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Joint European Canadian Chinese development of Small Modular Reactor Technology

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Abstract:
This deliverable outlines the results of the workshop on “Thermal hydraulics and neutronics of the SCW-SMR” held in June 2023 in Celje, Slovenia.

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Executive Summary

The workshop on “Thermal hydraulics and neutronics of the SCW-SMR” held in June 2023 in Celje, Slovenia, could be considered as one of the major milestones for the ECC-SMART project. It provided an opportunity for critical discussion and dissemination of knowledge concerning the Safety of Small Modular, Advanced and Fusion Reactors. This event not only marked a significant achievement in the project timeline but also showcased the progress of the project and distinguished future steps forward.

The Workshop took place under implementation of Task 6.3 of the Work Package 6 of the ECC-SMART project.
A key highlight of the workshop was the demonstration of active collaboration with other EU project teams in relation to the pre-licensing studies and the guidelines for the demonstration of the safety of the SCW-SMR concept. The workshop was devoted to the technical presentations by participants of the Euroatom funded HARMONISE, ECC-SMART and ELSMOR projects. This synergy was aiming to sharing insights, methodologies and best practices as well as to promote, sustain and increase the stakeholder’s awareness on the on-going efforts to develop strong safety cases in reactor safety for small modular, advanced and fusion reactors. The workshop plays an important role in fostering a collaborative environment within the EU scientific community.
The workshop also served as a platform for sharing findings of the ECC-SMART project with a broader audience, while the contributors emphasized the commitment of the project to transparent communication of its scientific advancements.

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List of acronyms and abbreviations

Acronym/Abbreviation	Definition
ALFRED	Advanced Lead Fast Reactor European Demonstrator
BelV	A technical safety organization in Belgium that provides nuclear safety assessments and inspections, part of the Belgian Nuclear Regulatory Body.
BME	Institute of Nuclear Techniques of the Budapest University of Technology and Economics
CAA	Civil Aviation Authority
CEA	French Alternative Energies and Atomic Energy Commission
CFD	Computational Fluid Dynamics
CIEMAT	Centre for Energy, Environmental and Technological Research
CO	Confidential
DG RTD	European Commission Directorate-General for Research and Innovation
EASA	European Union Aviation Safety Agency
EC	European Commission
ECC-SMART	(Joint) European Canadian Chinese development of Small Modular Reactor Technology
ELSMOR	European LWR Sustainable Operation and Reliability
ENEA	Italian National Agency for New Technologies, Energy and Sustainable Economic Development
ENEN	European Nuclear Education Network
ENSREG	European Nuclear Safety Regulators Group
EU-CON	European Union Confidential
EURATOM	European Atomic Energy Community
EU-RES	European Union Restricted
EU-SEC	European Union Secret
GIF	Generation IV International Forum
IAEA	International Atomic Energy Agency
JSI	Jožef Stefan Institute
KIT	Karlsruhe Institute of Technology
LFR	Lead-cooled Fast Reactor
NEA	Nuclear Energy Agency (part of OECD)
NFRP	Nuclear Fission and Radiation Protection
OECD	Organisation for Economic Co-operation and Development

PU	Public
RATEN	Technologies for Nuclear Energy State Owned Company, Romania
R&D&I	Research and Development and Innovation
RPV	Reactor Pressure Vessel
SCW-SMR	Supercritical Water-cooled Small Modular Reactor
SMR	Small Modular Reactor
STUK	STUK International: An organization involved in nuclear safety and radiation protection, providing expertise and services for the safe use of nuclear energy and radiation.
T-I RIPB	Technology-Inclusive Risk-Informed Performance-Based
VTT	VTT Technical Research Centre of Finland Ltd
WP	Work Package

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Annex 4: Feedback from students

1 Introduction

1.1 Project summary

The Joint European Canadian Chinese development of Small Modular Reactor Technology (ECC-SMART) is a multinational project focused on the development and licensing of the future Supercritical Water-cooled Small Modular Reactor (SCW-SMR).

The ECC-SMART project main objectives are:

- to provide science-based recommendations and methodologies for performing safety evaluations and safety improvements fostering the safety standards, including the experimental validation of essential items for safety demonstrations related to the SCW-SMR,
- to derive the most economical safety-driven SCW-SMR design requirements by identifying adequate solutions to key technical issues which drive cost and safety and their influence to the future licencing process,
- to increase the level of knowledge as well as the interest of the industrial partners and demonstrate the benefits of the SCW-SMR concept.

1.1.1 Purpose of this document

This document is the second deliverable of the Work Package 6 “Dissemination and communication” lead by ENEN and the first in series of the proceedings to be issued following the project workshops: Workshop on thermal hydraulics and neutronics of the SCW-SMR, Proceedings of Workshop on structural materials for GEN IV SMR concepts and Proceedings of the ISSCWR. It provides the Proceedings of the Workshop on thermal hydraulics and neutronics of the SCW-SMR held in Celje, Slovenia, in June 2023. The deliverable aims at the following objectives:

- to share insights, methodologies and best practices.
- to promote, sustain and increase the stakeholder’s awareness on the on-going efforts to develop strong safety cases in reactor safety for small modular, advanced and fusion reactors.

The deliverable also collects information provided in the presentations of the representatives of the ELSMOR and HARMONISE projects.

2 Workshop Programme

The Workshop on the Safety of Small Modular, Advanced and Fusion Reactors, held in Celje, Slovenia, in June 2023, focused on the safety and licensing aspects of advanced nuclear reactors and facilities. The two-day event featured a blend of in-person and virtual participation. The workshop began with an opening session, setting the purpose and welcome words from the organising team.

This was followed by a series of invited contributions addressing topics including regulatory viewpoints on EU-SMR pre-partnership, EURATOM Work Programme 2023-2025, OECD/NEA SMR Dashboard, IAEA activities on new technologies, etc.

The first day also included discussions on the fusion safety approaches and principles for aviation safety regulation in the EU. Project overviews of HARMONISE, ECC-SMART, ELSMOR and the ALFRED initiative were key highlights of the first day.

The second day delved into specific safety features, covering projects like McSAFER and ECC-SMART and exploring topics like thermal hydraulics and neutronics safety considerations. The workshop concluded with a moderated panel discussion that synthesized information from the sessions and aimed to formulate key messages.

The Programme of the workshop is provided in Annex 1.

Below is the detailed description of the contributions of the Workshop, outlining the key topics addressed, the insights shared by various experts and a summary of the significant discussions and outcomes that emerged from the sessions.

All presentations are provided in Annex 2.

2.1 EU-SMR pre-partnership activities – regulatory point-of-view, Eetu Ahonen, ENSREG, STUK (Remote)

The presentation titled "EU-SMR pre-partnership activities – regulatory point-of-view" by Eetu Ahonen focuses on the objectives and activities aimed at facilitating the safe design, construction and operation of Small Modular Reactors (SMRs) in Europe within the next decade. It covers various aspects such as market analysis, licensing, financing, supply chain adaptation and R&D&I roadmap. The presentation also delves into the establishment of a pre-licensing process based on commonly accepted safety assessments and the coordination of these efforts through various working streams and a steering committee. Additionally, it discusses the challenges and future steps towards the establishment of a European SMR partnership by the end of 2023.

2.2 Overview of Nuclear Harmonization and Standardization Initiative Regulatory Track and IAEA Activities on New Technologies Safety and Regulation, Paula Calle Vives, IAEA (In person)

The first presentation "Overview of Nuclear Harmonization and Standardization Initiative Regulatory Track and IAEA Activities on New Technologies Safety and Regulation" by

Paula Calle Vives from the International Atomic Energy Agency (IAEA) discusses the IAEA's role in advancing the harmonization and standardization of nuclear safety and regulation for new technologies. It covers the IAEA's activities in various areas, including Small Modular Reactors (SMRs), advanced reactor technologies and the specific challenges in safety standards and regulations for these new technologies. The presentation emphasizes the need for continual review and adjustment of safety standards and the importance of international collaboration in this rapidly evolving field.

The second presentation "Overview of Nuclear Harmonization and Standardization Initiative Regulatory Track and IAEA Activities on New Technologies Safety and Regulation" by Paula Calle Vives focuses on the Nuclear Harmonization and Standardization Initiative (NHSI) at the IAEA, specifically addressing regulatory activities and the harmonization of safety and regulation of new nuclear technologies. It covers the various working groups involved in the initiative, their goals and the processes they are undertaking to facilitate international cooperation and standardization in the regulatory landscape of nuclear technology. The presentation also discusses the challenges and solutions related to information sharing and multinational pre-licensing regulatory reviews.

2.3 OECD/NEA SMR Dashboard, Diane Cameron, OECD/NEA (Remote)

The presentation "SMR Dashboard" by Diane Cameron, Head of Nuclear Technology Development and Economics, provides a comprehensive overview of the development and deployment of Small Modular Reactors (SMRs) around the world. It includes an analysis of various SMR sites, reactor concepts and configurations. The presentation also discusses the progress indicators used by the NEA, such as licensing readiness, financing, siting, supply chain development, fuel availability and public engagement. These indicators help to track and understand the real progress of SMR deployment beyond technical feasibility. It emphasizes the variety of SMR concepts and the challenges and opportunities they present, highlighting the need for fuel qualification and supply chain readiness.

2.4 Fusion Safety Approaches for DEMO and ITER, Joelle Elbez-Uzan, EuroFusion

The presentation titled "Safety Approaches for DEMO and ITER" by Joelle Elbez-Uzan, Head of Safety Office, provides an in-depth analysis of the safety objectives and approaches for the ITER and DEMO fusion facilities. It discusses the comparison of these facilities with fission plants in terms of safety for workers, the public and waste management. The presentation delves into the general safety objectives for fusion facilities, highlighting the lower radiotoxic inventory and environmental legacy of fusion reactors compared to traditional nuclear facilities. It also covers the safety analysis for ITER and DEMO, focusing on routine, incidental and accidental scenarios and outlines the comprehensive safety case development for these complex nuclear facilities.

2.5 EURATOM Work Programme 2023-24-25, Cristina Fernandez Ramos, EC DG RTD (Remote)

The EURATOM Work Programme for 2023-2025, part of the broader Euratom Research and Training Programme (2021-2025), has been designed to significantly advance nuclear research and innovation in the European Union. With a substantial budget allocation of €1.38 billion, the programme seeks to enhance nuclear safety, security and radiation protection, alongside the management of radioactive waste and spent fuel.

Key aspects of the 2023-2025 programme include a focus on the safety of Small Modular Reactors (SMRs), the development of nuclear materials and the secure management and disposal of radioactive waste. The overarching goal is to improve and support nuclear safety, secure the supply of energy and provide radiation protection. In addition to these areas, the programme is poised to make significant contributions in the field of fusion energy.

The programme also emphasizes the development of nuclear skills and competences in Europe, aiming to maintain Europe's leadership in nuclear safety and waste management and achieve the highest levels of radiation protection. It supports research into non-power applications of ionising radiation and fosters synergy with other EU initiatives, such as Horizon Europe's Health activities and Europe's Beating Cancer Plan.

The Euratom Programme employs both direct and indirect actions to achieve its objectives. Direct actions are carried out by the Commission's Joint Research Centre, while indirect actions are undertaken by multi-partner consortia. The budget is allocated with €583 million for indirect actions in fusion research and development, €266 million for nuclear fission, safety and radiation protection and €532 million for direct actions by the Joint Research Centre.

Overall, the Euratom Work Programme 2023-2025 is a critical component of the EU's efforts to lead in nuclear research and innovation, promoting technological leadership and excellence while ensuring safety and security in the nuclear sector.

2.6 Aviation Safety Regulation, Yves Morier, retired at EASA and French CAA (In person)

The presentation titled " Principles for Civil Aviation Safety Regulation in Europe " by Yves Morier, retired at EASA and French CAA, provides a comprehensive overview of civil aviation safety regulation in Europe. The presentation covers a range of topics including the international and European context of aviation safety, and the historical context including the evolution of safety approaches over the years and the state of play of aviation safety today. It also delves into the process of developing regulations, the role of authorities and applicants in applying these rules and the importance of certificates and industry standards. Additionally, the presentation addresses new common challenges in aviation safety such as digitalization, the use of simulation, cybersecurity and artificial intelligence. The presentation concludes with a summary of the key topics discussed, emphasizing the continual evolution and importance of aviation safety regulation.

2.7 HARMONISE Project Overview, E. Urbonavičius, Lithuanian Energy Institute (In person)

The presentation "HARMONISE Project Overview" by E. Urbonavičius from the Lithuanian Energy Institute provides a detailed overview of the HARMONISE project, its

objectives and its role in harmonizing the licensing of innovative nuclear installations including fission and fusion reactors. The presentation discusses the historical context of nuclear regulatory frameworks, the need for harmonization in licensing processes and the specific activities and objectives of the HARMONISE project. It highlights the project's focus on analyzing safety assessments, perusing the licensing needs for innovative nuclear installations, examining risk-informed approaches in licensing and exploring harmonization and standardization in component assessments. The presentation also addresses the challenges and potential solutions for licensing innovative nuclear technologies.

2.8 ECC-SMART Project Overview, Monika Šípová, CVR (Remote)

The presentation "ECC-SMART Project Overview" by Monika Šípová provides a comprehensive look at the ECC-SMART project, which focuses on the development of Small Modular Reactor Technology. The presentation outlines the project's motivation, including the desire for a new, flexible power source with higher efficiency based on water-cooled reactor design and its emphasis on passive safety systems and modularity to decrease capital costs. It also covers the goals of the project, such as assessing feasibility, identifying safety features and addressing challenges in materials, thermal hydraulics, neutron physics and safety standards. The presentation reflects a collaborative effort involving various partners across Europe, Canada and China.

2.9 ELSMOR Project Overview, V. Tulkki, VTT (Remote)

The presentation "ELSMOR Project Overview" by V. Tulkki co-authored by M. Szogradi, S. Buchholz, S. Lansou, C. Lombardo, R. Ferri, N. Reinke, A. De Angelis, F. Davelaar, C. Liegeard, J. Bittan, K. Värri and M. Ricotti focuses on the European licensing of Small Modular Reactors (SMRs). The project aims to investigate selected safety features of Light Water SMRs, focusing on safety justification methodology for potentially challenging safety features. Funded by the Euratom research and training program, the project involves partners from 8 countries and covers research on methods for robust safety assessments, core cooling functions, containment and demonstration of the applicability of developed tools and methods, using a test case "E-SMR" (European SMR).

2.10 ALFRED - The European Initiative Towards Lead-Cooled Fast Reactors, Giacomo Grasso, ENEA (Remote)

The presentation "ALFRED - the European Initiative towards Lead-cooled Fast Reactors" by Giacomo Grasso, Head of Laboratory for Core Design, ENEA and Member of Expert Board FALCON Consortium, provides a comprehensive overview of the ALFRED project. This initiative focuses on the development and implementation of Lead-cooled Fast Reactor (LFR) technology in Europe. The presentation covers the design, features and benefits of ALFRED, emphasizing its role in advancing nuclear reactor technology with a focus on safety, efficiency and sustainability. It also discusses the project's roadmap, key milestones and the collaborative efforts involved in making ALFRED a reality.

2.11 McSAFER: High-Performance Advanced Methods and Experimental Investigations for the Safety Evaluation of Generic Small Modular Reactors, V. H. Sanchez-Espinoza, KIT (Remote)

The presentation "McSAFER: High-Performance Advanced Methods and Experimental Investigations for the Safety Evaluation of Generic Small Modular Reactors" by V. H. Sanchez-Espinoza and collaborators provides an overview of the McSAFER project. It focuses on enhancing the safety of water-cooled Small Modular Reactors (SMRs) through key thermal hydraulic experiments, development and improvement of simulation tools and analysis of SMR designs under transient conditions. The project combines experimental investigations with numerical simulations and aims to validate thermal hydraulic tools using McSAFER data. The presentation also covers the challenges, solution approaches and the current status of the project.

2.12 Safety Systems Required for a Supercritical Water-Cooled Reactor, Thomas Schulenberg, KIT (In person)

The presentation "Safety Systems Required for a Supercritical Water-Cooled Reactor" by Thomas Schulenberg offers an in-depth analysis of the safety systems necessary for the operation of Supercritical Water-Cooled Reactors (SCWRs). The presentation delves into general safety requirements for innovative reactors, comparing the safety systems of Boiling Water Reactors (BWRs) with those required for SCWRs. It highlights the unique aspects of SCWRs, such as their once-through steam cycle and the absence of a coolant recirculation system inside the reactor pressure vessel (RPV). Schulenberg also discusses various safety system requirements for SCWRs in different scenarios, such as load rejection, station blackout and steam/feedwater line breaks. The presentation concludes with an emphasis on the need for further design, analysis and optimization of these safety systems.

Supercritical water-cooled reactors (SCWR) are characterized by a once-through steam cycle, such that superheated steam, produced inside the reactor at supercritical pressure, is supplied directly to a high-pressure steam turbine. Different from a boiling water reactor (BWR), however, water and steam cannot be separated at supercritical pressure, and thus a coolant recirculation inside the reactor is impossible. On one hand, this simplifies the design significantly, as recirculation pumps, steam separators and dryers are not required anymore. On the other hand, however, the reactor control under normal operation as well as the residual heat removal systems are basically different then. By comparing both reactor types, common and different types of safety systems are proposed and their different safety strategies are discussed. For small modular reactors, in particular, a passive residual heat removal system is envisaged, which causes constraints not only for the safety systems to be developed but also for the design of the reactor core. The project ECC-smart is following such strategies by design, analyses and optimization studies.

2.13 Thermal Hydraulics safety considerations in ECC-SMART, Ivan Otic, KIT (In person)

The presentation " Thermal hydraulics safety considerations in ECC-SMART" by Ivan Otic from the Karlsruhe Institute of Technology (KIT) provides an overview of the ECC-SMART project, focusing on its thermal hydraulic safety aspects for Small Modular Reactor (SMR) technology. The presentation highlights the project's goals, including the development and validation of engineering models and heat transfer correlations for supercritical conditions. It also discusses the project's approach to improving and implementing system, subchannel and Computational Fluid Dynamics (CFD) codes for the safety analysis of SMRs. The presentation underscores the project's emphasis on advancing thermal hydraulic research and development for the next generation of nuclear reactors.

2.14 ECC-SMART Cladding Material, Alberto Sáez-Maderuelo, CIEMAT (In person)

The presentation "ECC-SMART Material Cladding Selection" by Alberto Sáez-Maderuelo provides an analysis of cladding material selection for Small Modular Reactors (SMRs) and Supercritical Water Reactors (SCWRs). It emphasizes the importance of cladding as the first barrier of reactor safety, discussing different material options and their properties, particularly in the context of the high temperatures and pressures in SCWRs. The presentation also addresses the challenges in selecting materials that can withstand these extreme conditions, focusing on corrosion behavior, mechanical properties and neutron resistance. Key materials discussed include Zr alloys, Ni alloys and stainless steels with more than 20% Cr, each evaluated for their suitability in the demanding environment of SCWRs and SMRs.

2.15 ECC-SMART Neutronics, Szabolcs Czifrus, BME (Remote)

The presentation "Neutron physics of SCW-SMR" by Szabolcs Czifrus focuses on the neutron physics aspects of SuperCritical Water-cooled Small Modular Reactors (SCW-SMRs). It discusses the development and application of neutronic models for SCW-SMR core analysis, including core design challenges, burnup cycle optimization and power profile achievement. The presentation emphasizes the importance of coupled neutronic-thermal hydraulic calculations and explores the impact of fuel enrichment and burnable absorbers on reactor operation and safety.

2.16 Towards pre-licensing of ECC-SMART Andrej Prošek/Ildikó Boros, JSI/BME (In person)

The presentation "Towards pre-licensing of ECC-SMART" by Andrej Prošek (JSI) and Ildikó Boros (BME) provides an overview of the pre-licensing efforts for the ECC-SMART project, focusing on Small Modular Reactors (SMRs) and Supercritical Water Reactors (SCWRs). It discusses the development of generic and specific safety criteria and requirements (WP5 Task 5.1), safety-related findings and conclusions of WPs 2-4 (WP5, Task 5.2), and the approach to pre-licensing studies (WP5, Task 5.3).

In the introduction the presentation emphasizes the need to comply fully with the highest safety standards in future SMR designs and that the economic viability of the future SMR will require the application of the application of innovative ideas in reactor design, such as combination of low power density fuels and accident-resistant or resilient materials.
Task 5 Task 5

Then the collection of the most important generic and design specific safety criteria and requirements judged to be applicable for the conceptual design developed within the ECC-SMART project are presented. The four key sources of information concerning international legislation or guidance applicable to nuclear reactors are: International Atomic Energy Agency (IAEA), Western European Nuclear Regulators Association (WENRA), Generation IV International Forum (GIF), European Union legal acts and international fora at European level. Four guiding principles and main approaches for the refinement and further development of the safety requirements and criteria have also been identified, substantiated and documented. Some conclusions for SCW-SMR drawn from national legislations of Finland, Canada, Czech Republic, UK and China are also presented.

InThen the work already done in the framework of WP5 Task 5.2 has been presented. First the collection of a priori knowledge of the participating experts and the preliminary results has been started. For this qualitative analysis the Phenomena Identification and Ranking Table (PIRT) method has been selected, which is a well-known systematic analysis tool for collecting expert opinions and has been widely applied for advanced reactor designs in different development phases. The PIRT methodology consists of two main steps; in the first step significant safety-related phenomena are collected based on the previous knowledge of participants and on the recent results of WPs. In the second step these phenomena are ranked by the participating experts based on their safety importance and the level of knowledge. This method ensures a comprehensive overview of important phenomena and the identification of knowledge gaps requiring further analysis. Preliminary results for WPs 2-4 are shown.

Finally, approach for performing pre-licensing study is presented. It is expected that the pre-licensing study will identify three sets of the safety criteria and requirements: (1) fulfilled with reasonable certainty within the limits of already available knowledge, (2) fulfilment is probable, further research needed and (3) fulfilment is improbable, design changes are needed. Assessment will start when WP5 Task 5.2 results will be fully available on resolving the basic conceptual issues involving material and thermal hydraulic challenges, as well as neutronic aspects of an active core with SCW as coolant and moderator. More details on this particular work are provided in Annex 3.

2.17 HARMONISE Project and Stakeholders Involvement, Mirela Nitoi, RATEN (In person)

The presentation "HARMONISE Project and Stakeholders Involvement" by Dr. Mirela Nitoi outlines the stakeholder engagement strategy for the HARMONISE project. It discusses the steps in developing the stakeholder network, identifying relevant stakeholders and strategies for engaging and maintaining connections with them. The presentation emphasizes the importance of a proactive and collaborative attitude from stakeholders and their responsiveness for the success of the project. It also highlights the various categories of stakeholders involved, including international organizations, nuclear regulators, industry partners and entities from non-nuclear communities like aviation and medical physics, illustrating the wide-ranging impact and collaboration efforts of the project.

2.18 The Vision for a Bidimensional Harmonisation in the Licensing Framework, Giacomo Grasso, ENEA (Remote)

The presentation "The Vision for a Bidimensional Harmonisation in the Licensing Framework" by Giacomo Grasso delves into the complexities and challenges of harmonizing licensing processes for nuclear power technologies. It examines the need for a two-dimensional harmonization approach, focusing both on technology and regulatory aspects across different countries. The presentation addresses the diverse technological landscapes and the varying national regulations, underscoring the importance of aligning these elements to enhance safety and streamline licensing procedures for nuclear technologies. Grasso's work is part of the broader HARMONISE project, which aims to facilitate the licensing of innovative nuclear power plants.

2.19 Towards Technology-Inclusive Risk-Informed Performance-Based (T-I RIPB) Regulatory Framework for Advanced Nuclear Facilities, Alex Matev, BelV (In person)

The presentation "Towards Technology-Inclusive Risk-Informed Performance-Based (T-I RIPB) Regulatory Framework for Advanced Nuclear Facilities" by Alex Matev presents an in-depth exploration of the regulatory framework required for advanced nuclear facilities. It delves into the need for a technology-inclusive, risk-informed and performance-based approach, analyzing the requirements for establishing a comprehensive regulatory framework and reactor oversight processes. The presentation also discusses deterministic and risk-informed approaches to regulatory framework establishment, emphasizing the significance of defense-in-depth implementation and the challenges associated with it.

2.20 Towards New Technologies, Lucien Allais, CEA (In person)

The presentation "Towards New Technologies" by Lucien Allais, as part of the HARMONISE Work Package 4 (WP4), discusses the integration of new technologies in the nuclear sector, particularly focusing on codes, standards and digital technology. It addresses the significance of these factors in reducing costs and lead times from design to operation and their role in responding to new regulatory requirements. The presentation outlines WP4 objectives such as identifying needs in codes, standards and digital technology and creating a map of existing codes and the areas needing expansion. The challenges include integrating innovations not yet standardized and responding to the varied conditions of different reactor types. The presentation also covers the methodology and targets of WP4, highlighting the need for a detailed map of covered topics and the development of uncovered topics, which is crucial for designing and constructing Generation II to IV nuclear facilities.

3 Involvement of the students

The workshop also underscored the dedication of the project to education and training. Partnership with the ENEN2plus project encouraged enhancing student education and career growth by providing its support for students.
12 students from all over Europe were involved in the activities which took place in the frame of the Workshop. Most of them are in the middle of their MSc or PhD theses related to mechanical engineering, materials studies, thermal-hydraulic research, innovative nuclear technologies, licensing of nuclear reactors and all of them plan to bring their input into SMR research activities in the future. Moreover, attending the Workshop provided the students with an excellent opportunity to share their experience, improve their soft skills and enlarge their professional network all of which they might benefit from in their future careers. The report on the selection process and feedback reports from the students, prepared as a requirement of the ENEN2plus project, demonstrate a deep interest and significant knowledge improvement of the involved students. All the materials are provided in Annex 4.
The workshop set the stage for future project activities as it was announced that similar collaborations and educational initiatives are planned for the remaining phase of the project, continuing the momentum gained from the workshop.

4 Conclusions

The Workshop on “Thermal hydraulics and neutronics of the SCW-SMR,” held in June 2023 in Celje, Slovenia, represents a considerable accomplishment within the ECC-SMART project, illustrating its profound commitment to the general disseminative goals outlined. By facilitating critical discussions and disseminating knowledge about the safety of Small Modular, Advanced, and Fusion Reactors, the workshop underscored the project's emphasis on informing, engaging, creating awareness, and promoting the project's aims, outputs, results, and impacts.
Involvement of the students from all over Europe, contributors from the ELSMOR, HARMONISE, McSAFER and ENEN2plus demonstrated a deep integration of Tasks 6.3 and 6.4 of Work Package 6 through this workshop. It also demonstrates a strategic approach to knowledge sharing and community building within the EU scientific area, particularly in the reactor safety. At the same time active collaboration with other EU projects highlights an exemplary model of synergy, focusing on sharing insights, methodologies, and best practices. This collaborative effort not only advances the project objectives but also enhances stakeholder awareness and supports the development of robust safety cases for the new reactor technologies.
Moreover, the role of the workshop as a dissemination platform was significantly enriched by its commitment to transparent communication of scientific advancements and to the education and training of future professionals in the field.
The success of the workshop in achieving these disseminative goals is a testament to the ECC-SMART project importance. By laying the groundwork for future collaborations and educational initiatives it ensures the sustained impact and visibility of the project contributions beyond its tenure. The strategic data management approach of the project further ensures that the project results are preserved, discoverable and reusable, aligning with the overarching aim of promoting a comprehensive and enduring understanding of reactor safety.

Annex 1: Workshop Programme

Annex 1 – Workshop Programme

Workshop on the Safety of Small Modular, Advanced and Fusion Reactors

projects HARMONISE, ECC-SMART, McSafer, ELSMOR

Hotel Evropa, Celje, Slovenia (https://hotel-evropa.si/)

June 20-21, 2023

Logistic information: https://r4.ijs.si/harmonise-workshop-sl
Hybrid. Connect to: https://zoom.us/j/99535416999?pwd=VDJTQVJJY1lnOWE2dWZPVGpvRDI4dz09
(Zoom) Meeting ID: 995 3541 6999 Passcode: 528709

Preliminary Program

Last updated: June 6, 2023

The safety and licensing aspects of the advanced nuclear reactors and facilities are crucial for reliable, safe and competitive construction and operation of future nuclear facilities. The Workshop participants will discuss the opportunities and challenges in researching and developing the technical approaches, methods and criteria for the development of safety cases of future nuclear facilities, which form the basis for the licensing process.

The two-day workshop will be devoted to the technical presentations by participants of projects HARMONISE, ECC-SMART, McSafer and ELSMOR, which will be enriched with insight from guests active in international organizations dealing with nuclear and non-nuclear safety cases and regulations.

The workshop will bring together the European and international efforts to promote, sustain and increase the stakeholder's awareness on the on-going efforts to develop strong safety cases for small modular, advanced and fusion reactors.

June 20, 2023	**9:00**	**Registration**			
Tuesday	**9:30**	**Opening**			
	9:30	Welcome	Leon Cizelj, Egidijus Urbonavičius		
	9:40	Purpose of the Workshop	Leon Cizelj, Kateryna Piliuhina		
	10:00	**Invited Contributions**	**Chair: Egidijus Urbonavičius**		
	10:00	EU-SMR pre-partnership activities – regulatory point-of-view	Eetu Ahonen	ENSREG, STUK	Remote
	10:45	Overview of Nuclear Harmonization and Standardization Initiative Regulatory Track and IAEA Activities on New Technologies Safety and Regulation	Paula Calle Vives	IAEA	On Site
	11:30	**Coffee Break**			
	11:45	**Invited Contributions**	**Chair: Mirela Nitoi**		
	11:45	OECD/NEA SMR Dashboard	Diane Cameron	OECD/NEA	Remote
	12:30	Fusion Safety approaches	Joelle Elbez-Uzan	EuroFusion	Remote
	13:15	**Lunch**			
	14:15	**Invited Contributions**	**Chair: Thomas Schulenberg**		
	14:15	EURATOM Work Programme 2023-24-25	Cristina Fernandez Ramos	EC DG RTD	Remote
	14:45	Principles for aviation safety regulation in EU	Yves Morier	Retired at EASA	On Site
	15:30	**Coffee Break**			
	16:00	**Projects focusing on SMR design and safety**	**Chair: Ivan Otić**		
	16:00	HARMONISE project overview	Egidijus Urbonavičius	LEI	On Site
	16:30	ECC-SMART project overview	Monika Šipova	CVR	Remote
	17:00	Elsmor project	Ville Tullki	VTT	Remote
	17:30	ALFRED: the European initiative towards Lead-cooled Fast Reactors	Giacomo Grasso	ENEA	Remote
	18:00	**Adjourn**			
June 21, 2023	**9:00**	**(safety relevant) features**	**Chair: Mitja Uršič**		
Wednesday	9:00	Overview of McSafer project	Victor Hugo Sanchez Espinoza	KIT	Remote
	9:30	Safety systems required for a supercritical water-cooled reactor	Thomas Schulenberg	KIT	On Site
	10:00	Thermal hydraulics safety considerations in ECC-SMART	Ivan Otić	KIT	On Site
	10:30	ECC-SMART material cladding selection: the first reactor safety barrie	Alberto Saez Maderuelo	CIEMAT	On Site
	11:00	**Coffee Break**			
	11:30	**(safety relevant) features**	**Chair: Andreas Ikonomopoulos**		
	11:30	Neutronics safety considerations of ECC-SMART	Szabolcs Czifrus	BME	TBC
	12:00	Towards pre-licensing of ECC-SMART	Andrej Prošek/Ildikó Boros	JSI/BME	On Site
	12:30	HARMONISE project and stakeholders involvement	Mirela Nitoi	RATEN	On Site
	13:00	The vision for a bidimensional harmonisation in the licensing framew	Giacomo Grasso	ENEA	Remote
	13:30	**Lunch**			
	14:30	**(safety relevant) features**	**Chair: Giacomo Grasso**		
	14:30	Towards Performance-Based Regulatory Framework for Advanced Nu	Alex Matev	BelV	On Site
	15:00	Towards new technologies, Codes and standards challenge	Lucien Allais	CEA	On Site
	15:30	**Coffee Break**			
	16:00	**Discussion/Summary/Wrap-up** moderated panel with invited speakers: discuss the information given at the workshop and try to formulate a few messages	panelists Yves, Thomas, Paula, moderator Leon		
	17:30	**Adjourn**			
	19:30	Teambuilding			
June 22, 2023	**9:00**	**Harmonize Project Meeting**			

Annex 2: Presentations

2.1 EU-SMR pre-partnership activities – regulatory point-of-view, Eetu Ahonen, ENSREG, STUK (Remote)

EU-SMR pre-partnership activities – regulatory point-of-view

Workshop on the Safety of Small Modular, Advanced and Fusion Reactors

Eetu Ahonen

20/06/2023

Contents

- Introduction of the pre-partnership
  - Structure
  - Objectives
- Activities of WS2 Licensing
  - Summary report
  - DG ENER study on licensing
- What’s next?

Introduction of the pre-partnership

Eetu Ahonen

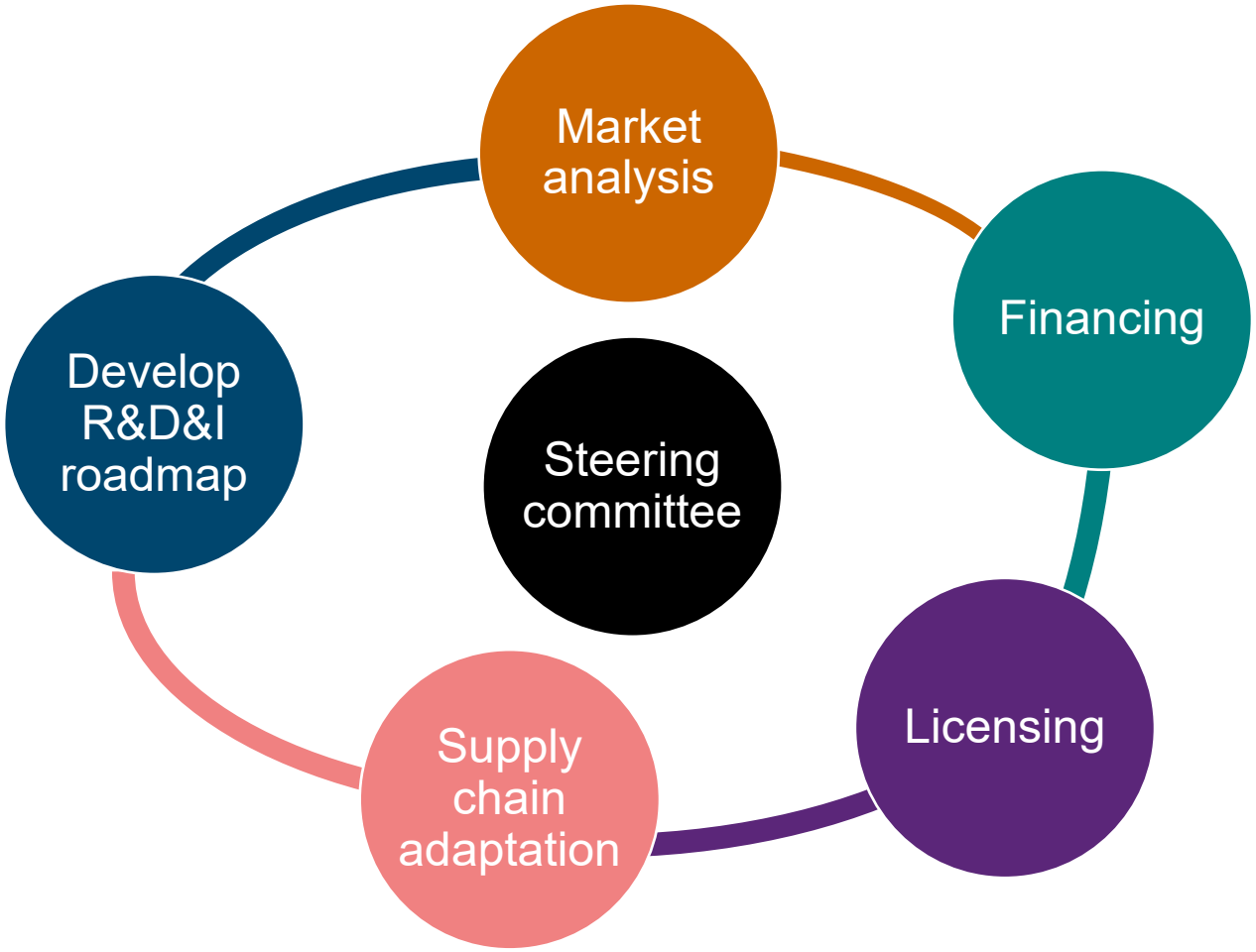
Objective: Enable safe design, construction and operation of SMRs in Europe in the next decade

- Partnership objective is to enable safe design, construction and operation of SMRs in compliance with the EU legislative framework in general and the Euratom legislative framework in particular

- Develop the necessary industrial supply chain in Europe
- Encourage the implementation of harmonized licensing process across EU
- Establish a strategic research agenda
  - LWR, as a mature technology to be deployed in 2030
  - Advanced SMR (Gen IV) designs matured by 2035 for long term prospect

Pre-partnership consists of 5 working streams & SC

- A partnership gathering different actors under 5 working streams
  - Market Analysis
  - Licensing
  - Financing
  - Supply chain
  - R&D&I
- A Steering committee to coordinate the work done by the work streams
  - Nucleareurope
  - SNETP
  - ENSREG
  - EC



WS1 Objective: identify needs of EU energy / power market & SMR capabilities

- Identify future needs of the EU energy/power market (electricity, industrial and residential heat, hydrogen), SMR capabilities for these needs in a context of high RES deployment, market size, and global competitiveness;
- SMRs as technology to replace coal and gas plants, help decarbonize assets/processes such as hydrogen production, district heating, industrial heat processes, and provide load balancing capabilities to Transmission System Operators (TSOs)
- Establish a list of sustainability criteria on a shortlist of SMR technologies (SMR/AMR)

- Topics: EU market size/needs, Technical-economic capabilities of SMRs, Market potential for SMR development

WS3 Objective: conducive investment environment for SMR development

Short term: Identify best structure for the EU SMR initiative

Medium to long term: Define needs for a conducive investment environment / framework for SMR development

Identify barriers and enablers

EC financial support to technology / innovation demonstrators

WS4 Objective: Identify key features of SMR supply Chain

- Identify the key features of SMR supply Chain (vs. current practice)
- Analyse the existing gaps and the main hurdles to overcome
  - Identify technology-independent hurdles and define roadmaps to address them
  - Formulate recommendations to systematically address technology-dependent hurdles from various partnerships

- Topics: Interaction with SMR/AMR, Interaction with supply chain, Standardization, possible use of non-nuclear high-quality components

WS5 Objective: Define R&D&I program coherent with market needs and licensing requirements

- Define R&D&I programme coherent with market needs and licensing requirements for SMRs development
- Identify the needed facilities to perform this programme
- Set up a coherent and consistent training and education programme

- Topics: Core / fuel, NSSS Integrated vessel and its internals, Passive systems, Severe Accidents, Modularity, Human Factors and autonomy, Hybridization / (Co)generation of heat / H2 / desalination

WS2 Objective: Establish a pre-licensing process based on commonly accepted safety assessments

- Identify the elements for establishing a European pre-licensing process based on commonly accepted safety assessments from different ENSREG members interested in the licensing of the same SMR design
  - Authorization remains the sovereign responsibility of member states
- Establish a clear state of play of activities in other fora (IAEA, SMR Regulators Forum, NEA Committees, WENRA, ENISS, CORDEL, etc.) in relation to SMR licensing
- Develop a common understanding on NPP licensing processes in different EU countries interested in SMR licensing
- Interaction with WS4 (Codes & Standards) and WS5 (R&D&I)
- WS2 consists of regulators from 15 countries' EU nuclear safety authorities & industry representative

WS2 activities

Key insight: Requirements can remain “unharmonized” if compliance demonstration is similar

Safety requirements

Established in various frameworks (IAEA, WENRA)

Built on the experience of what is already implemented

How to demonstrate compliance with the requirements that needs to be worked on

- Analogy
  - Unharmonized reqs: “Trousers must remain up”, “Underpants must not be revealed”
  - Harmonized compliance: show that a belt or suspenders fulfils both these requirements
- Further cooperation about compliance demonstration needed
- EU MS regulators have different expectations of demonstration

WS2 Report to be published in July

- Describes the current status of ongoing activities in different fora (NHSI, SMR RF, NEA etc.)
- Describes the main elements of NPP licensing in selected EU countries
- Describes the DG ENER study (more on that later)
- Identified future actions to support pre-licensing of SMRs

DG ENER study assesses specific potentially challenging design solutions relevant for SMRs

- Assess potential SMR specific safety concept and/or design issues that might be challenging for licensing in the EU MS
- Highlight differences in EU MS at level of laws, regulations & regulatory practices that impacts licensing of SMR in these MS
- 12-month project with a limited scope
  - Selected EU MS: FR, FL, CZ, SE, NL, RO, PL
  - SMR technologies deployable by early 2030s, primarily LWR
- Positive feedback from the first 3 issues to be covered
- Next 3 issues to be covered during summer and fall

What’s next?

European SMR partnership to be established at the end of 2023

- Pre-partnership phase finishing during summer
- Partnership structure and participation still open
- Regarding WS2, an objective is:
  - To have an efficient preparation for license application in different EU countries

Three key features for the objective to be reached

1

Engage in early dialogue between designer-licensees and regulators on main elements of the design options

2

Promote cooperation of “interested” regulators to carry out a joint safety pre-assessment on a mature design

3

Identify in an early phase potential blocking points in the safety requirements or licensing processes and arrangements for convergence

Further work identified related to the three key features

- Establish a way for the designer-licensee to initiate early dialogue with national regulators in different EU countries
- Define required information for an early dialogue (safety file etc.)
- Define the arrangements of the early dialog (topics, structure, outputs)
- Definition of commonly shared Safety Objectives for SMRs between the “interested” nuclear safety regulators
- Agree on the sufficient level of maturity to engage in a joint safety pre-assessment (probably plant-level design)
- Close collaboration needed between the different initiatives launched on SMRs at international level (IAEA, NEA, EU, WENRA, etc.) to ensure mutual benefits and avoid duplication
- Collaboration between Regulatory Bodies and EU research organizations could be a mean for the regulators to get a common understanding of the challenges related to SMRs key safety features.

