor technologies: PWR, EPR, VVER, HUALONG, AP1000, BWR, PHWR, CANDU, FBR, AGR and HTR…

As an actor of upstream research and continuous innovation, Velan constantly develops new technologies in order to anticipate the technical and regulatory requirements of future generation of Nuclear Reactors such as GENIII PWR reactors, GENIV sodium cooled Fast Breeder and HTR reactors or GENV "TOKAMAK" fusion reactors.

Terms of registration

Compagnie at Lyon, meeting on site at 10:00 a.m (precise address communicated later)

Access by public transport (tram or metro)

Required: have your identity papers on the day of the visit.

Both CEA and CIGEO visit are submitted to security clearance

CEA Marcoule

https://www.cea.fr/Pages/le-cea/les-centres-cea/marcoule.aspx

The CEA is a key player in research, development and innovation in four main areas: energy transition, digital transition, technology for the medicine of the future and defense and security. Its research activities at Marcoule site are involved in circular economy for low carbon energies. This centre also carries out highly technical clean-up and dismantling projects. During these visits, you will discover 3 facilities: Atalante (fuel cycle), G2/G3 (dismantling projects), and a waste conditioning facility.

Terms of registration

Departure at 7:15 a.m at Lyon Perrache train station

Expected return at 6:30 p.m at Lyon Perrache train station

2 hours journey by bus

Required: if you register for this visit, you agree to send us a copy of your ID (both sides) by email before Thursday, May 19 at 3pm.

ANDRA - Cigéo

https://international.andra.fr/

Cigéo (Industrial Centre for Geological Disposal) is the deep geological disposal facility for radioactive waste to be built in France. Cigéo will serve for disposal of highly radioactive long-lived waste produced by France's current fleet of nuclear power plants, until they are dismantled. This waste results from the reprocessing of spent fuel from these plants. Until the disposal facility is built, the centre includes the Bure Underground Research Laboratory (URL). The scientific and technological research carried out within the Callovo-Oxfordian host clay layer at the Bure URL has supported the Cigéo project for more than 15 year today. Located at - 490 m depth, it now represents a 1,800-metre network of drifts, monitored by more than 11 000 sensors, where over 50 experiments and studies are conducted in real conditions. More than 1000 samples have been drilled for characterisation purposes.

Terms of registration

Departure on Thursday June 2nd afternoon (by bus, to be confirmed), from Lyon

4 hours journey by bus

FISA 2022
EURADWASTE'22

ANNEX 5- LIST OF H2020-EURATOM FISSION PROJECTS

Background information

When preparing any Euratom WPs, principles of 'Openness and transparency' with the stakeholders and MSs are applied, and can summarise as follows:

The preparation and implementation of Work Programme were, and will be, based on openness and transparency. Its priorities were set by the Commission together with MSs, taking into account: (a) the opinion of the Euratom Scientific and Technical Committee (STC); (b) results from the 2021 (and previous) stakeholder consultation[1] (more than 360 replies); (c) inputs and documents published by national public authorities; (d) European Joint Programmes in fusion, radiation protection and radioactive waste management; and (e) academia and nuclear research stakeholders, including European technology platforms or fora.

The Commission received stakeholders' position papers, complemented by impact assessments in relation to H2020 (mid-term, ex-post in 2022) and Horizon Europe (ex-ante) research programmes public consultations, but also various comments from Member States Programme Committee representatives, where a highly important role of public and private research organisations, and universities is highlighted thanks to their involvement in EU/Euratom research, innovation and training actions, as well as within European Joint Programme e.g. EUROfusion, EURAD or CONCERT. The latest EU collaborative platforms (fora or initiatives) strategic documents, roadmaps or review reports are valuable contributions inter alia from the Sustainable Nuclear Energy Technology Platform (SNETP)[2] – composed of the three major pillars, Generation II & III Alliance (NUGENIA), the European Sustainable Nuclear Industrial Initiative (ESNII) and Nuclear Cogeneration Industrial Initiative (NC2I) – the Implementing Geological Disposal Technology Platform (IGD-TP)[3] and the Multidisciplinary European Low-Dose Initiative (MELODI)[4] and other European fora such as the European Nuclear Energy Forum (ENEF)[5], the European Nuclear Safety Regulators Group (ENSREG)[6], the European Technical Safety Organisations Network (ETSON)[7], the Nuclear Europe Industrial Association (ex- European Atomic Forum (FORATOM))[8], the European Energy Research Alliance Joint Programme on Nuclear Materials (EERA JPNM)[9], the Generation IV International Forum

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[1] The stakeholder consultation was open between 18 December 2020 and 17 January 2021.

[2] https://snetp.eu/

[3] https://igdtp.eu/

[4] https://melodi-online.eu/

[5] https://energy.ec.europa.eu/topics/nuclear-energy/nuclear-safety/european-nuclear-energy-forum-enef_en

[6] https://www.ensreg.eu/

[7] https://www.etson.eu/

[8] https://www.nucleareurope.eu/

[9] http://www.eera-jpnm.eu/

(GIF)[10], the Heads of the European Radiological Protection Competent Authorities (HERCA)[11], the International Commission on Radiological Protection (ICRP)[12], the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)[13], together with dedicated international working groups and review reports of the Nuclear Energy Agency (OECD/NEA)[14] and the International Atomic Energy Agency (IAEA)[15] at international level. The HE Euratom Work Programmes and the calls for proposals linked to it are published on the EU 'Funding and tender opportunities' portal[16].

Euratom work programmes are drafted, negotiated, finalised and monitored in collaboration with MS representatives at the Programme Committee(s). And for the Euratom indirect actions (RTD WPs), open competitive calls are launched on a 2 years' basis, and evaluated with the support of independent experts. A process which is proven to be robust for all of parties involved, which allowed the selection of the most innovative and state of the art projects, having a high EU added value. Challenges related to budget constraints, and reached between MS on the thematic areas, capitalisation and continuity between actions remain a true challenge also because of the staff turnover at all levels, acute knowledgeable technical staff ever decreasing within the European Institutions and MS representations. So far, we've managed maintained a certain continuity despite many head winds!
These is also complementing Information shared through the EC CORDIS website, view all H2020 Euratom projects summaries and public deliverables on CORDIS https://cordis.europa.eu/

H2020 Euratom projects (All), Summary Query available at: https://cordis.europa.eu/search?q=contenttype%3D%27project%27%20AND%20(programme%2Fcode%3D%27H2020%27%20OR%20programme%2Fcode%3D%27H2020-Euratom%27)%20AND%20(%27euratom%27)&p=1&num=100&srt=Relevance:decreasing

Funding and Tenders Participant portal https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/home

Dedicated page on HE Euratom 2021-27 Euratom Calls for proposals https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/programmes/euratom2027

[10] https://www.gen-4.org/gif/

[11] https://www.herca.org/
[12] https://www.icrp.org/
[13] https://www.unscear.org/
[14] https://www.oecd-nea.org/
[15] https://www.iaea.org/
[16] https://ec.europa.eu/info/funding-tenders/opportunities/portal/screen/programmes/horizon

Euratom WP2021-22 https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/euratom/wp-call/2021-2022/wp_euratom-2021-2022_en.pdf


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ANNEX 6 - EURATOM STC OPINION FROM 2018

STC Opinion

Legacy messages from the 2013-2018 Mandate

Euratom Scientific and Technical Committee

July 2018

STC Opinion

Legacy messages from the 2013-2018 Mandate

STC-2018-10 FINAL

Euratom Scientific and Technical Committee

FOREWORD

The Euratom Scientific and Technical Committee (STC) is an advisory body established by the Euratom Treaty. The members of the STC are appointed in a personal capacity by the Council of the European Union. The role of the STC is laid out in the provisions of the Euratom Treaty and includes the delivery of opinions on relevant scientific and technical issues, in particular in relation to the Euratom research and training programme.

The Legacy Messages from the 2013-2018 STC have been prepared as a handover note for the new members to be nominated in 2018 by the Council for a 5-year mandate.

OPINION

1. STC visibility and influence

The Euratom Scientific and Technical Committee (STC) is the only scientific and technical advisory body formally enshrined in the Euratom Treaty (Article 134) and active since 1957.

For over 60 years, the STC has provided independent, authoritative advice and opinion on all aspects of nuclear technology. Its members are appointed from all Member States, for a five-year renewable term, as independent experts in nuclear medicine and radiation protection, in nuclear fission reactor systems and fuel cycles, waste management and thermonuclear fusion. The STC is also responsible for nominating the experts advising the Commission on the basic standards for radiation protection (the Article 31 Expert Group) and on the assessment of the health impact of radioactive release from nuclear facilities (the Article 37 Expert Group).