2.2 Harmonise IAEA Part I: IAEA Activities, Paula Calle Vives, IAEA (In person)

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Workshop on the Safety of Small Modular, Advanced and Fusion Reactors

20-21 June 2023

Overview of Nuclear Harmonization and Standardization Initiative

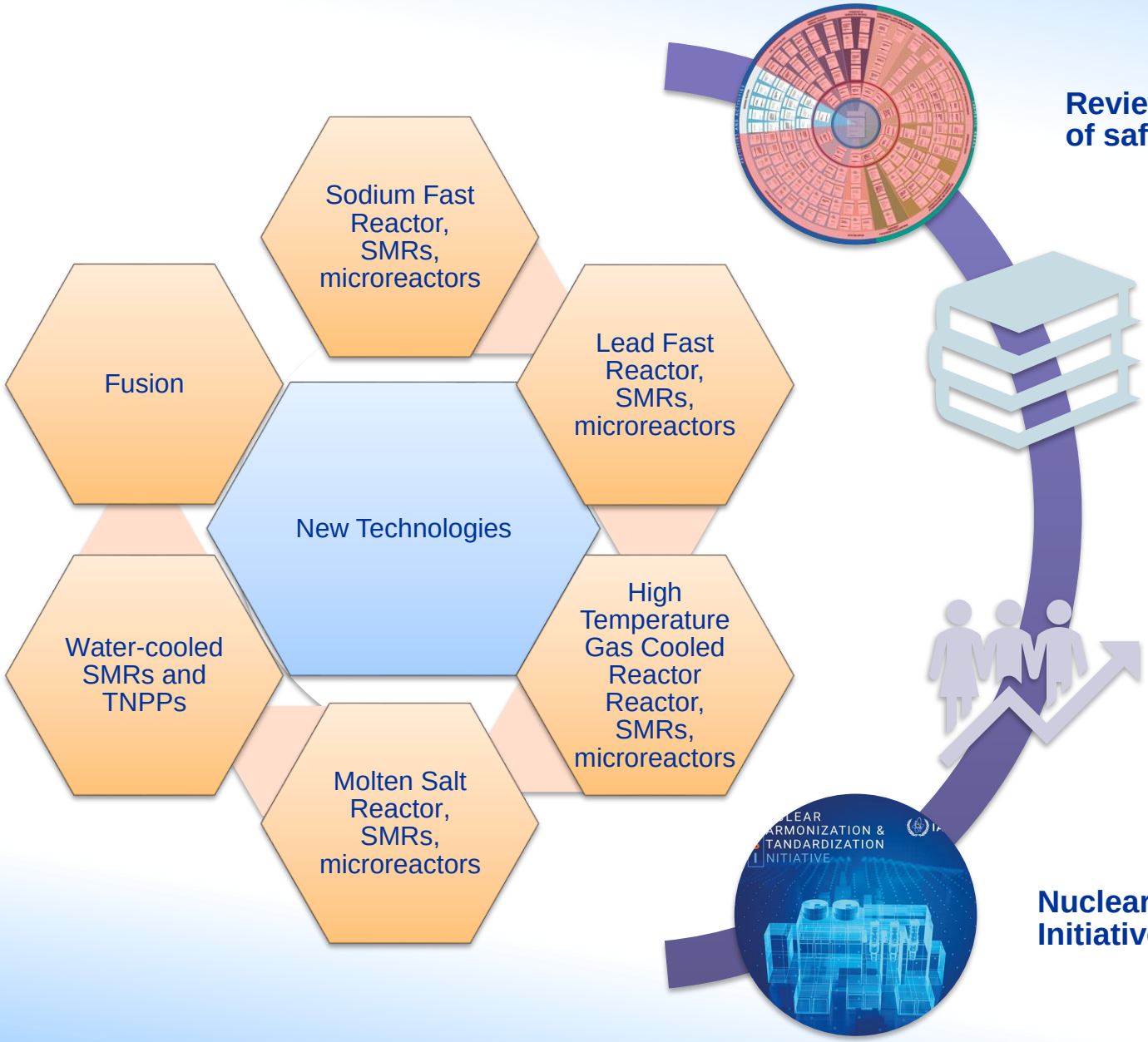
Regulatory Track and IAEA Activities on New Technologies Safety and Regulation

Paula Calle Vives

Technical Lead for New Technologies

Regulatory Activities Section / *NSNI*

IAEA Activities on New Technologies Safety and Regulation



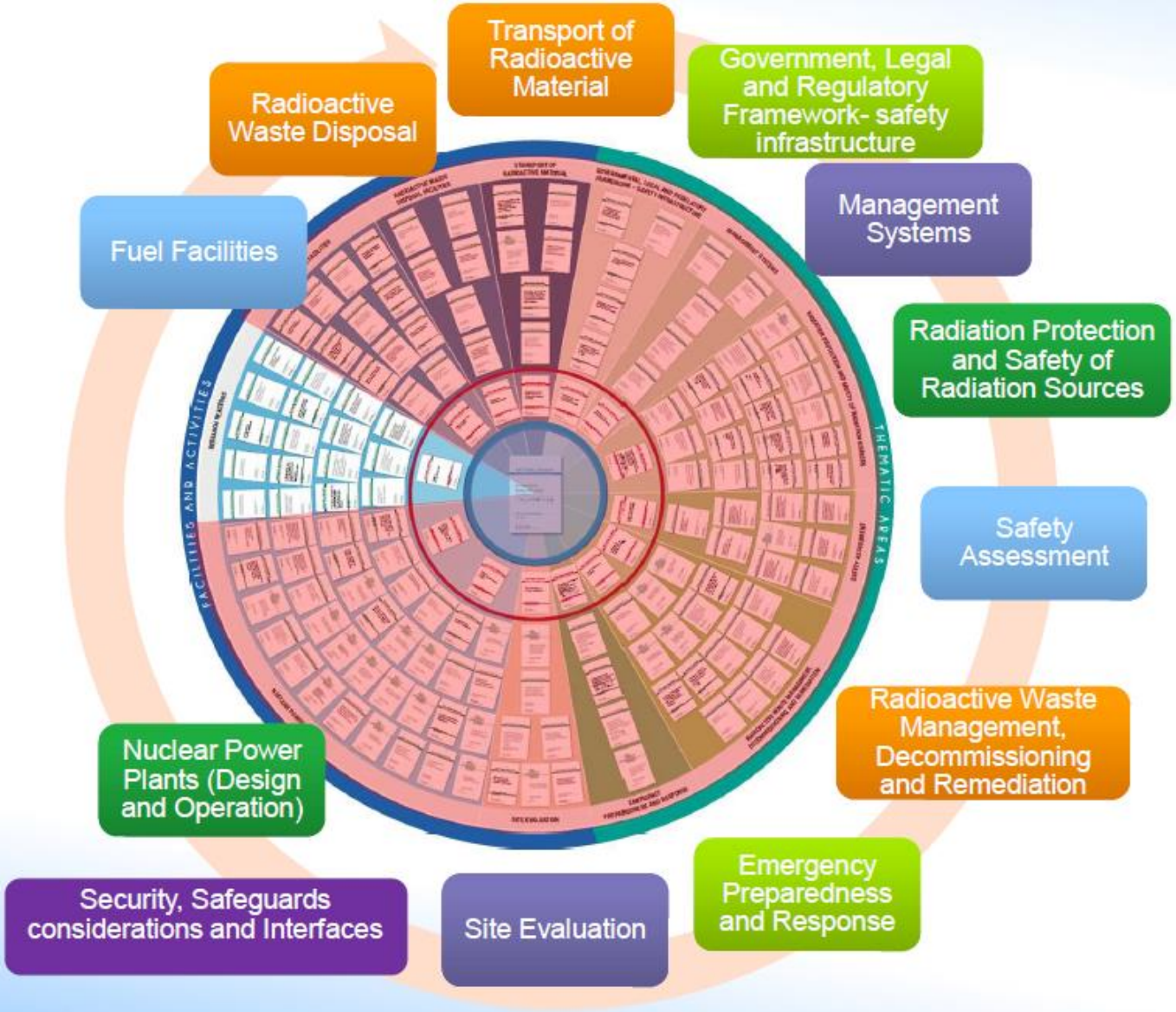
Review and adjustment of applicability of safety standards

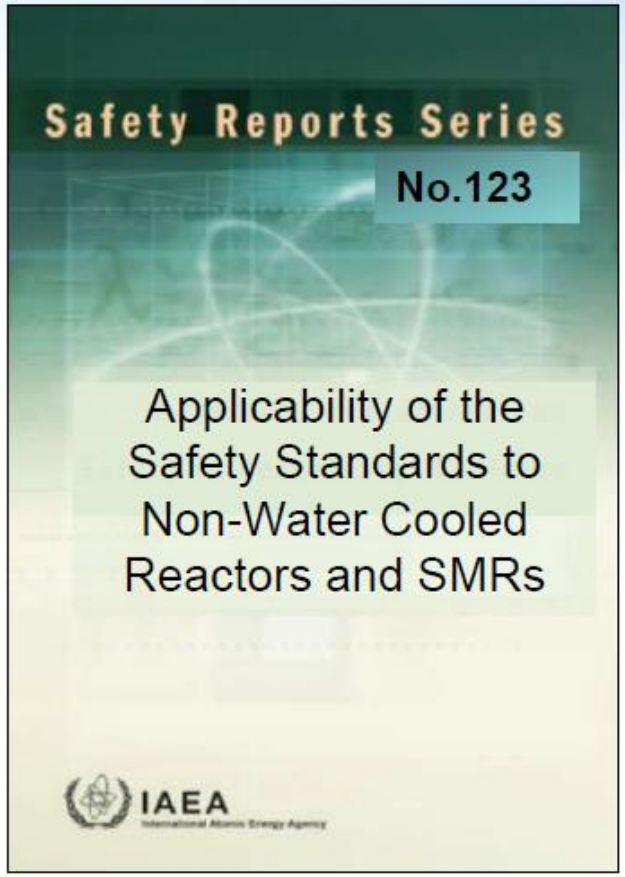
Practical application of safety standards and gathering experiences

Repository of knowledge and capacity building (technical documents, webinars, training, technical meetings and conferences)

Nuclear Harmonization and Standardization Initiative (NHSI)

Review and Adjustment of Safety Standards (1/3)





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IAEA Safety Standards Applicability Review (2/3)

IAEA

Applicability to design and safety analysis for non-water cooled SMRs and design and transport of TNPPs

- Clarification of intent may be possible
- Direct application may lead to ‘unwanted’ results

Differences with large WCRs may have safety implications not captured in safety standards

- Phenomena, failure modes, hazards, source term, waste
- Design features, manufacturing approaches
- Alternative operating models
- Deployment models (supply chain, waste management, decommissioning, regulation, transport)

How to consider designs for which there is a lack of regulatory and operating experience?

- Design
- Manufacturing
- Safety Assessment
- Interface Safety Security Safeguards

Need for increased cooperation among regulators

Review and Adjustment of Safety Standards (3/3)

Siting	Design and Const	Com. and Operation	Fuel Cycle Facilities	Protection and Safety	Management of waste and spent fuel	Decommision.	LMfS	Safety Assessment	Emergency Preparedness and Response	Legal and Regulation Transport
SSR-1 SSG-35 SSG-9 SSG-18 SSG-21 NS-G-3.6 NS-G-3.1 NS-G-3.2	SSG-30 SSG-52 SSG-56 SSG-53 SSG-63 SSG-62 DS524 SSG-68 SSG-67 SSG-64 SSG-69 SSG-34 SSG-39 SSG-51 **SSR2/1** SSG-38	SSG-50 SSG-13 SSG-48 **SSR2/2** SSG-74 SSG-75 SSG-76 SSG-77 SSG-28 SSG-54 SSG-70 SSG-71 SSG-72 SSG-73	SSG-27 SSG-43 **SSR4** SSG-5 SSG-6 SSG-7 SSG-42	**GSR Part3** GSG-8 DS500 GSG-7 GSG-9 GSG-10	GSG-16 SSG-45 SSG-1/DS512 SSG-31 SSG-23 **GSR-Part 5** GSG-1 WS-G-6.1 GSG-3 **SSR-5** SSG-14 SSG-29 SSG-15 SSG-40 SSG-41	WS-G-5.1 W-G-5.2 **GSR-Part6** SSG-47	GS-G-3.5 **GSR-Part2**	**GSR-Part4** NS-G-2.13 SSG-25 SSG-2 SSG-3 SSG-4	**GSR-Part7** GSG-2 GSG-11 SSG-14 GS-G-2.1 SSG-65	GSG-6 SSG-12 **GSR-Part1** GSG-13 GSG-12 SSG-16 **SSR-6**

Fit for purpose in current state

No 'review' recommended (issues may be covered by separate publication)

SSC 'review' to be initiated or ongoing (In Medium-Term Plan for safety standards)

SSC 'review' can be initiated in the long term

SSC 'review' of the safety standard can be initiated when information is obtained

Other IAEA Publications Safety and Regulation

IAEA

Advice on practical application of safety standards documents

Repository of knowledge

Subject to Priorities, Resources and Budget

Cross-cutting	Siting and External Hazards	Design	Commissioning and and Operation	Protection and Safety	Safety of Fuel Cycle Facilities	Management of waste and spent fuel	Safety Assessment	EPR
Effective int. cooperation in the regulation of SMRs	Application of Graded Approach for Site Evaluation	Design approach for Non-WCRs	Operation and commissioning of SMRs	-Consultancy Meeting to decide way forward on radiation safety challenges	-Technical Meeting on Safety of Fuel Manufacturing for Advanced Reactors	Physico-chemical and radiological characteristics and safe management of novel wastes from SMR and novel waste for non-water-cooled reactors	Safety Analysis for SMRs	Publication on EPR for SMRs
3S for SMRs	Siting and Design aspects of SMRs in relation to External Hazards: special issues in the application of Safety Standards	Technical Meetings on HTGRs, MSR, LMFRs Safety	Severe accident and accident management for Non-WCRs				**New Safety Guide**: Safety demonstration of innovative technology in reactor designs	
Design and regulation for TNPPs		Internal Hazards for Non-WCRs						
Chemistry of coolants and materials								
Repository of opex, tests experiments								

Other IAEA Publications Safety and Regulation

TECDOCs under preparation

IAEA TECDOC SERIES

International Experience in the Regulation of Fusion Facilities

IAEA TECDOC SERIES

Experiences on Design Safety and Safety Assessment for Fusion Facilities

Technical Meeting on Fusion Design Safety and Regulation

23-25 Oct 2023, Vienna

- Exchange information on national activities and experiences
- Compile inputs for the preparation of the path forward to developing principles and key concepts

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International Atomic Energy Agency
Atoms for Peace and Development

SMR REGULATORS' FORUM

Gathering Experience on Licensing SMRs

SMR RF's Timeline

2012
First talks about creating an international forum to discuss regulatory issues for SMRs

2013
Several IAEA MS express interest at the INPRO Dialogue Forum on Licensing and Safety Issues for SMRs

2014
The IAEA organizes 2 consultancy meetings resulting in the preparation of draft ToRs and a Pilot Project Plan

2015
Two-year pilot project (Phase 1) starts

2017
Definition of Phase 2 topics of work

2018
Publication of the Pilot Project Report

Work on Phase 2 starts

2019
Publication of interim reports on Phase 2 topics

2020
Definition of Phase 3 topics of work

Work on Phase 2 reports continues

2021
Publication of Phase 2 reports (May 2021)

Work on Phase 3 starts

2022
Publication of interim reports on Phase 3 topics

Work on Phase 3 continues

Outcomes

- Position statements on regulatory (policy and technical) issues
- Suggestions for revisions of, or drafting of, IAEA documents, especially on potential enhancements to the IAEA Safety Standards with respect to SMRs
- Generation and sharing of information that regulators may use to enhance their regulatory framework
- Description of regulatory challenges and discussion on path forward
- Suggestions for high level issues to be raised to international codes and standards organizations for dispositioning

Sharing Experience on Licensing and Regulating SMRs

SMR RF – Working Group Topics - Phase 3

Licensing WG	Design and Safety Analysis WG	Manufacturing, Construction, Commissioning, Operations WG
- Framework for mutual recognition of regulators' assessment/joint assessments/ collaboration - Implications of SMR supply chain on licensee's core safety capabilities - Harmonization	- Integration of Security, Safeguards and Safety-by-Design principles - Clarifying requirements for confinement and design provisions for containment	- Regulatory Considerations in Long Lead Items - Capabilities of the supply chain when supporting licensees - Implications of SMR deployment on Configuration Management

In Progress Now

IAEA
International Atomic Energy Agency
Atoms for Peace and Development

Thank you!

NUCLEAR HARMONIZATION & STANDARDIZATION INITIATIVE

IAEA

Workshop on the Safety of Small Modular, Advanced and Fusion Reactors

20-21June 2023

Overview of Nuclear Harmonization and Standardization Initiative Regulatory Track and IAEA Activities on New Technologies Safety and Regulation

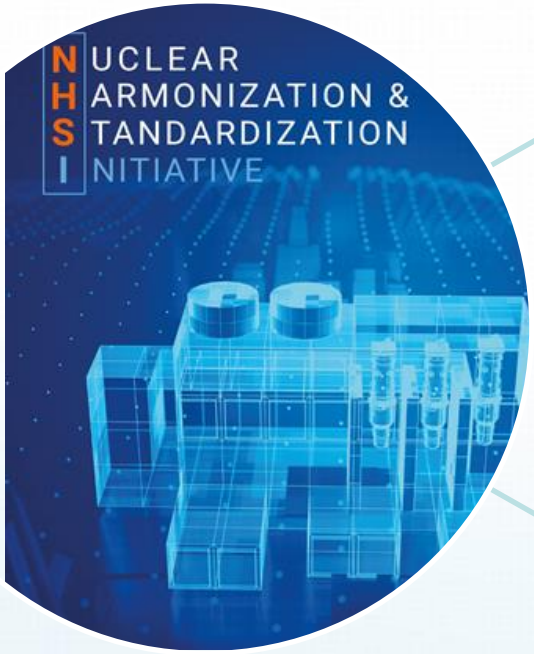
Paula Calle Vives

Technical Lead for New Technologies

Regulatory Activities Section / *NSNI*

NHSI Background

Effective Global Deployment of **Safe and Secure** Advanced Nuclear Reactors



Harmonization of Regulatory Approaches Track

- WG1: Framework for information exchange
- WG2: Multinational pre-licensing regulatory reviews
- WG3: Leveraging other regulatory reviews AND working together

IAEA as facilitator
within and between the tracks

Standardization of Industrial Approaches Track

- TG1: Harmonization of high-level user requirements
- TG2: Common approaches to Codes & Standards
- TG3: Experiments and simulation codes validation
- TG4: Acceleration of nuclear infrastructure implementation for SMR

Regulators

Governments

Technology Holders

Operators and other end-users

International Organisations and Associations

NHSI Regulatory Track Goals

NHSI WG1

Establish the arrangements for information sharing

- Agreements to share controlled information
- Repository collating publicly available information (regulatory review outcomes)

NHSI WG3

Review processes that enable increased cooperation reflecting current international initiatives

- Leveraging other regulatory reviews
- Collaborative reviews

NHSI WG2

Multinational pre-licensing review (allow MS not involved in the review to use review outcome)

- Early identification of design "showstoppers"
- **Commitment to avoid duplication**

PLATFORM FOR IMPLEMENTATION
From early 2024: implementation, lessons learned and process improvement

Timeline and Expected Outcomes

2022

- Work plans and outline of publications for each WG
- Key inputs, experience available, cooperation with ongoing projects
- Start development of publications
- Define interface between tracks

2023

- WG/TG meetings and continue developing publications
- NHSI progress meeting (plenary) in June 2023
- Targeted interface meetings between tracks

2024

- Completion of draft publications
- Interface meetings between Industry and Regulatory Track
- Recommendations for future work

NHSI Track Publications:

- Publication to establish information sharing needs by regulators, potential impediments to information sharing, and potential solutions
- Publication to establish the focus areas and process for a multinational pre-licensing design review
- Publication to establish an approach on how one regulator's reviews can be used by another regulator and how regulators can work together during ongoing reviews

The success of this Initiative will require **clear commitment** and **support** from Governments, regulatory bodies and industry

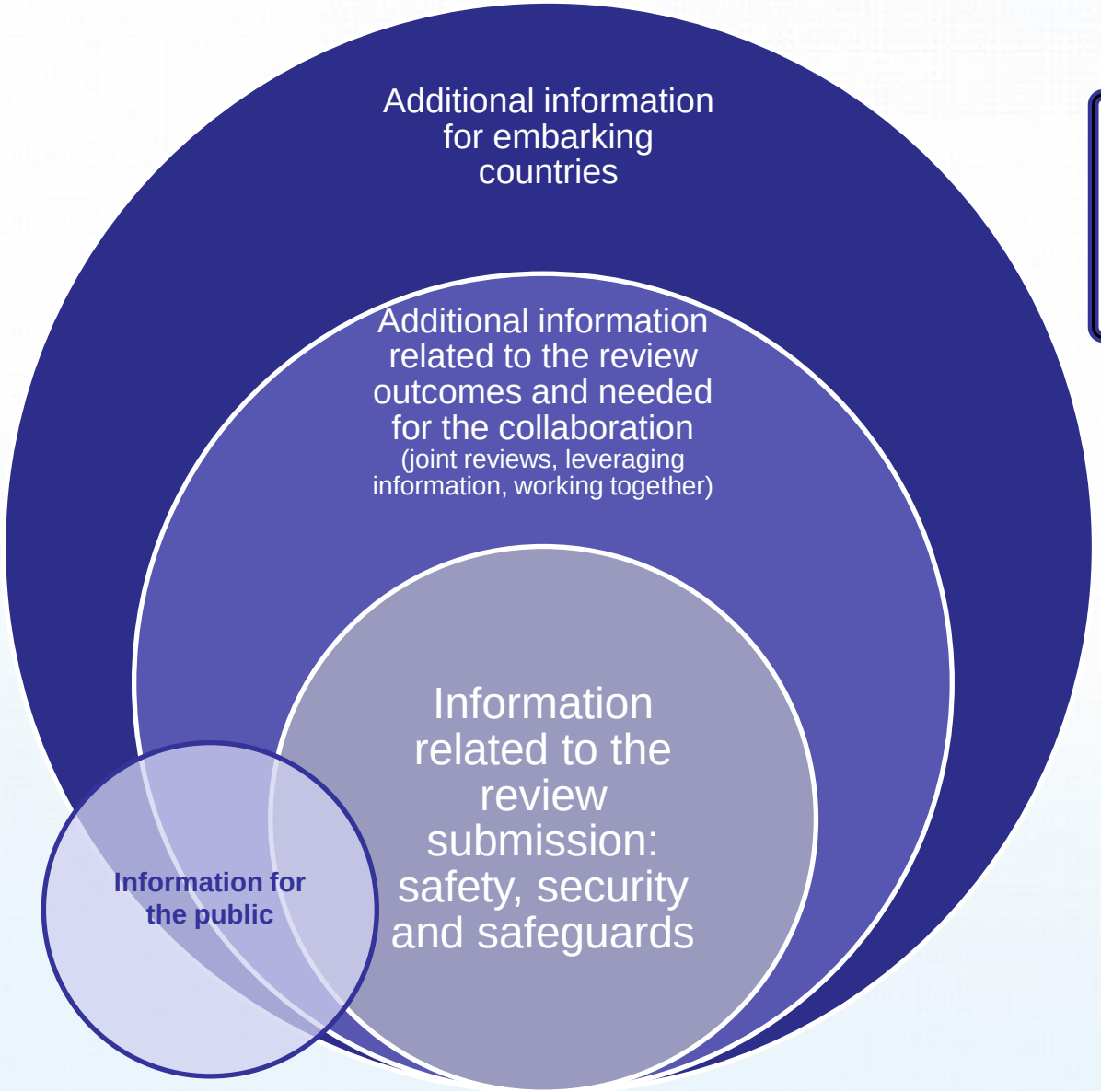
NHSI Regulatory Track Working Group 1

WG1 focus is on the identification of information sharing needs by regulators, potential impediments, and potential solutions

- Facilitate the information sharing needed for regulators to share the outcomes of their reviews or to work together with specific target on the **design review**
- Regulatory reviews may be done by a single regulator or several regulators, under national processes or international processes developed as part of MS bilateral or multilateral arrangements
- **With industry membership**

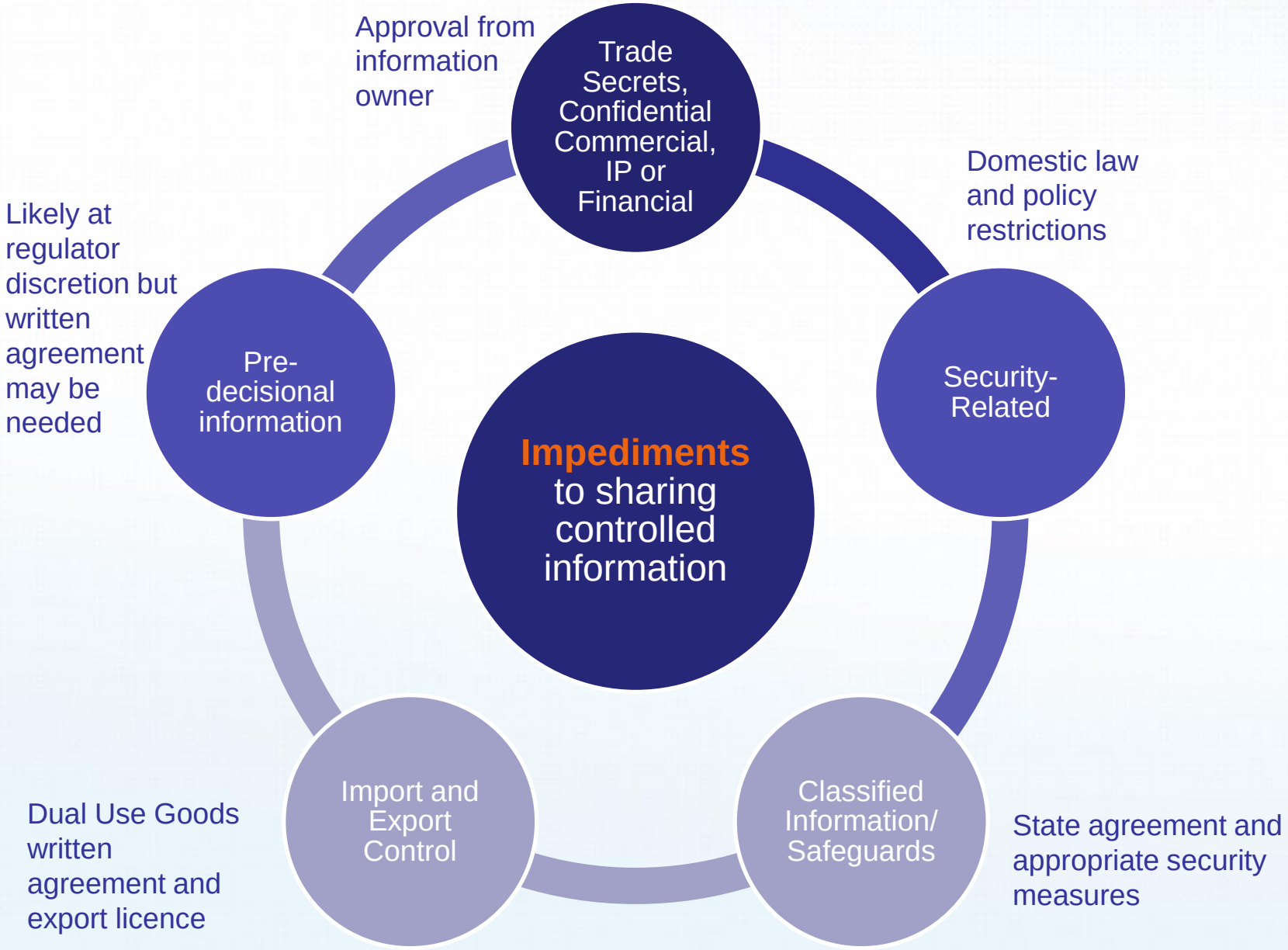
NHSI Regulatory Track Working Group 1 Overview (1/3)

Information Needs to Facilitate Cooperation – **During Design and Safety Reviews**



- What type of information needs to be shared and the level of detail - Is this controlled information?

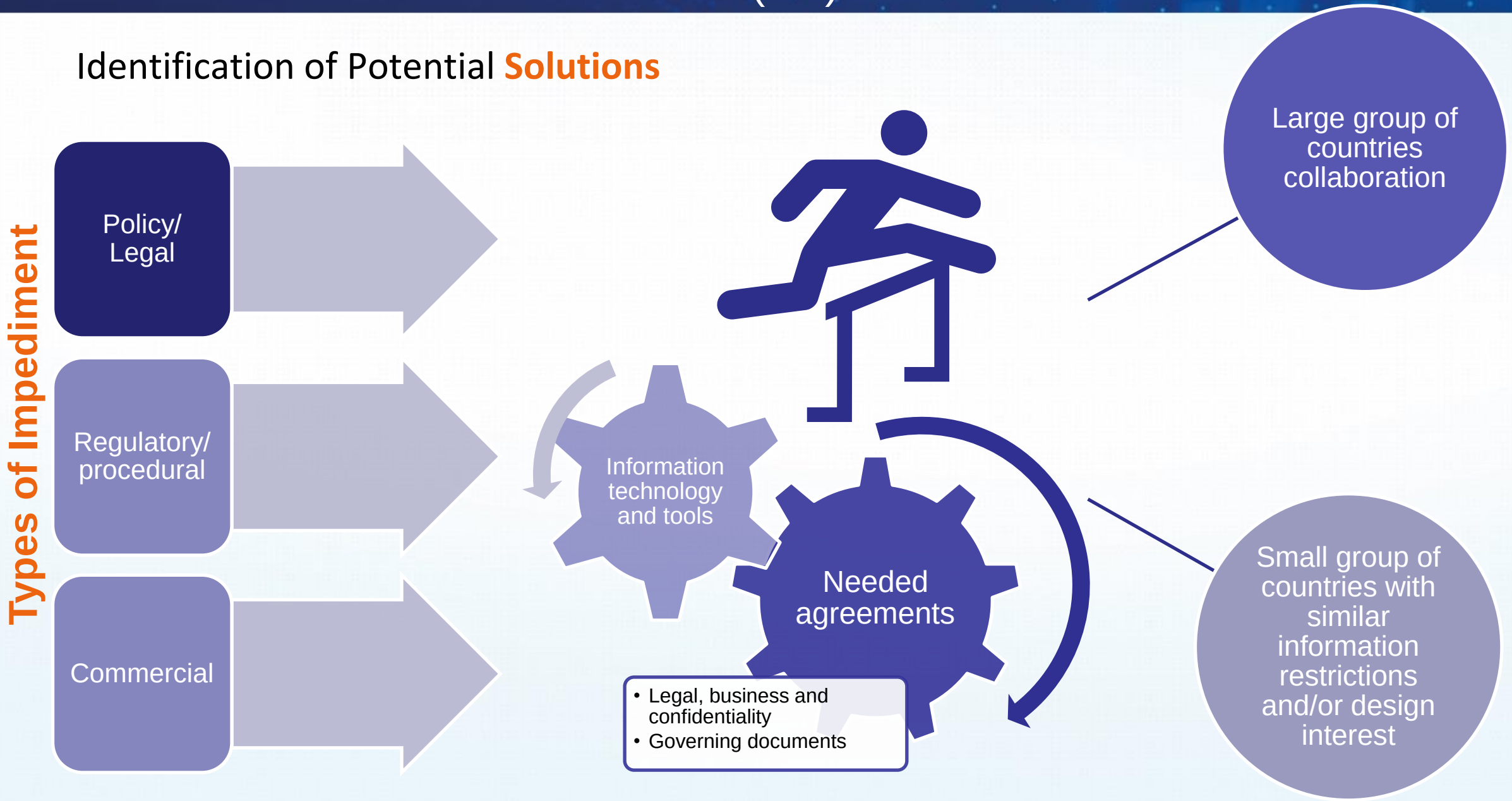
NHSI Regulatory Track Working Group 1 Overview (2/3)



- Written **information sharing agreement** needed for controlled information but can be difficult to established:
  - Threshold determination – 'need to know' if many parties involved
  - Differences in domestic law and policies for handling and protecting information

NHSI Regulatory Track Working Group 1 Overview (3/3)

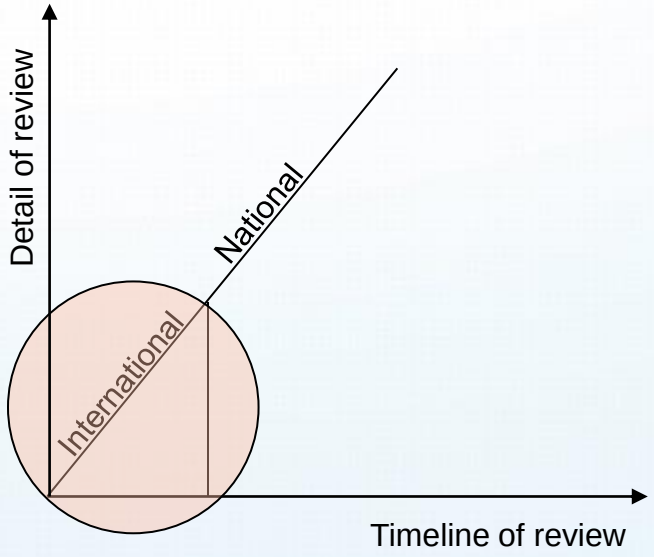
Identification of Potential **Solutions**



NHSI Regulatory Track WG2

WG2 focus is on the development of a process and reference framework for multinational pre-licensing regulatory review

- **NPP design** without site specific aspects to the maximum extent
- Provides an early identification of design showstoppers that would be a barrier to future licensing
- Consideration of **water-cooled SMRs** at first (non-water-cooled reactors may be considered beyond 2024)
- Consideration of a design that is at least basic engineering design

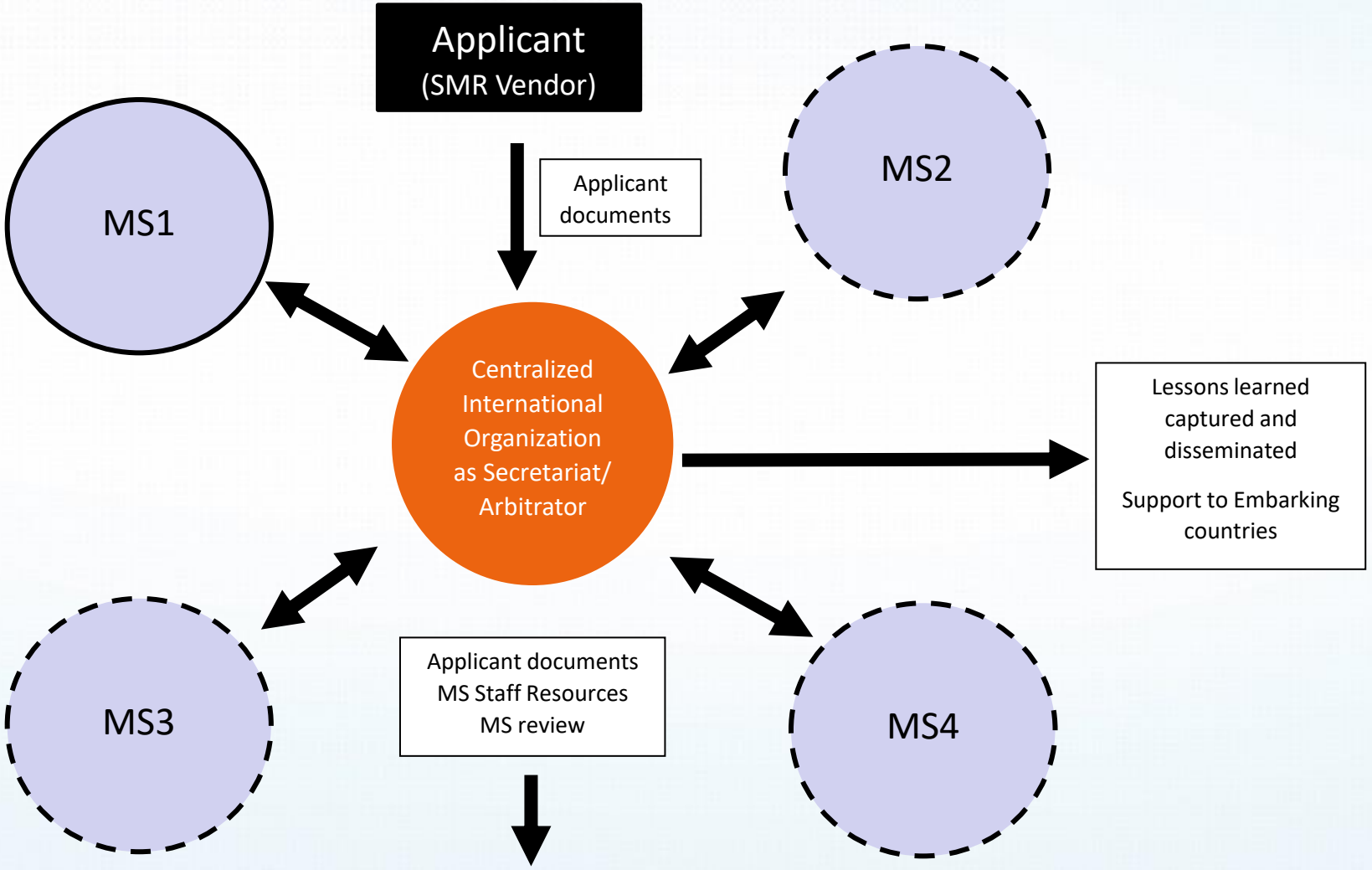


NHSI Regulatory Track Working Group 2 Overview (1/2)

***Process** under consideration:*

Advantages:

1. Oversight of access to pre-licensing review
2. Unbiased secretariat and arbitrator
3. Administrative management
4. CIO gathers experience of implementation of the process and helps dissemination and process refinement- improvement



Provides input into the National Licensing Processes of involved MS ***but also potentially of other MSs***

NHSI Regulatory Track Working Group 2 Overview (2/2)

What NHSI WG2 TECDOC will ideally include:

- ✓ **The contents of the vendor submission**
- ✓ The review process including engagement with vendor and how to decide the scope of the review
- ✓ Expectations on review team capability
- ✓ **How the review is to be documented**
- ✓ How the decision can be integrated in the national licensing or pre-licensing process

Vendor submission

↓

Agreement of scope of the review and international review team

↓

Document the review

↓

Consideration in national review process

- ✓ **Reference framework**
  - List of topics that could be considered and why
  - International standards set the baseline for review
  - Participating MS and applicant can agree on specific criteria for each focus area on a case-by-case basis
  - There may be more than one requirement attributed to various MS.
  - Focus on SMR key issues, areas that may lead to design changes, areas for which there are differences among countries regulations

NHSI Regulatory Track Working Group 3 Background

WG3 focus is on how to leverage the reviews of other regulators and how regulators can work together during ongoing regulatory reviews

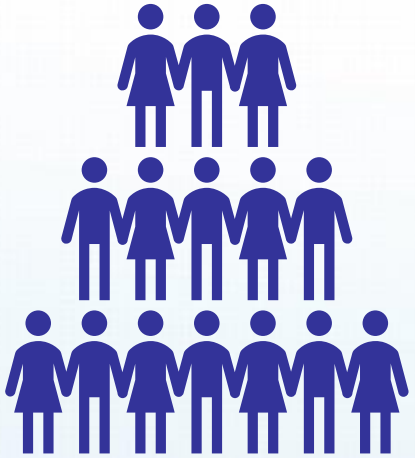
- Regulatory reviews carried out by member states during the pre-licensing and licensing processes, with focus on safety and security aspects
- WG#3 Led by the **SMR Regulators' Forum**

NHSI Regulatory Track Working Group 3 Overview (1/3)

Collaborative Reviews

- Pre-licensing or licensing parallel reviews

Leveraging other regulators reviews



Documenting Lessons Learned

SMR REGULATORS' FORUM

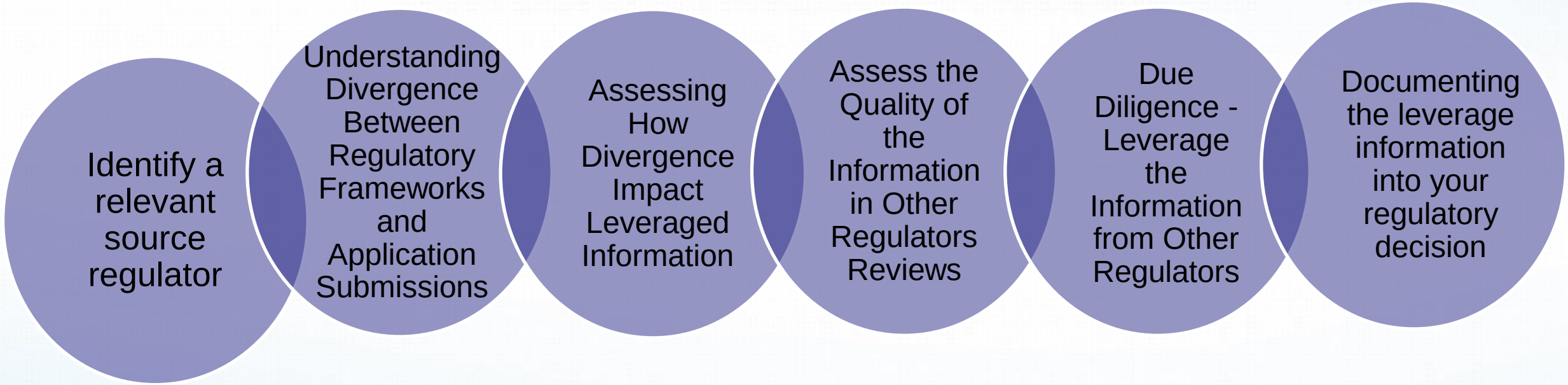
NHSI Regulatory Track Working Group 3 Overview (2/3)

NUCLEAR HARMONIZATION & STANDARDIZATION INITIATIVE

IAEA

Preconditions for Reviewing Regulatory Body (Regulator B) for Leveraging Other Regulatory Reviews

- "Approach to Leveraging Information":



- Regulator B establishes their trust level with Regulator A
  - Trust? Confidence? Maturity? Comfort level? Review Ownership? – Regulator B decides
- Trust level helps to determine the amount of due diligence
- Less regulatory divergence aids in establishing trust and helps the due diligence process
- Due Diligence, including formation request process to be based on UAE experience with Korea
- Incorporation of Intelligent Customer Principles into the Leveraging Regulatory Review Process

NHSI Regulatory Track Working Group 3 Overview (3/3)

Multiple Regulators Working Together in a Design Review

- Completely separate process from the process on leveraging information
- Based on France/Finland/Czech Nuward review and CNSC/USNRC collaboration approach

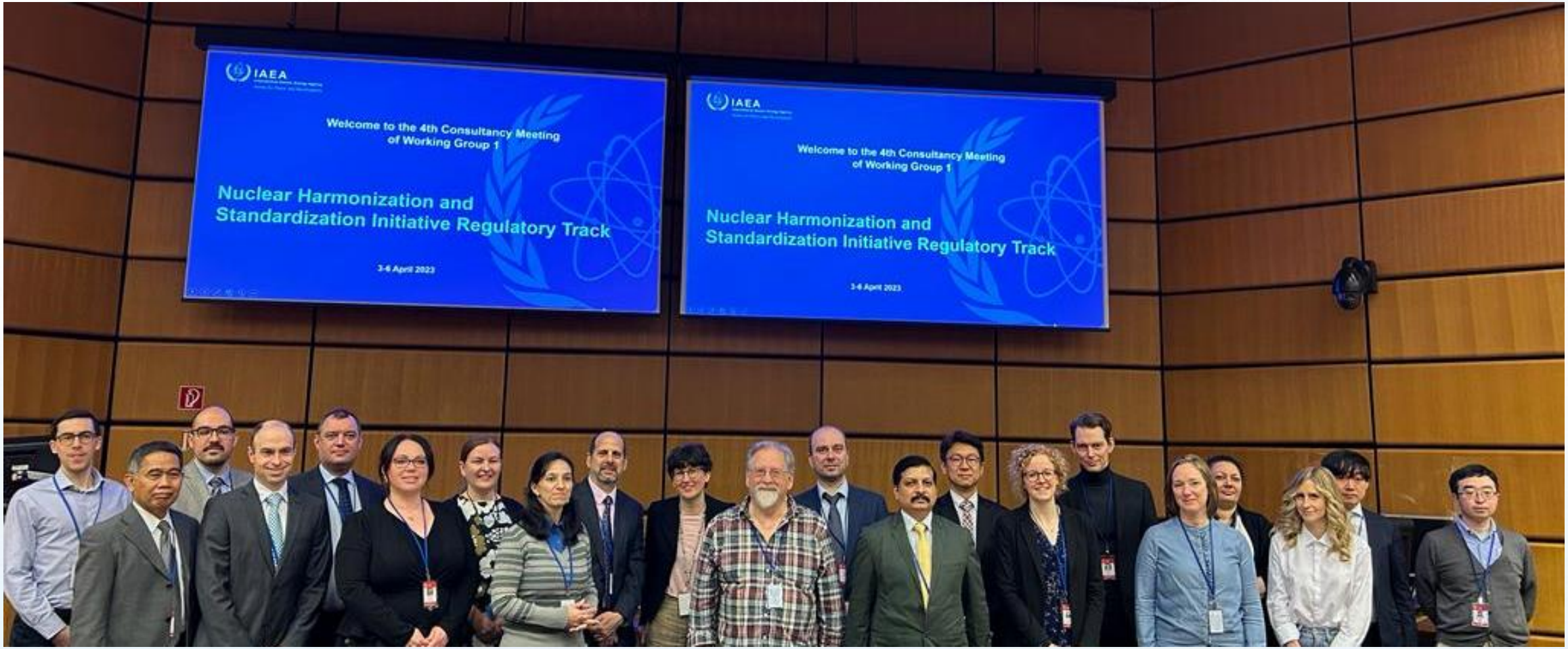
Documenting Lessons learned

- UAE / Korea Collaboration
  - UAE to draft with Korea to review
- Nuward collaboration
  - Czech Republic to lead with Finland and France to review
- CNSC/USNRC collaboration
  - US to lead with Canada to review

NUCLEAR HARMONIZATION & STANDARDIZATION INITIATIVE

Questions?

IAEA



NHSI Industry Track

Topic 1

Harmonisation of High-Level User Requirements

Scientific Secretary: Mr. Benoît Lepouzé
b.lepouze@iaea.org

Topic 1 Objectives

Topic 1 - Harmonisation of high-level user requirements

The focus is to work with utility organisations, which have existing user requirements, to define a high-level user-requirement document, to which they would agree on sharing and could refer to in their own documents.

What are user requirements?

- A comprehensive list of conditions that a future users expect a design to comply with.
- Help technology holders to develop designs in line with the needs of embarking countries.
- Serve as a basis for Bid Initiation Specifications (BIS) preparation.

Create an international reference

- Helps the structure BIS
- Helps the vendors take into account operating needs
- Helps the regulators see what future licensees expect
- Harmonizes existing user requirements references

User-oriented

- Always keeps the point of view of the future user
- Builds on experienced nuclear users but also includes views from non-traditional users
- At IAEA level, not a set of requirements but of considerations (users are free to decide on their requirements)

Neutral

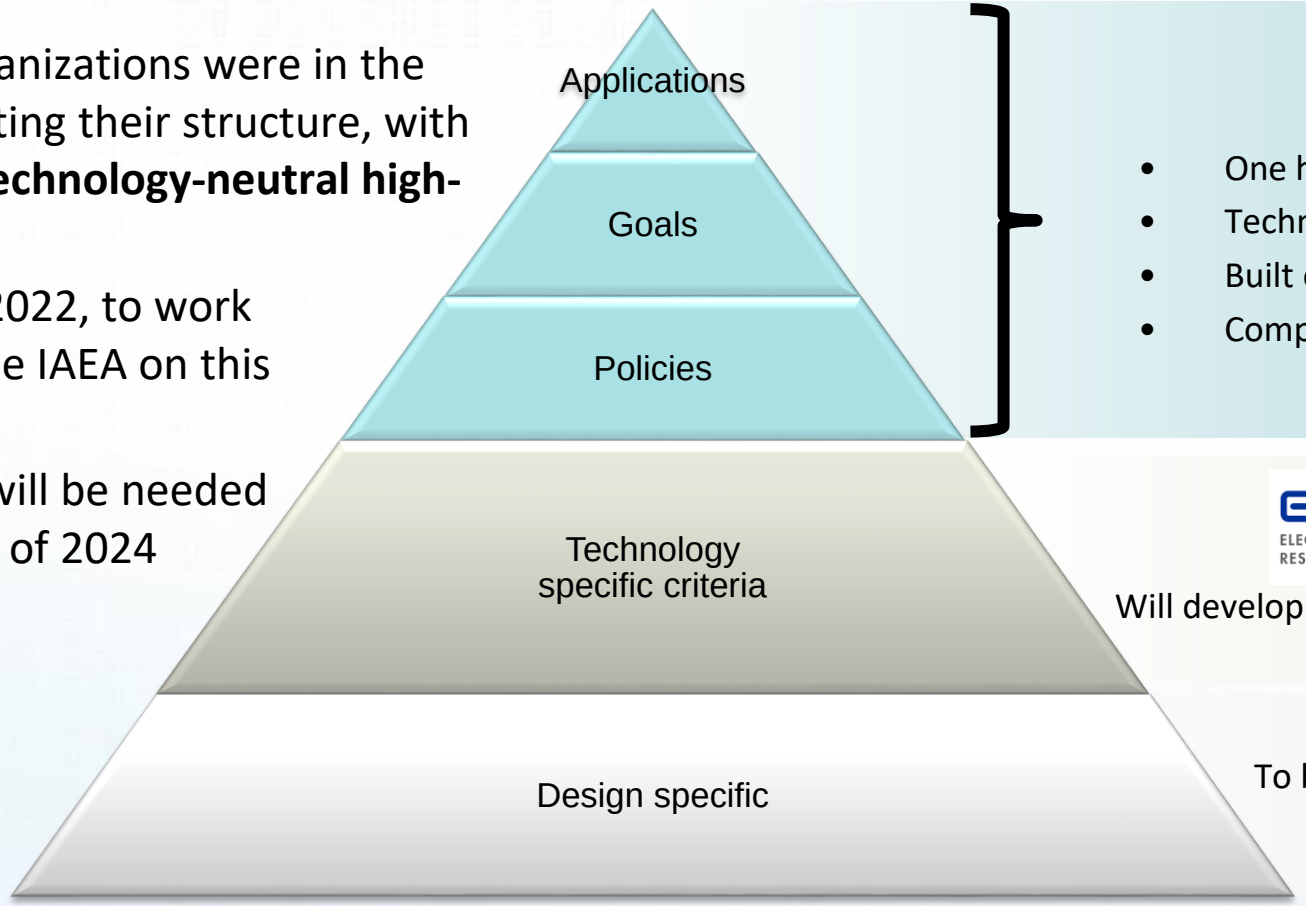
- Keeps as many options open to avoid shutting out innovative solutions
- Avoids being prescriptive and focus on expected functionality
- Remains technology neutral (utility organizations may describe technology specific criteria but will remain design-independent)
- Is open to future revision (living document)

Cross-cutting

- Addresses every aspect of a nuclear facility
- Refers to existing document and standards (and especially the IAEA Safety Standards) to avoid recreating references
- Serves as a reference for future deeper harmonisation

Topic 1 Concept

- Three utility organizations were in the process of updating their structure, with the need for a **technology-neutral high-level document**
- They agreed in 2022, to work together with the IAEA on this document
- This document will be needed in the beginning of 2024



- One high-level document
- Technology-neutral
- Built on the contributions of utility organizations
- Completed with input from non-traditional users

IAEA
International Atomic Energy Agency
Atoms for Peace

EPRI ELECTRIC POWER RESEARCH INSTITUTE | CUR | EUR

Will develop their own technology specific requirements (LWR, MSR, HTGR, FR…)

To be detailed by technology owners when responding to BIS

Topic 1 Timeline

Phase 1
Planning and Alignment

Phase 2
Drafting

Phase 3
Consultation

Phase 4
Publication Process

Fall 2022

Summer 2023

Winter 2023-24

Phase 1– Planning and Alignment

- Discussions with embarking countries
- Completion of users' survey
- Alignment with existing utility organizations

Phase 2 – Drafting

- Consultancy meetings with representatives from utility organizations
- Feedback in NHSI plenary meeting

Phase 3 – Consultation

- **Workshop on Generic User Requirements (China, 4-8 September 2023)** ***Feedback from MS on the first draft***
- Consultancy meeting (Q4 2023) *Consultation of non-traditional users (oil companies)*

Phase 4 – Publishing

- Technical meeting (Q2 2024) *Presentation of the final draft*
- Start of the publication process
- Preprint of the document (referred to by the utility organisations)
- Final publication

NHSI Industry Track

Topic 2

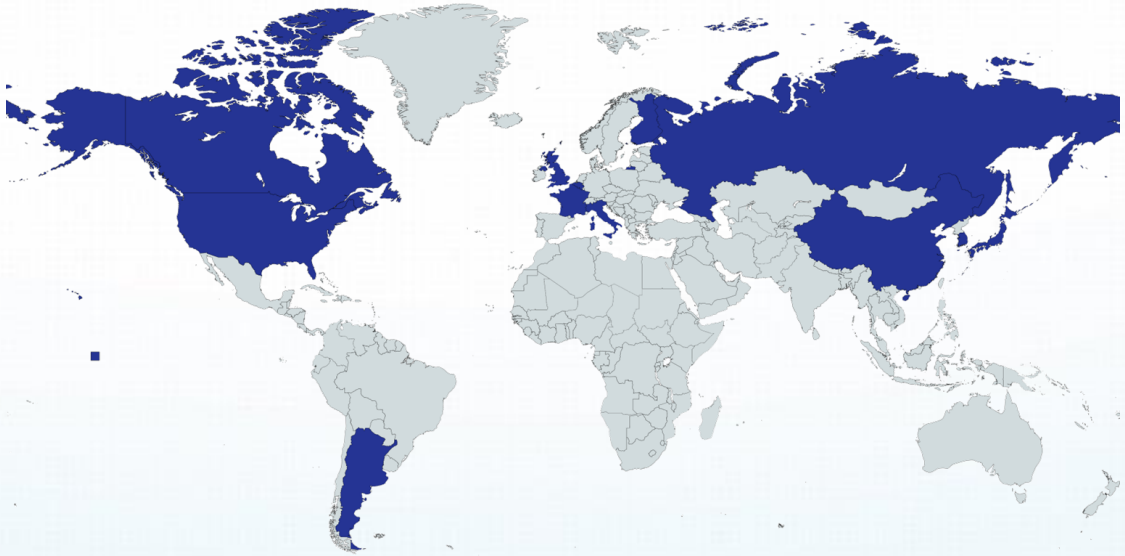
Common Approaches on Codes & Standards

Scientific Secretary: Mr. Pekka Pyy
p.t.pyy@iaea.org

Topic 2 Objectives

Topic 2 - Common Approaches on Codes and Standards

The focus is to create an info base allowing for the high-level comparisons of C&S (Quality and management requirements and the component manufacturing related inspection information; Suitability assessment process used for industrial grade components; Engineering and design related C&S; Advanced manufacturing standards, etc.)



Mission & Vision :

- **Identify** similarities and differences
- **Understand** why they exist
- **Share** information on the findings
- **Develop** common approaches
- **Harmonize** where possible

Deliverables:

publications, white papers, information sharing platform for the IAEA Member States

Platform for Information Sharing

NHSI Topic 2 Scope

I. Codes & Standards

A. QUALITY AND MANAGEMENT SYSTEM STANDARDS USED WIDELY IN THE MEMBER STATES (APPLICALBE TO SMRS)*

B. ENGINEERING STANDARDS FOR THE DESIGN AND CONSTRUCTION OF SMRS (WNA TO LEAD) *

C. EQUIPMENT QUALIFICATION STANDARDS FOR NUCLEAR (SMRS) FACILITIES *,**

D. C&S USED IN VARIOUS SMRS (AND THEIR PROJECTS) *

E. C&S FOR ADVANCE MANUFACTURING (AM) TO BE USED FOR SMRS (AND THEIR PROJECTS)

II. Oversight & Acceptance

A. A USE OF STANDARD, PROVEN SERIALLY MANUFACTURED INDUSTRIAL/COMMERCIAL-GRADE ITEMS) *,**, [3]

B. NON-NUCLEAR CODES, STANDARDS, LAW AND REGULATIONS RELEVANT TO SMR DEPLOYMENT *

C. OVERSIGHT ACTIVITIES REQUIRED BY CODES, STANDARDS, LAW AND REGULATIONS *

Agreed products (see above):

*Data sharing

**White paper

[3] Publication

Topic 2 Timeline

Phase 1– Planning and Alignment

Phase 2 – Developing Contents & Deliverables

Phase 3 – Harvesting the Fruits

Phase 4 – Long-Term Collaboration

2022

- **Kick-off** (1-2 Dec 2022) Virtual
- Scoping and beginning to plan
- Ad-hoc planning meetings on need basis
- **First Working Meeting** ("February 2023" CM –date based on Doodle poll) Virtual

2023

- Workshop (12-14 April 2023), IAEA/Vienna, Hybrid
- 18 May, NHSI Ind Track call
- NHSI plenary, 27 June 2023
- 10-11 July CM 2023, Hybrid
- 14-15 Sept CM 2023, Hybrid
- TG2 stakeholder call, autumn
- Meetings on need basis for different TG2 activities

2024

- **Technical Meeting**, 11-15 December 2023 (nominations)
- CM Spring 2024
- CM Autumn 2024 (TBD), Virtual
- Final TG2 meeting, end of 2024 (TBD) – Spin-offs
- Meetings on need basis for different TG2 activities

2025

- **Platform Operation**
- Spin-off Coordinated Projects (TBD)
- Recurring meetings (TBD)
- What else (TBD)

NHSI Industry Track

Topic 3

Experimental Testing and Validation for Design and Safety Analysis Computer Codes

Scientific Secretary: Ms. Eve-Lyne Pelletier
e.pelletier@iaea.org

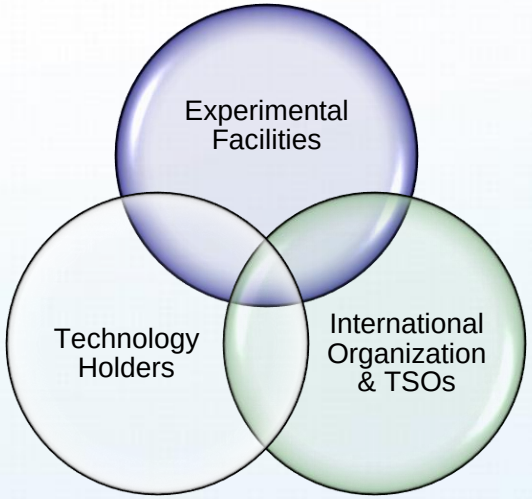
Topic 3 Objectives

Topic 3 - Experimental Testing and Validation for Design and Safety Analysis Computer Codes

The focus is to establish a global cooperation mechanism for experiments and code validation for SMRs, between entities operating experimental facilities, technology holders and potentially TSOs.

Objectives: Through collaboration and information sharing, assist the industry with:

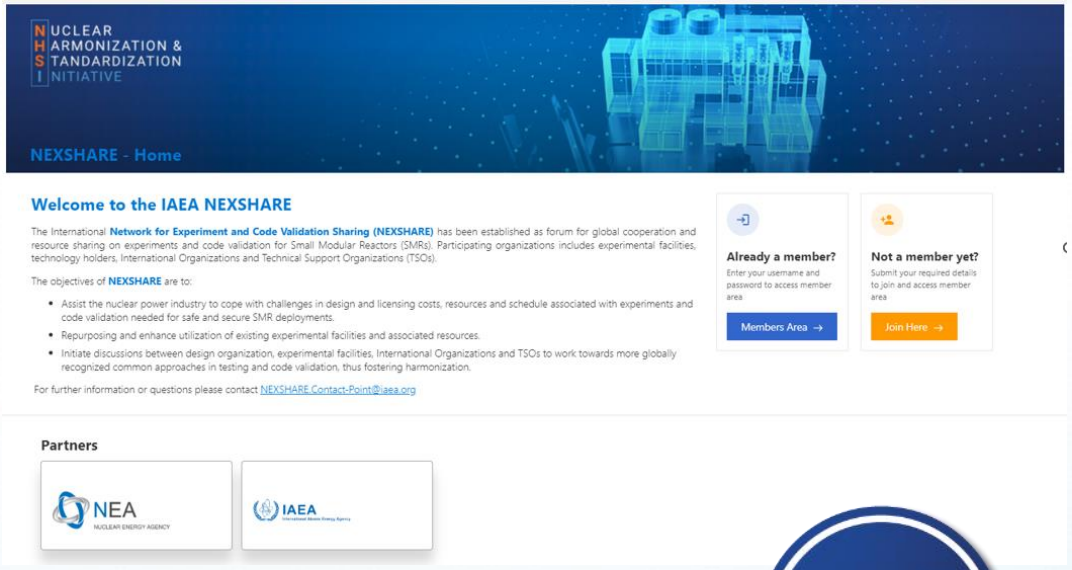
- The resources and schedule challenges associated with experiments and code validation needed for design and licensing of SMRs
- Support repurposing and enhance utilization of existing experimental facilities
- Share information on existing experimental programs and initiatives
- Initiate discussions between design organizations, experimental facilities, International Organizations and TSOs to work towards more globally recognized common approaches in testing and code validation, thus fostering harmonization.



Topic 3 Outputs

1. **Network:** design organizations, experimental facilities, International Organizations and TSOs

2. **NEXSHARE - Network for Experiments and Code Validation Sharing :** webtool/platform for the network that:
   - ✓centralize relevant information
   - ✓share information on the past and future events
   - ✓details and means to contact of the network participants
   - ✓opportunity for sharing and initiate collaborations



3. **Workshop**: (potentially bi-annual) event supporting the Network by providing a platform to discuss ongoing experimental programmes and needs, and identify opportunities for collaborations

4. **Publications**: As defined by the Network (e.g. best practices, priorities, etc)
   - ✓First publication expected is a booklet of participating experimental facilities for SMRs

NEX SHARE

Topic 3 Timeline

Phase 1
Planning and Alignment

Phase 2
Define Collaborations

Phase 3
Implement Activities

Phase 4
Long-Term Collaboration

Winter 2022

Summer 2023

Winter 2024

Phase 1– Planning and Alignment

- Gather needs from vendors
- Define the high level plan
- Mapping of International Organizations
- Definition of the scope for TSOs

Phase 2 – Define Collaborations

- Mapping of experimental facilities, available data, codes and TSOs
- Engagement of participating organizations
- Scope the Workshop
- Prepare the Terms of Reference for the Network
- Specifications for the Collaboration Network

Phase 3 – Implement Activities

- Setup, populate and launch the Network and issue the publication
- **Workshop (Q2 2024)**
- Evaluate potential IAEA-led collaboration(s)

Phase 4 – Long-Term Collaboration

- Implement the mechanisms for long-term governance, oversight, maintenance & update...

NHSI Industry Track

Topic 4

Acceleration of nuclear infrastructure implementation for SMR

Scientific Secretary: Ms. Michelle Scott
m.l.scott@iaea.org

Topic 4 Objectives

Topic 4 - Acceleration of nuclear infrastructure implementation for SMR

The focus is to bring together technology holders, owner/operators, International Organizations and other industry stakeholders to consider possible innovative approaches to support accelerated infrastructure.

- Develop a TECDOC that will:
  - Provide a forward-looking view on how some infrastructure issues addressed in the Milestones Approach could be graded in time or resources.
  - Discuss earlier industry engagement needed to enable accelerated deployment of SMRs and Microreactors.
  - Identify obstacles to these new approaches.

- Inform the next update to the Milestones Approach document in the 2027/2028 timeframe.

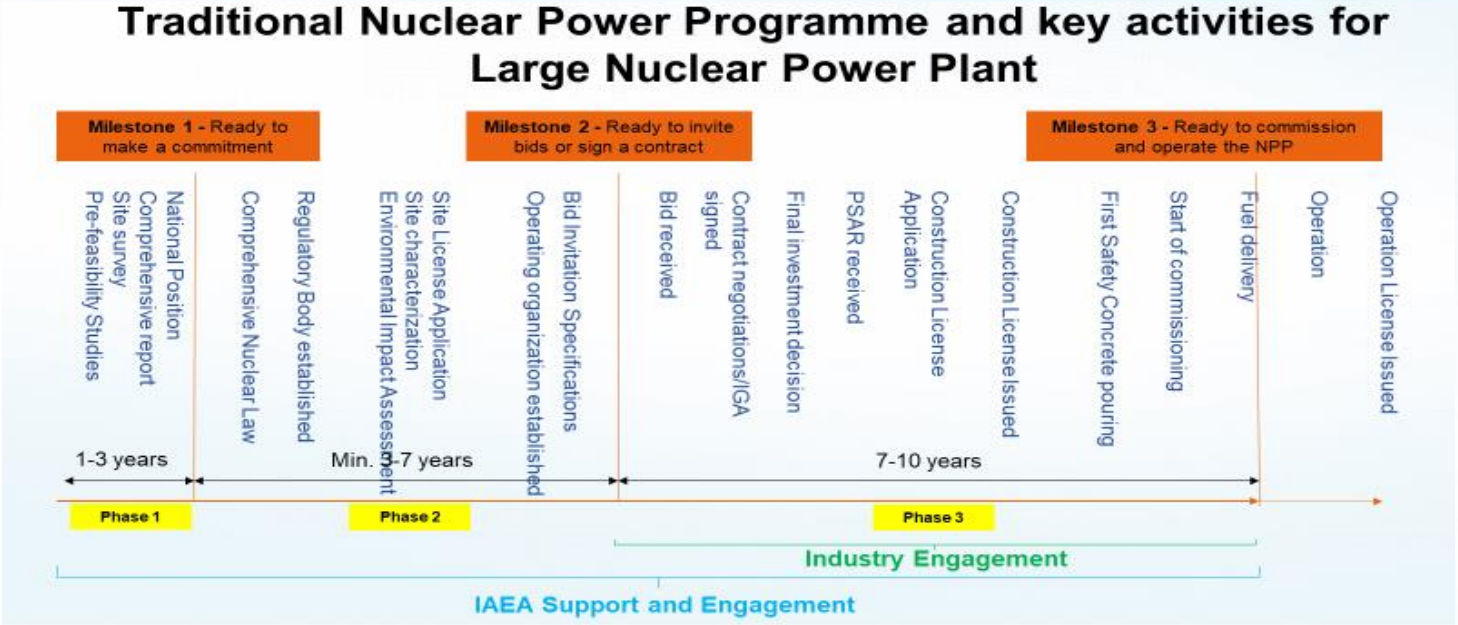
Topic 4 Concept

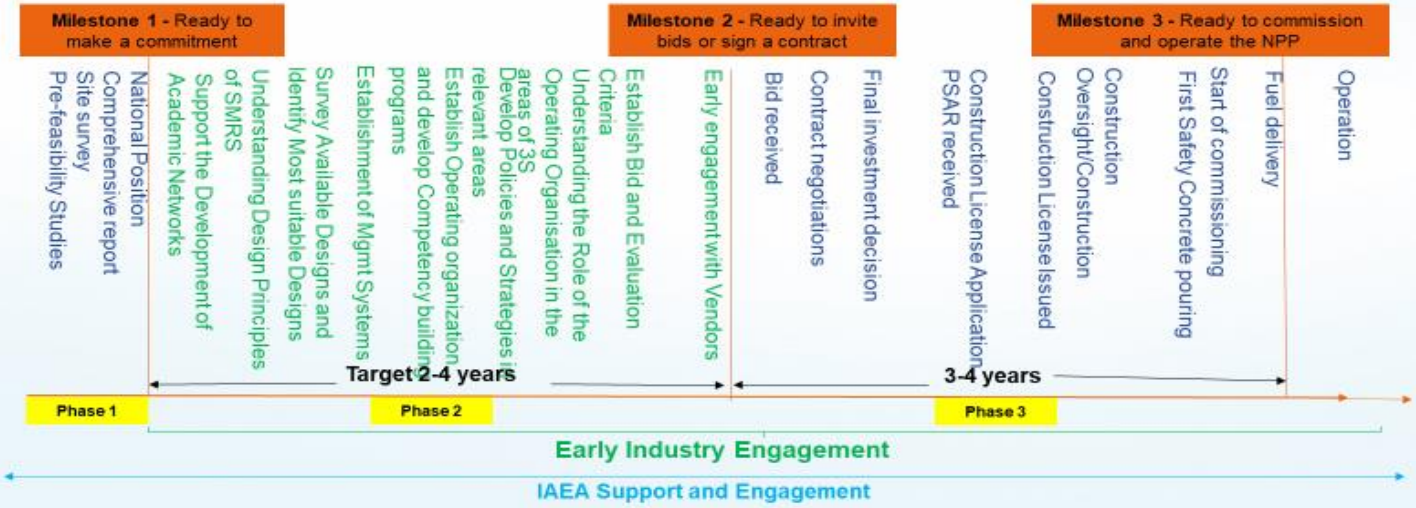
What is needed?

Review the 19 infrastructure issues in each phase: can some of the infrastructure be accelerated or graded ?

Examine the potential for early engagement between vendors and embarking countries.

Document innovative deployment models and their impact on the infrastructure development





NUCLEAR HARMONIZATION & STANDARDIZATION INITIATIVE

Topic 4 Timeline

IAEA

Phase 1
Planning and Alignment

Phase 2
Define Collaborations

Phase 3
Implement Activities

Phase 4
Long-Term Collaboration

Winter 2022 | Summer 2023 | Winter 2024

- **1st CM Meeting** (8-10 November 2022) on Legal Frameworks for SMRs and MRs
- **Kick-off Meeting** (20 December 2022) Virtual meeting to Share Information on Infrastructure Development, discuss role and input to TECDOC, and Scope possible early engagement support to Member States

- **2nd CM Meeting (**3-5 May 2023**)** Hybrid on Deployment models for SMRs and Microreactors with Vendors
- **Q2 3rd CM Meeting** Hybrid on Deployment models for SMRs and Microreactors with Owners/Operators
- Q3 Follow-up Discussion Meeting (27 July 2023) Virtual meeting with NHSI Participants to provide status update
- Develop Initial Draft input of TECDOC

- 4th CM Meeting, Hybrid meeting on Regulatory framework & Capacity Building
- 5th CM Meeting (18-20 September 2023) Hybrid meeting to review TECDOC content
- Q4 Virtual with NHSI Participants - Status Update – *To be determined*
- **Q1 2024, Technical Meeting,** Hybrid meeting to collect Member States and experts feedback on the draft TECDOC
- Submit final draft in 2024

****Additional meetings for the TECDOC will be based on results and recommends from the CMs held*

2.3 OECD/NEA SMR Dashboard, Diane Cameron, OECD/NEA (Remote)

NEA
NUCLEAR ENERGY AGENCY

NEA SMR Dashboard

Diane Cameron
Head of Nuclear Technology Development and Economics

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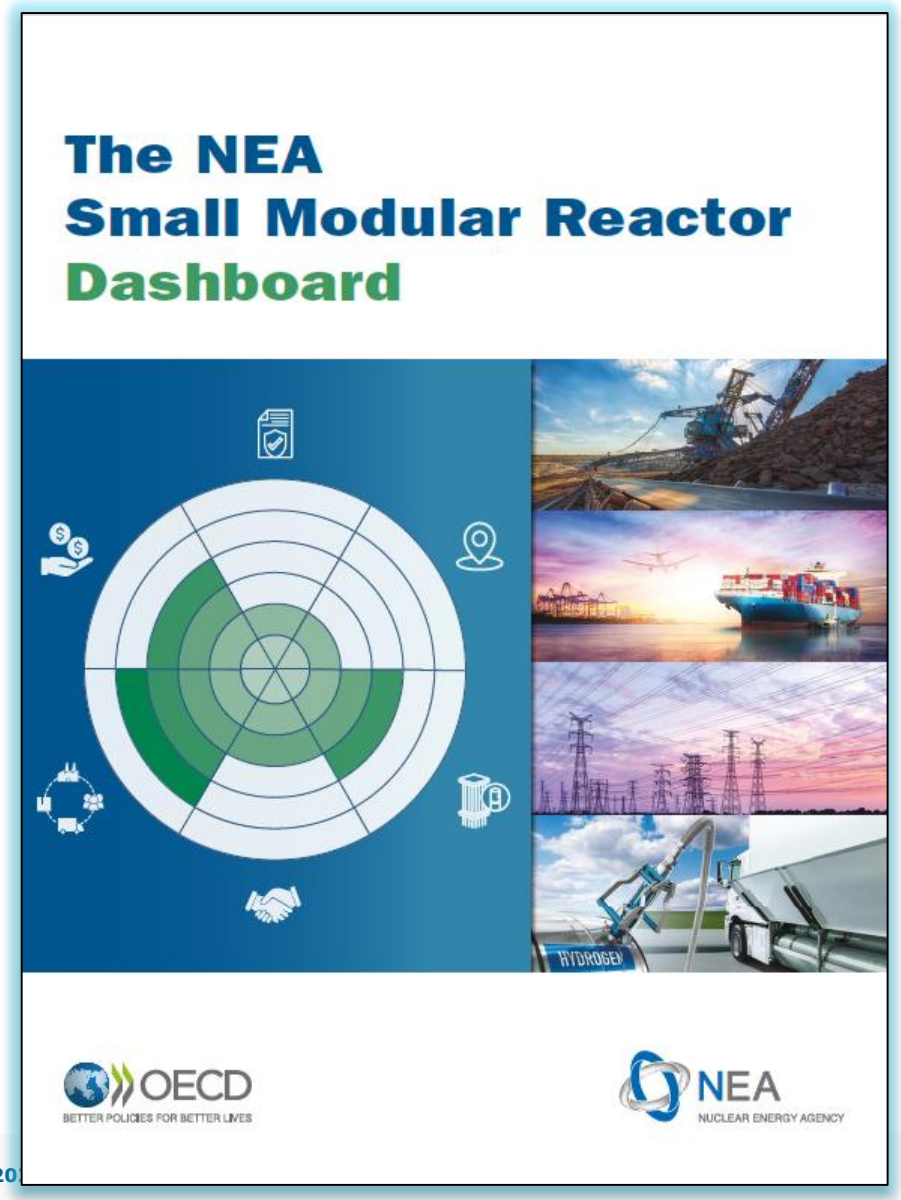
Workshop on Safety of Small and Modular Reactors, Celje, Slovenia, 20-21 June 2023)

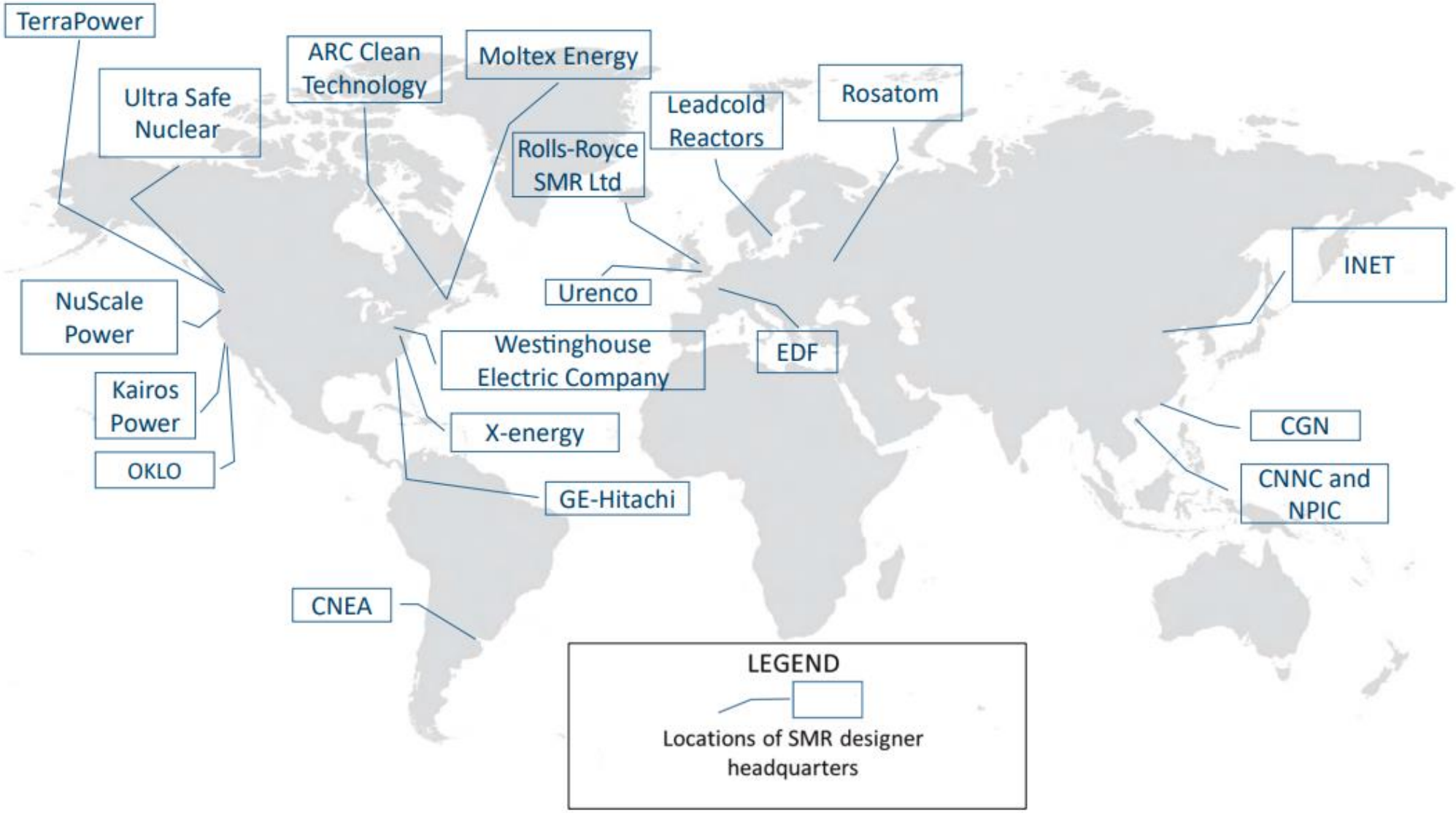
NEA SMR Dashboard



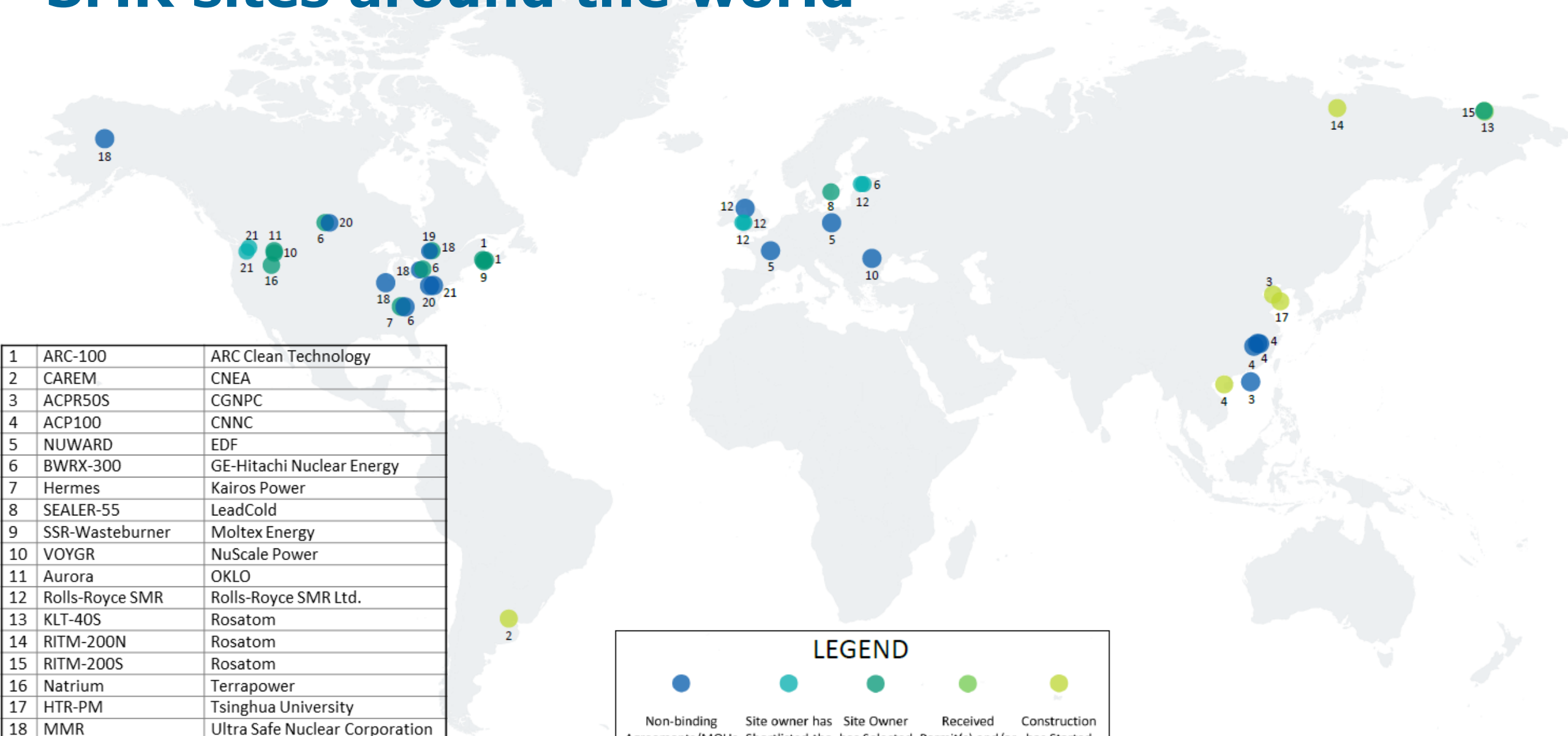
Launched in March 2023

www.oecd-nea.org/SMR-dashboard

SMRs under development around the world

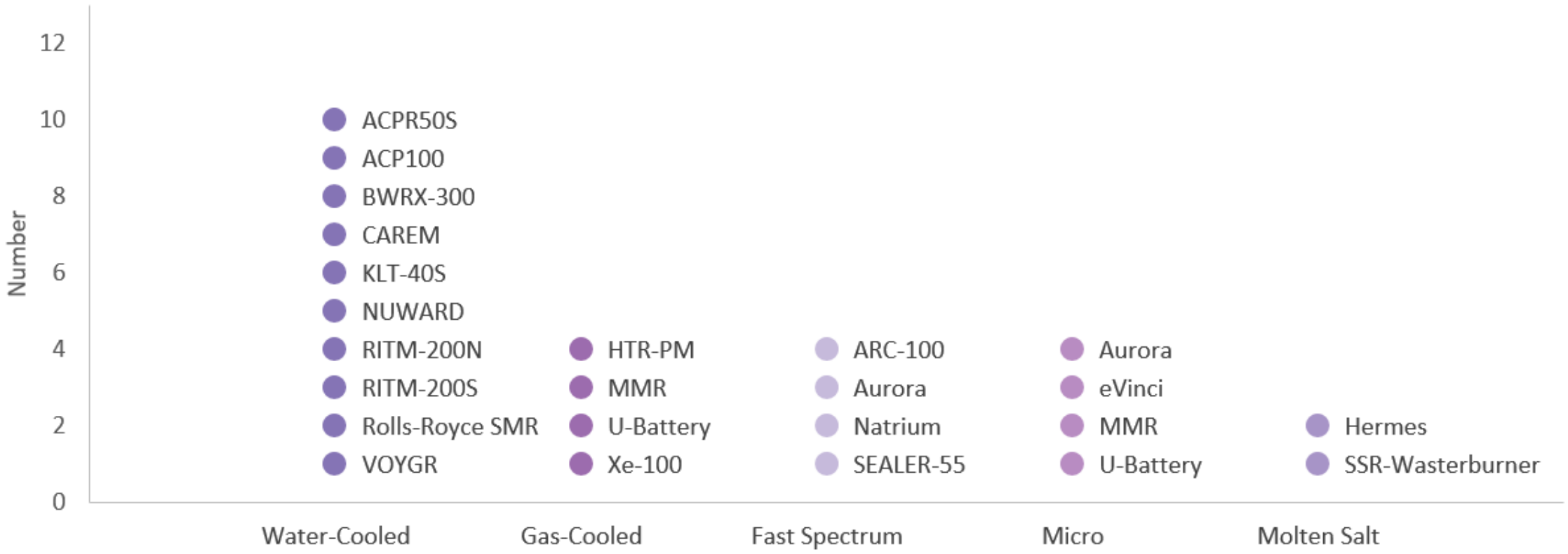


SMR sites around the world



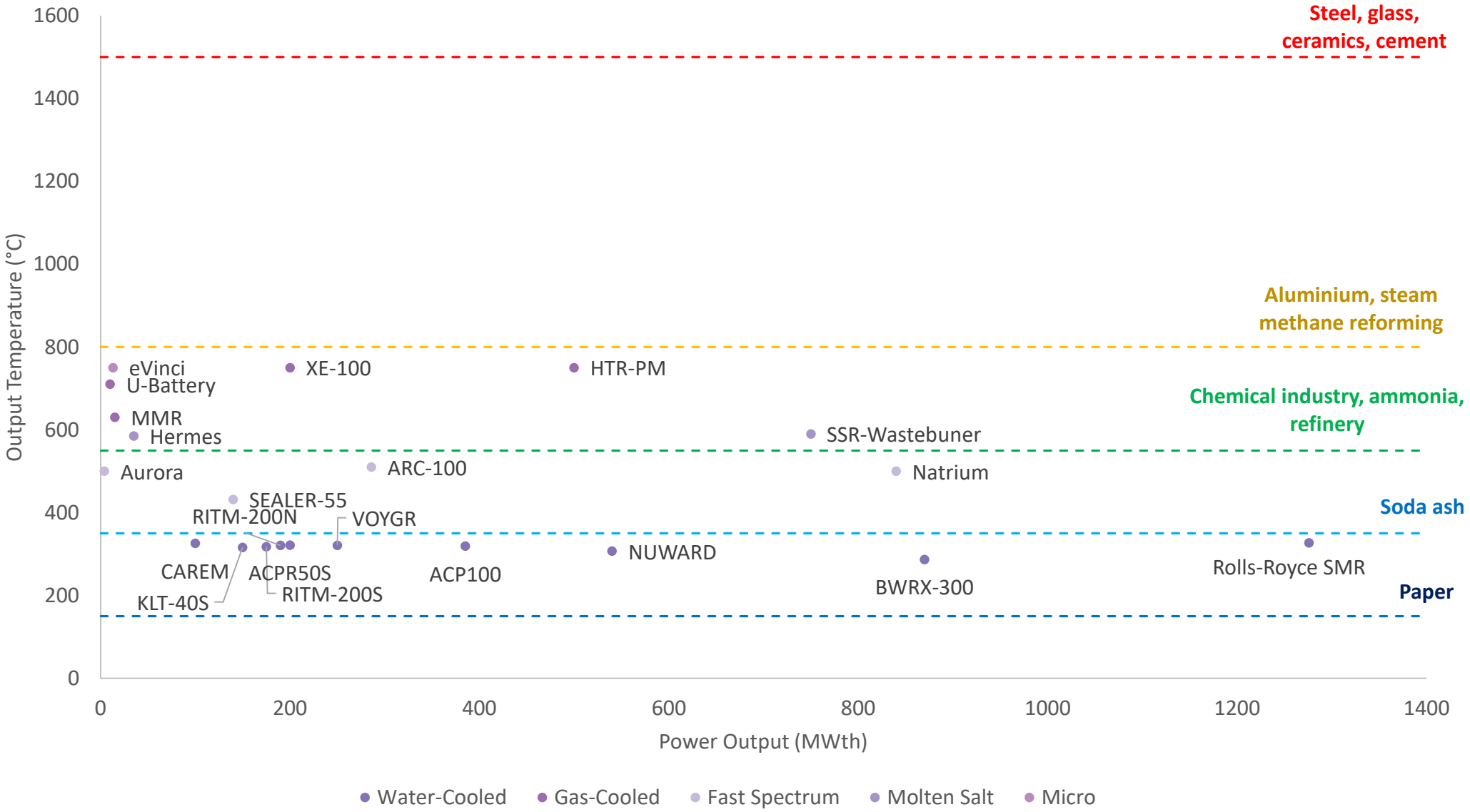
1	ARC-100	ARC Clean Technology
2	CAREM	CNEA
3	ACPR50S	CGNPC
4	ACP100	CNNC
5	NUWARD	EDF
6	BWRX-300	GE-Hitachi Nuclear Energy
7	Hermes	Kairos Power
8	SEALER-55	LeadCold
9	SSR-Wasteburner	Moltex Energy
10	VOYGR	NuScale Power
11	Aurora	OKLO
12	Rolls-Royce SMR	Rolls-Royce SMR Ltd.
13	KLT-40S	Rosatom
14	RITM-200N	Rosatom
15	RITM-200S	Rosatom
16	Natrium	Terrapower
17	HTR-PM	Tsinghua University
18	MMR	Ultra Safe Nuclear Corporation
19	U-Battery	Urenco
20	eVinci	Westinghouse Electric Company
21	Xe-100	X-Energy