The STC has always provided valuable advice even in times unfavourable to the development of nuclear energy. It is vital that the STC continues to be seen as a source of unbiased evidence-based scientific advice that allows the Commission to take informed policy decisions. The STC must not be perceived as a body the sole purpose of which is to promote nuclear energy. It is imperative that the next STC wilfully maintains its visibility and influence as the first-choice 'go to' Advisory Body in matters nuclear for the Commission; in particular given the plethora of other advisory bodies which exist but which are not mandated by the Treaty.

It is also important that the next STC continues to remain proactive in terms of giving advice and to maintain its responsiveness to the needs of the Commission and Parliament. Recognising that political constraints do influence decisions on research funding within the Euratom budget, the future STC should pay close attention to the political side of projects and thus develop its opinions and advice in such a fashion that progress with projects is not hampered. Finally, account shall be taken of the varying and, possibly, opposing interests of participating countries in some domains, be these linked or not with the scientific objectives of the projects.

2. Working Practice

During the 2013-2018 mandate the STC has performed its duties through formal meetings including visits to three of the Joint Research Centre (JRC) sites (Geel, Ispra and Karlsruhe) and by more frequent meetings or interactions by email of Working Groups (WGs) covering Infrastructure, Radiological Protection, Future Systems and Fuel Cycles, Decommissioning and Fusion. The main discussions, evidence gathering and drafting took place within these WGs before the STC's formal Opinions are concluded in the plenary meetings.

The future STC membership should understand how important proactive participation and contributions to the WGs are to enable the STC's role to be fulfilled.

3. Importance of past work, opinions and advice

During the 2013-2018 mandate and over the preceding decade various STC Opinions, Reports and Inputs to the Commission were drafted and published. Much of the work will still be relevant to the new STC.

The Opinions developed over this STC's mandate are particularly important from the point of view of ensuring key recommendations are progressed and actioned. A summary of the key points made is provided here for the benefit of new members

On many previous occasions, the STC had emphasised the need for Europe to stay abreast of international developments in the nuclear sector and retain, through active participation in collaborative research, important influence on key safety and environmental protection issues internationally. The 2013-2018 STC provided a detailed, multifaceted Opinion covering Future Fission Systems and Fuel Cycles, Radiological Protection, Infrastructure, Waste Management and Decommissioning and a separate stand-alone Opinion on the Fusion Roadmap. It drew the following important conclusions that will be relevant to the future STC:

- The significant role played by nuclear energy in certain Member States as a component of low carbon electricity supply and contributing to the competitiveness of European Industry;
- The understanding that all EU Member States, even those with no nuclear power plants, have an interest in ensuring nuclear safety throughout the EU;
- The importance of a European contribution, both as regards safety culture and technological and industrial know-how, in ensuring that appropriate attention is paid to the safety, sustainability, non-proliferation and competitiveness aspects of advanced, so-called Generation-IV, systems as progress is made internationally towards industrial scale deployment of these systems around the middle of the 21st Century;
- The need for Member States to prioritise which advanced systems and associated fuel cycles should be supported in order to ensure meaningful progress with the limited resources available;
- Maintaining flexibility within current and future Euratom programmes to keep abreast of these emerging technologies, including those given high priority internationally in key third countries and

paradigm shifts such as a possible recourse to smaller modular reactors;

- Ensuring a vibrant education and training culture, involving basic academic education and continuous professional development, focused on advanced technology across all nuclear topics to guarantee that a new generation of experts will be available when needed and to maintain high levels of safety throughout the sector;
- The important role played by nuclear technology and related competence and expertise in the fields of medicine, radiation protection and non-energy applications, and the need in general for the Euratom programme to be seen as an integral part of the broader Horizon 2020 initiative and later Framework Programmes, able to capitalise on synergies over a much wider range of research areas;
- The need for a strongly coordinated nuclear fusion research programme focussed on the implementation of the Fusion Roadmap;
- The need for a robust, enduring and efficient infrastructure base across the EU to underpin all aspects of research and innovation throughout the sector;
- The importance of including decommissioning and dismantling R&D which reflects the need to grow capacity and capability to undertake these activities in the future and stimulate exchange of good practice and efficient and effective knowledge management.