Reactor concepts

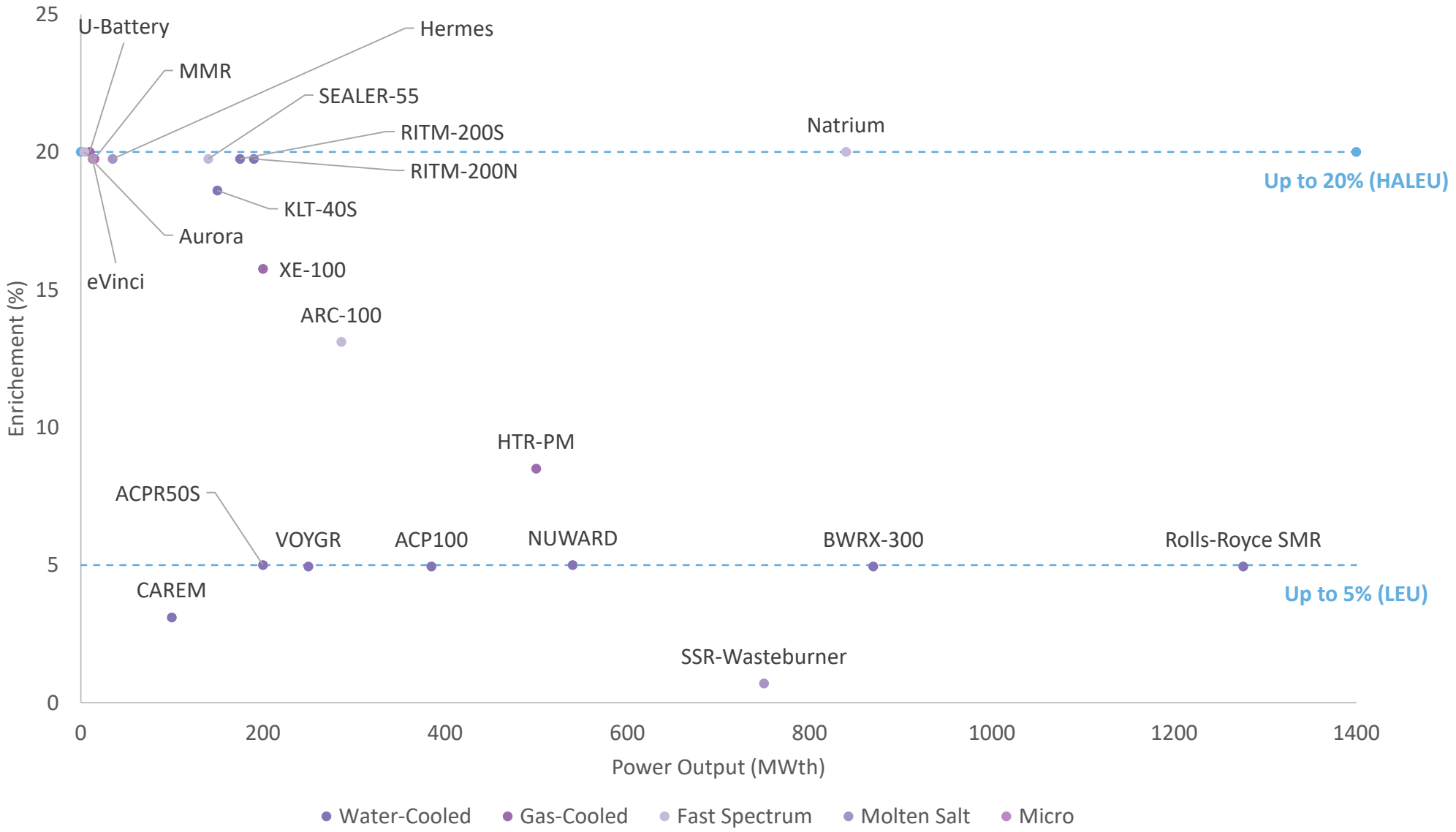


Reactor configurations

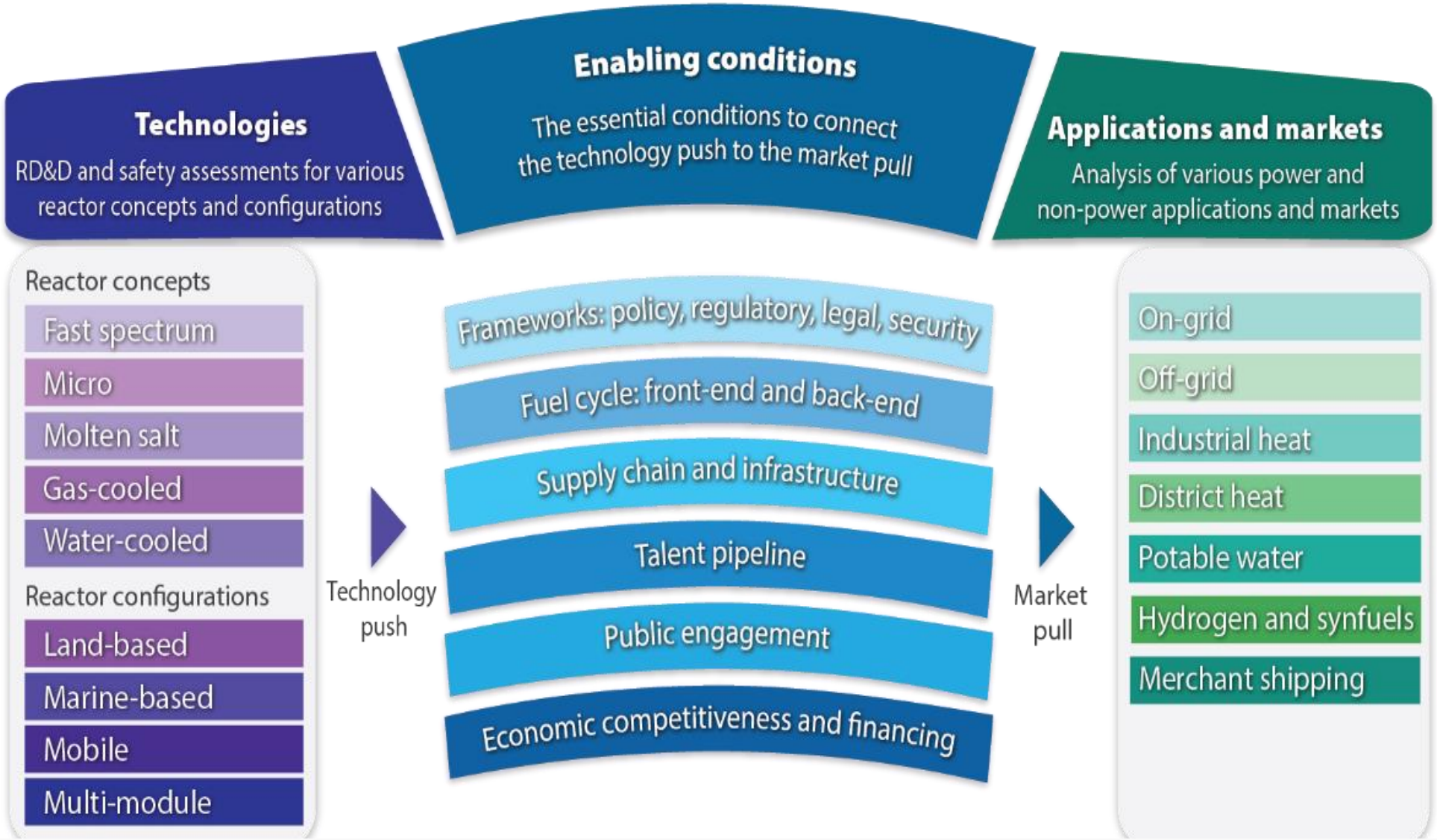
Sizes and temperatures



Sizes, temperatures, enrichment requirements



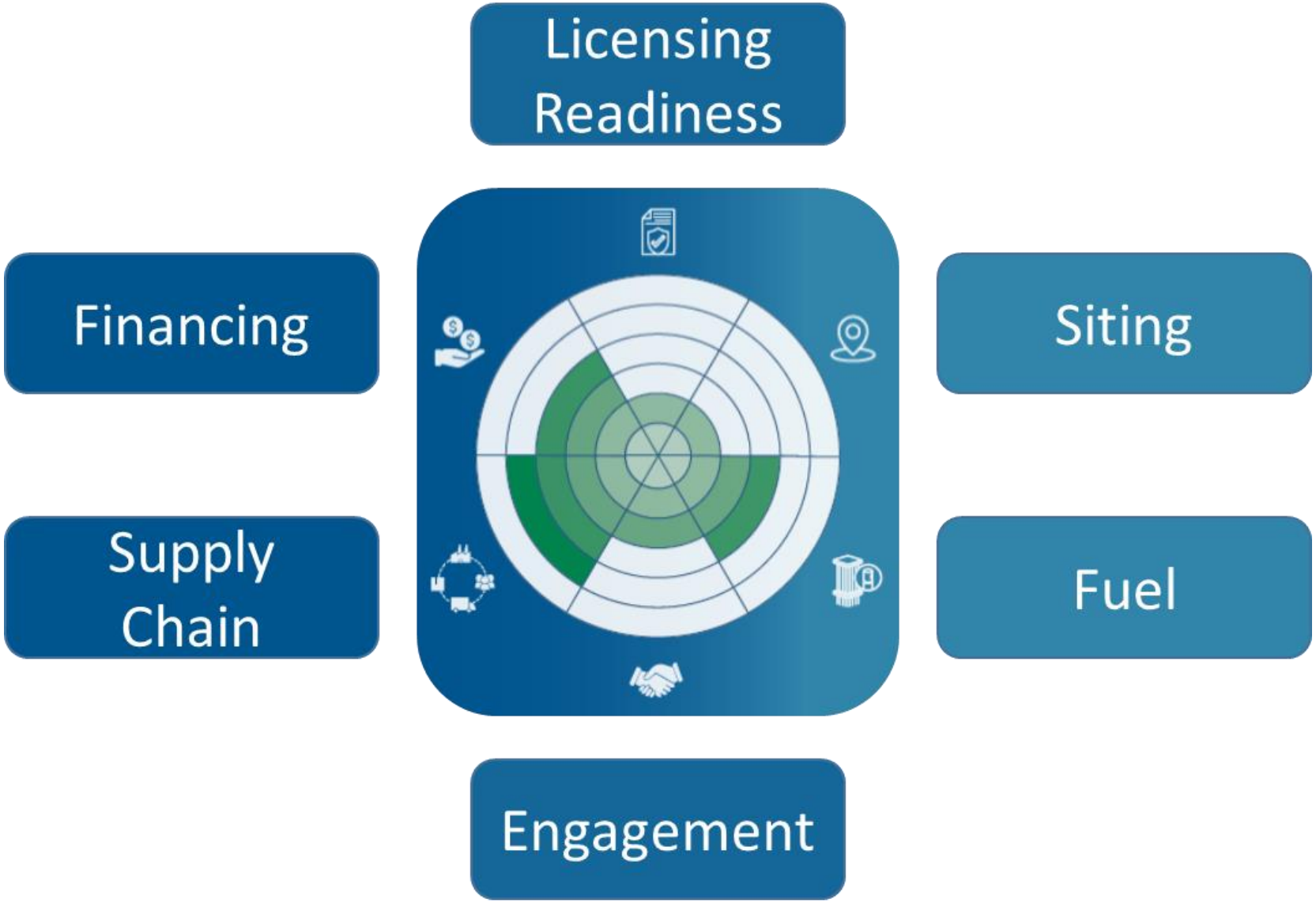
To understanding real progress:
Look beyond technical feasibility



https://www.oecd-nea.org/jcms/pl_73775/the-nea-small-modular-reactor-smr-strategy

Tracking progress: *Six new indicators by NEA*

- "Technology readiness level" is useful, but only reveals part of the picture
- NEA defines six additional indicators of progress
- With NEA's new indicators, the picture becomes more clear



Tracking progress with criteria-based indicators

Licensing	No information	Pre-licensing	Licence/construction/design certification application submitted	Design approved	Licence to construct approved	Licence to operate approved
	* Bonus for multiple jurisdictions					
Siting	No information	Non-binding agreements /MOUs/non-binding announcements	Site owner has shortlisted the technology	Site owner has selected the technology	Received permit(s) and or licence(s) for construction on the site	Construction has Started on the site
	* Bonus for multiple sites					
Financing[1]	No information	At least one announcement	Five or more announcements or USD100 million	Ten or more announcements or USD500 million	FOAK is fully financed	FOAK financed + progress for NOAK finance
Supply Chain[2]	No information	Supplier days /events/workshops/trade shows/non-binding agreements/MOUs/non-binding announcements	Binding contracts for services & materials	Partnerships/joint ventures/consortia - all with EPCs	FOAK construction ongoing/complete	NOAK construction ongoing
Engagement[3, 4]	No information	One or more engagements	Three or more engagements	Five or more engagements	Seven or more engagements	Ten or more engagements
Fuel	No information	Non-binding agreements & studies with national labs for RDD/Lab-scale production of fuel	Contracts/agreements with fuel supply chain (uranium/conversion/enrichment/fabrication)	Operating fabrication facility producing fuel, or uses same fuel as existing/generation-III commercial reactors	Contracts for fuel for FOAK	Fuel loading has begun

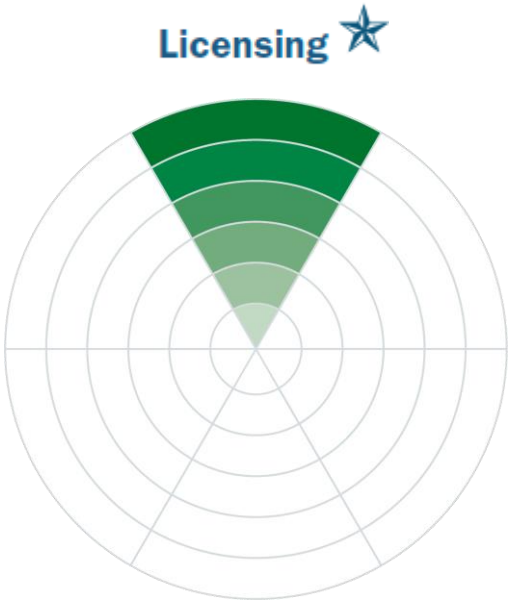
(1) Types of financing announcements in scope: Funding from private investors; government grants; loans; loan guarantees; cost sharing agreements; public-private partnerships; equity partnerships; announcements of becoming publicly traded; announcements of sizeable investments; power purchase agreements; financing approval from rate payers; export credit financing; bank financing; multilateral development bank financing.

(2) Types of suppliers of interest in scope: Engineering, procurement and construction organisations; universities, labs and research institutions when they are supplying research and development services to an SMR project.

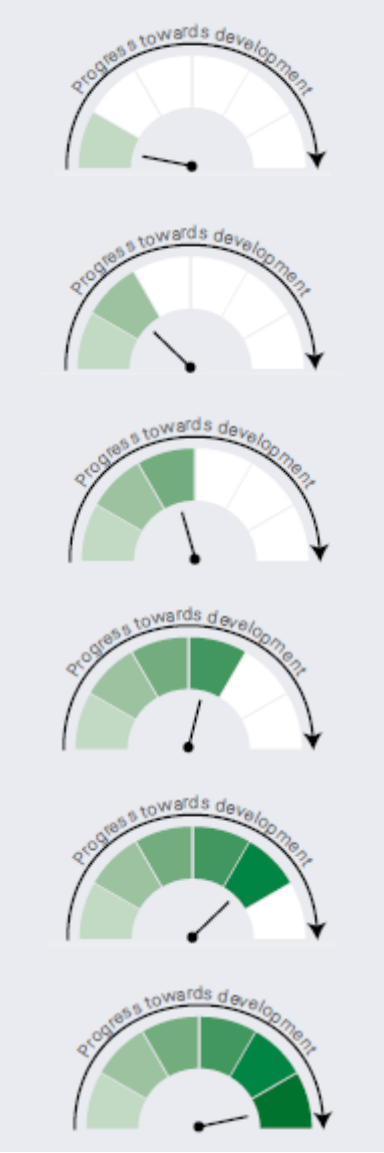
(3) Types of stakeholders for 'Engagement' in scope: Subnational governments; Indigenous governments; labour unions; non-governmental organisations; civil society organisations; community organisations; universities; end users and customers; advisory boards.

(4) Types of announcements for 'Engagement' in scope: Memorandums of understanding; endorsements; town hall meetings; benefit-sharing agreements.

Licensing Readiness



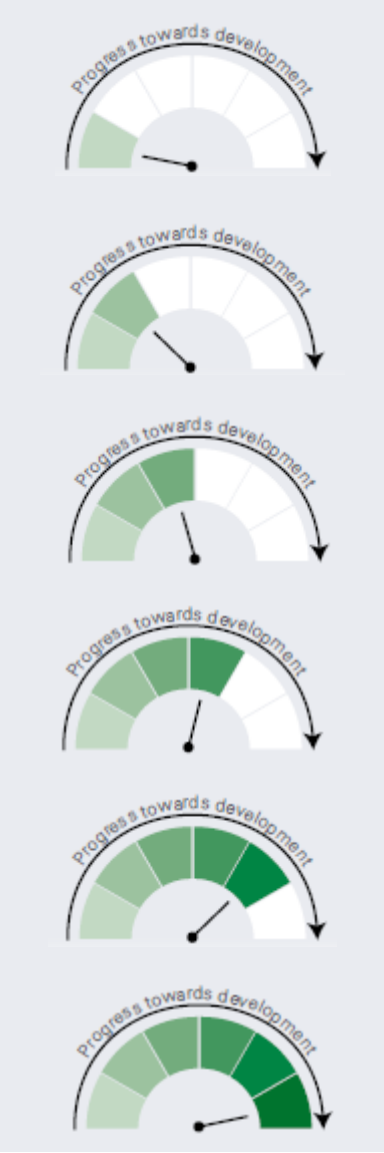
- Currently there are no SMRs licensed to operate outside of China or the Russian Federation.
- The progress criteria for licensing closely follow international licensing pathways, from pre-licensing activities with regulators, design approval, followed by construction and operating licensing.
- A bonus is given to SMRs with licensing activities in multiple jurisdictions at any level.



No information available from verifiable public sources related to licensing or pre-licensing activities.
Evidence of pre-licensing activities, including for example the UK Generic Design Assessment and the Canadian Vendor Design Review process.
Licence, construction, and/or design certification application submitted, including for example by progressing through the US Nuclear Regulatory Commission's Design Certification process.
SMR design is certified or approved by licensing authority.
Licence to construct the SMR is approved by licensing authority.
Licence to operate the SMR is approved.

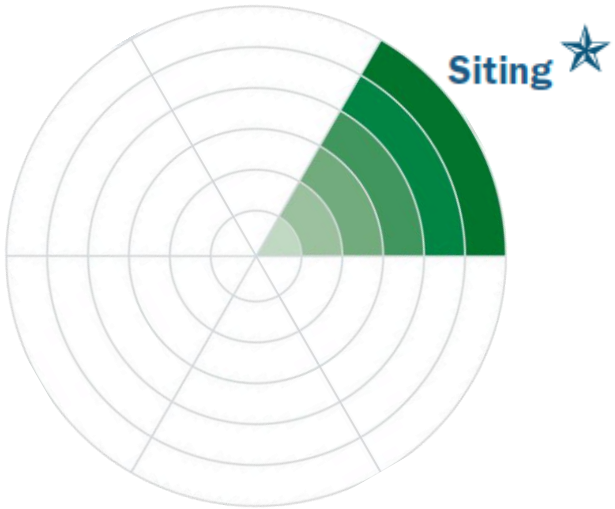
Financing

- Different SMR projects will require different levels of financing and will pursue different business models and strategies.
- Public announcements are utilised to indicate progress in this category, with two pathways of ascension:
  1. The number of financing announcements, or
  2. The amount of funding raised.
- The pathways converge when it can be verified that an SMR first-of-a-kind is fully financed.

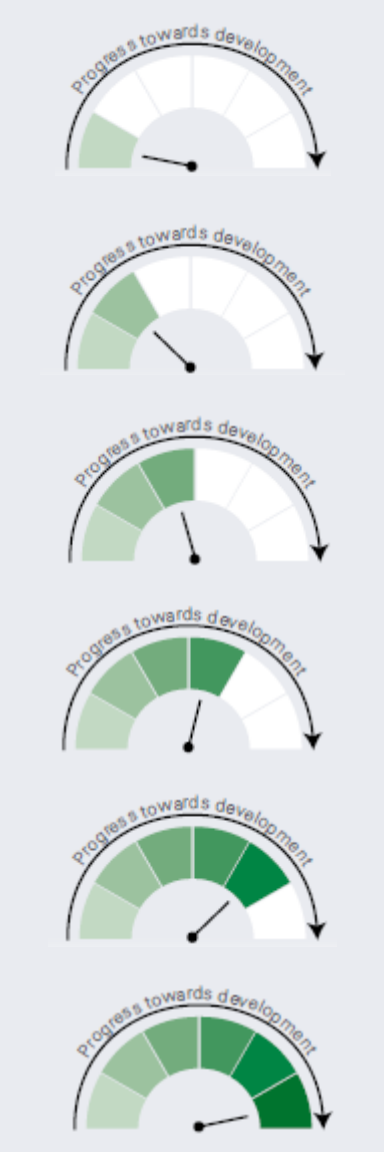


	No information available from verifiable public sources related to financing.
	At least one public announcement related to financing.
	Five or more public announcements related to financing or USD100 million in financing publicly announced.
	Ten or more public announcements related to financing or USD500 million in financing publicly announced.
	Evidence that the First-of-a-Kind (FOAK) is fully financed.
	Evidence that the FOAK is fully financed plus progress towards financing for N^{th}-of-a-kind (NOAK).

Siting

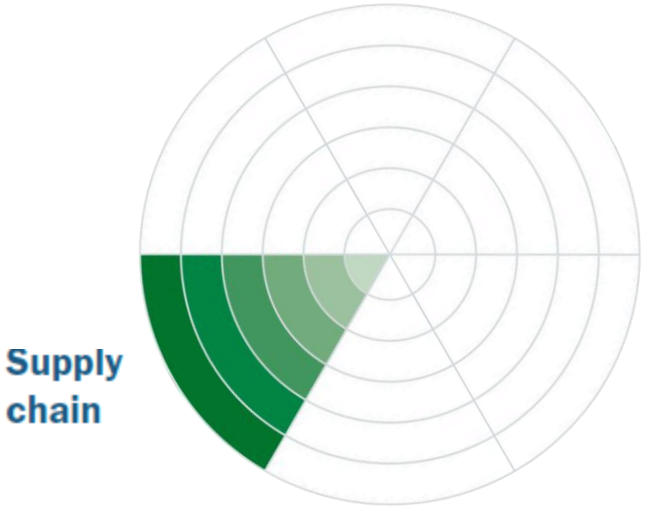


- Siting requirements vary greatly between different SMR configurations.
- The progress criteria reflect whether the site owner has publicly selected the SMR for their site.
- The next factor is whether the site has been licensed and is ready for that specific SMR to be constructed.
- A bonus is given to SMR technologies making progress at multiple sites.



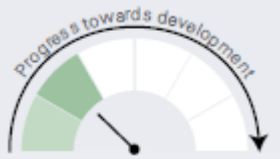
No verifiable public information from a site owner is available related to siting.
Non-binding announcements by a site owner, or non-binding agreements or MOUs are in place with a site owner.
A site owner has shortlisted the SMR for demonstration or deployment at a specific site.
A site owner has selected the SMR for demonstration or deployment at a specific site.
Construction permit(s) and or licence(s) have been granted for the SMR at a specific site.
Construction of the SMR has started at a site.

Supply Chain



- This category maps the maturity of the supply chain for each reactor through verifiable public announcements by suppliers and partners.
- Progress criteria are based on increasing levels of commitment by suppliers in the SMR supply chain.
- Ongoing construction of the SMR at a licensed site is an indication of maturity of the supply chain.

No verifiable public information available from suppliers in the SMR supply chain.



Evidence of supplier days, supply chain events, workshops, trade shows, non-binding agreements, MOUs, and/or non-binding announcements by suppliers in the SMR supply chain.

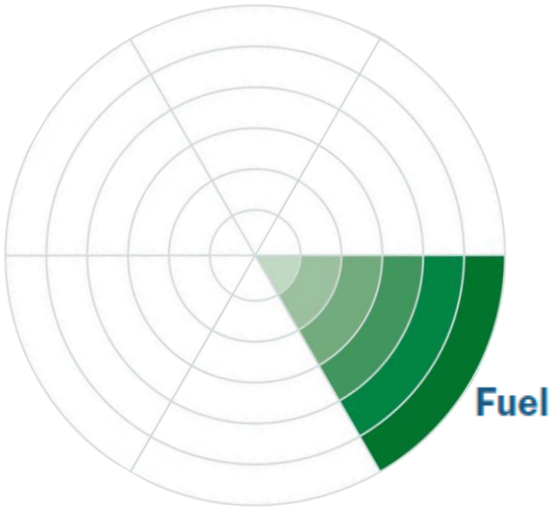
Binding contracts with supply chain for services & materials by suppliers in the SMR supply chain.

Partnerships, joint ventures, and/or consortia with Engineering, Procurement, and Construction (EPC) companies for supply chain related services or materials.

First-of-a-kind (FOAK) construction is ongoing or complete at a licensed site.

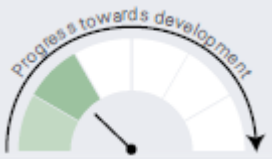
N^{th}-of-a-kind (NOAK) construction is ongoing or complete at additional licensed sites.

Fuel



- Most light water SMR designers plan to leverage commercially available low-enriched uranium fuel.
- Other SMRs plan to utilise fuels which span a range of compositions and levels of enrichment.
- Progress criteria are based on steps towards the commercial supply of qualified fuel.
- Contracts to fully supply fuel for the first-of-a-kind (FOAK) SMR is an indication of maturity.

No verifiable public information available from fuel suppliers in the SMR fuel supply chain.



Evidence of non-binding agreements and/or studies with national labs for research-scale or lab-scale production of fuel.

Contracts or binding agreements with fuel supply chain including for example related to uranium production, conversion, enrichment, and/or fabrication fabrication.

A fuel fabrication facility is producing fuel suitable for the SMR, or the SMR uses the same fuel as existing and/or generation-III commercial reactors.

Evidence of contracts to fully supply fuel for the first-of-a-kind (FOAK) SMR.

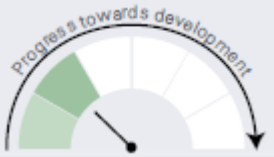
Fuel loading for the FOAK SMR has begun.

Engagement

Engagement

- Public engagement and rust are vital to the success of an SMR.
- In some regions, projects cannot advance without strong engagement with Indigenous communities from the onset.
- The progress criteria consider memoranda of understandings (MOUs), endorsements, town hall meetings, and benefit-sharing agreements with: governments; labour unions; non-governmental organisations; civil society organisations; community organisations; universities; end users or customers; and advisory boards.

No information available from verifiable public sources related to engagement with civil society (defined above).



Evidence of one or more engagement activities with civil society.

Evidence of three or more engagement activities with civil society.

Evidence of five or more engagement activities with civil society.

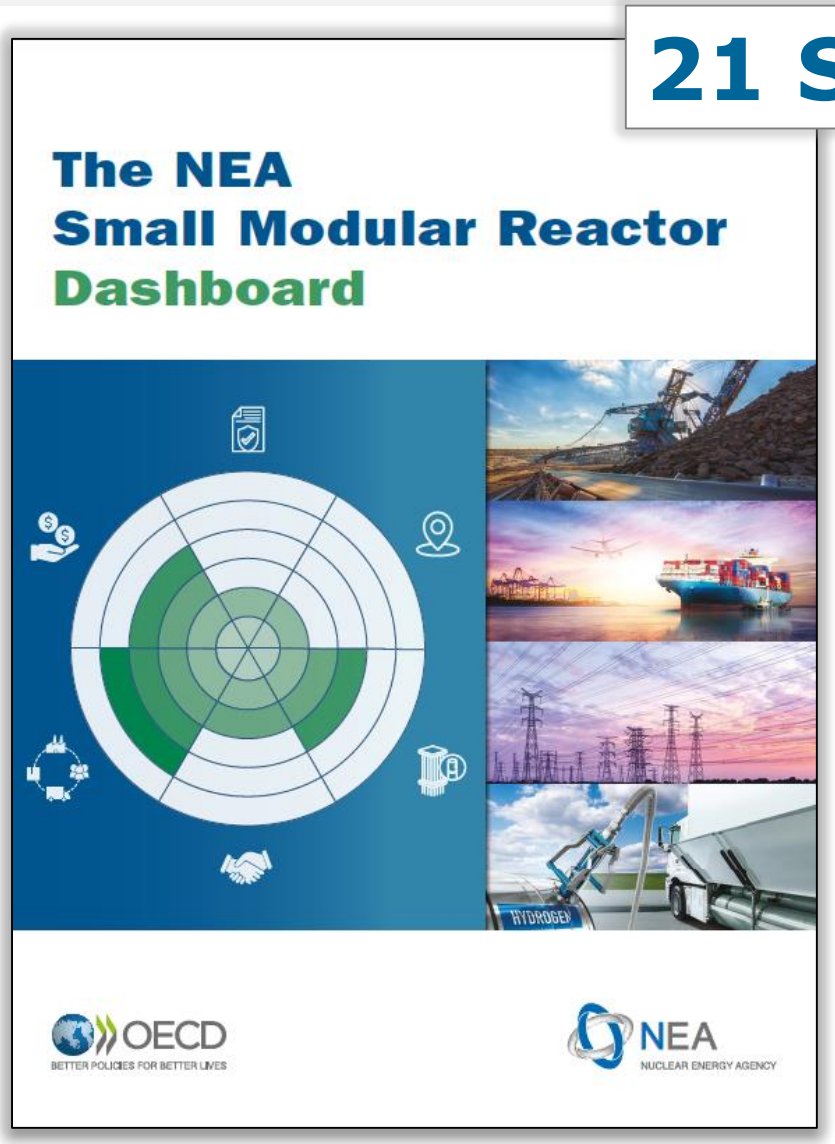
Evidence of seven or more engagement activities with civil society.

Evidence of ten or more engagement activities with civil society.

Our approach

- ✓ Objective criteria
- ✓ Applied consistently
- ✓ Verifiable public sources
- ✓ Validation with vendors
- ✓ Independent verification
- ✓ Fully referenced

The first volume launched on March 13, 2023

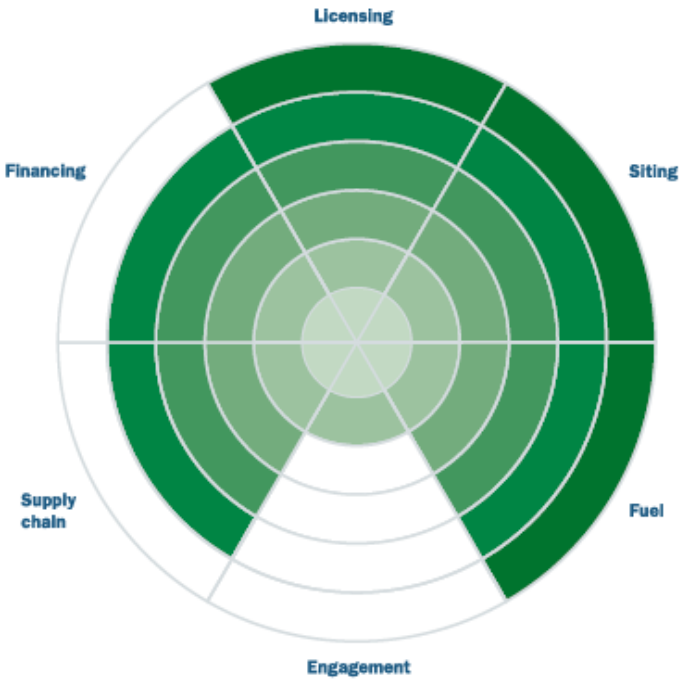


21 SMRs

arc CLEAN TECHNOLOGY
CAREM25
中广核 CGN
中核集团 CNNC
HITACHI
INET
Kairos Power
LeadCold
moltex clean energy
OKLO
NATRIUM
NUSCALE Power for all humankind
nuward
ROSATOM
ROLLS ROYCE SMR
UBATTERY Local Modular Energy
ULTRA SAFE NUCLEAR
Westinghouse
X energy

The logos represented were preferentially sourced from the websites dedicated to the SMR or the design organisation associated with the SMR. Minor modifications were applied related to sizing and colouring

HTR-PM



★ Active in multiple jurisdictions or countries.

Design organisation	INET
Thermal Power (MWth)	500
Outlet Temperature (°C)	750
Spectrum (thermal/fast)	Thermal
Fuel type	TRISO pebble
Fuel (LEU/HALEU/HEU)	HALEU

Licensing

Siting

Financing

Supply chain

Engagement

Fuel

Assessment of HTR-PM's progress to deployment

Licensing

The HTR-PM reactor is fully licensed. It is operating and connected to the electrical grid.

Siting

The HTR-PM is connected to the electrical grid as Shidaowan Nuclear Power Plant in Shandong province.

Financing

The First-of-a-Kind (FOAK) HTR-PM is operating and has been fully financed.

Supply chain

The HTR-PM is owned by a consortium composed of China Huanend, China Nuclear Engineering Corporation and Tsinghua University's Institute of Nuclear and New Energy Technology. China National Nuclear Corporation (CNNC) collaborated with the consortium to provide Engineering, Procurement and Construction (EPC) services, to manufacture fuel elements and for the construction. Up to 93.4% of the equipment was manufactured domestically.

Engagement

The HTR-PM project is owned by a consortium that includes Tsinghua University's Institute of Nuclear and New Energy Technology.

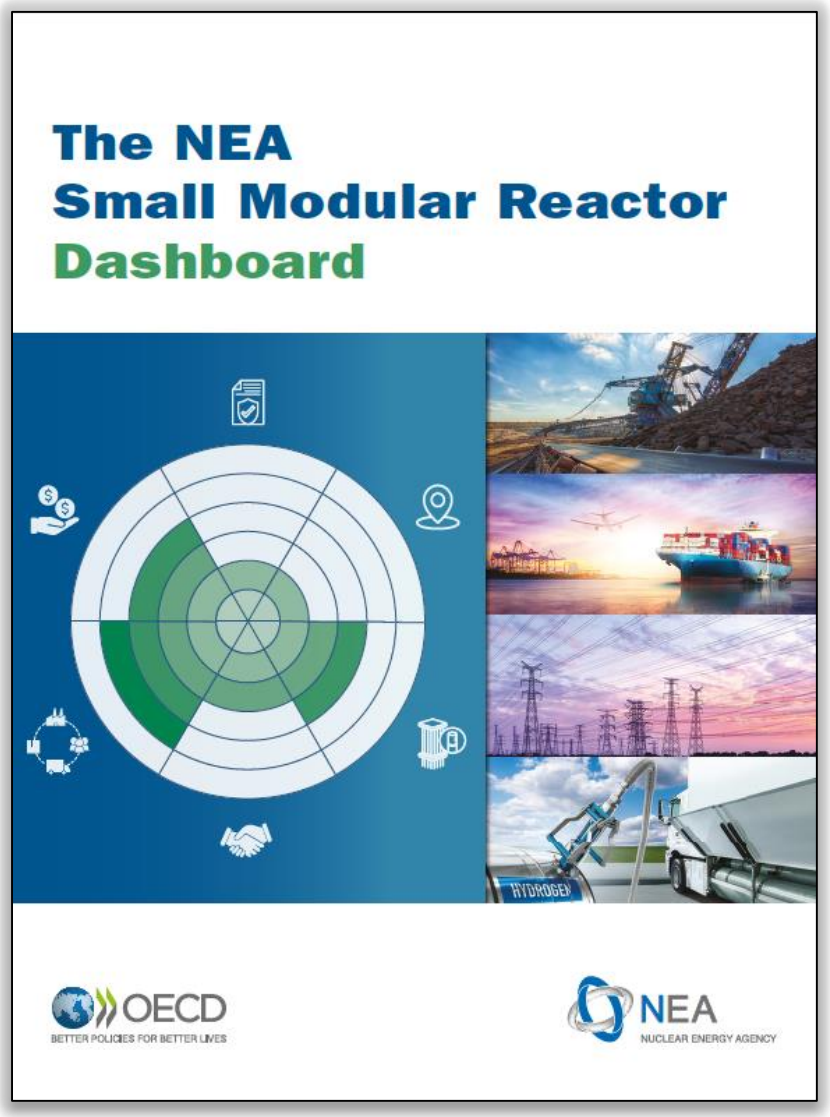
Fuel

HTR-PM fuel is licensed for operation.

Key learnings

- ✓ Six new indicators by NEA contribute to evidence-based situational awareness
- ✓ Variety of SMR concepts, configurations, applications and markets is an asset and a challenge
- ✓ Russia and China leading on deployment with multiple land and marine-based SMRs already in operation
- ✓ Real and rapid progress towards deployment in North America and Europe
- ✓ Timelines are near-term and accelerating
- ✓ Many business models and financing strategies, public and private financing are unlocking and accelerating
- ✓ Fuel qualification and commercial availability is critical path
- ✓ Readiness of regulators, supply chain, and fuel suppliers may become limiting factors
- ✓ Many developers are focused on first-of-a-kind, the paradigm shift to fleet deployment has not started yet

The next volume



- 20-30 SMRs are under consideration for the next volume
- Target launch date July 19th at the Clean Energy Ministerial

Email us to propose your SMR for a future edition:

NEA.SMR.Dashboard@oecd-nea.org

Thank you

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2.4 Fusion Safety Approaches for DEMO and ITER, Joelle Elbez-Uzan, EuroFusion

Safety Approach for Fusion Facilities
ITER and DEMO cases

Joelle Elbez-Uzan
Head of Safety office

This work has been carried out within the framework of the EUROfusion Consortium, funded by the European Union via the Euratom Research and Training Programme (Grant Agreement No 101052200 — EUROfusion). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Commission. Neither the European Union nor the European Commission can be held responsible for them.

Outline of the presentation

- Main **safety objectives for ITER and DEMO** & comparison with fission plants
  - Workers
  - Members of the public
  - Waste
- **Safety approach**
- **Overview of nuclear safety risks**
  - Inventories
  - Routine and accident scenarios
  - Comparison of consequences

SAFETY OBJECTIVES

Why do we need general safety objectives for fusion facilities?

Fusion facilities will be a nuclear facility involving both risks from:

- radioactive materials (tritium, Activated products)
- toxic hazardous materials (lithium, mercury, hydrazine, beryllium…)
- conventional risks (fire, explosion…)

Whatever its regulatory status, there will be a need for the protection from undue hazards:

- **the workers**
- **the public**
- **the environment**

➢ **General safety objectives are established to guide design and future operation of these nuclear facilities**

Safety objectives for DEMO and ITER

Added value from fusion reactors in terms of safety objectives

- **Lower radiotoxic inventory** (reduces impact and allows to use a graded approach)
- **No long term consequences of accident scenarios**
- **Lower environmental legacy** (less long-lived nuclides and waste issues)

General safety objectives for ITER

- Maintain radiological doses as low as reasonably achievable (ALARA)
- Respect dose limits

Global collective dose objectives : 500 p.mSv

	For personnel	For the public and environment
Normal situations	As low as reasonably achievable, and in any case less than: Maximum individual dose **≤ 10 mSv/yr** Average individual dose **≤ 2.5 mSv/yr**	Releases less than the limits authorised for the installation, Impact as low as reasonably achievable and in any case less than: **≤ 0.1 mSv/yr**
Incidental situations	As low as reasonably achievable and in any case less than: **< 10 mSv** per incident	Release per incident less than the annual limits authorised for the installation. **< 0.1 mSv** per incident
Accidental situations	Take into account the constraints related to the management of the accident and post-accident situation	No immediate or deferred counter-measures (confinement, evacuation) **< 10 mSv** No restriction of consumption of animal or vegetable products
Hypothetical accidents	No cliff-edge effect; possible counter-measures limited in time and space	

- Defense in depth
  - Multiple levels of protection
  - Use passive safety features wherever possible
- Definition of just two safety functions:
  - Confinement of radioactive material
  - Protection from exposure to ionizing radiation
  - Other functions in support of these, for example fire protection to protect confinement barriers

DEMO general safety objectives

	Workers	Public	Environment
Routine	ALARA	ALARA	Environment legacy: minimisation of waste No situation impacting environmental matrixes (ground, water, fauna, flora)
	5 mSv/y average	**0.1 mSv/y**	
	10 mSv/y max	less than authorized limits	
Incidents	ALARA	less than annual authorized limits per incident	
	10 mSv max	0.1 mSv per incident	
DBA	Accidental doses less than 50 mSv for emergency situations necessitating an intervention preventing others to receive doses	No immediate or deferred counter mesures (no sheltering, no evacuation)	No accident leading to exceed World health Organization food and water quality criteria
	Constraints from implementation of accident / post-accident management	**< 10 mSv effective dose for both short term and long term** situations for fence and most exposed populations	
DEC	Constraints from implementation of accident / post-accident management < 100 mSv	**No cliff edge effects**; no sheltering; counter measures limited in time and space	

Comparison with other recent nuclear facilities

Recent PWR (EPR)

EPR Finland	Workers	Public
Normal	**10 mSv/y** (total) and less than 0.5 mSv/y (internal)	Normal: 0.1 mSv/y
Incident	20 mSv/event	Cat 2: 1mSv/event
Accident	/	Cat 3-4: 5mSv
DEC	/	DEC: 20 mSv

Collective dose < 50 h.mSv for the 1st year of operation

EPR France	Workers	Public:
Normal	**5 mSv**	Normal: 1 mSv/y
Incident	20 mSv	Cat 2: 1mSv
Accident	/	**Cat 3-4: 10 mSv**
DEC	/	DEC: **limited sheltering, no evacuation beyond close vicinity**

Collective dose < 350 h.mSv

Future PWR (EPR2) (under discussion with the French regulator)

EPR2			Public
Accidents without core melt (DEC-A)			10 mSv effective dose
			50 mSv thyroid
Accidents with core melt (DEC-B)	24h		50mSv effective dose for the closest populations
	7 days	3 km	50 mSv effective: no evacuation above 3 km
		5 km	10 mSv effective: no shetering above 5 km
		5 km	50 mSv thyroid: no iodine ingestion above 5 km
	Long term		**No food restriction above 5 km**
			Dose due to deposits : less than 100 mSv, averaged over 5 y, after the 1st year

Other DEMO main safety objectives

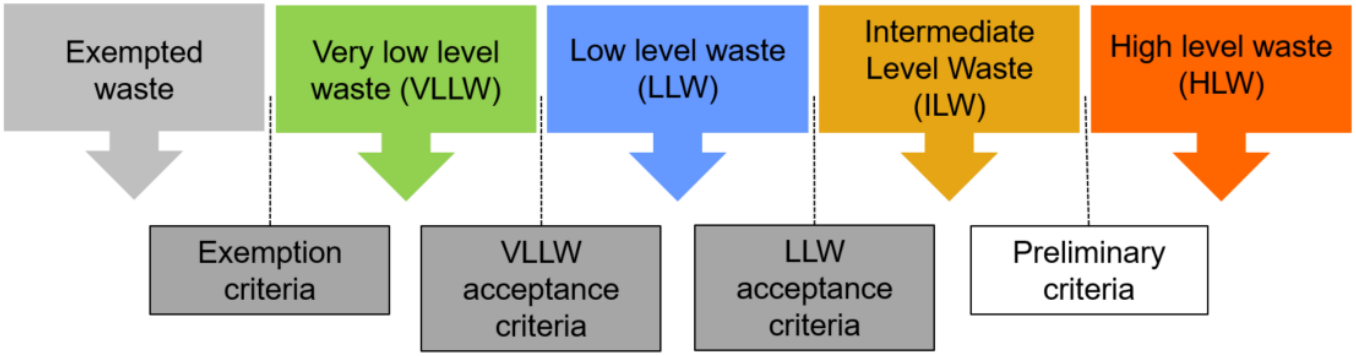
Waste

- **For DEMO, the following measures are adopted**:
  - **DEMO design shall minimize liquid and solid radioactive waste** hazards, toxicity and volumes and ensure that the legacy to the future generation is limited.
  - **Radioactive waste is covering operational waste** (component/equipment replacement, process & housekeeping waste) and decommissioning waste.
  - **The DEMO plant shall minimize the amount of radioactive waste produced** (e.g. by applying the ALARA criterion for material choices, appropriate radiation shielding, waste separation and recycling in Active Maintenance Facility, and long term waste immobilization)
  - **The DEMO plant shall minimise long-term geological disposal waste**

Other DEMO main safety objectives

Waste

- **For DEMO, the following measures are adopted:**
  - Recycling shall be considered as much as possible
  - Use of AIEA General Safety Guide GSG-1 on Classification of Radioactive Waste

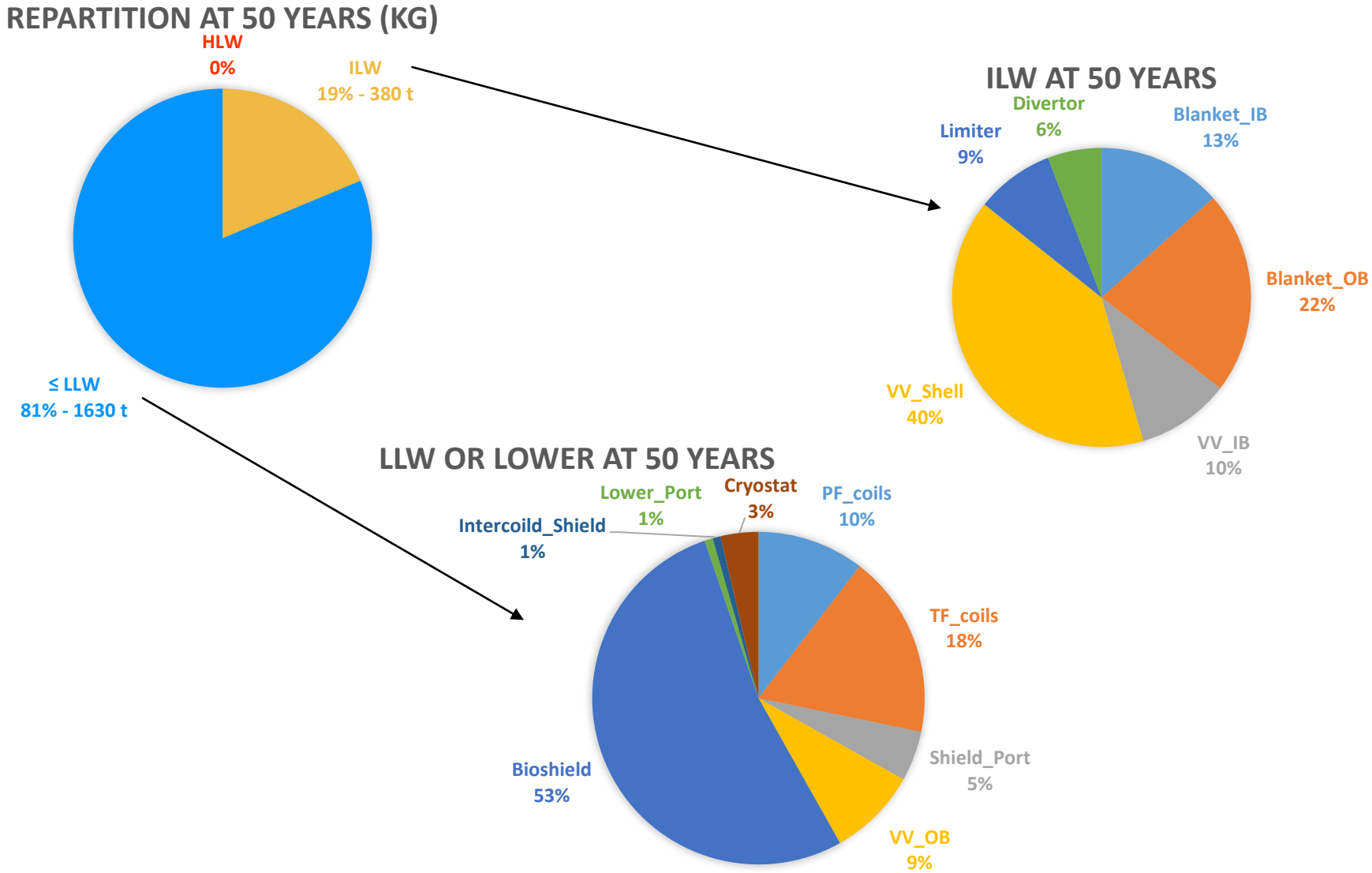


- Criteria are site/country dependant
- Final disposal as HLW (using decay heat as preliminary criteria) shall be prevented by
  - Adequate choice of materials and impurities,
  - High efficiency detritiation of breeder materials and neutron multipliers,
  - Interim storage (< 50 years) before final disposal.

Other DEMO main safety objectives

Waste

- For DEMO tok machine, considering French or UK limits



SAFETY APPROACH

Safety approach

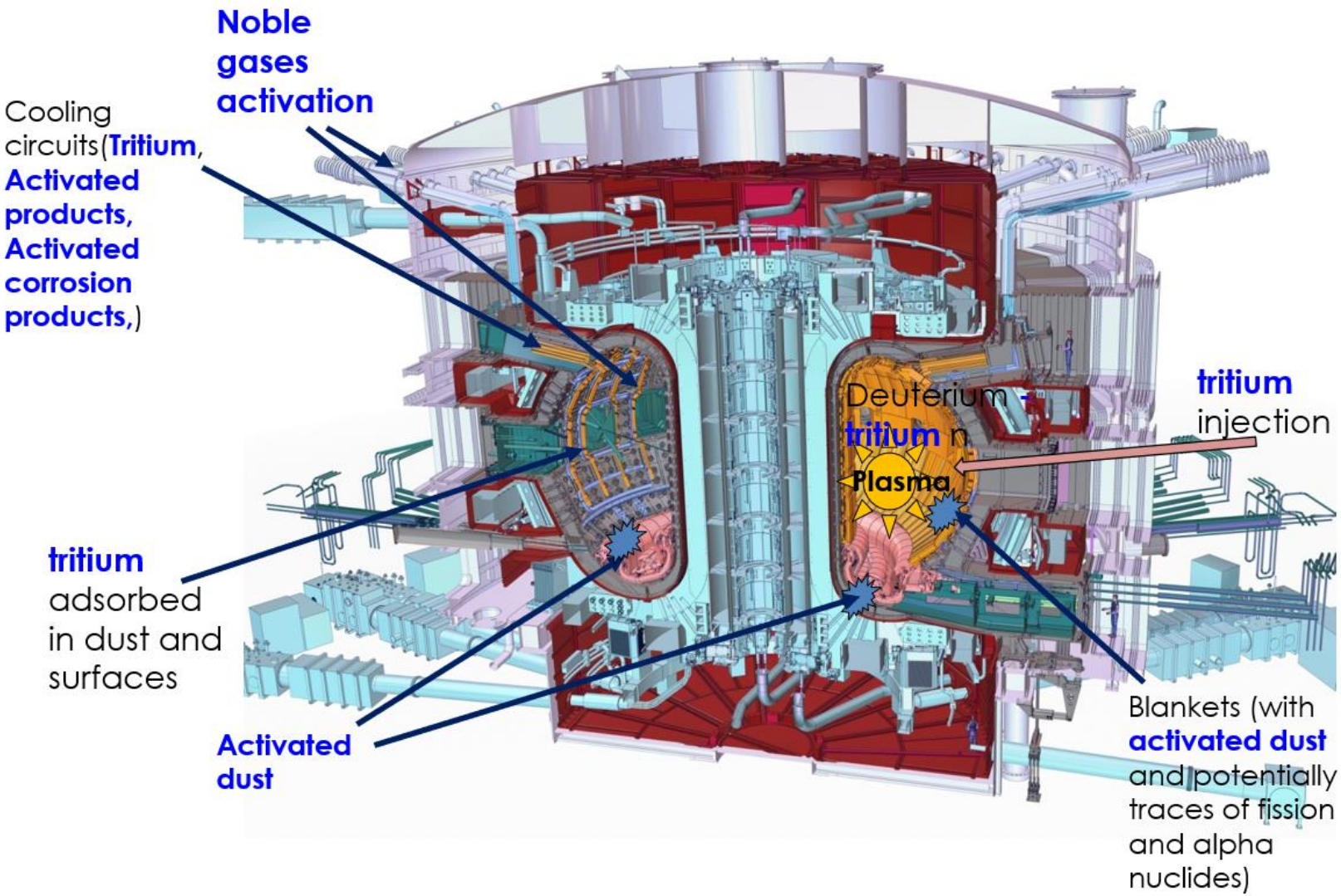
- **Safety approach is deterministic** aiming at assessing causes and consequences of events without probabilistic approach (no enough feedback
- **The safety demonstration** shall include all situations, from normal operation to hypothetical accidents including DEC scenarios
- **the safety requirements shall be proportionnate** to the risks and be implemented to demonstrate that :
  - the facility is in safe conditions for all operation states
  - The impact is below safety objectives
  - The consequences are ALARA

ITER and DEMO Nuclear Safety Functions

	ITER	DEMO
Safety Functions	• Confinement of chemical and radioactive materials • Limitation of exposure (interne, externe)	• Confinement of chemical and radioactive materials • Limitation of exposure (interne, externe) • Power dissipation (cooling function) ?
No safety functions	• Reactivity • Power dissipation (cooling function)	• Reactivity

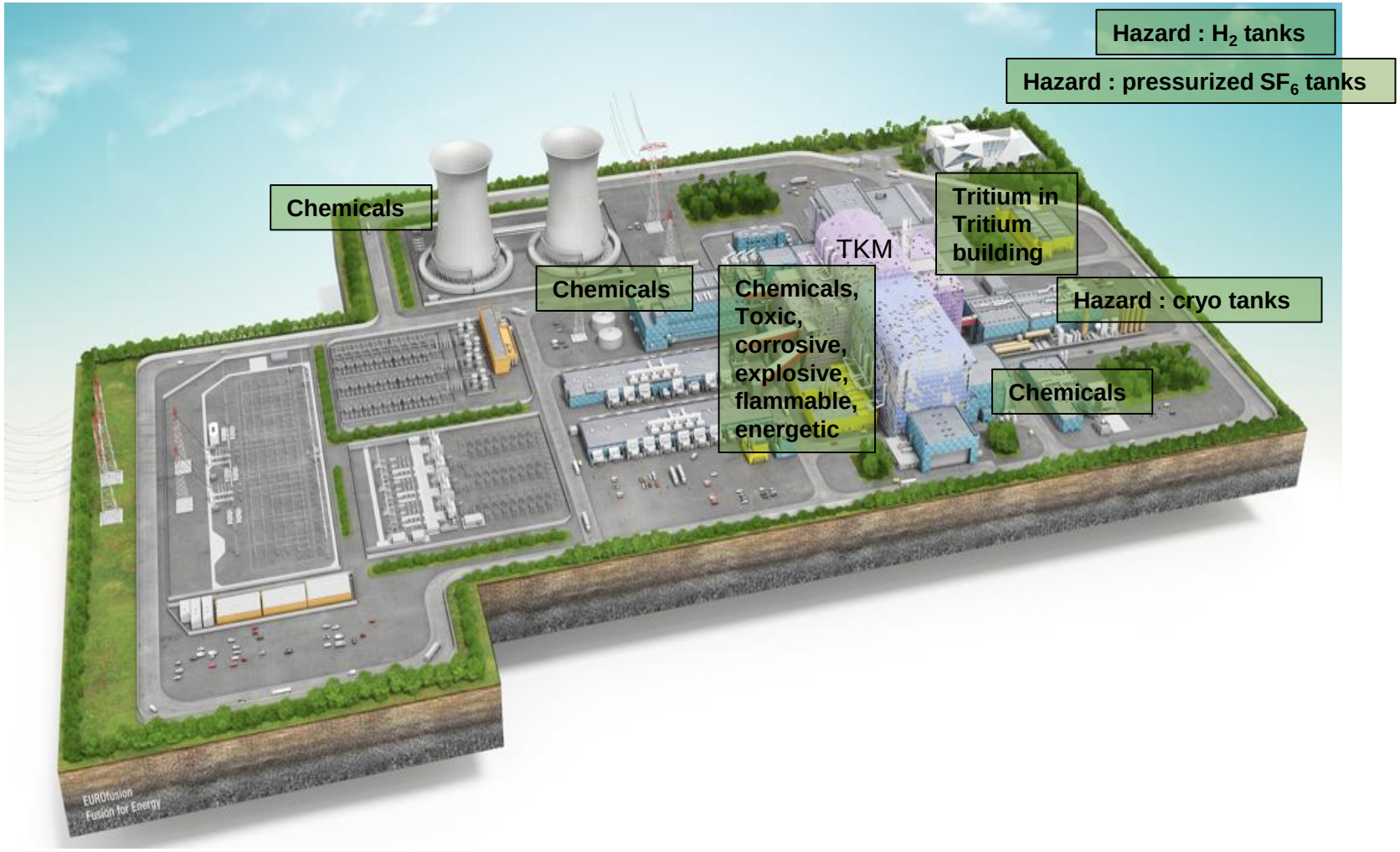
OVERVIEW OF SAFETY RISKS FOR ITER AND DEMO

Overview of risks in ITER and DEMO



Example of ITER Tokamak , similar to DEMO

Overview of risks in ITER and DEMO



Example of DEMO site (buildings else than TKM building)

How to build Safety Cases?

- The safety cases need to demonstrate the fulfilment of the top-level safety objectives

- The safety analysis comprises the study of **abnormal situations, incidents, as well as accidents in which hazardous inventories are involved**

- BUT the safety case is not reduced only to it. It also comprises the study of routine situations (including maintenance)=> **Normal operation study**

Normal operation study

- **The normal operating conditions** cover the plasma pulses and the maintenance periods
- It is based on
  - **the analysis of the various sources** of hazardous materials, radioactive or not;
  - **the assessment of internal and/or external occupational exposure** to hazardous materials during both nominal operation and maintenance operations where the highest level of exposure is expected;
  - **the impact of hazardous materials liquid and gaseous releases** into the environment.

Internal and external hazards

Internal hazards analysis

- Internal fire,
- Internal explosion,
- Thermal releases,
- **Plasma transients**,
- Internal flooding,
- Missile effects and pipe whip,
- Mechanical risks,
- Chemical risks,
- **Cryogenic risks**
- **Magnetic/ electromagnetic risks**

External hazards analysis

– Hazards relating to the natural environment:
  - Earthquakes,
  - Extreme climatic conditions,
  - External flooding,
  - External fire…

– Hazards relating to human activities:
  - Aircraft crashes,
  - Hazards associated with the industrial environment and communication routes…

Reference Events

- Depending on the likelihood of each event/hazard, the accidents have been classified into :

- ***INCIDENTS : when they are likely to occur several times in the whole ITER lifetime***

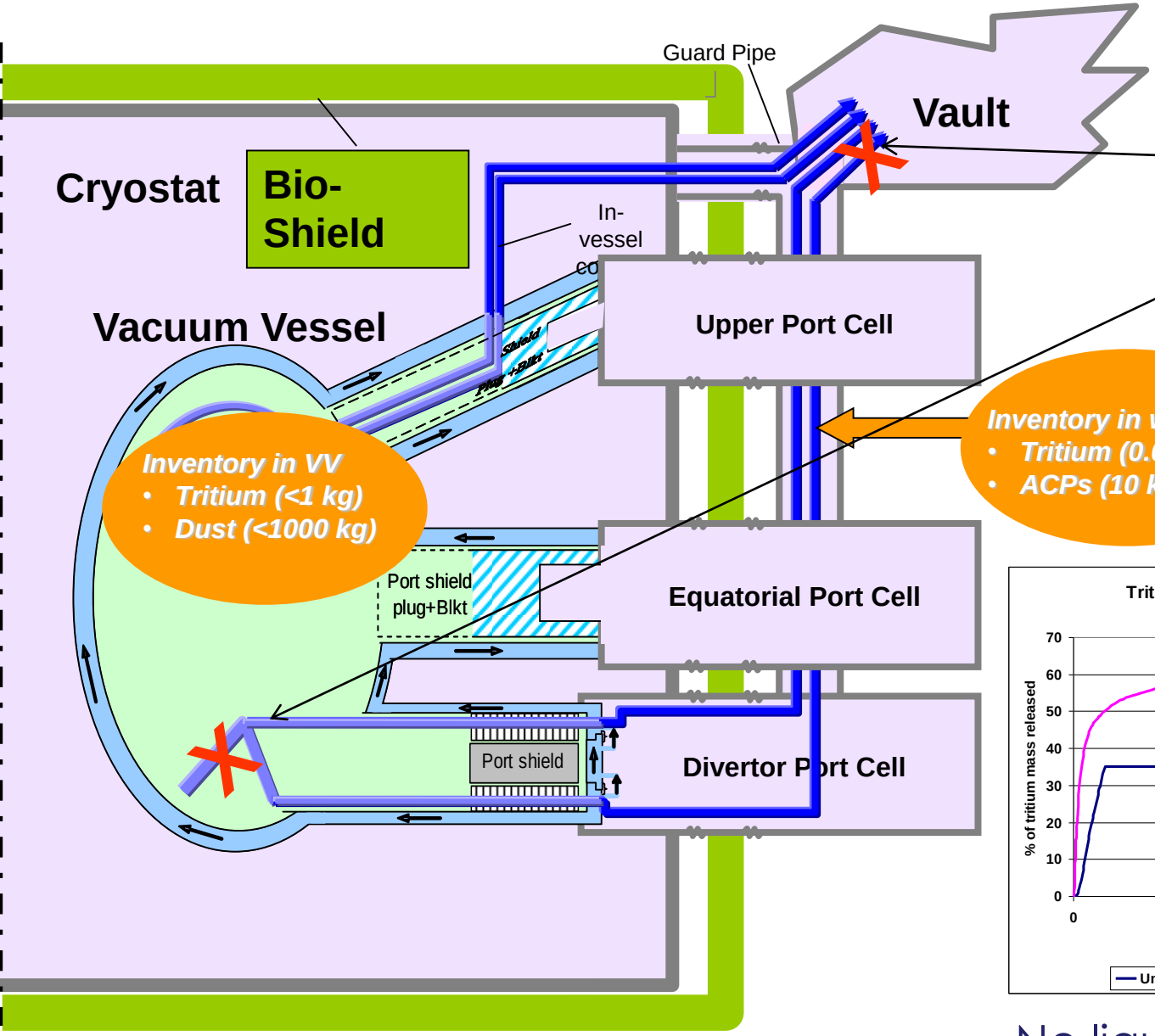
- ***DESIGN BASIS ACCIDENTS : when they are likely not to occur in the whole lifetime, but the failure of a safety line of defense could create the accident***

- ~~***BEYOND DESIGN BASIS ACCIDENTS***~~ **->** ***Design Extended Conditions :*** corresponding to postulated accident conditions that are not considered for design basis accidents, but that are considered in the design process for the facility in accordance with best estimate methodology, and for which releases of radioactive material are kept within acceptable limits.

Example list of ITER Reference Events

No.	Event title	Category
Loss of power		
L1	Loss of off-site power for 32 hours	accident
In-vessel events		
V1	In-vessel FW pipe leakage	incident
V2	Multiple FW pipe break	accident
V3	Loss of vacuum through one VV/cryostat penetration line	accident
Ex-vessel PHTS events		
X1	Loss of divertor heat sink	incident
X2	Pump trip in divertor HTS	incident
X3	Pump seizure in divertor	accident
X4	Large VV coolant pipe break	accident
X5	Large DV ex-vessel coolant pipe break	accident
X6	Heat exchanger leakage	incident
X7	Heat exchanger tube rupture	accident
X8	Coolant pipe break inside Port Cell	accident
Maintenance events		
E1	Stuck divertor cassette and failure of cask	accident
Tritium plant and fuel cycle events		
T1	Tritium process line leakage	incident
T2	Accident with transport hydride bed	accident
T3	Isotope separation system failure	accident
T4	Failure of fueling line	accident
T5	Fire in the T-plant	accident
T6	Leak of tritiated water from Water Detritiation System	accident
Magnet Events		
M1	Toroidal field coil short	accident
M2	Arc near confinement barrier	accident
Cryostat Event		
C1	Cryostat air ingress	accident
C2	Cryostat water ingress	accident
Hot Cell Events		
H1	Loss of confinement in hot cell	accident
H2	Fire in the hot cell	accident

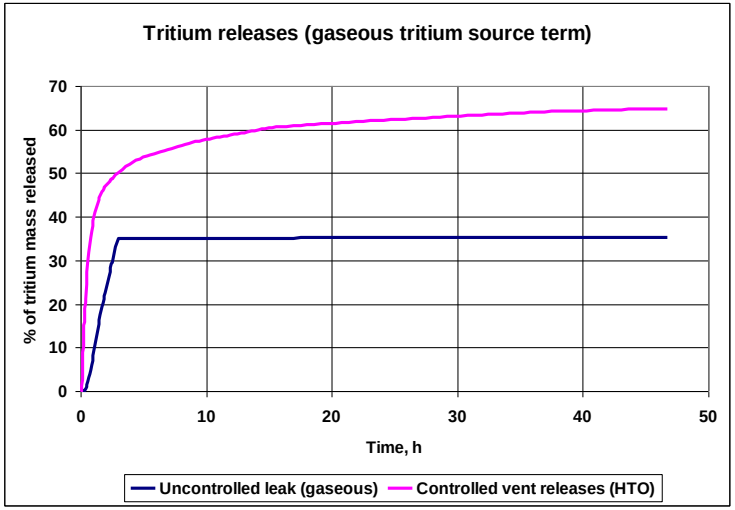
ITER: Large ex-vessel DV pipe break



Initiating event :
failure of cooling pipes in the vault (cat III event), and inside the VV (all together cat IV)

Inventory in water
- **Tritium (0.005 g/m3)**
- **ACPs (10 kg/loop)**

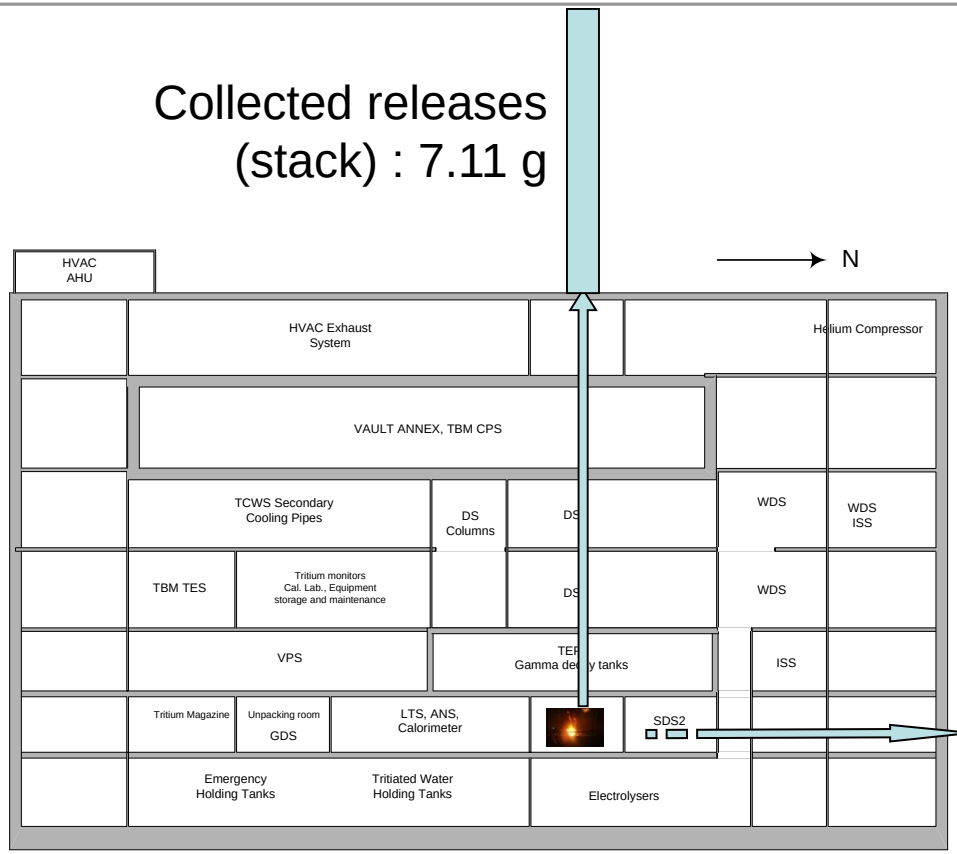
Doses to the public :
Fence : 98 µSv
Public : 18 µSv



No liquid releases

ITER: Fire in a room located in the Tritium plant

Collected releases (stack) : 7.11 g

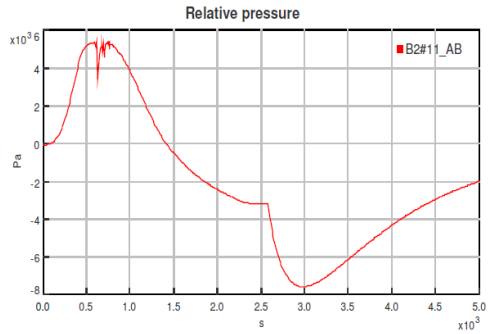


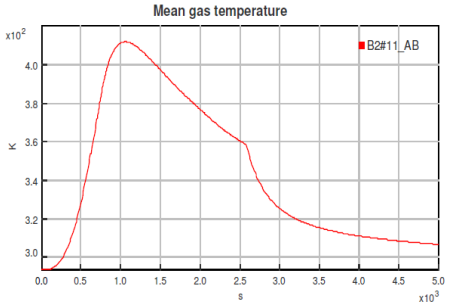
Scenario: fire in a room

- All the tritium is released into the room
- During 30 s tritium released through HVAC without detritiation factor at stack level
- During 5 minutes, Detritiation systems are considered as non efficient
- Detritiation systems are considered with lower efficiency (90%) after 5 minutes

Maximum inventory in a fire sector < 70 g-T)

Direct releases : 0.24 g (ground level)





Doses :

- **Fence : 1.07 mSv**
- **Public : 0.17 mSv**

DEMO: Example of DBA Reference events

Under evaluation

- Loss of off-site power for 32 hours
- In-vessel events: PHTS pipe leakage/break, loss of vacuum through one VV/cryostat penetration line, BB in-vessel events TBD…
- Ex-vessel PHTS events: loss of heat sink, pump trip/seizure, pipe break, heat exchanger leakage or pipe rupture, coolant pipe break, BB ex-vessel events TBD…
- Fire, explosions
- Tritium plant and fuel cycle events: line leaks, tritium plant system failure (as Water Detritiation System failure) …
- Magnet events: TFC short, arc near confinement barrier…
- Cryostat or cyrogenic events: air, water, He ingress …
- Hot cells/Active maintenance Facility events: stuck cask, loss of confinement, fire…

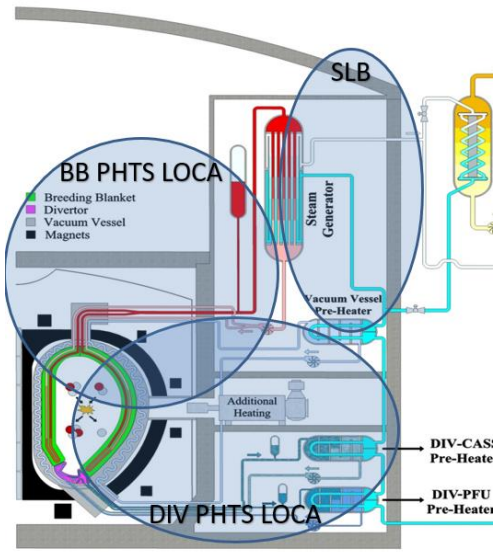
DEMO: Examples of Design Extension Conditions (DEC)

Under evaluation

- **Scenarios where several confinement systems** can be affected by one or several independent failures, leading to a confinement bypass (e.g. scenarios leading to the break of the vacuum vessel together with the opening of relief panels to discharge the energy to the environment, pipe whipping effects from high energy line breaks…)
- **Multiple failures scenarios leading to a high release of mass** or energy higher than the ones used in the design of building systems leading to a non compensated breach in the last confinement system (e.g. failure of cryogenic fluids together with loss of coolant scenarios, explosion scenarios, generalised fire scenarios),
- **Combination of smaller accident scenarios** (e.g. combination of loss of coolant events and loss of vacuum accidents),
- **Common causes failures that may affect redundant trains.**

DEMO: Overview of some accident scenarios in TKM

- LOFA (Loss of Flow Accident) (FP8): these scenarios cover the scenarios such as total station black-out: Some scenarios are still under modelling, but no releases to the environment identified so far
- Loss of heat sink (FP8) : no releases to the environment
- WCLL pipe break : 9 g of tritium released in the rooms
- Plasma event (FP8) : no releases to the environment
- Fire accident (FP9): the tritium inventory in the affected circuit is released into the room, and then to the stack,



- Loss of coolant accidents (FP8) :
  - In Box LOCA from WCLL or from HCPB
  - In-VV LOCA from HCPB and from WCLL, and from DIV-PHTS
  - Ex-vessel LOCA (FP8): from **BB-PHTS for WCLL** and from DIV-PHTS

Driver: ex-vessel LOCA (**BB-PHTS-WCLL**) with around 7 microSv at 0.5 km

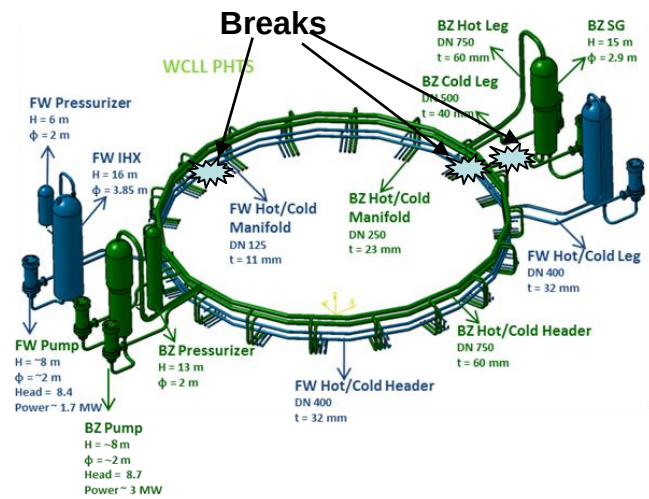
- Loss of vacuum accident (LOVA) in vacuum vessel (FP9):
  - with WCLL design : no direct releases to the environment and only filtered streams from VVPSS are going to the stack, radiological consequences << 1 mSv
  - with **HCPB design** : depending on the duration of plasma unmitigated disruption duration, the releases at the stack may be from 0 (all confined) , up to 195 g of dust and 29 g of HTO
- Combined scenarios

DEMO: Reference combined events

Category	System	PIE	Event	Reference BDBA	Safety Concern
LOCA	WCLL HCPB	LFV1 LDV1	Wet confinement bypass	Large (or subsequents) in-vessel LOCAs of the FW-PHTS combined with a common cause failure of the NBI ports gate valves.	Hydrogen production Radioactive material mobilization
LOVA	WCLL HCPB	VVA1 LVV2	Dry confinement bypass	LOVA in VV due to port plugs and gate valves failure	Hydrogen production Radioactive material mobilization
LOCA LOFA	WCLL HCPB	LMO1 LMO2 LMO3	Decay heat removal	Out-of-vessel loss of cooling accident from the breeder primary cooling loop, with consequent loss of off-site power and loss emergency AC generators powering DHRS.	Hydrogen production
LOCA LOVA	WCLL HCPB	LVV2 LFV1 LDV1 AOP2 AOP1	Hydrogen deflagration and detonation	In vessel LOCA from the breeder primary cooling loop with consequent loss of off-site power and loss emergency AC generators powering DHRS.	Hydrogen production *(Structure loads)* Radioactive material mobilization
LOCA LOFA LHS	WCLL HCPB	LBO1 LBO3 VVA1 LVV2 HA99 LVO1 FF1	Fusion power shutdown	Ex-vessel and In-vessel LOCA without the trigger of the plasma shutdown system	Hydrogen production Radioactive material mobilization *(Structure loads)*
External events	WCLL HCPB		Loss of Confinement	Seismic events/aircraft crash/external explosion/flooding with consequent loss of off-site power and loss emergency AC generators powering DHRS.	Hydrogen production Radioactive material mobilization

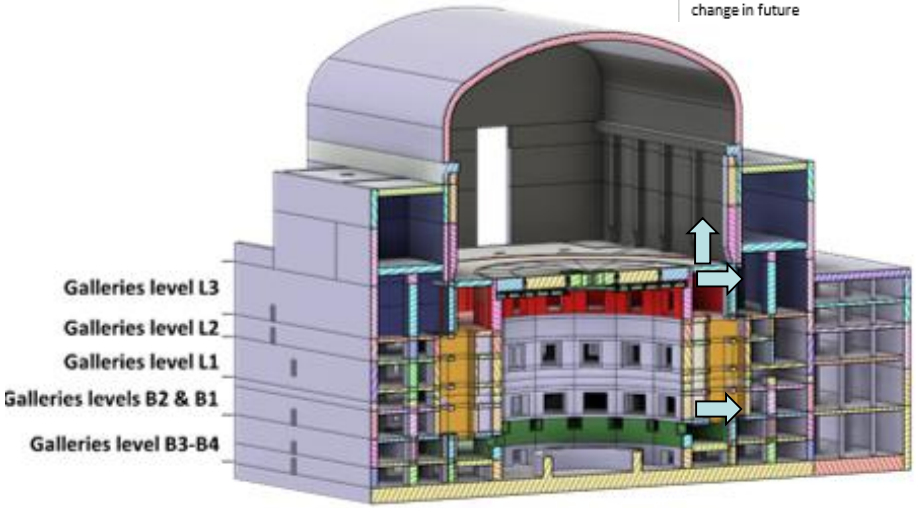
DEMO: Focus on ex-vessel LOCA for WCLL-PHTS

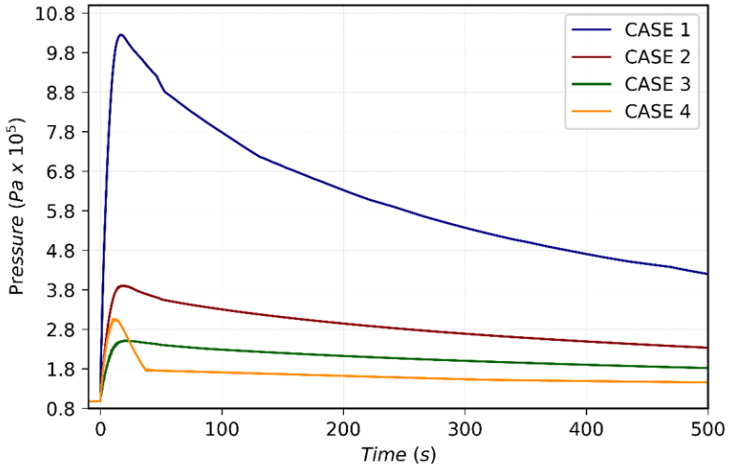
- **Scenarios based on sensitivity studies** : double ended guillotine break at several locations (breeding zone and manifolds): BZ is the driver
- Pressure: 155 bar abs, T=325C, Break section: 0.23 m2
- **Several expansion volumes considered for LOCA energy**
  - Case 1 : only the UPC/LPC/shafts
  - Case 2: whole vault
  - Case 3: vault and BB rooms
  - Case 4: vault, BB and dome



Building Area	Free Volume
Top Maintenance Hall & Dome	205597 m³
Upper Pipe Chase	9709 m³
Vertical Shaft	1800 m³
Lower Pipe Chase	6033 m³
PHTS Area	49775 m³

*Values related to the current state of the design and could change in future

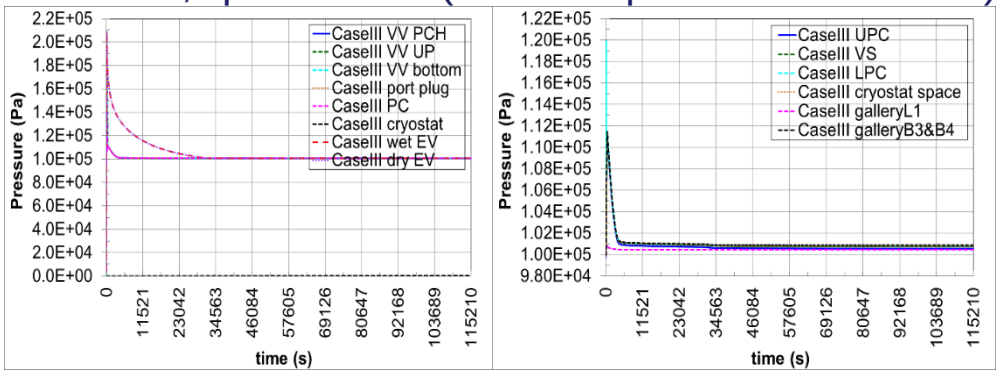


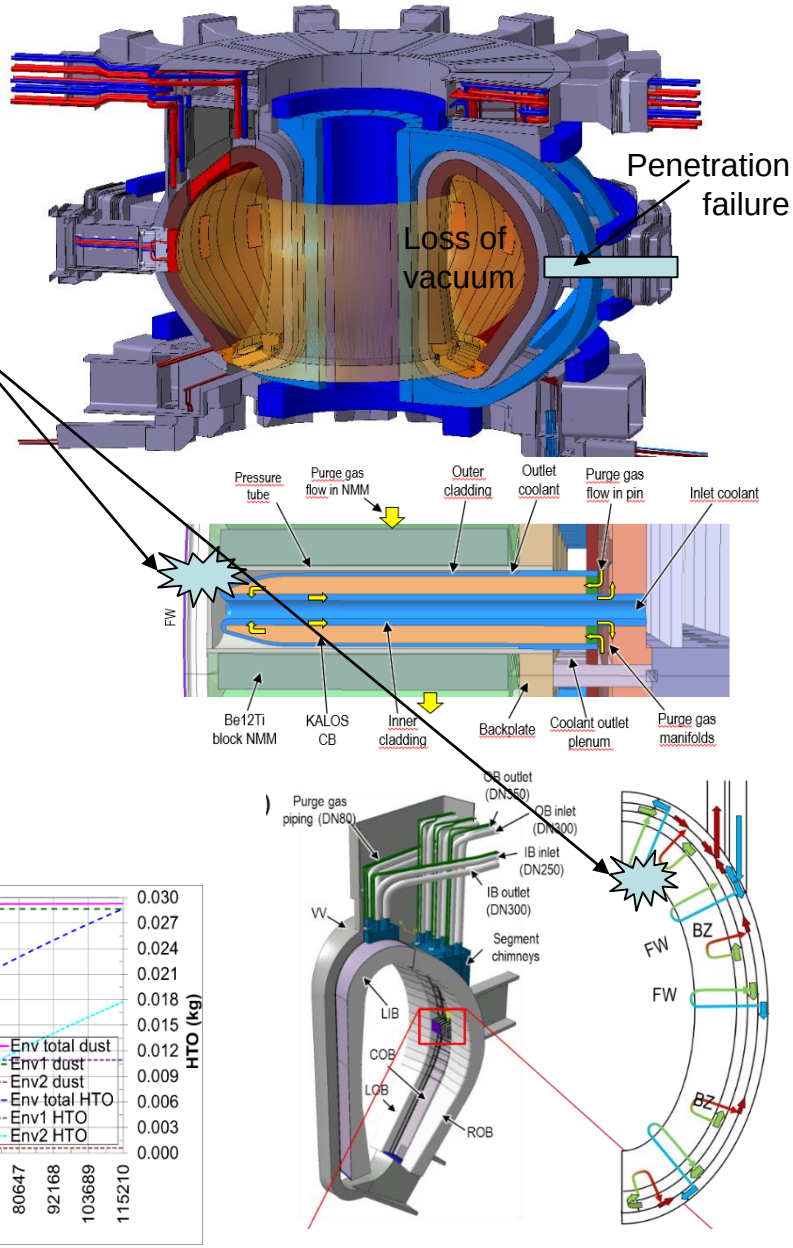


Current design work on expansion volumes, relief panels, increased design pressure and spray system

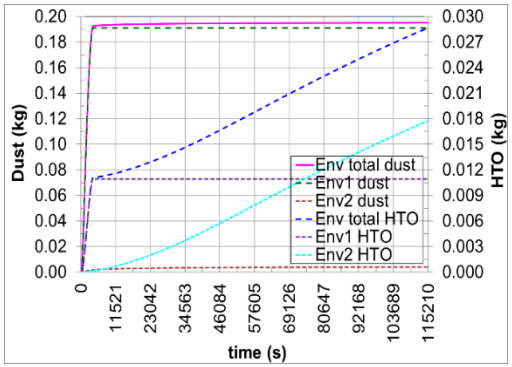
DEMO: Focus on LOVA for HCPB

- Loss of vacuum accident (LOVA) in vacuum vessel with HCPB design (Helium at 80 bar, 300-520C range)
  - Penetration failure
  - Plasma disruption : cases with/without operational plasma mitigation system (1 ms or 3.7s duration, driving case : 3.7 s)
  - For 3.7s case, the FW temperature increases above 700C and leads to additional failures of pressurised helium pipes ruptures, pressurising the VV, port cells (via the penetration failure)





- Radioactive dust and tritium is released into the environment via the room pressure



Summary

- ITER and DEMO main safety objectives are ambitious
- Safety requirements are based on a proportionate approach of the risks
- Lower long term impact from these fusion facilities even in accident conditions (radiological consequences, waste, no chain reaction, no long term cooling needs…)
- Lessons learnt from other nuclear facilities and continued R&D will even lower these risks

Thanks for your attention.
Any question?