Furthermore, in view of the findings of the WGs set up to provide detailed input in deriving its Opinion, STC would in particular like to emphasise for action by a future STC:

- The urgent need for a coordinated and coherent approach to infrastructure investment that must be undertaken if the EU is to ensure value for money, appropriate leverage both between and within the 'direct actions' and 'indirect actions' components of the Euratom research and training programme, and enduring capacity and capability in facilities that underpin nuclear technology and that are vital for Member States in all related fields, including those essential for medicine and radiation protection, security and safeguards;
- The risks inherent in continued underinvestment in advanced nuclear systems, and that failure to grasp opportunities at either the European level or in support of leading Member States will mean that the EU is no longer able to fulfil its potential and occupy its rightful position in the evolving international initiatives in this field;
- That, in this regard, Europe is in danger of ceding leadership in both advanced reactor systems and fuel cycle technologies to China, India and Russia, and in so doing will fail to bring to bear its significant expertise, know-how and influence so vital in ensuring the highest standards of safety, security, waste management and non-proliferation are achieved and maintained globally;
- The need to continue the R&D efforts on waste management and geological disposal associated with the existing reactor fleet;
- The significant cross-cutting benefits that can be realised between fission and fusion energy research programmes as the latter evolves from one focused on basic plasma physics to one focused more on technology and nuclear-related aspects;
- The need to maintain the effort in radiation protection research where the focus remains the area of low-dose risk, which has important implications for EU citizens in view of the growing exposure from medical diagnostic and therapeutic practices and in which research actions should therefore be co-funded by the Horizon 2020 health programme, enabling the limited Euratom funding to be focused on priorities related to nuclear technology, such as the efficient production of radioisotopes for medical purposes and biological research;
- The need for the European programmes to include R&D in the field of Dismantling and Decommissioning to maintain capacity and capability to undertake these activities in the future.
- The paramount importance of guaranteeing an adequate supply of experts and trained workers in view of the increasing demand across the full scope of disciplines coupled with the ageing and imminent retirement of a generation of experts and the role that the Euratom programme, as a research and training programme, can and should play in ensuring this supply.

Additionally, the following topics are those where the retiring STC feels particular attention should be paid by the incoming STC.

4. Socio-economic research

Previously, the STC had recommended that specific actions might need to be taken to better inform, contextualise and communicate different aspects of nuclear energy (both fission and fusion). It is important that regulation of the sector is proportionate to the risk. Security of supply, cost and environmental impact as well as radiation must be set into context in comparing nuclear energy at the system level with other sources of energy. Perception of risk and proportionality in comparing nuclear waste with hazardous wastes from other sectors should also be investigated. It would be particularly helpful in gaining broader support for advanced nuclear technology to encourage early and unbiased assessments of new technological options under research. Such assessment studies on a European Level should include comparison with other energy options.

It is suggested that the new STC works with the Commission to better address these issues in the coming mandate.

5. Safety and Operation of Nuclear Reactors: technology, safety culture and human factors

The EU had previously shown strong leadership in fission reactor design and operation with stringent safety requirements. Challenges in the development of nuclear energy include issues related to the technological process, economics and scale of waste management operations and public acceptability and the emergence of new technologies not developed in the EU internationally.

Since the first demonstration of the possibility to ignite and control the fission nuclear reaction in 1942, the number of reactors ever built is in the range of 400 and the number of severe accidents (e.g. Chernobyl, Fukushima) is low but with huge social and political impact, highlighting the importance of safety culture and human factors.

The STC should encourage the Commission as well as the international community more generally to foster further convergence on approaches to nuclear safety within their research portfolio considering technical processes intertwined with safety culture and human factors.

6. Fusion Roadmap Assessment

A comprehensive review was undertaken by the STC Fusion WG in 2018 and is part of the final formal Opinion from the 2013-2018 mandate so very relevant going forward. It was recommended that a further critical review of progress against the revised Roadmap should be made by the new STC. It was also recommended that lessons learned from ITER should be assimilated and that further DEMO-relevant development efforts should be considered in parallel with ITER in the areas of advanced materials, high temperature superconductors, advance diverter concepts and steady state concepts particularly the stellarator.

7. The Joint Research Centre (JRC)

Historically, the STC has not delved deeply into the research carried out by the JRC nor commented on the balance of funding between direct (JRC) and indirect (RTD) actions. Visits and scrutiny carried out during the 2013-2018 mandate, including the asking of detailed formal questions, reinforced the view that there is some potential for further integration and bridging of research from both direct and indirect actions within the Euratom Programme and with the wider future research portfolios. Good progress has been made and a future STC will need to oversee how the synergies between direct and indirect actions and the wider synergies from the non-nuclear parts of the Horizon 2020 programme can be further pursued.