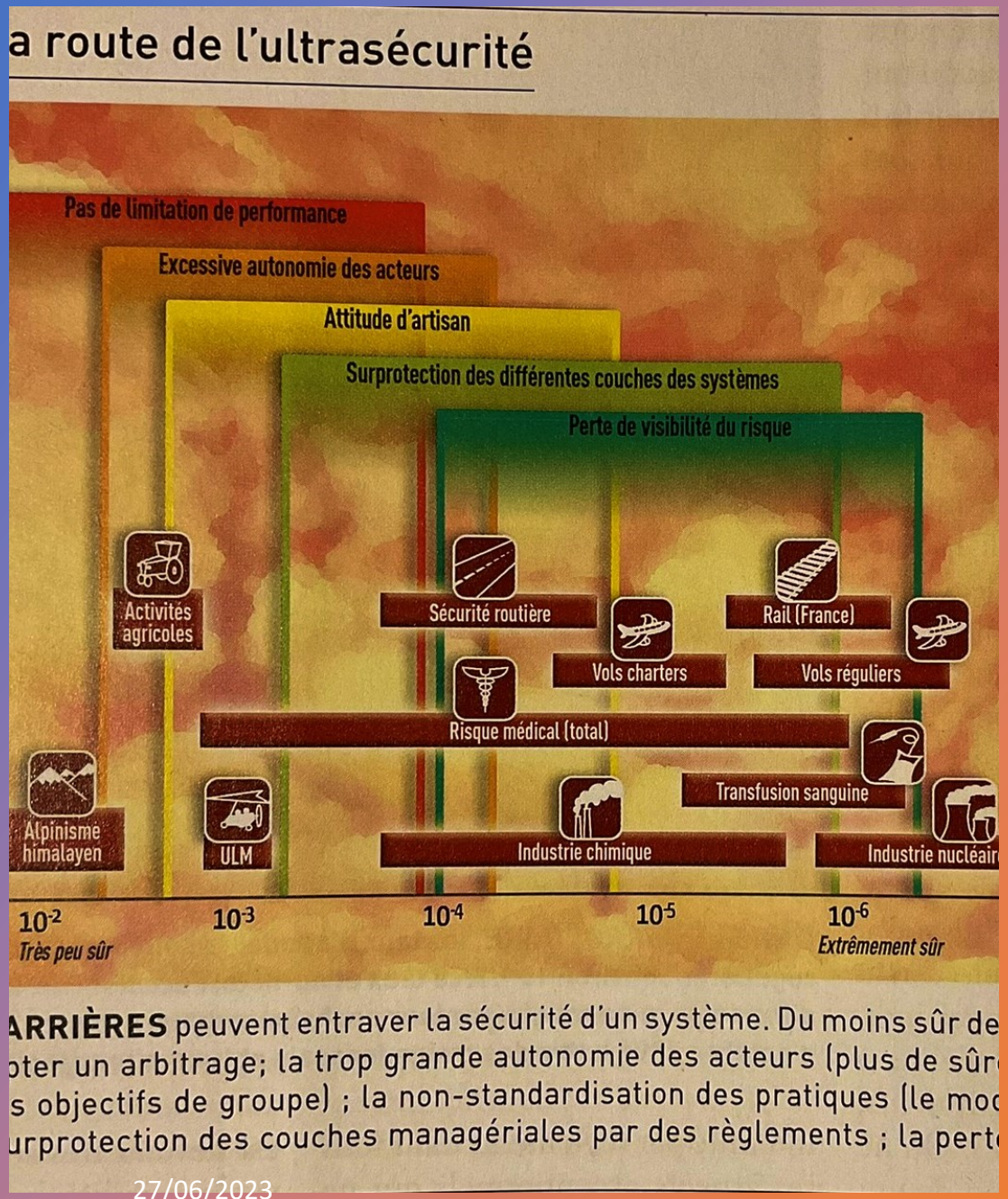
2.5 EURATOM Work Programme 2023-24-25, Cristina Fernandez Ramos, EC DG RTD (Remote)

2.6 Aviation Safety Regulation, Yves Morier, retired at EASA and French CAA (In person)

Principles for Civil Aviation Safety Regulation in Europe

Yves Morier

Retired at EASA and French CAA



Focus of the presentation

- SAFETY regulation to protect crews, passengers and people on the ground.
- Large Civil Transport Airplane:
  - Civil? EU regulations do not address State Aircraft and operations (e.g, Military, Police, etc.) unless State elect to opt-in.
  - Large? To simplify airplanes> 5700kg;
- Picture: Credit La Recherche- Prof Rene Amalberti

Other Aviation Regulation

- Traffic rights and Freedoms
- Facilitation
- Slots
- Passenger rights
- Privacy
- Conventions

Topics to be covered (I)

- The international context:
  - International Civil Aviation Organisation (ICAO)
- The European Context:
  - The EU Aviation safety act: Regulation 2018/1139
  - Role and responsibilities of the Commission, the EASA and Member States.
- The historical context:
  - The evolution of safety approaches during the years.
  - The evolution of aviation and associated lessons-learned during the same period
  - The state of play of Aviation safety today.
- The elaboration of regulations:
  - Drafting
  - Consultation
  - Review of comments
  - Adopting
- The role of the Authority, the role of the applicant when applying the rules
  - Possibility for the Authority to use qualified entities to perform certain tasks

Topics to be covered (II)

- The domains covered by regulation:
  - Total system approach
- The key role of certificates to demonstrate capability
- Use of industry standards and role of Standardisation Organisations
- Importance of Bilateral Aviation Safety Agreements to facilitate recognition of non-EU approvals
- The importance of occurrences reporting and analysis and of incidents and accidents investigation
- New common challenges: digitalisation, use of simulation, cybersecurity, artificial intelligence
- Summary/ Conclusion

International Civil Aviation Organisation

- ICAO: foundation of the aviation safety system
  - Convention:
    - balance between sovereignty and free circulation
    - Convention define the conditions for circulation (e.g., certificate of airworthiness for aircraft, licences for pilots) that are defined in the annexes
  - Annexes:
    - General: 19 annexes covering all domains of aviation
      - Annex 1: Licences
      - Annex 2: rules of the air
      - Annex 6: Operations
      - Annex 8: Airworthiness of aircraft
      - Annex 11: Air Traffic Services
      - Annex 14 : Aerodromes
      - Annex 16: Environmental protection
      - Annex 17: Security
      - Annex 19: Safety Management
  - National or regional regulations are based on ICAO Annexes with the possibility to notify differences

European context and role of the main Actors

- Basic regulation 2018/ 1139 on common rules in the field of civil aviation and establishing a European Union Aviation Safety Agency
  - Objectives: principal objective is to establish and maintain a high level of aviation safety
  - Scope: all domains of civil aviation
  - Exclusions: low risk aircraft, military and state aircraft and operations, small aerodromes
  - Substantive requirements. Notably obligation for certificates as a general principle
  - Introduces the concept of a repository of information
  - Essential requirements for all domains
  - Rulemaking:
    - See slides 14 and 15

European context and role of the main Actors

- **Commission:**
  - adopts the Regulations based on EASA opinion (recommendation);
  - decide on follow-up of Member States monitoring.
- **Member States**
  - issue for organisations and people under their jurisdiction:
    - Licences,
    - Air Operator Certificates (AOC), Authorisation for Specific Category, Light Unmanned Aircraft Operator Certificate
    - Training Organisation Approvals,
    - Production and Maintenances Approvals,
    - Individual Airworthiness Certificates
    - Aerodromes certificates and ATM/ANS approvals
    - Implement the rules
- **EASA:**
  - Issue approvals in relation to design, Approval of non-EU organisations except for foreign drone operators.
  - Issues opinions and non-binding documents(e.g., certification specifications, means of compliance, guidance)
  - Organise monitoring of Member States

- Approvals are recognised in all Member States
- Possibility for Re-allocation of responsibilities

Short history (I)

Aviation safety regulation followed closely the development of commercial aviation that started in 1919

National authorities were set-up in the 1920'.

Internationally:

CINA (1919 - 1939)	ICAO (1944 -)	ECAC (1955 -)	EUROCONTROL (1963 -)	JAA (1969 – 2009)	EASA (2002 -)

Short history (II)

Evolution of the safety approaches:	Evolution of the rulemaking approaches	Industrial context	In- service experience large airplanes

• From reactive to proactive. More specifically:
  • Technical era (approx. 1945-1980)
  • Human factor era (approx. 1965 – 1995)
  • Organisational era (approx. 1980 – 2005)
  • Total system era (approx. 2005 -)
	• Enabler or barrier?
	• From prescriptive to performance-based requirements
	• Introduction of aviation safety programs and plans.
		• Some important milestones – See slide 11	• Some noteworthy issues – See slide 12
			• Historic overview (source Airbus)
			  • See slide 13
			  • Improvements, plateau
			  • Not a reason for complacency

History - Industrial Context: design

- From VFR biplanes to IFR monoplanes: 1920-1940
- FIRST GENERATION JETS AND TURBO PROPS: 1950’
- First glider fully composite material: 1957
- CONCORDE: 1969 - 2003
- WIDEBODIES: 1969- 1972
- Large twins, ETOPS, Glass cockpit and FMS: 1980’
- A320 FLY-BY-WIRE: 1988
- GPS: end 1980’-early 1990’
- Second generation wide bodies: 1990’
- REGIONAL JETS: EARLY 1990’
- Very light Jets: early 2000’
- Civil Tilt Rotor: 2003

- VERY LARGE AIRCRAFT: A380: 2005
- Extensive use of composites: A350/ B787: 2010’
- CIVIL DRONES: FROM 2010
- Sub-orbital aircraft : from 2010
- EVTOL/STOL: FROM 2013
- ELECTRIC PROPULSION: FROM 2015
- Hybrid Air Vehicles Airlander Airship: 2017
- Clean Sky demonstrators: 2017, 2022
- New Supersonic aircraft demonstrator: from 2022
- AUTONOMY: SINGLE PILOT 2030?, FULL: 2035?
- LARGE HYDROGEN AIRCRAFT: 2035?

Experience in service – Large Aeroplanes

- 1950:
  - Airframe fatigue
- 1960:
  - Propeller induced whirl mode flutter
  - Bird strikes
- 1970
  - Cargo doors
  - ACAS Anti-collision systems
  - Ground Proximity warning systems
- 1980:
  - Cabin safety, fire protection
  - Aging Aircraft
- 1990:
  - Cargo compartments,
  - fuel tank safety
  - Icing
  - Arc Tracking
- 2000:
  - Automation
  - Cold fuel
  - Security precautions in aircraft
- 2010
  - Assumptions on pilot reactions.

Historic Overview – Large airplanes
Source Airbus

FOUR GENERATIONS OF JET

1 Early commercial jets

From 1952

Dials & guages in cockpit. Early auto-flight systems

Comet, Caravelle, BAC-111, Trident, VC-10, B707, B720, DC-8, Convair 880/990

2 More integrated auto-flight

From 1964

More elaborate auto-pilot and auto-throttle systems

Concorde, A300, Mercure, F28, BAe146, VFW 614, B727, B737-100 & -200, B747-100/200/300/SP, L-1011, DC-9, DC-10

3 Glass cockpits & FMS

From 1980

Electronic cockpit displays, improved navigation performance and Terrain Avoidance Systems, to reduce CFIT accidents

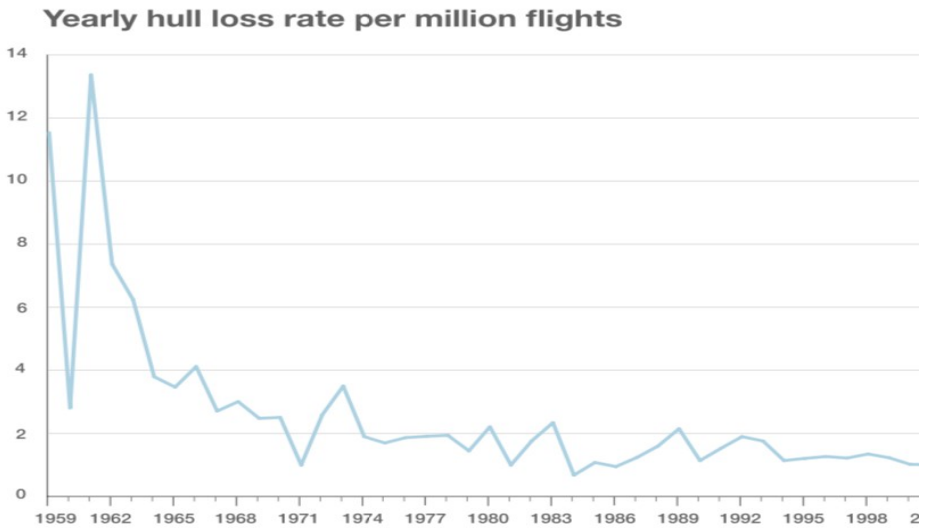
A300-600, A310, Avro RJ, F70, F100, B717, B737 Classic & NG/MAX, B757, B767, B747-400/-8, Bombardier CRJ, Embraer ERJ, MD-11, MD-80, MD-90

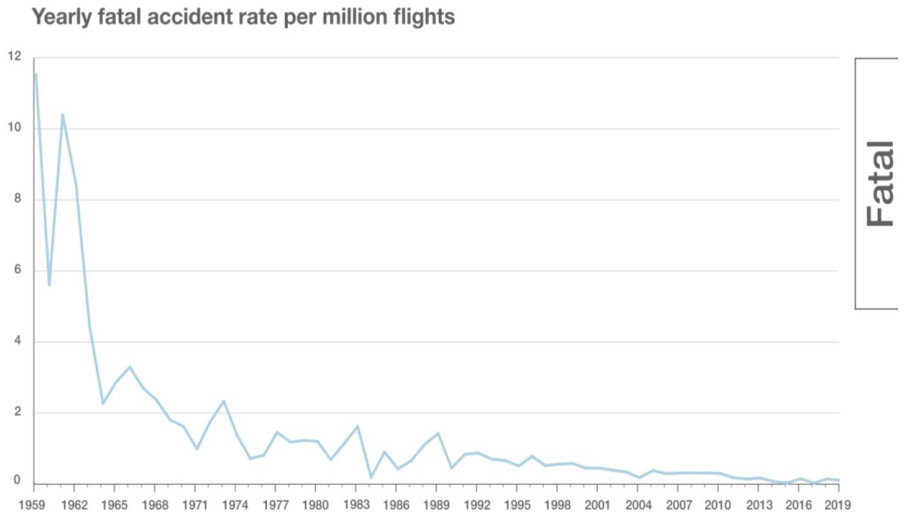
4 Fly-By-Wire

From 1988

Fly-By-Wire technology enabled flight envelope protection to reduce LOC-I accidents

A220, A318/A319/A320/A321, A330, A340, A350, A380, B777, B787, Embraer E-Jets, Sukhoi Superjet





The elaboration of regulations(I)

- **Drafting:**
  - Prescriptive and performance-based requirements are used
    - Trend is towards the latter: mandate what to do and not how to do it.
    - Legal certainty must be maintained
  - Hard Law: Essential Requirements in Aviation Act, detailed requirements in implementing/ delegated act
  - Soft Law: Acceptable Means of Compliance; Guidance Material; Industry Standards
    - Industry Standards very important for new technologies
  - Rules are usually a balance between what is technically possible, what is socio-economically feasible and what is politically expected.
- **Consultation :**
  - Consultation of the aviation community: Notice of Proposed Amendment; System of consultative Bodies, possibility to set-up working groups
  - Notice of Proposed Amendment (NPA) include proposed rule, explanatory note and impact assessment

The elaboration of regulations(II)

- **Review of comments :**
  - Incorporate changes, Comment Response Document records the process.
- **Adopting :**
  - EC adopts binding regulations on proposal from EASA with processes involving Council, Parliament and Member States
  - EASA adopts non-binding requirements
- IMPORTANT NOTE:
  - Regulations are not the only way to ensure safety:
    - Research and safety promotions are also powerful tools

The role of the Authority, the role of the applicant when applying the rules

- The applicant (e.g., operator (airline), aircraft manufacturer) is responsible for complying with the requirements.
- The authority check that the applicant indeed complies:
  - In the case of an aircraft type certificate, perform verifications in accordance with the level of involvement defined for the project.
  - In the case of an organisation approval by a system of audits. Today the trend is to risk-based monitoring for renewal of approvals
- Authorities issue approvals and perform safety oversight and when necessary, enforcement.
- In EU rules are defined for the authorities and they are monitored by the Commission assisted by EASA

The domains covered by Aviation Safety Regulation in Europe

https://www.easa.europa.eu/en/regulations

More and more a total system approach is used:

- State Aviation Safety Plans (Example European Plan for Aviation Safety (EPAS))

Organised by domains:

- Initial Airworthiness; Continuing Airworthiness, Operations, Licencing of personnel, Air Traffic Management/ Air Navigation Services, Aerodromes
  - Importance of interfaces

Organised by category of aircraft:

- E.g., airplanes, helicopters, balloons, airships, etc.

Separation between commercial and non-commercial activities:

- Notable exception Innovative Air Services

The key role of certificates

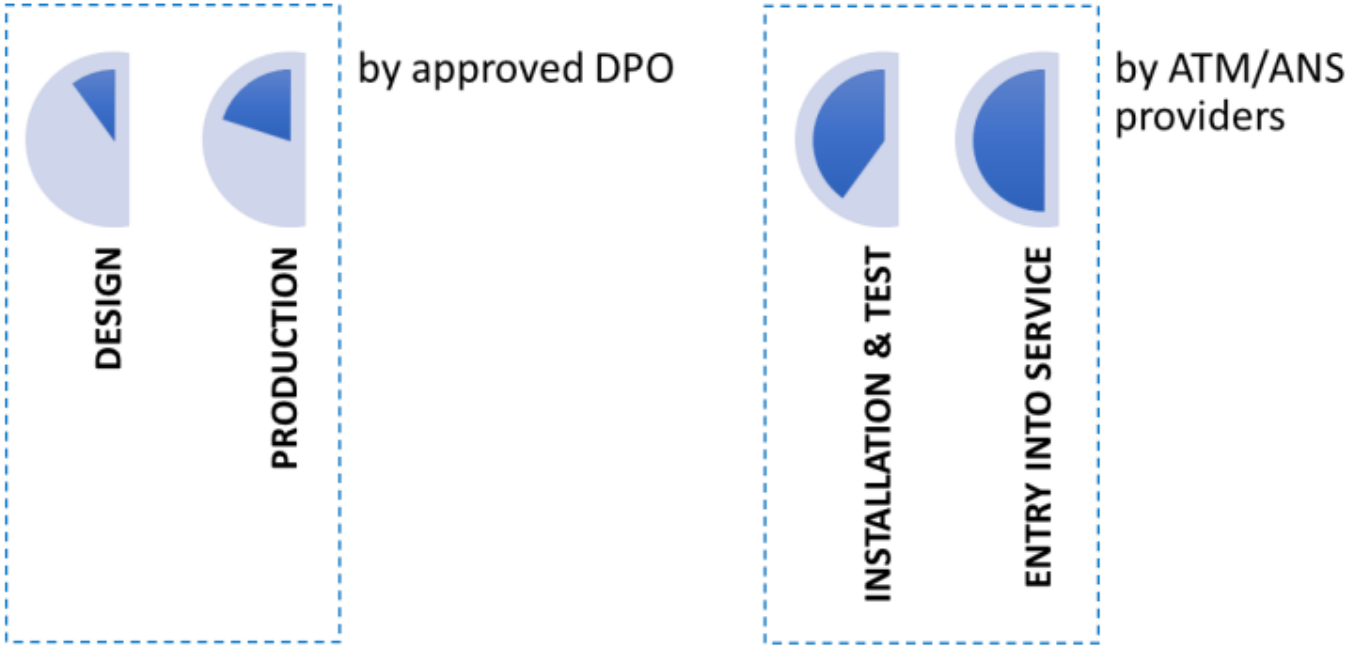
- Overview:
  - Aircraft and equipment approvals
  - Licences for Pilots, Air Traffic Controllers, Mechanics issuing a release into service
  - Aerodromes certificate
  - ATM equipment approval
  - Approvals of organisations:
    - Design Organisation
    - Production Organisation
    - Maintenance organisations
    - Air Operator Certificate
    - Training organisations (Pilots and Mechanics)
    - Air Navigation Service providers
    - Aerodrome operators

Aircraft

- Usually Aircraft, engines and propellers designs receive a Type or Restricted Type Certificate (TC/RTC), but there are exceptions for low-risk aircraft.
  - TC/RTC:
    - Based on Technical requirements (e.g., Certification Specifications in EU, FARs in the US)
    - Concept of special conditions to address in particular novel technologies
    - Based on a demonstration of capability usually a Design Organisation Approval
    - Includes Flight Manual, Maintenance Instructions and in EU Operational Suitability Data.
    - Certifying Authority defines its level of involvement
    - To correct design issues, Airworthiness Directives are usually mandated by the State of Design that is expected to take a leading role.
      - Other States usually adopt the Airworthiness Directives.

ATM equipment approval

- Regulatory framework on the conformity assessment of ATM/ANS systems and ATM/ANS constituents (ATM/ANS equipment) is under development
- https://www.easa.europa.eu/en/document-library/opinions/opinion-no-012023



Concept of Licence

- For certain categories of safety-related professions but not all.
- Include requirements for:
  - Age
  - Experience
  - Medical Aptitude
  - Theoretical Training
  - Practical Training,
  - Examination and Test
  - Ratings
  - Renewal

Concept of Organisation Approval

- Way of demonstrate a capability to perform a function or a service.
- Includes requirements for
  - Key personnel
  - Policies
  - Equipment and facilities
  - Staff and staff training
  - Procedures and manuals
  - Management system possibly covering several domains such as safety, security, environment
  - Occurrence reporting and analysis system
- May allow privileges:
  - E.g., start an activity or issue an approval without intervention of the Authority.

Use of industry standards and role of Standardisation Organisations

- Aviation has been using industry standards since almost the origin
  - The Society of Automotive Engineers (SAE) became interested in aviation in 1916
- Standards are even more important now that rules are more performance based than before:
  - The approval of small drones used in Visual Line of Sight is using the EU system of conformity assessment put in place by the legislative framework for products
- The most often used Standardisation Organisations are:
  - ISO: worldwide, not only aviation
  - EUROCAE: European based, aviation
  - CEN/CENELEC/ETSI : European based, not only aviation and supported by ASD-STAN for aviation
  - SAE: US based, automotive
  - RTCA: US based, aviation electronics
  - ASTM: US based, not only aviation
- They cooperate actively which is very important.

Importance of Bilateral Aviation Safety Agreements to facilitate recognition of non-EU approvals

- Bilateral Aviation Safety Agreements: Signed by EU
  - General:
    - Enable reciprocal acceptance of findings of compliance and approvals
    - High level of Safety
    - High level of regulatory cooperation
  - Existing ones:
    - Brazil, Canada, China, Japan, UK, USA
- Working Arrangements: Signed by EASA after agreement of the Commission
  - General:
    - Defines working relationships to facilitate each other validation of certificate
  - Existing ones:
    - 38 in total

The importance of occurrences reporting and analysis and of incidents and accidents investigation

- Two types of occurrence reporting and analysis exist:
  - Mandatory occurrence reporting to the authority
  - Confidential occurrence reporting systems.
- Airline have put in place Flight Data Monitoring
- Accidents and incidents investigation is defined by ICAO Annex 13
  - Accident investigation authorities must be independent
  - Establish causes but not responsibilities
  - Purpose is to avoid re-occurrence of a type of accident

New common challenges: digitalisation, use of simulation, cybersecurity, artificial intelligence

- **Digitalisation:**
  - For example, use of digital twins for design and maintenance of aircraft
  - Another example are remote control towers
- **Simulation:**
  - Not only for training but also for design and maintenance
- **Cybersecurity:**
  - Part-IS (Information Systems) regulation published, completing regulatory framework for cyber-resilient aviation
    - https://www.easa.europa.eu/en/newsroom-and-events/news/part-regulation-published-completing-regulatory-framework-cyber-resilient
  - EASA activities on cybersecurity:
    - https://www.easa.europa.eu/en/domains/cyber-security
- **Artificial Intelligence:**
  - Human centric approach to AI in aviation, trustworthy AI
    - https://www.easa.europa.eu/en/domains/research-innovation/ai

Summary/ Conclusion

- Focus of presentation was to present aviation safety regulation relative to large transport airplanes
- The following topics were addressed:
  - The international and EU context
  - An historical perspective
  - The process to develop rules
  - Domains of Aviation Safety regulations
  - Respective roles of the Authority and the Applicant
  - The various certificates and their importance.
  - The role of Industry Standards.
  - Accidents and incidents investigations
  - New challenges

BACK-UP SLIDES

Principles for measures taken to implement EASA Basic Regulation (2018/1139)

- When taking measures under this Regulation the Commission, the Agency and the Member States shall:
- (a) reflect the state of the art and best practices in the field of aviation, and take into account worldwide aviation experience and scientific and technical progress in the respective fields;
- (b) build on the best available evidence and analysis;
- (c) allow for immediate reaction to established causes of accidents, serious incidents and intentional security breaches;
- (d) take into account interdependencies between the different domains of aviation safety, and between aviation safety, cyber security and other technical domains of aviation regulation;
- (e) lay down, where possible, requirements and procedures in a manner which is performance-based and focuses on objectives to be achieved, while allowing different means of achieving compliance with those performance-based objectives;
- (f) promote cooperation and efficient use of resources between authorities at Union and Member State level;
- (g) take non-binding measures, including safety promotion actions, where possible;
- (h) take into account the international rights and obligations in the field of civil aviation of the Union and of the Member States, including those under the Chicago Convention.

2.7 HARMONISE Project Overview, E. Urbonavičius, Lithuanian Energy Institute (In person)

Harmonising Fission & Fusion Reactor Licensing

Project overview and major objectives

E. Urbonavičius
Lithuanian Energy Institute
Breslaujos g. 3, LT-44403 Kaunas, Lithuania

Overview

- Introduction
- Historical context
- Status at the beginning of HARMONISE
- Activities for harmonization of licensing
- HARMONISE project
- Summary

Introduction

harmonise
Harmonising Fission & Fusion Reactor Licensing

- The current nuclear regulatory framework appeared in the 1960s for licensing early NPP designs and since then it has undergone substantial modifications because of major nuclear accidents and in response to challenges posed by the licensing of Generation III designs.
- Innovative fission and fusion installations encompass novel technologies that drive the need for developing new licensing procedures.
- The legal framework and procedures applied in the field of nuclear power are very rigid, which significantly limits new technologies coming to operating NPPs
- There is a broad agreement on the need to review the existing regulatory framework, incorporate novel concepts and endow it with sufficient capabilities for assuring safety during design and enabling proper regulatory oversight during operation of innovative facilities.

Historical context

harmonise
Harmonising Fission & Fusion Reactor Licensing

- While States opted for differing national regulatory frameworks, the Three Miles Island and Chernobyl accidents acted as catalysts for change mandating the need for international cooperation on nuclear safety and radiation protection leading to harmonised approaches notwithstanding that both are national responsibilities.
- Achieving harmonisation requires establishing internationally agreed safety standards and supporting their global adoption.
- As such, IAEA has recognized that: “Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences.”

Status at the beginning of HARMONISE

harmonise
Harmonising Fission & Fusion Reactor Licensing

- In order to achieve political, scientific, technical and economic harmonisation among the Member States, EC introduced in 2003 two joint directives identified as the “nuclear package”.
- The former directive defined general principles regarding nuclear site safety while the latter dealt with the management of spent fuel and radioactive waste in a legally binding sense at EU level.
- Another directive on funds for NPP decommissioning and waste management until final storage was taken out and appeared as recommendations in 2006.
- The nuclear package did not reach majority in the Council and in 2008 the EC presented a new draft directive on nuclear safety with a focus on NPP safety. In 2014, the Council Directive 2014/87/Euratom amended Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations.

Status at the beginning of HARMONISE

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- Despite the broad consensus State legislations maintain diverse definitions and interpretations in their application of basic safety principles while being consistent with the IAEA Safety Standards.

Activities for harmonization of licensing

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- At present there are a number of initiatives in different fields of activities to approach common understanding and approach in licensing, operation and decommissioning of NPPs, e.g. ETSON – European Technical Organisations Network, WENRA – Western European Nuclear Regulators' Association, WANO – World Association of Nuclear Operators, etc.
- IAEA is a key player in achieving common understanding in all stages of nuclear fuel life-cycle – The SMR Platform and Nuclear Harmonization and Standardization Initiative (NHSI)
- Several publications have been published recently:
  - OECD NEA report „Harmonising the nuclear licensing process for emerging technologies: A glogal path forward"
  - EC report "Exploring regulatory options for fusion power plants"
  - UK report "Towards Fusion Energy. The UK government's proposal for a regulatory framework for fusion energy"

Activities for harmonization of licensing

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- Nuward small modular reactor (SMR) design is the case study for a European early joint regulatory review with involvement of French, Czech and Finnish nuclear safety regulators.
- Report by EUROfusion Working Group on Licensing for Fusion “The Regulation of Fusion Power Plants”
- Study on the Applicability of the Regulatory Framework for Nuclear Facilities to Fusion Facilities, Final report by GRS and KIT, December 2021.
- A number of national initiatives to review national legislation to take into account SMRs and other innovative reactors.

HARMONISE project

- HARMONISE project (Coordination and Support Action) started on June 1, 2022. Project duration 36 months
- Project coordinator – Lithuanian Energy Institute
- 17 partners from 10 European countries, coming from research organisations, regulators, SME and EU JRC.
- Several partners are members of ETSON (European Technical Safety Organisations Network)

HARMONISE project

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- Taking as a basis the IAEA fundamental safety objective, the HARMONISE project has set five Objectives:
  - Objective 1: To analyse preliminary safety assessments of innovative fission and fusion installations
  - Objective 2: To peruse the licensing needs for innovative nuclear installations
  - Objective 3: To examine risk-informed, performance-based (RIPB) approaches in licensing reviews and regulatory decision-making
  - Objective 4: To delimit harmonisation and standardisation on component assessments, methodologies, codes and standards
  - Objective 5: To learn from earlier experience in harmonisation efforts

HARMONISE project

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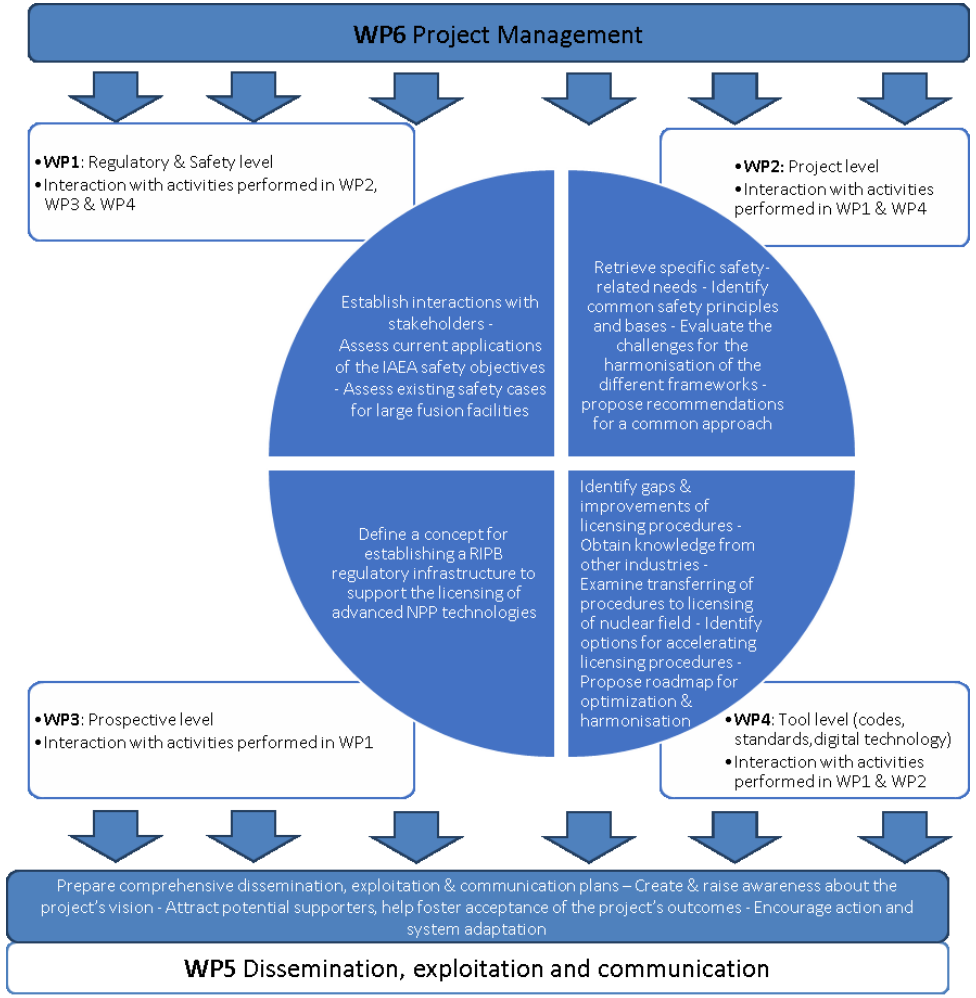

Work is organized in 6 WPs, one for project management (WP6), one for dissemination and data management (WP5) and four for actual action implementation

- WP1 – interaction with stakeholders
- WP2 – review of LFR ALFRED and fusion DEMO licensing issues
- WP3 – risk-informed, performance-based approach in licensing
- WP4 – harmonisation and standardisation on component assessments, methodologies, codes and standards

HARMONISE project

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- The major activities in HARMONISE will be to collect all stakeholders and to listen to their perspectives trying to identify the common approach and suggest the ways how licensing of innovative NPPs and FPPs could be simplified
- Identifying the licensing needs for innovative technologies incorporated in future fission and fusion reactors requires an exhaustive analysis to determine whether, or not, current codes and standards address these needs.
- “Licensing exercises” will be performed for Gen-IV LFR ALFRED and fusion power plant DEMO to identify the bottlenecks and suggest the ways to improve licensing process
- Possibilities to implement Risk-Informed Performance-Based approach in licensing will be explored.
- New technologies need to be detailed and grouped into different categories depending on the qualification and licensing process. In order to ensure that this analysis is performed in a robust manner, HARMONISE will solicit the expertise of Standards Development Organisations responsible for code development.
- Possibilities to implement “numerical twins” in nuclear licensing will be investigated as well.

HARMONISE activities for NPPs

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- The evaluation of IAEA documents is focused to the level of General Safety Requirements (GSR) and Specific Safety Requirements (SSR). In addition, a few Specific Safety Guides are evaluated, too.
- The scope of the conducted evaluation is limited to safety and does not extend to nuclear security.

Evolutionary and Innovative Design

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- Evolutionary and Innovative Design (EID) reactor concepts are partly different compared to typical large power light water reactors. Typical differences are:
  - Use of an integral and compact design,
  - In case of SMRs a lower core inventory and lower thermal power,
  - Increased use of passive systems,
  - A modular design with the possibility of manufacturing entire components in factories,
  - A modular plant concept (multi-block units) with common systems (e.g., control room, turbine),
  - transportable or floating SMR & MMR concepts
  - Gen-IV concepts

Multi-module concepts

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- SMRs are new types of nuclear reactors that can be deployed in multiple units at a single site. Some of these concepts share common systems. These are for example the control room and turbine. Therefore, these concepts might pose some challenges for licensing, such as how to account for the interactions and dependencies among multiple modules, how to ensure the quality and reliability of the manufacturing and supply chain, and how to define the scope and boundaries of the license application
- The current regulatory guidelines on safety aspects of human factors are rather sparse. The IAEA SSG-76 describes, among other things, the shared responsibility of the shift supervisor of the entire plant and the block supervisors to be appointed. Here, care must be taken to ensure that agreements also exist for multi-module plants that prevent the accidental isolation or shutdown of systems of the wrong module and that work on one module cannot impair the safe operation of the other module(s).

Factory-build, factory-fuelled concepts

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- Most SMR concepts have a compact integral design to enable them to be manufactured in a factory and to facilitate transport to the plant site. However, the compact design of SMRs can pose a challenge for carrying out the necessary inspections, works and maintenance, not only during the manufacturing phase, but also throughout the life of the SMR.
  - For example, the regulations and standards for the welding of safety-relevant components require the welds to be inspected and tested without failure. The manufacturing processes would have to be coordinated accordingly to ensure accessibility for the necessary inspections and tests.
- SMR suppliers may choose to manufacture components with long lead times or entire modules before a license is issued to the end customer. Thus, the authority may not be able to monitor certain safety-relevant manufacturing processes (e.g., forging of large components).

Factory-build, factory-fuelled concepts

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- The transport of SMR modules involves a number of regulatory and technical challenges:
  - in the case of modules that are already loaded with fuel and sealed, care must be taken to avoid possible criticality during transport by taking appropriate measures in the design.
  - the integrity of the modules must be ensured at all times by appropriate monitoring systems.
  - The transport of a module loaded with fuel also requires careful consideration involving all parties and states involved (in the case of cross-border transports).
  - Harmonised standards may be necessary in the states concerned. The transport of reactor vessels is a particular challenge, as there is as yet no certified packaging (cask) large enough for most (or all) reactor cores.

Supply chain

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- The various EID concepts lead in part to additional requirements with regard to supply, transport, dismantling and disposal.
- In order to optimise costs, the longest possible fuel cycles are aimed for Light-water SMR concepts largely use conventional fuel elements based on UO_2 and an enrichment of <5 % (LEU, low enriched uranium).
- The floating Russian reactor Akademik Lomonosov uses fuel elements with an enrichment close to 20 % (HALEU).
- Newly developed fuel assemblies are required for both SMR concepts based on Gen IV technology and for concepts of microreactors with fuel cycles of up to 20 years, whereby HALEU is often used here as well.
- If such concepts are to be used, a corresponding infrastructure for the production of such fuel elements is necessary.
- Consequently, there are also requirements regarding reprocessing and the disposal of radioactive waste.

Cogeneration

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- For SMR the process heat can be used for the cement industry, for hydrogen production, seawater desalination, coal gasification or simply as district heating.
- From the manufacturers' point of view, a smaller emergency zone is seen as an advantage of SMRs, so that the local distance between heat generation and consumption is smaller and thus heat losses are reduced.
- cross-contamination (impairment of the respective plants in both directions, such as by radioactive fission products and chemical substances), operational aspects, e.g., due to power fluctuations, feedback effects of the industrial plants on the NPPs and vice versa have to be avoided.
- Furthermore, a mutual understanding of the different corporate cultures (e.g., safety culture) is necessary.

Use of novel technologies

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- SMRs differ from classical large power LWRs in terms of technology.
- Integral design with increased use of passive systems is applied.
- Due to an integral design and passive safety systems, the requirements for safety systems for classical NPPs cannot be directly transferred to SMRs.
- The new design or feature or practice shall also be adequately tested as far as possible before commissioning and monitored in operation to verify that the behaviour of the installation meets expectations.
- Combination of several inherent and passive systems increases the complexity of the overall system and the uncertainties with regard to effectiveness. Thus, it is necessary to establish clear criteria for evaluating passive systems.

Inherent safety

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- The design features of small reactor cores may result in inherent safety features that improve the overall safety of SMRs.
- An important challenge in SMR designs is to achieve a well-balanced safety concept based on the use of optimal combination of active, passive and inherent safety features.
- All inherent safety characteristics that are provided by the design and credited in the safety demonstration should be duly substantiated. The requirements and criteria for this demonstration should be defined beforehand and developed, which may need particular guidance.

Practical Elimination

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- The practical elimination of an event sequence provides that certain conditions, related to the plant state, are either physically impossible or the probability of occurrence is very low while the statistical certainty is high.
- These conditions can be eliminated by design measures, for example by developing inherently safe systems or by providing systems that mitigate accidents in different states and protect the barriers against a wide range of challenges.
- The aim is to reinforce the DiD concept of the facility through targeted analysis of conditions that have the potential for “unacceptable radioactive releases”.
- Practical elimination should not be seen as an alternative to measures to mitigate the effects of severe accident scenarios.

Core degradation

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- For different reactor designs, different accident sequences might be relevant and must be postulated. However, core melt cannot – for all designs – be assumed as the most severe accident, especially not for molten salt reactors with liquid fuel and reactors with TRISO-type fuel.
- The formulation “melting of fuel” or “core melt” is inadequate and needs to be changed to be generally applicable.
- The related safety objectives should be interpreted to mean “accidents which would lead to large or early releases”.

Application of DiD concept

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- DiD is generally divided into five levels. Should one level fail, the subsequent level comes into play to ensure that a single failure, whether an equipment failure or a human failure, at one level of defense, and even a combination of failures at more than one level of defense, does not propagate to jeopardize defense at subsequent levels.
- If, for new reactor designs, certain severe accident conditions can be considered as practically eliminated, it can potentially be argued that some of these measures are not required.
- Safety features at level 4 DiD are necessary to assure fundamental safety functions, particularly containment of radionuclides, in all credible severe accident scenarios so far as is reasonably practicable. The inclusion of additional features for accident scenarios involving multiple failures needs to be considered to improve resilience to common cause failure.

Barrier concept

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- The implemented barrier concept of an EID might be different compared to typical three barriers of large LWR plants. One example is the MSR.
- According to WENRA, as long as there are significant radioactive inventories in NPP, a multi-barrier approach is considered necessary. The number and kind of barriers will depend on the design characteristics of new reactor designs and definition of what is considered as minimum will need detailed analyses.

Siting

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- When assessing a site, all activities associated with the project, including the effects of construction and operation of multiple modules (or units) at a single site, shall be considered in the permit application. This also applies in the case of construction with some modules and possible later expansion or replacement of modules.
- some EID concepts envisage the structures being largely built underground, questions regarding seismic load-bearing capacity, chemical stresses, groundwater, etc. must be clarified. In contrast to typical LWRs, the construction of EIDs is envisaged in arctic or subarctic regions, so corresponding weather conditions and ground conditions must be considered.
- Even if the concept is based on a modular design with several modules/blocks with low individual power at one site, the design should take into account the potential consequences of a simultaneous failure of several or even all units due to external impacts. This applies in particular to the definition of the emergency planning zone (EPZ).

Commissioning

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- For some EID components, it may be necessary to carry out commissioning tests at the manufacturer's premises and thus off-site.
- Some off-site commissioning tests may also be the last opportunity for a regulatory authority to inspect certain parts of a module.
- Commissioning test procedures must take into account possible damage during transport to the site.
- In the case of passive safety-related concepts, it is possible that they cannot be fully tested during commissioning.
- This is especially true for those systems that are not used during normal operation or are not used under the same boundary conditions as during incidents. Therefore, the licensee must carry out alternative tests for verification and prove their applicability.

Operating and operation experience

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- In order to reduce costs, manufacturers are trying to reduce the number of staff required when designing SMRs while maintaining the level of safety. To this end, the manufacturers are proposing to automate operation further than in conventional NPPs. Among other things, the aim is to have several reactor modules monitored and controlled centrally from one control room.
- Due to high level of automation the role of operators in a highly automated plant may be very different from that typical of today's NPPs.
- Some providers also offer unmanned facilities that are operated and monitored remotely. Remote operation (monitoring) poses some challenges, such as ensuring cyber security and physical protection.
- In the case of multi-module concepts, it is important that operators are aware of the possible differences between the modules/units. Especially if new modules/units are added later, the design may have evolved from the original.

Recommendations for fusion licensing

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- The radiological potential of fusion facilities is currently assessed to be treated either in the frame of nuclear safety (DEMO and ITER) or in the frame of radiological protection (W7-X). As the ITER purpose and approach to design is the closest to the future FPPs, at the moment, its licensing experience could be considered as very relevant.
- No IAEA safety standards for fusion facilities are issued, however, review demonstrated that the fundamental safety principles and generic safety requirements are in general applicable not only to the fission but also to the fusion technologies.
- The proposed recommendations are based on the review of safety case documentation for fusion facilities using the deuterium-tritium reaction to produce energy in a plasma that is magnetically confined.

Recommendations for fusion licensing

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- **Recommendation 1: Harmonisation of safety fundamentals and safety requirements** Investigate the possibility of harmonizing fission and fusion requirements by technology neutral formulation of IAEA safety fundamentals and safety requirements. Technology neutral regulation might increase the credibility of licensee and regulator because of reduced probability to avoid exemptions in the licensing process that pose potential negative perception of avoiding fulfilling requirements. Further, particularities of fusion technology should be covered by agreed technology specific requirements and recommendations, that could facilitate the development of national legislation on fusion power plants.
- **Recommendation 2: Internationally harmonized licensing process** To facilitate the licensing process of future fusion power plants, the best licensing practices from the fission power plants and existing fusion facilities should be compared. This could be used for an internationally harmonized licensing process of future fusion power plants.
- **Recommendation 3: Internationally harmonized safety case structure and content** Development of an internationally harmonized proposal of safety case structure and content for fusion power plants would optimize the preparation of the entering licensing documentation and facilitate the licensing at regulator level in newcomer countries.
- **Recommendation 4: Internationally harmonized general design certification** Internationally accepted design approval independent on the site selection might facilitate global and larger deployment of fusion power plants in newcomer countries.

Recommendations for fusion licensing

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- **Recommendation 5: Harmonise fundamental safety functions definitions** In principle, fusion technology does not create a need for new fundamental safety functions. However, their definitions could be reformulated to enable harmonised applicability to fission and fusion technologies.
- **Recommendation 6: Plant states** Categorization of the plant states within safety case according to the IAEA conventions to operational states (normal operation and anticipated operational occurrences) and accident conditions would simplify licensing. Adaptation of DEC subdivision and consideration of multiple failure conditions to be practically eliminated is needed.
- **Recommendation 7: Communication on defence in depth principle implementation** Exhaustive representation of the safety architecture enables transparent and systematic assessment of defence in depth principle by providing information on which, why and how each provision is available during each plant conditions and over the lifetime of the facility. A technical report specifically dedicated to the safety assessment of the defence in depth principle implementation into the safety architecture might be important for the licensing process facilitation and to systematically demonstrate the reduced probability for the design back fitting. The ISAM methodology might be used.
- **Recommendation 8: Single failure criterion** Additional guidance on requirements addressing the single failure criterion would be needed.
- **Recommendation 9: Minimize dose to workers, public and environment** R&D in mitigation strategies and systems must be pursued to minimize dose to workers, public and environment.

Recommendations for fusion licensing

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- **Recommendation 10: Approach for classification** A standardized approach for the classification of all provisions which contribute to the safety of the installation might be considered. Further, systems and components classification shall consider the need for optimization to avoid unnecessary constraints that would have negative drawbacks, for example in terms of construction, implementation, maintenance and availability.
- **Recommendation 11: Communication on fusion power plant particularities** The applicants of first-of-a-kind fusion power plants should enter the licensing process with fully developed design supported with systematic technical reports on proof-of-concept. Technical reports could be communicated with regulators in the early stages of technology development.
- **Recommendation 12: Codes and standards** In parallel to safety important component classifications and qualification relevant codes and standards shall be identified as soon as possible. A technical report with justification of the selected codes and standards might facilitate the licensing process. Existing codes and standards may not be available for some safety important components of fusion power plants. Thus, the process to develop new specific or adopting existing or propose technology neutral codes and standards shall start as soon as possible. Development or modification of codes and standards should be supported with R&D.
- **Recommendation 13: Database with operational experiences** It is necessary to establish the database with operational experience on safety related data in a structured, systematic and effective way. It is recommended to invest R&D resources in operating experience data collection and storage, in standardized manners that are usable by different countries and organizations.

Recommendations for fusion licensing

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- **Recommendation 14: Validated computer codes** Only computer codes with adequate verification and validation shall be used in the licensing process. Thus, it would be reasonable to develop a detailed experimental R&D roadmap in support of computer code development and validation.
- **Recommendation 15: Independence of computer codes** Different sets of independent technology specific computer codes are needed by the technology developer/licensee and regulator, respectively.
- **Recommendation 16: Uncertainty quantification of input data** R&D activities are recommended to improve uncertainty quantification of input data and to perform sensitivity analysis of results. It is recommended to identify key safety parameters for sensitivity analyses and uncertainty quantification, to improve the completeness and the accuracy of the uncertainty of the input data, and to perform sensitivity analyses especially where the validation of the simulation codes is rather scarce.
- **Recommendation 17: Implementation of a systematic activity based on the PIRT approach** Identification of safety related phenomena featuring large uncertainty and high importance in ensuring compliance with the radiological safety objectives. The application of a systematic approach for an independent, agreed and comprehensive phenomena identification and assessment resulting in a ranked determination of their uncertainty and importance (through qualitative or quantitative methods) will mainstream future research and development efforts in the area of fusion safety.

Summary

- HARMONISE will take advantage of the accomplishments achieved by current and earlier research and cooperation initiatives in standardisation and nuclear safety, in EURATOM and outside, considering also the outcomes of the EU stress tests.
- A review of available Evolutionary and Innovative Designs is performed.
- A review of the current international activities for licensing of fission and fusion reactors is performed and a number of recommendations are suggested
- HARMONISE will suggest solutions but decisions are to be later taken by the responsible decision making bodies.

Thank You

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European Commission
Joint Research Centre

This project has received funding from the European Commission-Euratom under Grant Agreement No 101061643

2.8 ECC-SMART Project Overview, Monika Šípová, CVR (Remote)

ECC smart

Joint European Canadian Chinese development of SMAll modular Reactor Technology

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CVŘ
Centrum výzkumu Řež

This project has received funding from the Euratom Research and Training programme 2019-2020 under Grant Agreement No 945234.

Outlook

- Development towards ECC-SMART
- ECC-SMART:
  - Numbers
  - Consortium
  - Motivation
  - Challenges and WPs
  - Activities of CVR
  - Education and training
  - Events
  - Publications
- Conclusions

Development towards ECC-SMART

renaissance 90s of 20th century

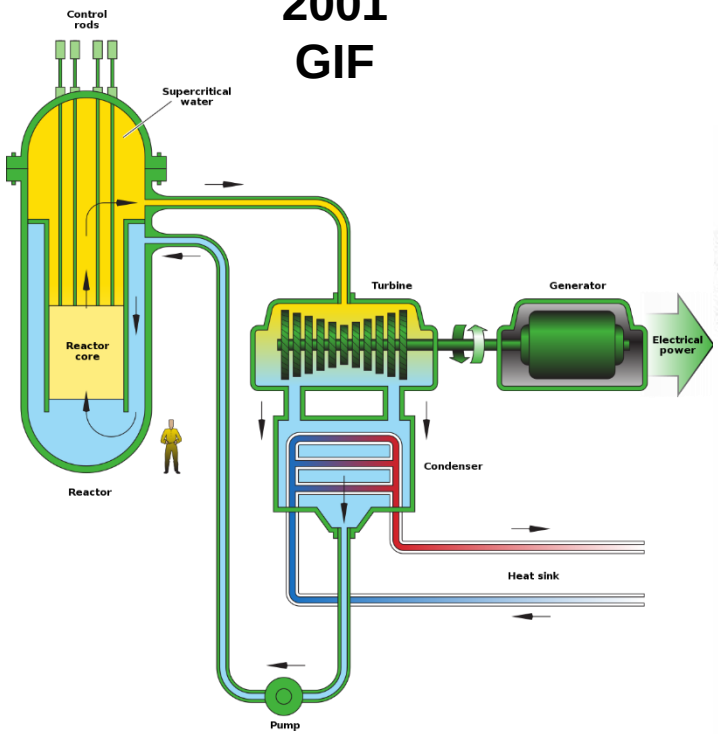
HPLWR 2002-2004

FQT-SCW 2011-2014

60s of 20th century

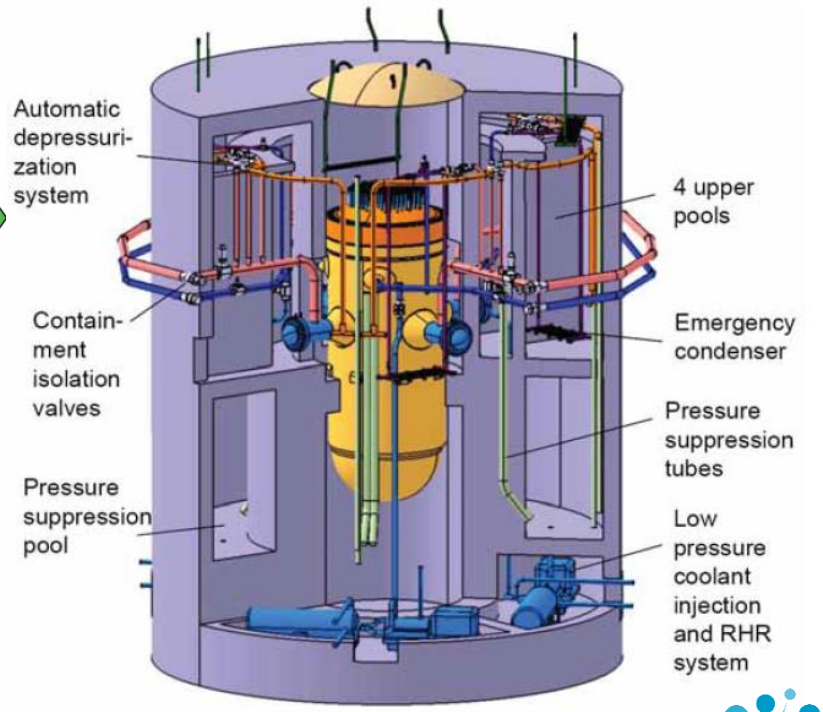
A pressurized water-cooled reactor with a closed loop primary system at supercritical pressure.

2001 GIF



SCWR as one of the promising reactor concepts of GenIV.

HPLWR-phase 2 2006-2010



2020-2024

SCW-SMR

SuperCritical Water-cooled **Small Modular Reactor**

ECC-SMART: **Numbers**

- Funded under Horizon 2020 – NFRP 2019-2020
- Duration: 1.9.2020 – 28.2. 2025 (52M)
- Total budget: 8 911 950 €
- EC contribution: 3 997 237,5 €
- Total effort: 958 PM
- Coordinated by CVŘ (Research Center ŘEŽ) – Dr. Monika Šípová

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ECC-SMART: **Consortium**

20 partners :

- 15 European
- 1 Canadian
- 3 Chinese
- 1 Ukrainian partners

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ECC-SMART: **Motivation**

A TRANSCONTINENTAL PROJECT TO BRING THE POTENTIAL OF **SUPERCRITICAL WATER SMRs** A STEP **CLOSER TO REALITY**.

Motivation:

- New and flexible power source with higher efficiency.
- Based on water-cooled reactor design.
- Passive safety system.
- Modularity of the reactor as one way how to decrease the capital cost.
- Reaching GIF requiremnts (Sustainability, Economics, Safety and Reliability, Proliferation Resistance and Physical Protection).

Development towards ECC-SMART

SCWR → HPLWR → SCW-SMR (ECC-SMART)

→ decrease the **electric power** output from 1000 MWe to 200-300 MWe

→ **horizontal placement of fuel assemblies**

→ increase **heat up stages** through the core up to 7

→ decreasing the **active length of the fuel rods** to approx. 1.6 m

→ decreasing the max. coolant **temperature**

→ number of fuel rods is kept the same (20x20)

→ passive residual heat removal by natural convection

SMR as a feasible way to build a new reactor technology using supercritical water

T. Schulenberg and I. Otic, "Concept of a Small Modular SCWR With Horizontal Fuel Assemblies"
ASME J of Nuclear Rad Sci. Jul 2022, 8(3): Paper No: NERS-21-1074 https://doi.org/10.1115/1.4052191

ECC-SMART: **Goals**

Assess the feasibility and identification of safety features of an intrinsically and passively safe SCW-SMR, taking into account specific **knowledge gaps related to the future licensing process and implementation of this technology**

collect all experience from design studies in EU, Canada and China to derive a joint design requirements document following the **design targets**

- The electric power output of the SMR should be around 200 to 300 MW.
- The specific plant erection costs (€/kW installed electric power) should be less 30% compared with SMR concepts based on a PWR.
- The power plant shall remove the residual heat without the need of electric power at least within a time period of 3 days.
- The specific fuel cost (€/MWh electric power) shall be smaller than those of SMR concepts based on a PWR, which may be accomplished by a higher efficiency compensating higher fuel production costs.

The main objectives of the project are:

- define **the design requirements** for the future SCW-SMR technology,
- develop **the pre-licensing study** and **guidelines** for the demonstration of the safety in the further development stages of the SCW-SMR concept,
- identify **the key obstacles** for the future SMR licencing,
- propose **strategy for this process**.

ECC smart

ECC-SMART: **Challenges**

- **Supercritical water** as coolant.
- Find **materials for fuel cladding** to withstand the high pressure and high temperature environment.
- The establishment of a **water-chemistry control strategy** to suppress water-radiolysis effect and minimize activation-product transport.
- **Conceptual design** ensuring the passive system.
- The optimization of the fuel assembly geometry and configuration to **enhance the power output and safety** characteristics.
- Using alternative fuel as **MOX** (mixed oxide fuel).
- Legislation issues and licencing challenges.

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WP2 – Materials Testing

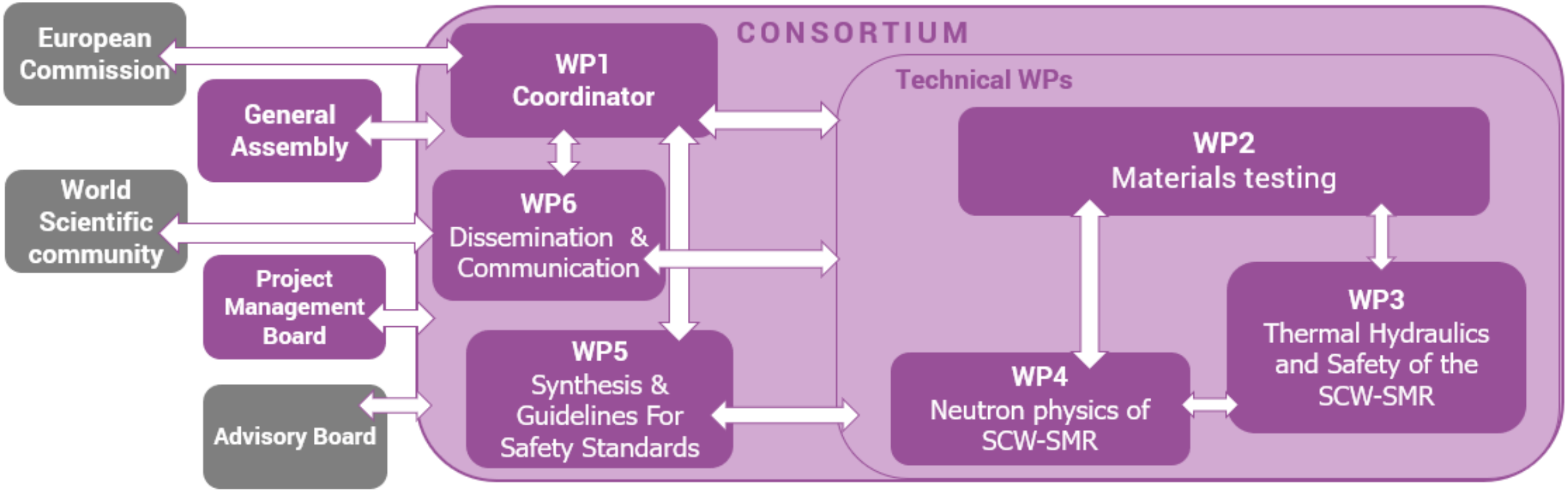
WP3 – Thermal Hydraulics and Safety of the SCW-SMR

WP4 – Neutron physics of SCW-SMR

WP5 – Synthesis & Guidelines For Safety Standards

ECC-SMART: **Structure**

For the ECC-SMART the strong cooperation among the WPs is crucial as can be seen from the scheme below.



This project has received funding from the Euratom Research and Training programme 2019-2020 under Grant Agreement No 945234.

www.ecc-smart.eu

ECC-SMART project

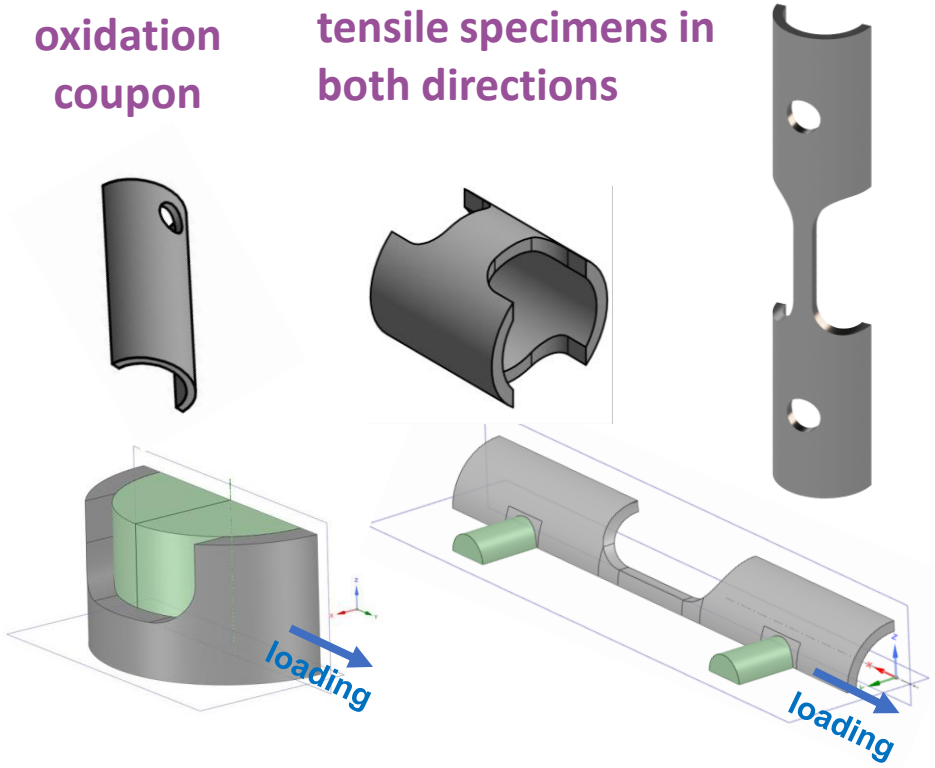
External Newsletters

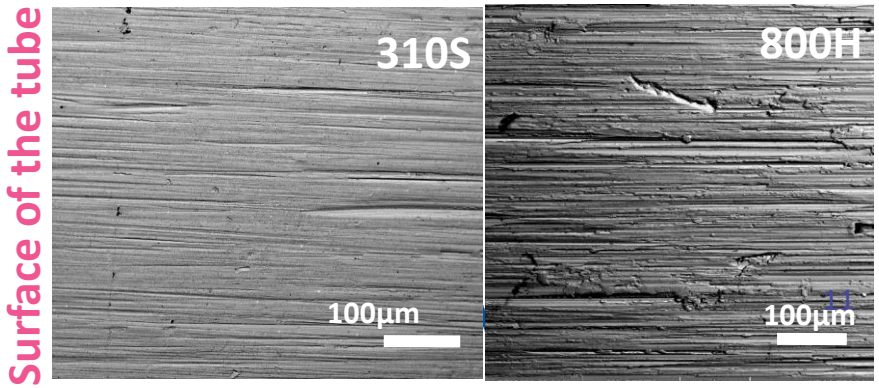
WP2: Material testing

Leader: **CIEMAT**

Contributors: CVR, JRC, STUBA, ENEN, RATEN, VTT, CNL, SJTU, VSCHT, USTB

- **Fuel cladding** as a critical component from material point of view.
- Main set up of specimens was manufactured from **310S, 800H** tube → geometry closer to reality.
- AFA (alumina forming alloy) has been included.
- Test matrix consist of > 700 specimens.
- Tests focused on radiolysis and **irradiation** by neutrons and protons.
- Assessment of EAC in longitudinal and tangential directions in SCW-SMR under expected environmental conditions (380 and 500 ºC SCW).
- Assessment of corrosion resistance using exposure and **electrochemical tests** in SCW-SMR environmental conditions (380 and 500 ºC SCW)
- Analysis of **oxide layers in terms of roughness** to be further included in T-H experiments planned in WP3.





ECC smart

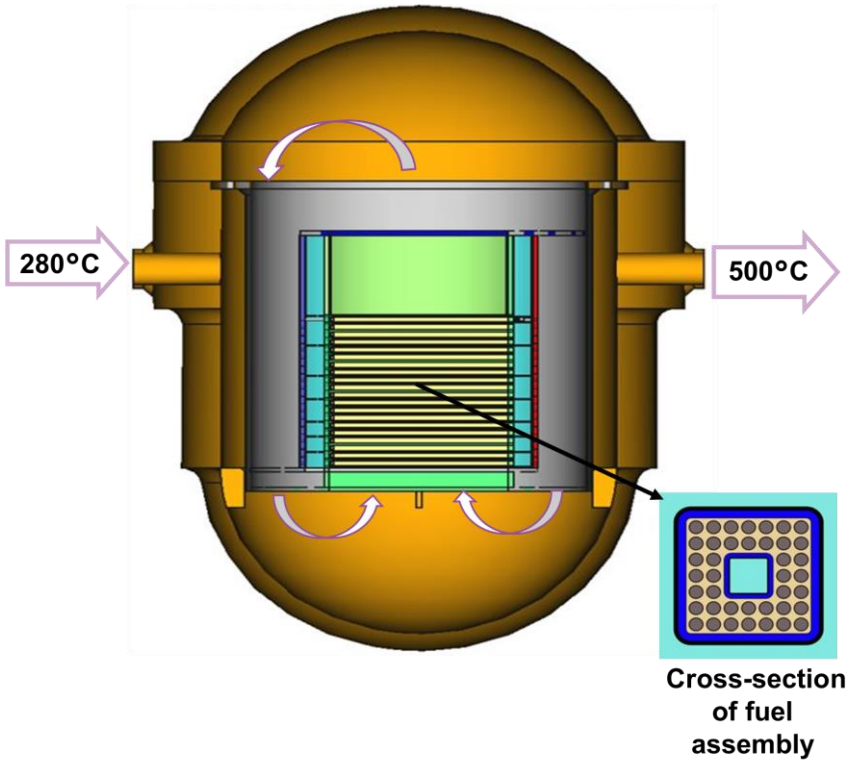
WP3: Thermal Hydraulics and Safety of the SCW-SMR

Leader: **KIT**

Contributors: CVR, UNIPI, USFD, ENEN, BME, UNOTT, IPP, CNL, KTH, NPIC

- The **innovative design concept** - using the experiences from design of SCWR concepts coming from Europe, Canada and China.
  - modeling of heat transfer
  - modeling of flow
  - structural calculations
  - extension of database
  - benchmarking activities
- Thermal-hydraulics in relation to (1) fuel pins, (2) fuel assembly and (3) reactor core.
- Assessment of the effect of surface roughness as well as the changes in conductivity caused by the corrosion of fuel cladding
- **Coupling of system code** and neutronic code towards iterative design analysis and development.
- Progress in **passive safety system** assessment.

Cross-section of the SCW-SMR core



ECC smart

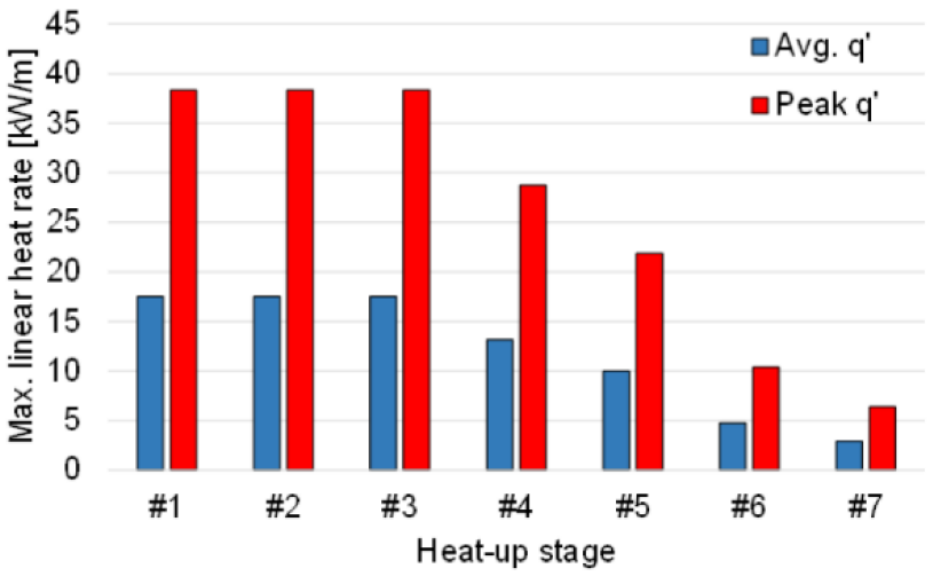
CVŘ Research Centre Řež

WP4: Neutron physics of SCW-SMR

Leader: **BME**

Contributors: UNIPI, ENEN, RATEN, CNL

- Core layout proposal based on the innovative design.
- Optimize the fuel assembly geometry and configuration to enhance the power output and safety characteristics.
- High BoC effective multiplication factor (k_{eff}).
- Slow decrease of the reactivity to follow the 7 heat-up stages proposed for innovative concept in WP3.
- The aim is to reach **2-years long cycle**.
- Using alternative fuel such as **MOX** (mixed oxide fuel).
- Selection of **fuel cladding materials** such as 310S and 800H with high amount of **Ni** is challenging.



ECC smart

CVŘ Research Centre Řež

WP5: Synthesis and Guidelines for Safety Standards

Leader: **JSI**

Contributors: CVR, JRC, CIEMAT, ENEN, BME, IPP, VTT, KIT

- Progressive safety-related outputs gathering.
- Focus on **pre-licensing** and **safeguards** documentation.

Challenges:

- European Legislation is not prepared to address specific features of SMR technologies as they usually address large power units.
- Nuclear Standards are missing to cover super critical application (High pressure and High Temperature).
- The graded approach and the practical elimination concepts should be a start point for the implementation of SMR in the European NPP portfolio.
- Definition of Passive Systems is also an open issue in the European legislations.

ECC-SMART: **Activities at CVŘ**

WP1: Coordinator of the project ECC-SMART

WP2: Materials Testing

- Purchase of the materials, manufacturing and distribution of specimens for whole consortium >700 sp.
- Basic characterization of key materials.
- Finite element analysis of test set-ups for tensile and slow strain rate tests.
- Neutron irradiation of candidate materials and following exposure in SCW.
- Assessment of the effect of neutron irradiation on corrosion behaviour of candidate materials.

WP3: Thermo-hydraulice and safety

- Long-term exposure in SCW for WP3 to describe the effect of corroded surface on the character of the coolant flow.
- Manufacture of **3 m lenght instrumented specimen for WP3** to perform experiments on heat transfer etc. → validation of codes

WP5: Synthesis and Guidelines for Safety Standards

- Deliverable 5.4: Guidelines for the demonstration of the safety of the SCW-SMR concept.

WP6: Communication and Dissemination

Leader: ENEN

Contributors: CVR, JRC, CIEMAT, JSI, BME, IPP, VTT

- Main activities:
  - **Inform** the nuclear community and the public about the project LinkedIn, website
  - Provide internal communications platform SharePoint
  - Ensure project **visual identity** logo, project templates
  - Organisation of **events** such as workshops and corresponding symposiums

Education and trainning

10 universities involved (incl. 2 Chinese)

Dedicated budget & efforts to E&T activities

20% from the project budget and 30% of person-months

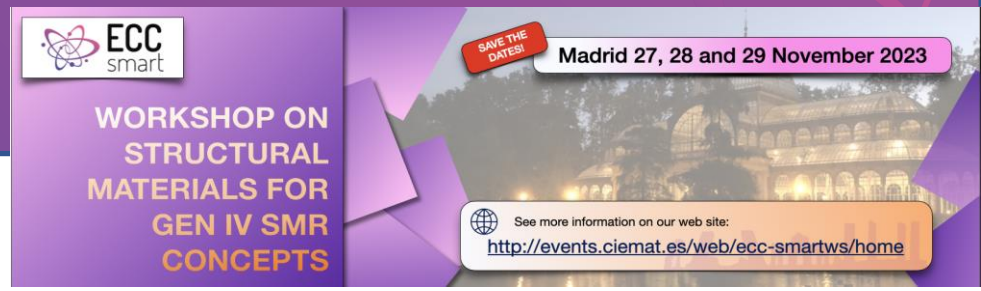
3 groups of proposed activities

(1) Young researchers' participation in the research activities (several Ph.D.theses are in progress)
(2) Participation of young scientists in the events organized by the consortium members
(3) Internship and specific training organized by the consortium members

Events & Dissemination activities

- Workshop on Materials (November 2023, CIEMAT, Spain)
- Training and workshop with focus on irradiation effect (1-2 Q/2024, CVR, Czech Republic)
- ISSCWR-11 (2024, on behalf of cooperation with GIF-SCWR)
- Newsletter (Internal and External)
- Publications

Workshop on Materials



Joint workshop with EERA JPNM

WORKSHOP ON STRUCTURAL MATERIALS FOR GEN IV SMR CONCEPTS

- **Venue: Madrid (CIEMAT), Spain → contact: alberto.saez@ciemat.es**
- **Topics:**
  - State of the art of structural and cladding materials for GenIV reactors including SMR.
  - Influence of environment, coolant and radiation, on structural and cladding materials for SCW SMR.
  - Physical modelling and advanced microstructure examination.
  - Advanced testing methods and non-destructive examination.
  - Development of advanced materials solutions and fabrication process.

Workshop on PIE

- **Workshop on post-irradiation examination**
- **Venue: Řež (CVŘ), Czech Republic**
- **Content:**
  - Presentations focused on irradiation by neutrons vs.protons; irradiation damage; PIE; testing of irradiated material; qualification of structural material for NPP;
  - Excursions (LVR15, CVUT – Vrabec I and II);
  - Practical PIE in CVR.
- **Contact: monika.sipova@cvrez.cz**

Publications

- 19 publications
- 8 peer-reviewed open access research articles
  - Deteriorated heat transfer influence on the stress-strain state of SMR SCWR fuel bundles (doi.org/10.1115/1.4052590)
  - Overview of a theory for planning similar experiments with different fluids at supercritical pressure (doi.org/10.3390/en14123695)
  - Concept of a Small Modular SCWR with Horizontal Fuel Assemblies (doi.org/10.1115/1.4052191)
  - Transfer matrix method analysis of extremely nonlinear flow characteristics using channel approach (doi.org/10.1016/j.ijheatmasstransfer.2022.122531)
  - On the limitations of positron annihilation spectroscopy in the investigation of ion-implanted FeCr samples (doi.org/10.3390/met11111689)
  - A shape function approach for predicting deteriorated heat transfer to supercritical pressure fluids on account of a thermal entry length phenomenon (doi.org/10.1016/j.nucengdes.2022.111923)
  - Characterisation of observed heat transfer deterioration modes at supercritical pressure with the aid of a CFD model (doi.org/10.1016/j.anucene.2022.109376)
  - A study on the corrosion behaviour of stainless steel 08Cr18Ni10Ti in supercritical water (doi.org/10.1016/j.corsci.2022.110853)

→ Corrosion Science, Journal of Nuclear Engineering and Radiation Science, METALS, Nuclear Engineering and Design

Conclusions

- The project is close to the end of the second report period (M36).
- All deliverables and milestones have been submitted.
- Despite the complicated situation caused by COVID, the close cooperation among WPs and within the group has been established.
- The consortium and its members are active in the cooperation with the other EU projects.
- Young researchers are succesfully involved and the results are published in the scientific journals.
- The project activities are performed and headed towards objective completion.

Find out more on ECC-SMART

- Contacts:
  - Coordinator
    - Project coordinator: **Dr. Monika Šípová** (monika.sipova@cvrez.cz)
    - Project administrator: **Eliška Krychová** (eliska.krychova@cvrez.cz)
  - WP leaders
    - **WP2 Materials Testing**
      - **Alberto Sáez Maderuelo** (CIEMAT) alberto.saez@ciemat.es
    - **WP3 Thermal Hydraulics and Safety of the SCW-SMR**
      - **Ivan Otic** (KIT) ivan.otic@kit.edu
    - **WP4 Neutron physics of SCW-SMR**
      - **Szabolcs Czifrus** (BME) czifrus@reak.bme.hu
    - **WP5 Synthesis and Guidelines for Safety Standards**
      - **Leon Cizelj** (JSI) leon.cizelj@ijs.si
    - **WP6 Communication and Dissemination**
      - **Gabriel Pavel** (ENEN) gabriel.pavel@enen.eu

ecc-smart.eu

ECC-SMART LinkedIN

CORDIS
EU research results

Cordis (ID945234)

ECC smart

Thank you for your Attention!

monika.sipova@cvrez.cz

JOINT EUROPEAN CANADIAN CHINESE
DEVELOPMENT OF SMALL MODULAR REACTOR TECHNOLOGY

This project has received funding from the Euratom Research and Training programme 2019-2020 under Grant Agreement No 945234.

2.9 ELSMOR Project Overview, V. Tulkki, VTT (Remote)

ELSMOR
Towards European Licensing of Small Modular Reactors

VTT

ELSMOR: towards European Licensing of Small Modular Reactors

V. Tulkki, M. Szogradi, S. Buchholz, S. Lansou, C. Lombardo, R. Ferri, N. Reinke, A. De Angelis, F. Davelaar, C. Liegeard, J. Bittan, K. Värri, M. Ricotti

ELSMOR

ELSMOR – General

- towards European licensing of SMRs
- Project aims at investigating selected safety features of LW-SMRs
- Focus on safety justification methodology for potentially challenging safety features of LW-SMRs
- Project website: www.elsmor.eu
- Funded from the Euratom research and training programme 2014-2018 under Grant Agreement No. 847553

ELSMOR – Project consortium

- 15 Partners
- 8 countries involved

ELSMOR – Concept

Small modular reactors aim to achieve the required safety levels through innovative safety features, including extensive use of passive safety features. This needs to be verified concept by concept, but competences to do that must be demonstrated and gaps understood.

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

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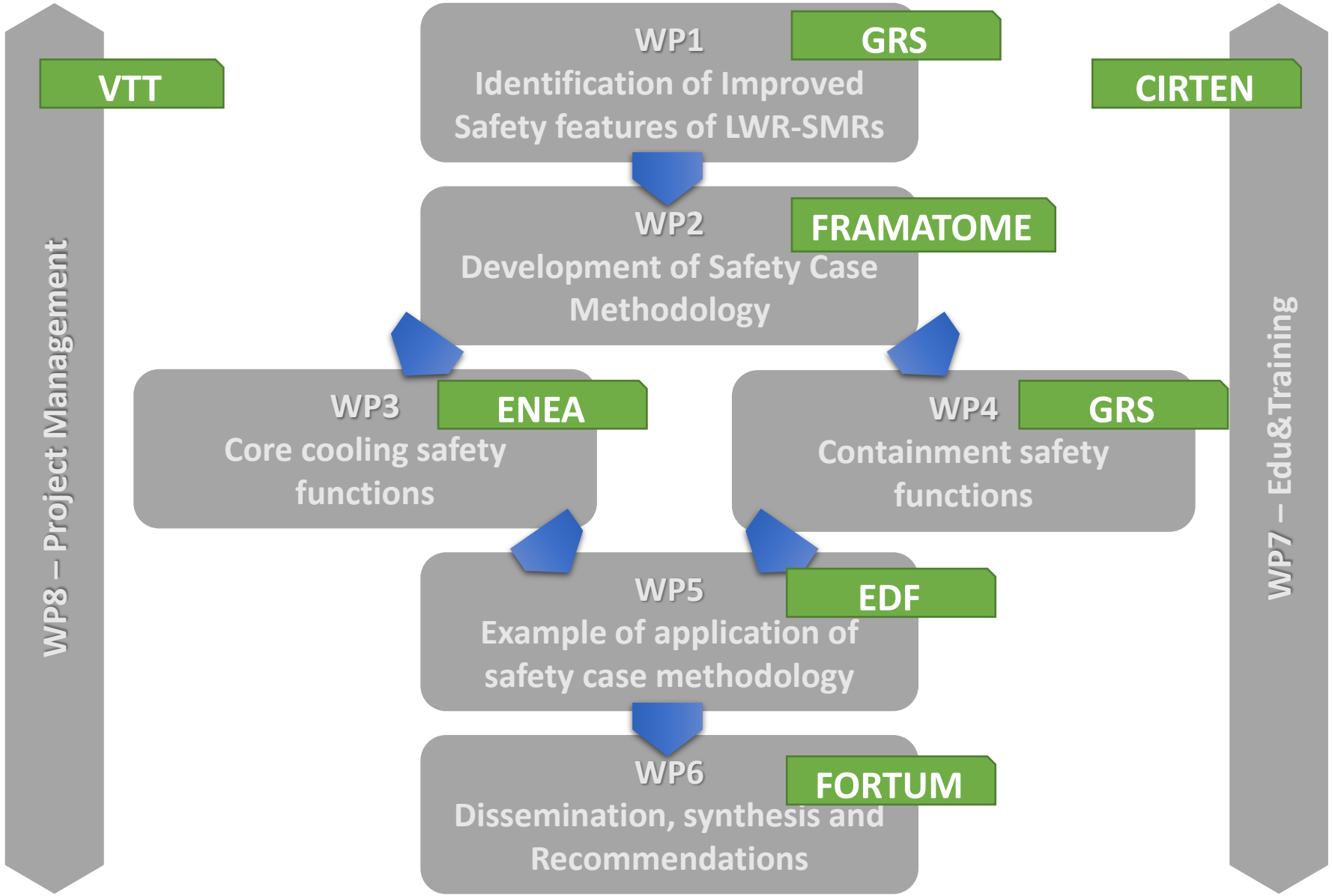
Towards European Licensing of Small Modular Reactors



WP1: Review of improved safety features of LW-SMR

- Screening of numerous safety directives and guidelines
  - No SMR specific directives and guidelines
  - Application of given regulations basically possible also for SMR
- Review of 21 LW-SMR designs
- Identification of potential challenges for SMR safety demonstration
- Documentation in public deliverable D1.1 (on ELSMOR Website http://www.elsmor.eu)

WP2: Development of safety analysis methodology for LW-SMRs

WP2 focuses on developing a methodology to support the safety demonstration of LW-SMRs as well as a gap analysis.

- Complementary methodology development
  - Assessing the applicability of technology neutral Integrated Safety Assessment Method (ISAM) developed by GIF and a systems engineering approach
- Various aspects of SMRs
  - High-level objectives (reactivity control, core cooling, containment)
  - Multi-unit plants, human factors, decommissioning, fuel management

Comments the potential topics of interest, may not apply to all designs

Many issues that need to be decided by the regulator, here we aim to provide tools for assessment

WP1 & WP2: Safety features of SMRs and safety case methodology [1,2]

- International bodies:
  - EU legislation: high-level technology-neutral, directly applicable
  - IAEA: no SMR-specific guidance has been published, PWR-relevant rules are still valid
  - WENRA: requires extended safety demonstration along with the reinforcement of the Defence-in-Depth concept. Earlier Beyond Design Basis Accident (BDBA) scenarios are now considered as design extension conditions (DEC), e.g. core melt and multiple failure cases
  - ENSREG: reiterates the guidelines of other international bodies
- State-level regulations:
  - EU countries (France, Germany, Lithuania) in principle follow international auspices or do not consider new applications
  - Non-EU countries: Canada, UK → non-prescriptive; USA → prescriptive
- Regarding advanced SMR designs:
  - Strong differences compared to larger PWRs e.g. fuel cycle management, boron-free operation, reactivity control
  - Extensive use of passive safety systems for decay heat removal

- **<u>Current safety demonstration methodologies face challenges regarding:</u>**
  - Multi-unit siting (shared equipment, failure cross-effect)
  - Severe accident mitigation (practical elimination, emergency planning zones)
  - Impact of passive safety systems on reliability assessments

DiD levels		Objective	Essential means	Radiological consequences	Associated plant condition categories
Level 1		Prevention of abnormal operation and failures	Conservative design and high quality in construction and operation, control of main plant parameters within defined limits	No off-site radiological impact (bounded by regulatory operating limits for discharge)	Normal operation
Level 2		Control of abnormal operation and failures	Control and limiting systems and other surveillance features		Anticipated operational occurrences
Level 3	3.a	Control of accident to limit radiological releases and prevent escalation to core melt conditions	Reactor protection system, safety systems, accident procedures	No off-site radiological impact or only minor radiological impact	Postulated single initiating events
	3.b		Additional safety features, accident procedures		Postulated multiple failure events
Level 4		Control of accidents with core melt to limit off-site releases	Complementary safety features to mitigate core melt, Management of accidents with core melt (severe accidents)	Off-site radiological impact may imply limited protective measures in area and time	Postulated core melt accidents (short and long term)
Level 5		Mitigation of radiological consequences of significant releases of radioactive material	Off-site emergency response intervention levels	Off-site radiological impact necessitating protective measures	-

[1]

[1] S. Buchholz, M. Ricotti, O. Martin et al.: WP1 D1.1 Improved safety features of LW SMR, ELSMOR report, 2020
[2] S. Lansou: WP2 D2.12 Synthesis: summary of methodology recommendations for LW SMR safety assessment, ELSMOR report, 2022

Safety of Operation and human factors issues

- **Operations and Human Factors regarding SMR specificities:**
  - **Impact of passive safety systems on human supervision:**
    - **different Passive Safety Systems in terms of level of passiveness (IAEA definitions related to "intelligence", mobile mechanical part, fluid motion)**
    - **System dependency could be more complex than with active systems**
    - **If the plant safety systems are not so passive, HOF issues are linked to automation issues (supervision of safety system status and ability of the team to intervene)**
- **Impact of multi-unit plant operation on supervision:**
  - **Every Unit**
    - might be **in different operational state**
    - might **share support systems**
    - might be **concerned by the same aggression** /crisis /extreme situation (or cascade effect)
    - might be **with different design/technology** due to cost effect over time

WP 2 passive systems reliability

The main issue concerning the introduction of passive systems is to know how their reliability can be sufficiently demonstrated as system driving forces (gravity, conduction) can be small. Two sources of uncertainties exist concerning driving forces:

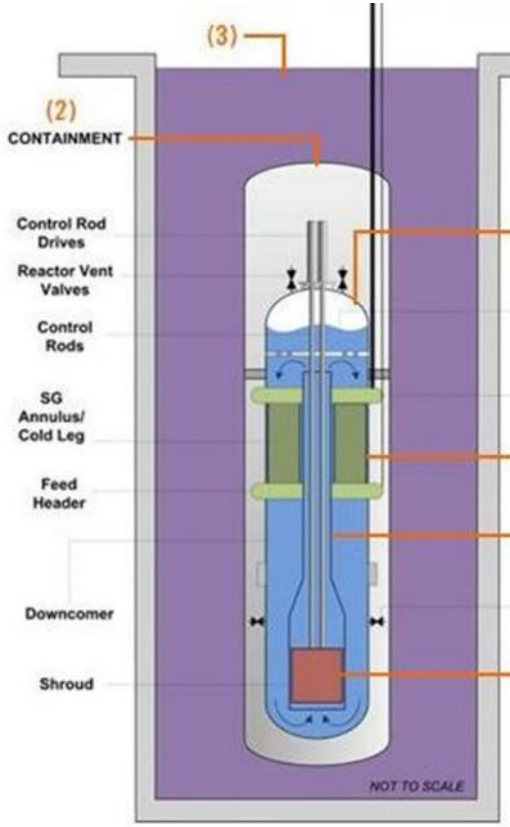
- Uncertainties related to the quantity of these driving forces and the factors they depend on (heat transfer coefficients and pressure losses for example),
- Uncertainties related to the effects of the plant conditions and human actions. There may be considerable variations of the importance of these uncertainties between normal and accidental situations.