8. Research in support of radiological protection, notably regarding medical applications of radiation

Previously, the STC had noted that the negative perceptions of nuclear energy and of radiation do not seem to apply to medical uses of the technology. It is also clear that there is a lack of understanding among many politicians and public alike about the origins of medical isotopes used to cure cancers or improve medical diagnostics.

The Radiological Protection WG delivered a comprehensive report as part of the STC Opinion and engaged extensively with the Article 31 Group of Experts in identifying the main issues on which to concentrate:

- The need to focus on the main exposures : medical with special attention to new techniques (hadrontherapy, α emitters and correct compliance with justification) and to children (who are not little adults), radon and potential accidental exposures directly or via the contamination of the environment (on-site and off-site, short- and long-term, back to “normality”)
- The need to focus on biological effects to determine trustworthy short- and long-term impacts on health and on the main radiobiological issue, i.e. the differences in individual response to ionising radiations which pave the way to three clinical features and shall have important consequences in the future of radiological protection:
  - The complications and side effects of radiation therapy when there are no errors in dose delivery (radiosensitivity)
  - Radio-induced or radio-favoured cancers (radiosusceptibility)
  - Non-cancer late degenerative effects such as radio-induced cataracts or cardiovascular effects (radiodegeneration)
- Ethical issues are not to be forgotten. There are consequences to a personalized approach due to individual differences. Low-dose effects research takes its full place and meaning for radiosusceptible persons who are certainly cancer-prone in general (whatever the genotoxic compounds). This may represent up to 20% of the population as a continuum between normal and very abnormal, a true public health issue.
- The need to develop and favour stem cell therapy for the treatment of radiological burns
- The importance of focusing on education of and clear information to the public, including transparency in risk communication and stakeholders empowerment to cope with psychosocial effects

- The training of professionals not to lose competences at time of 'pappy/mammy boom' retirement.

Research into nuclear medicine is included within the Euratom Treaty although 'medical treatment' is beyond the scope, so the STC recommended that there should be greater efforts to develop beneficial links with the much larger EU health research programme. It would also seem sensible for the future STC to recognise the advantages of aligning some Euratom research which is focused on medical applications with topics which could benefit e.g. Generation IV systems.

The STC will also have to consider issues related to the need for an ongoing reliable supply of radioisotopes for use in the EU.

9. Euratom-relevant Infrastructure

Given that Europe needs to keep its capability in carrying out experimental and safety programmes on both nuclear fission and fusion aiming at maintaining further developments in nuclear energy, special attention should be given to infrastructure which will underpin:

- Development of new and innovative concepts and technologies;
- Plant safety and risk assessment;
- Management of severe accidents;
- Improved reactor operations;
- Thermal hydraulics and coolant interactions;
- Integrity assessment of systems, structures and components;
- In service inspection, inspection qualification and non-destructive evaluation;
- Numerical simulation of existing and future reactor technologies;
- Nuclear fuels;
- Materials behaviour;
- Spent fuel, waste management and decommissioning;
- Radioisotope production and nuclear medicine;
- Codes and standards, harmonisation and pre-normative research.

Europe also needs to keep its capability to carry out experimental programmes to develop nuclear fusion into a safe, economic, environmentally benign and valuable energy source. This requires the maintenance of competences in the following fields:

- Robust burning plasma regimes, the conventional physics solution for power exhaust, validation of tritium breeding blankets, aiming at making ITER a success;
- Heat exhaust, materials and tritium breeding and advanced components, in order to realize the innovations necessary for DEMO;
- Design and system development (remote maintenance and heating and current drive), intrinsic safety, stellarators, theory and modelling (for extrapolation to DEMO and fusion power plants) aimed towards competitive cost of electricity;

The Infrastructure WG recommended the set-up of a programme on nuclear research infrastructures in Horizon 2020 and beyond with the following main objectives:

- Improve the present nuclear energy technology, based on fission reactions as well as to bring nuclear fusion to a commercial available energy technology;
- To increase the synergies between fission and fusion.
- To foster the application of nuclear and ionizing radiation techniques to health, industry, food and agriculture, cultural heritage and environment.
- To contribute to an increase of the public understanding of nuclear matters.

It importantly identified the need for the STC to scrutinise the role JRC infrastructure plays within the EU overall nuclear research infrastructure, so that optimum use is made of existing and planned assets within the individual Member States given the findings and recommendations of the Infrastructure WG.

10. Advanced nuclear systems including SMRs and fuel cycles

The 2013-2018 Opinion covered these topics in detail, it is recommended the future STC carefully scrutinise the Commission's proposals for future calls for research against the recommendations and monitors progress made.

11. Decommissioning

Previously the STC recommended that, given the number of power plants which will need to be decommissioned across the EU, it is important that efforts to maximise the sharing of information and lessons learned are encouraged and international collaboration facilitated. The STC will need to ensure that an early good understanding of risks is developed to avoid overly complicated and expensive solutions and that appropriate attention is given to the challenge of developing the necessary human resources.

What has changed more recently is the increased focus on and likely increase of the pace of decommissioning activities in the nuclear power and non-power sectors along with the divergence of opinion on the need for nuclear power, including an increase in the potential for new nuclear build in some member states and accelerated decommissioning in others . This has added impetus to geological disposal and long-term management of wastes and costs of existing decommissioning activities and the ability to maintain a skills base to support this.

There has also been a significant change in relation to the Low Carbon Agenda. If the EU is to meet its targets, it would seem there will be a future role for nuclear and continued R&D spending on fusion and SMR and other advanced systems if not LWR technology and those areas where Europe might wish to maintain its engineering and scientific capability.

The points from the Decommissioning WG for the future STC are:

- The technology and research to support the engineering side of decommissioning is mature. This is consistent with earlier STC opinions and should probably be re-affirmed

- Where there is a gap, it is in relation to Europe's ability to characterise the radioactive inventory in relation to the wide range of differing and evolving standards across member states. This means there is potential impact on costs if radionuclide concentrations are overestimated and risk to reputation if radioactive waste content is underestimated leading to inappropriate disposal of the waste, leading to a loss of public confidence.

- The need to maintain R&D spending to support a forward cohort of engineering and scientific capability and skills to enable the EU to manage its own facilities and embark increasingly on decommissioning – and, as it seems more likely, be an intelligent client to those parts of the supply chain both internal and external to the EU.

12. Opening up other research fields for Euratom research

The outgoing STC has indicated for a number of years that the budget for fission research within the Euratom Framework Programme is insufficient to enable the most important topics to adequately progress. It has sought to encourage and recommend that synergy is sought from cross-cutting initiatives in other EU research fields, *inter alia* materials and medicine and from the basic research programme as well from the fusion programme. The future STC will need to continue to press for this to happen. The future STC should also consider supporting increased funding for activities that can and should be pursued in parallel to ITER and are of critical importance at the DEMO and reactor stage for fusion energy, as described in Section 6.

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FISA 2022
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ANNEX 8 - LIST OF ABBREVIATIONS

FISA 2019 LIST OF ABBREVIATIONS AND ACRONYMS

ABET	Accreditation Board for Engineering and Technology
ADRIANA	ADvanced Reactor Initiative And Network Arrangement
ADS	Accelerator-Driven System
AFCEN	Association Française pour les règles de Conception, de construction et de surveillance en exploitation des matériels des Chaudières Electro Nucléaires
ALFRED	Advanced Lead Fast Reactor European Demonstrator
ALLEGRO	European Gas-Cooled Fast Reactor Demonstrator
ALLIANCE	European Radioecology Alliance
ANENT	Asian Network for Education in Nuclear Technology
ASTM	American Society for Testing and Materials
ASTRID	Advanced Sodium Technological Reactor for Industrial Demonstration
ATF	Accident Tolerant Fuels
CANDU	Canada Deuterium-Uranium Reactor
CBRN	Chemical, Biological, Radiological and Nuclear
CCS	Carbon Capture and Storage
CEN	Comité Européen de Normalisation / European Committee for Standardization
CENELEC	Comité Européen de Normalisation Electrotechnique / European Committee for Electrotechnical Standardization
CERN	European Organization for Nuclear Research
CfD	Contract for Difference
CSA	Coordination and Support Action
CSP	Concentrated Solar Power
CERN	European Organization for Nuclear Research
DEMO	DEMOnstration fusion Power Plant
DEVCO	EC Development and Cooperation Directorate General
D-T	Deuterium-Tritium
EC	European Commission
ECTS	European Credit Transfer System
ECVET	European Credit System for Vocational Education and Training
EEPR	European Energy Programme for Recovery
EERA	European Energy Research Association
EESC	European Economic and Social Committee
EFSI	European Fund for Strategic Investments
EFTS	Euratom Fission Training Scheme
EGE	European Group on Ethics in Science and New Technologies
EHRO-N	European Human Resources Observatory in the Nuclear Energy Sector
EIB	European Investment Bank
EII	European Industrial Initiative
EIT	European Institute of Technology
EJP	European Joint Programme
EMINE	European Master in Innovation in Nuclear Energy (KIC InnoEnergy)
EMSNE	European Master of Science in Nuclear Engineering
ENEF	European Nuclear Forum Energy
ENEN	European Nuclear Education Network Association
ENEF	European Nuclear Forum Energy
ENIQ	European Network for Inspection and Qualification
ENS	European Nuclear Society
ENSRA	European Nuclear Security Regulators' Association
ENSREG	European Nuclear Safety Regulators Group
EPR	European Pressurised Reactor
ERASMUS+	EU's programme to support education, training, youth and sport in Europe

ERC	EC European Research Council
ERDF	Cohesion Policy funds and European Development Regional Funds
ERIC	European Research Infrastructure Consortium
ESFRI	European Strategy Forum on Research Infrastructures
ESNII	European Sustainable Nuclear Industrial Initiative
ETKM	Education, Training and Knowledge Management
ETP	European technology platform
ETS	Emissions Trading System
ETSON	European Technical Safety Organisations Network
EU	European Union
EUA-EPEU	European University Association European Platform of Universities in Energy
EURADOS	European Radiation Dosimetry group on dosimetry research
EURAMED	European Alliance for Medical Radiation Protection Research
F4E	Fusion for Energy
FIIF	Fusion Industry Innovation Forum
FNR	Fast Neutron Reactor
FOAK	First Of A Kind
FORATOM	European Atomic Forum
FR	Fast Reactor
FUSENET	European Fusion Education Network
GFR	Gas-cooled Fast Reactor
GHG	Green House Gas
GIF	Generation-IV International Forum
H2020	Horizon 2020 - The EU Framework Programme for Research and Innovation
HERCA	Heads of the European Radiological Protection Competent Authorities
HLM	Heavy Liquid Metal
HTGR	High Temperature Gas-cooled Reactor
HTR	High Temperature Reactor
HTRR	High Temperature Research Reactor
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IGD-TP	Implementing Geological Disposal Technology Platform
InnovFin	H2020 Risk Sharing Finance Facility
INPRO	International Project on Innovative Nuclear Reactors and Fuel Cycles
IP	Implementation Plan
ISO	International Organization for Standardization
ITER	International Thermonuclear Experimental Reactor
JET	Joint European Torus
JPNM	EERA Joint Programme on Nuclear Materials
JRC	European Commission's Joint Research Centre
KIC Inno	Knowledge and Innovation Community InnoEnergy
LANENT	Latin American Network for Education in Nuclear Technology
LCEE	Low Carbon Energy and Efficiency
LFR	Lead-cooled Fast Reactor
LLW	Low Level Waste
LTO	Long Term Operation
LWR	Light Water Reactor
MA	Minor Actinides
MELODI	Multidisciplinary European Low Dose Initiative
MFF	Multiannual Financial Framework
MMO	Man-Machine Organisations
MOU	Memorandum of Understanding
MOX	Mixed Oxide Fuel
MS	Member State
MSCA	EC Marie Skłodowska-Curie Actions

MSR	Molten Salt Reactor
MYRRHA	Multi-Purpose Hybrid Research Reactor for High-tech Applications
NC2I	Nuclear Cogeneration Industrial Initiative
NEA	OECD Nuclear Energy Agency
NERIS	European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery
NGNP	New Generation Nuclear Plant
NI2050	OECD/NEA Nuclear Innovation 2050 roadmap
NKM	Nuclear Knowledge Management
NPP	Nuclear Power Plant
NUGENIA	Nuclear Generation II and III Association
NURESIM	Nuclear Reactor Simulation Platform
OECD	Organisation for Economic Co-operation and Development
ODS	Oxide Dispersion-Strengthened
P&T	Partitioning and Transmutation
PIE	Post-Irradiation Examinations
PINC	Nuclear Illustrative Programme
PRPPWG	GIF Proliferation Resistance and Physical Protection Working Group
PSA	Probabilistic Safety Assessment
PWR	Pressurised Water Reactor
Q	Fusion Energy Gain Factor
R&D	Research and Development
R&D&I	Research Development and Innovation
R&I	Research and Innovation
RCC-MRx	Règles de Conception et de Construction pour les Matériels mécaniques des structures à hautes températures et des Réacteurs expérimentaux et à fusion
RES	Renewable Energy Source
RI	Research Infrastructure
RSFF	Risk Sharing Finance Facility
RSWG	GIF Risk and Safety Working Group
RTD	EC Research and Innovation Directorate General
SAMG	Severe Accident Management Guidelines
SCWR	Supercritical Water-cooled Reactor
SET-Plan	Strategic Energy Technology Plan
SETIS	Strategic Energy Technology Information System
SFR	Sodium-cooled Fast Reactor
SIAP	Senior Industry Advisory Panel
SMR	Small Modular Reactor
SNETP	Sustainable Nuclear Energy Technology Platform
SRIA	Strategic Research and Innovation Agenda
STC	Euratom Scientific and Technical Committee
STEM	System for the Education and Training of Scientists and Engineers
TWG	Temporary Working Group
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
VHTR	Very High Temperature Reactor
WENRA	Western European Nuclear Regulators Association

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ANNEX 9 - REFERENCES

- SFEN
  - https://www.sfen.org/
  - https://www.sfen.org/evenement/fisa-2022-euradwaste-22/

- Selected articles are published in a special issues of EPJN
  - https://www.epj-n.org/
    - https://www.epj-n.org/component/toc/?task=topic&id=1727
    - https://www.epj-n.org/component/toc/?task=topic&id=1722
- The 2nd ORIENT-NM workshop was held on 31 May 2022 at FISA 2022 2nd ORIENT-NM WORKSHOP - 31 May 2022 at FISA 2022
  - http://www.eera-jpnm.eu/orient-nm/events/230-
  - Main webpage of this initiative EERA-JPNM Joint Programme on Nuclear Materials http://www.eera-jpnm.eu/
- Side event ENEN PhD Event & Prize Year 2022, a summary is attached and details are also available at https://enen.eu/index.php/phd-events/phd-ep-year-2022/
- Side event ENS YGN workshop, AWARD and PRIZE Pitches', Posters and Ehibitions documentation are also included
- SNETP FORUM 2022 annual event gathering was organised on THU all day. Documentation is attached and should be available within the Euratom4U App.

  Also available at the SNETP dedicated webpage https://snetp.eu/2022/06/13/snetp-forum-2022-presentations-and-proceedings-available/
- Pictures of the Conferences and Events of the week are available, I have generated a summary overview of each days, and the photographer album is open and publically available at https://www.timdouet.fr/-/portfolio/clients/fisa-cea-2022-lyon
- PUBLICATIONS
  - FISA 2022 - EURADWASTE '22, 10th European Commission conferences on EURATOM research and training in safety of reactor systems & radioactive waste management : programme overview https://op.europa.eu/en/publication-detail/-/publication/0b7748f5-e08d-11ec-a534-01aa75ed71a1

- o FISA 2022, 10th European Commission conferences on EURATOM research and training in safety of reactor systems & radioactive waste management : book of abstracts https://op.europa.eu/en/publication-detail/-/publication/3e9e0802-e08c-11ec-a534-01aa75ed71a1/language-en/format-PDF/source-search

- o EURADWASTE ’22, 10th European Commission conferences on EURATOM research and training in safety of reactor systems & radioactive waste management : book of abstracts https://op.europa.eu/en/publication-detail/-/publication/d65cd77d-e08a-11ec-a534-01aa75ed71a1/language-en/format-PDF/source-search

- The application Euratom4U was created and designed for the event by Superevent from the Netherlands, the perfect all-in-one event platform to power in-person, virtual and hybrid events: https://superevent.com/

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FISA 2022, the 10th European Commission (EC) conference on Euratom Research and Training in Safety of Reactor Systems was held under the auspices of the French Presidency of the Council of the European Union (EU) in Lyon, on 31 May - 3 June 2022. It was co-organised together with the CEA and concurrently with the 10th EURADWASTE '22 conference on the management of radioactive waste and geological disposal in Europe. FISA 2022 technical sessions covered progress of the research carried out through 60 projects such as safety of existing nuclear installations; severe accidents prevention and mitigation including emergency management; advanced nuclear systems and fuel cycles for increased safety and sustainability, numerical simulation and digitalisation, innovative materials, low dose radiation protection, decommissioning, research infrastructures, education & training and mobility of researchers, as well as cross-cutting actions such as International Cooperation. The proceedings include written contributions from invited presentations and posters, session summaries and panel reports.

Studies and reports

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