Yet, there is no common international methodology to license and assess the safety of passive safety features.

WP 2 passive systems reliability

Uncertainties relative to T-H passive systems assessment can be divided into the following classes:

1. **uncertainties related to T-H analysis:** approximations in the modeling of physical phenomena, in the numerical solutions, lack of precision of the values adopted for boundary and initial conditions, parameters used as inputs in the models.
2. **uncertainties related to T-H performance:** factors on which the magnitude of the engaged forces and counter-forces depends on. These factors largely depend on specific plant configurations and conditions.
3. **uncertainties related to probabilistic analysis:** uncertainties related to development of the probabilistic model: data uncertainties, model uncertainties and completeness uncertainties; mainly concerning plant level uncertainties.



In the work we have aimed to to identify, classify and evaluate such uncertainties, and to summarize the results of uncertainties analysis. In this format, a complete description of the uncertainties is carried out, including their impact to PRA analysis and sensitivity studies.

WP 2: Some Conclusions

- SMR safety follows the same Defence-in-Depth principle as large power reactors, but with stronger emphasis on passive safety features. This creates some challenges, such as
  - Function of passive features and their uncertainties
  - Independence of DiD levels when passive systems are ”always on”
- The use of innovative design options in certain SMR projects may raise some extra issues, for instance, for boron free concepts.
- The design of a multi-unit facility, which is an SMR specificity as several modules would be operated on the same facility, is an issue to consider
- Assessment of severe accidents; their practical elimination, the effect of multiple units, the effect on emergency planning zones etc. which are finally questions for the decision makers and authorities

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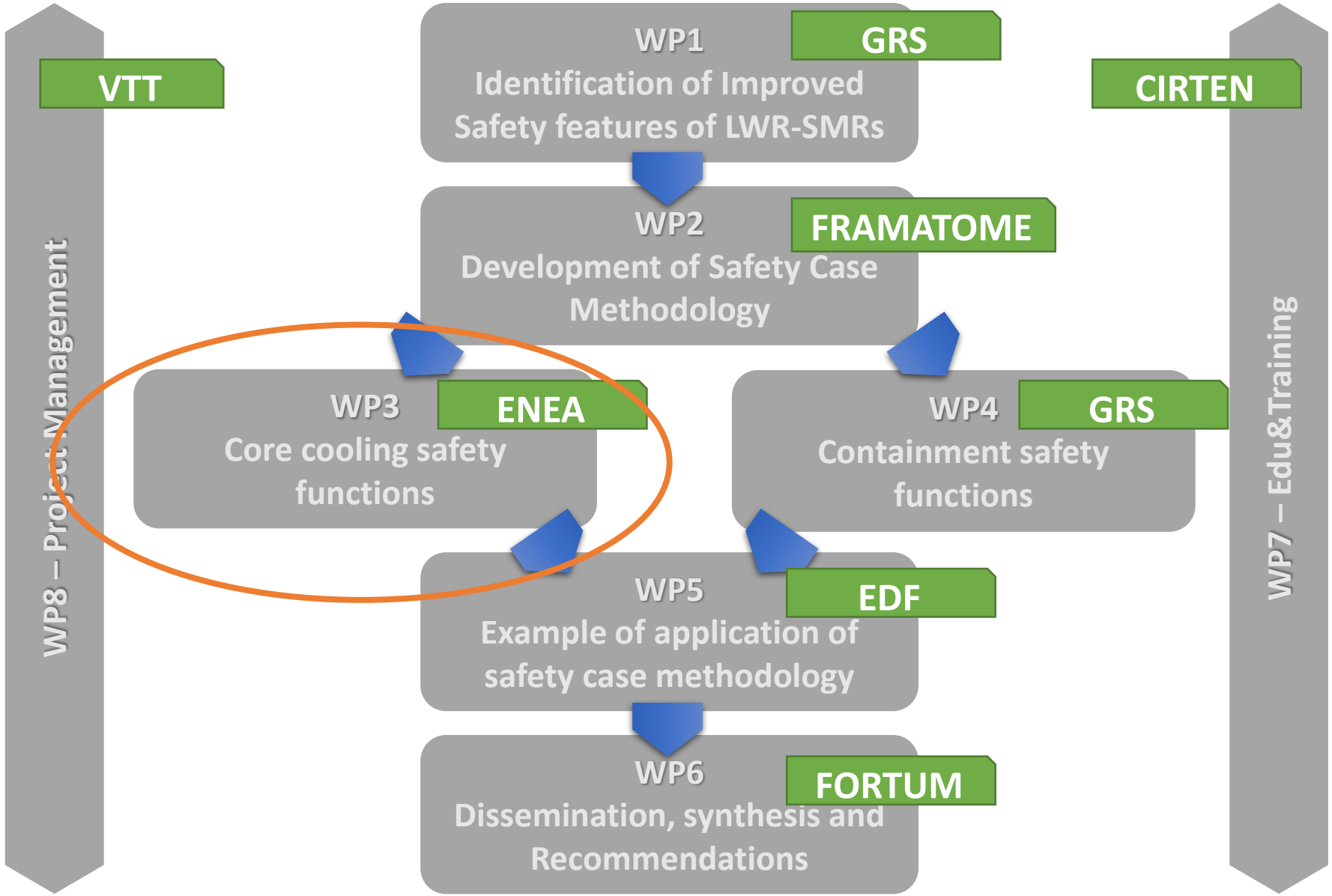


WP3: Core cooling safety functions [3,4]

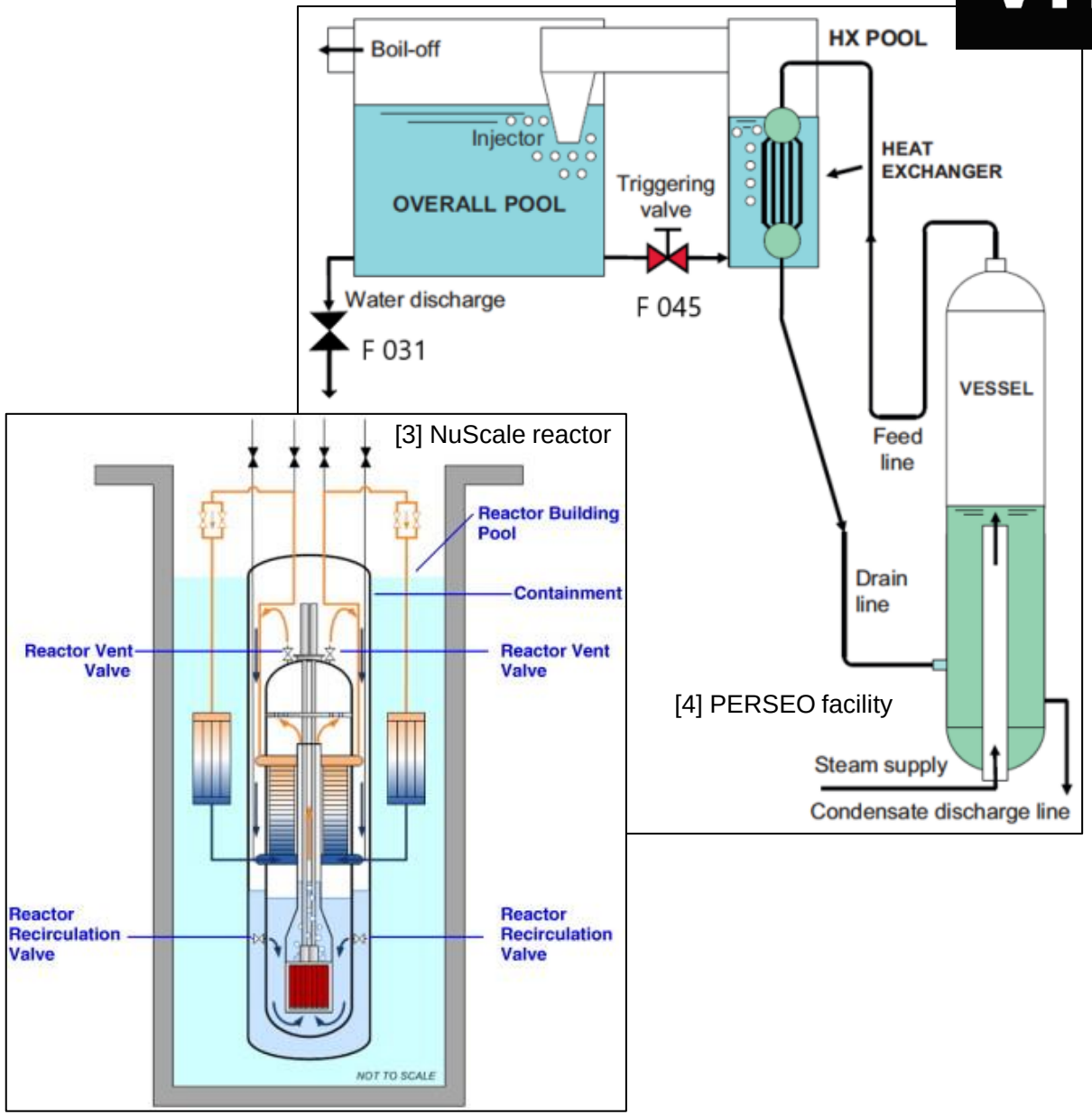
- Simplified Phenomena Identification Ranking Table (PIRT) with respect to SMR passive safety systems to support subsequent experimental tasks.

- Important phenomena concerning loss of off-site power scenario:
  - Fouling and non-condensables in the safety condenser
  - Gas-liquid interfacial friction
  - Steam chugging in the safety condenser pool

- Regarding loss-of-coolant accidents:
  - Water hammer effect in the passive loop
  - Departure from nucleate boiling in the core
  - Steam condensation in the UP, safety injections
  - Non-condensable in the SG

- Previous experimental campaigns were reviewed (HERO-2, PERSEO, PANTHERS, PANDA, EHRS) with respect to relevant phenomena.

- **<u>Gaps in know-how:</u>** natural circulation with diminishing driving forces, heat transfer in compact heat exchangers in the presence of non-condensables.



[3] F. Morin, P. Olita, S. Lorenzi et al.: WP3 D3.1 Elaboration of simplified PIRT transients for SMR PWR, ELSMOR report, 2020
[4] C. Lombardo, P. Meloni, K. Nikitin et al.: WP3 D3.2 Description of some relevant experiments for SMR safety, ELSMOR report, 2021

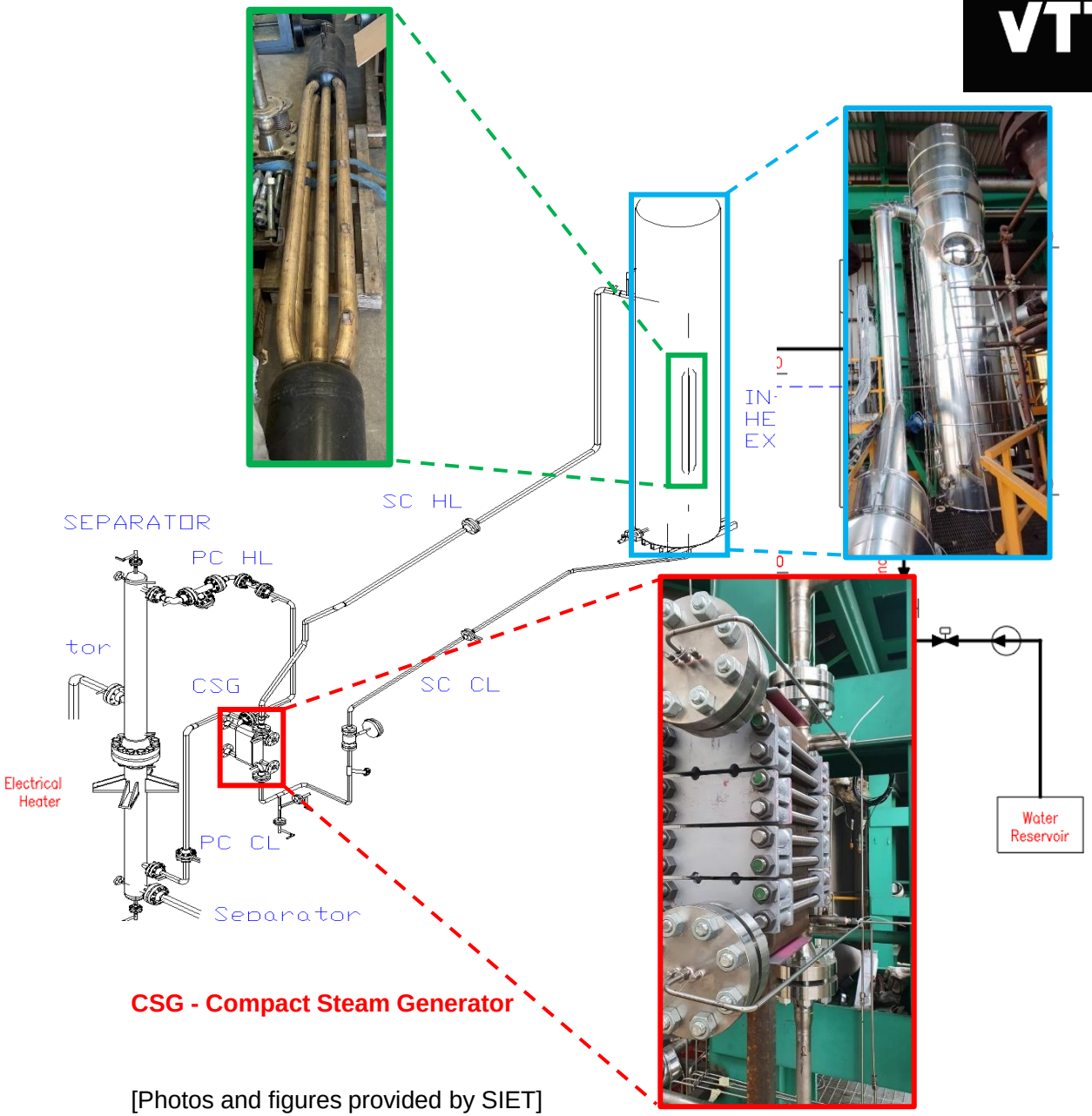
WP3: Core cooling safety functions

- Addressing data scarcity issues a new experimental facility was built at SIET (Piacenza, Italy).

- The experimental campaign, completed during Q1 2023, featured 81 steady state points focusing on:
  - Impact of non-condensable (N_2) on a compact plate-type heat exchanger
  - One- and two-phase flow conditions in the primary loop
  - Natural circulation
  - Various filling ratios on the secondary side (reflux condensation in the SG)

- <u>Key takeaways:</u>
  - The performance of the plate-type HX was satisfying in general
  - At very low secondary side filling ratios the circulation was unstable leading to reduction in HX power
  - Non-condensable presence did not hinder the operation of the HX

- The obtained data is the basis of subsequent code benchmarking with a few selected cases and lumped-parameter (LP) codes (AC^2, Apros, CATHARE, RELAP5).



[Photos and figures provided by SIET]

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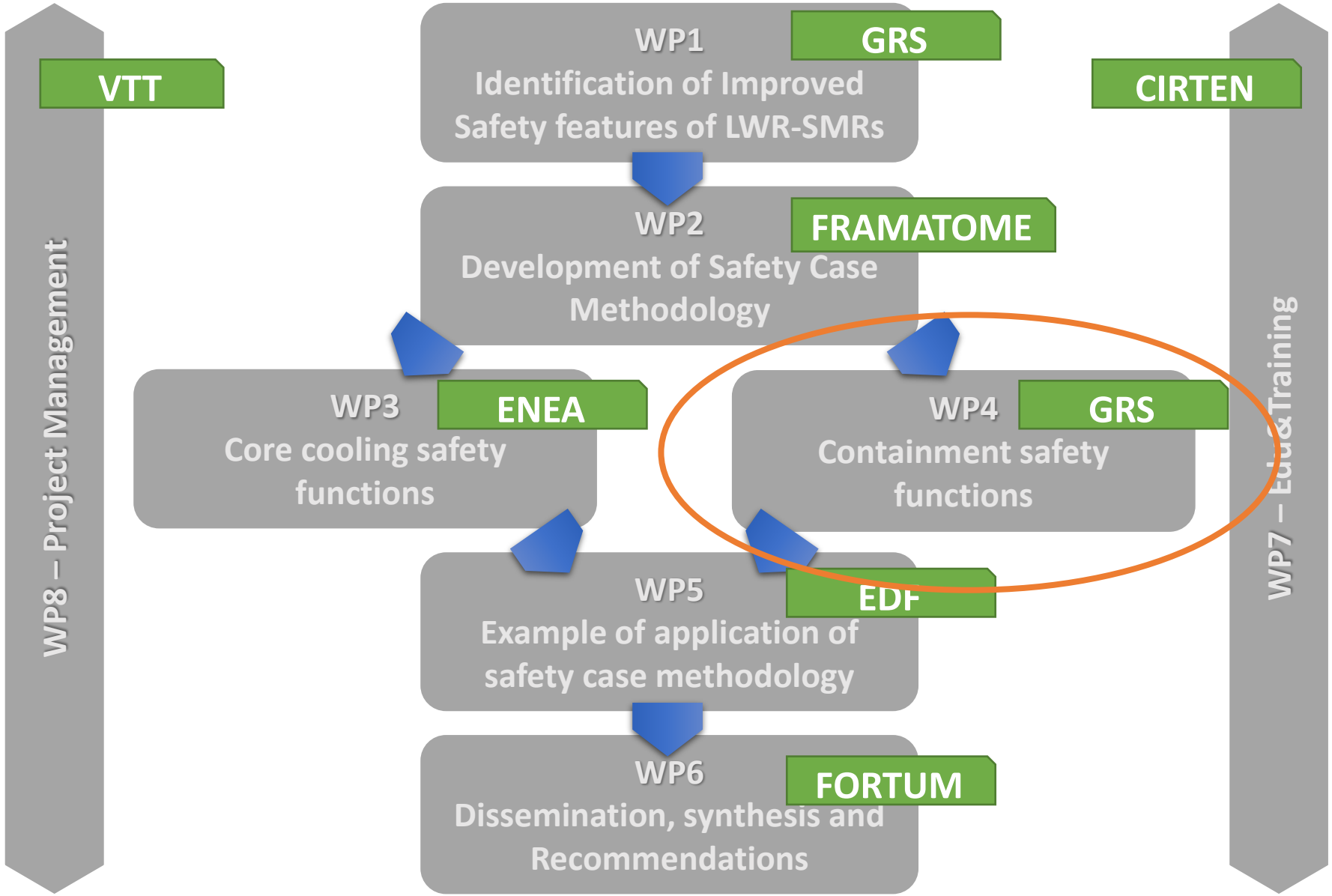
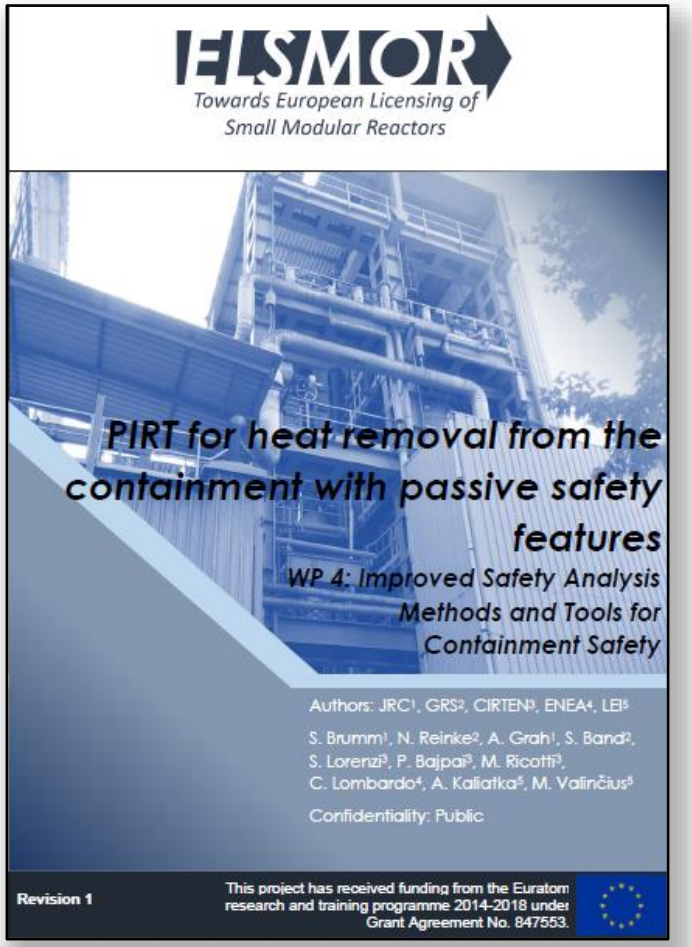


WP4: Submerged containment

- WP looks at the submerged containment of iPWR
- Elaboration of a PIRT on containment heat removal for DBA and DEC including severe accidents
  - Focus on submerged containments
  - Phenomena by relevance and knowledge level
- Review of experiments at characteristic length for containment walls
  - Not available, need for scaling
- Simulation of a test case for a submerged containment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Towards European Licensing of Small Modular Reactors

PIRT for heat removal from the containment with passive safety features

WP 4: Improved Safety Analysis Methods and Tools for Containment Safety

Authors: JRC[1], GRS[2], CIRTEN[3], ENEA[4], LEI[5]

S. Brumm[1], N. Reinke[2], A. Grah[1], S. Band[2], S. Lorenzi[3], P. Bajpai[3], M. Ricotti[3], C. Lombardo[4], A. Kaliatka[5], M. Valinčius[5]

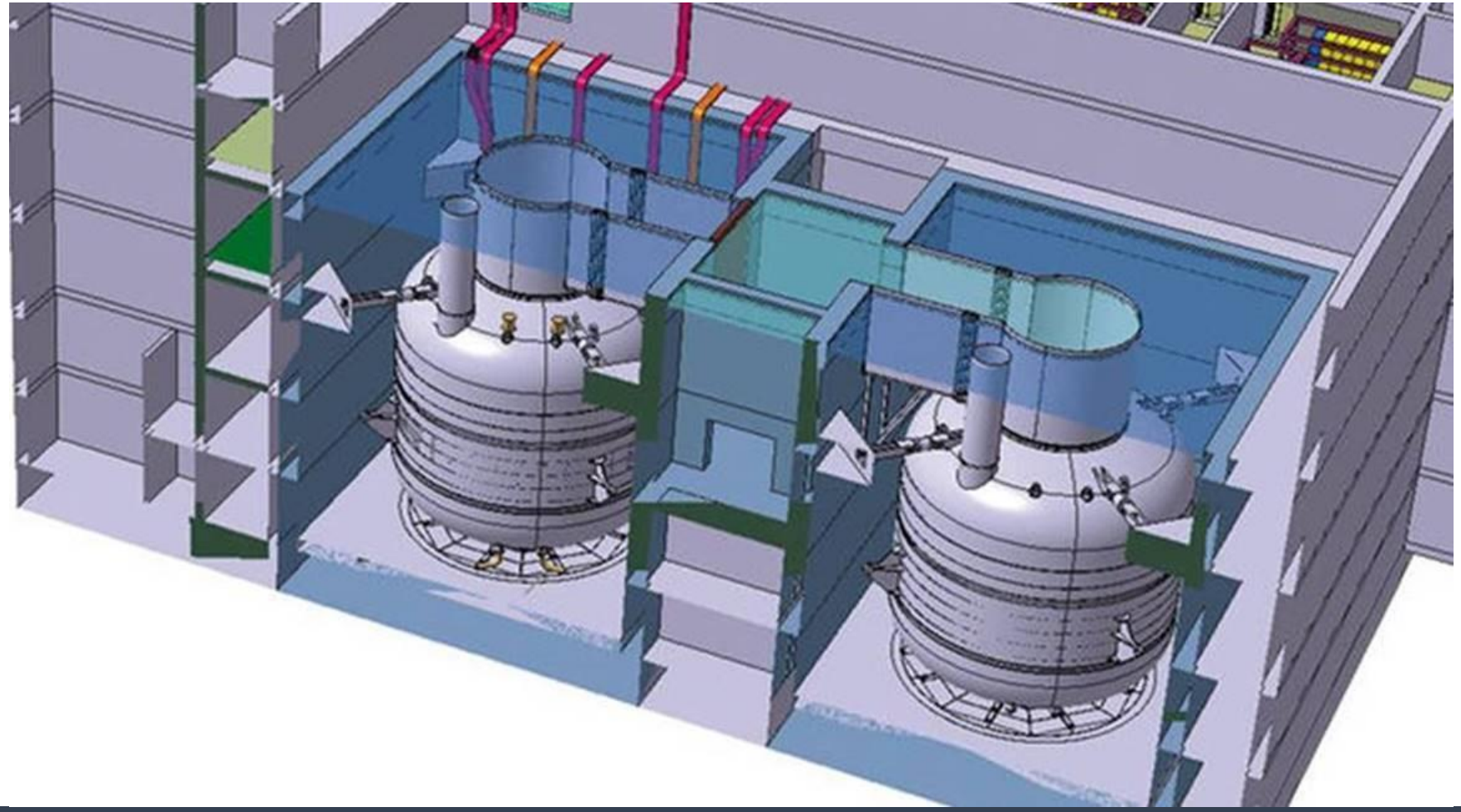
Confidentiality: Public

Revision 1

This project has received funding from the Euratom research and training programme 2014-2018 under Grant Agreement No. 847553.

WP 4 Code assessment and development

- Focus on NUWARD "water wall"



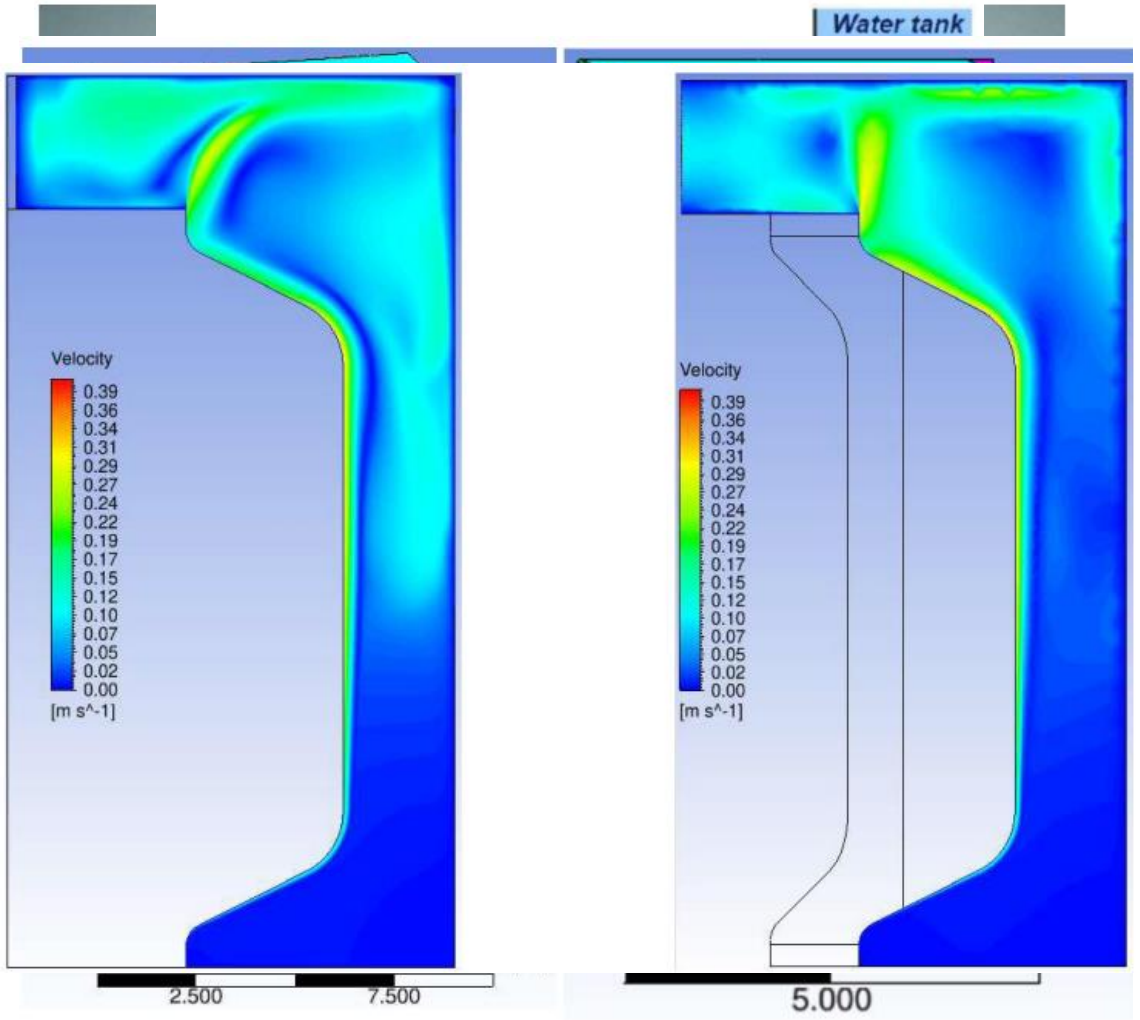
WP4: Containment safety functions [5]

- Studies on the submerged containment concept including:
  - CFD and Lumped Parameter code benchmarking using a NUWARD^{TM}-based geometry (E-SMR)
  - PIRT with 42 phenomena concerning SBO, LOCA and DECs

- Major sources of uncertainties:
  - Water wall behaviour
  - Heat transfer processes in the containment (passive loop, containment wall)
  - Late phase of accident with core degradation
  - Scarcity of adequate experimental data with respect to diffusion dominated flows

- CFD codes struggle with computational resources due to domain sizes, nonetheless 2D axisymmetric boundary conditions can be used effectively to shorten simulation times.

- Lumped parameter codes showed consistency with CFD simulations (flow fields, stratification) but also failed to capture small-scale phenomena (boundary layer effects) due to limitations of spatial discretization.



[Provided by JRC]

[5]

[5] S. Brumm, N. Reinke, A. Grah et al.: WP4 D4.1 PIRT for heat removal from the containment with passive safety features, ELSMOR report, 2021

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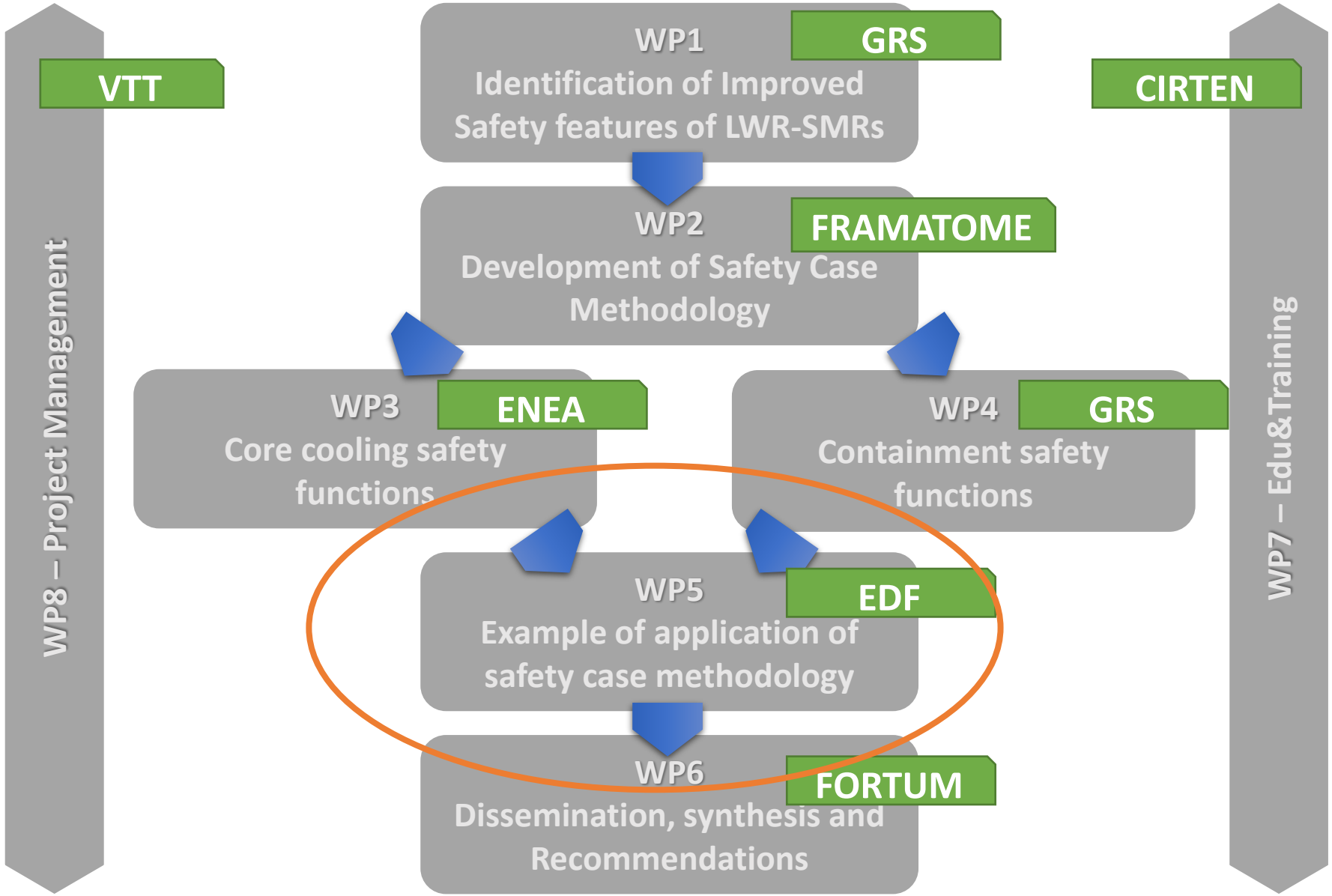
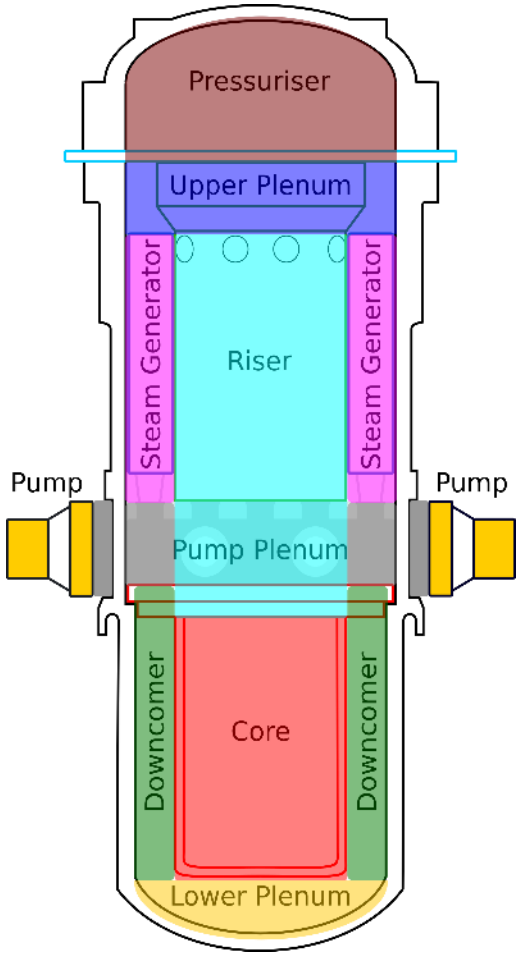


WP5: Development of new reference data set

- Scarce public data for NUWARD design
  - Previous simulation excercises have extensively used Nuward design as there have been more information
- Definition of E-SMR (European SMR) for simulations
  - Aim to create a public benchmark model for use
  - Understanding of safety approach, platform for further development
  - First out of consortium use in future TANDEM project
- Parallel creation of system code models
  - ASTEC, CATHARE, APROS, AC², RELAP, MELCOR
  - Analysis of DBA and severe accident



WP5: Example of application of safety case methodology

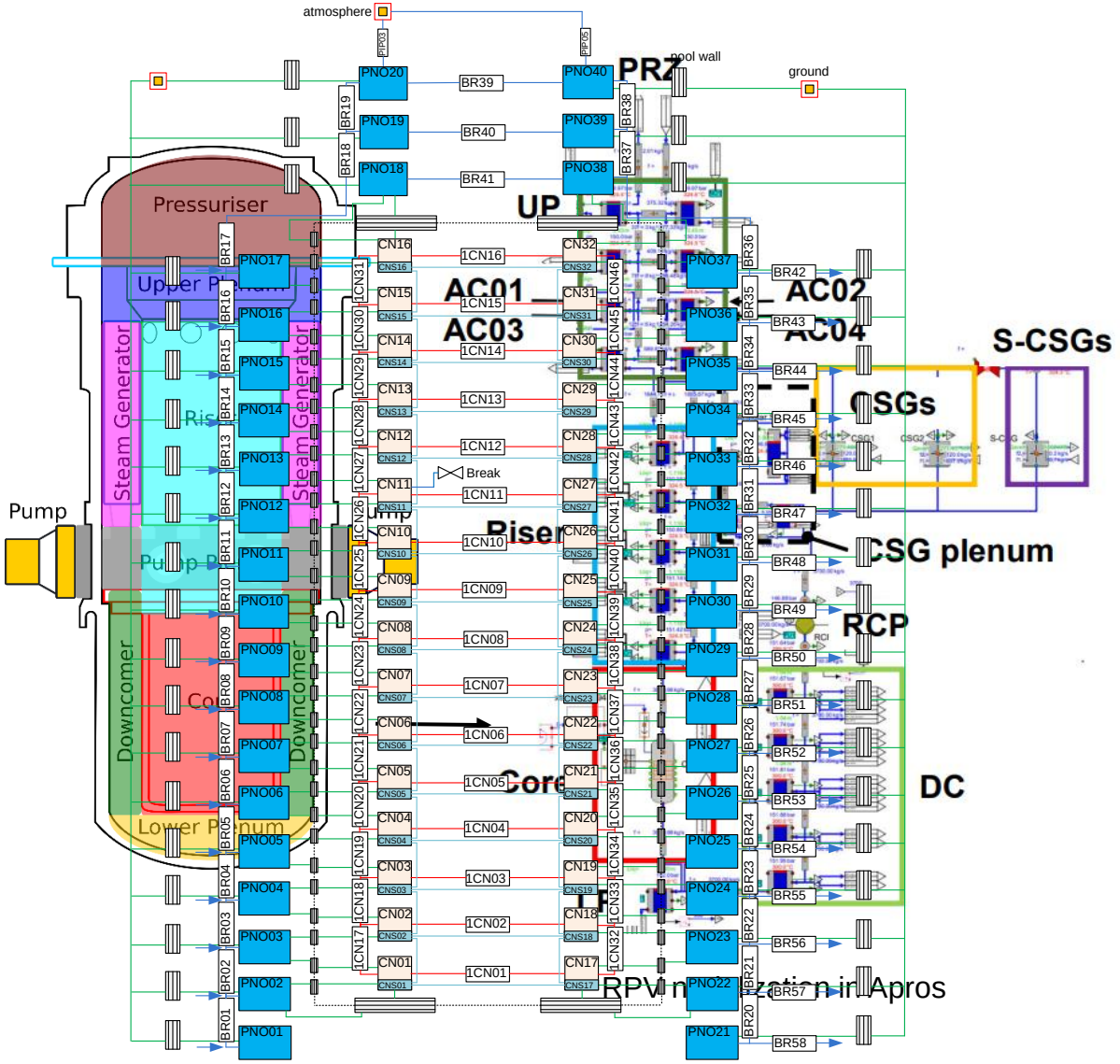
- Using conceptual SMR designs (NuScale, NUWARD™) the European SMR was conceived by EDF, GRS, Polimi and VTT.

- The onion-structured (Apros) model features:
  - Primary system (main components, heat structures)
  - Containment
  - Passive safety systems (ACCs, passive condenser (P-COND))
  - Water wall with pool wall heat structures and ground boundary condition
  - Secondary system (boundary conditions)
  - I/O systems, basic trip and control logics

- Design Basis Accident (DBA) analyses: SBO and LOCA scenarios

- DEC analyses reiterating DBA studies without passive safety systems

Property	Value
Core / CSG power	540 / 90 MWth
Primary / secondary coolant pressures	150 / 45 bar
Primary / secondary flow rates	3700 / 240 kg/s
Core inlet / outlet temperatures	300.0 / 324.5 °C
Containment / water wall free volumes	1732 / 5481 m^3
Containment / water wall coolant inventories	125 / 5457 t



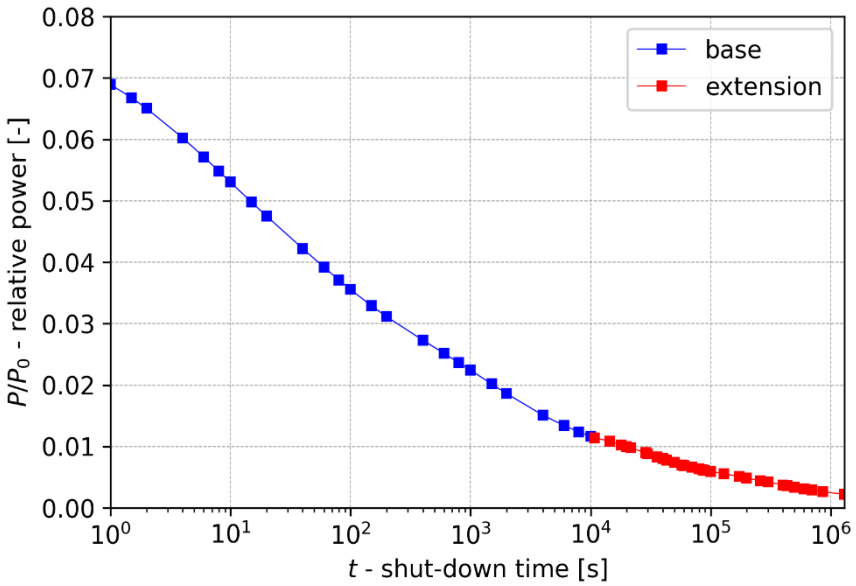
RPV nodalization in Apros

WP5: Example of application of safety case methodology (Apros results)

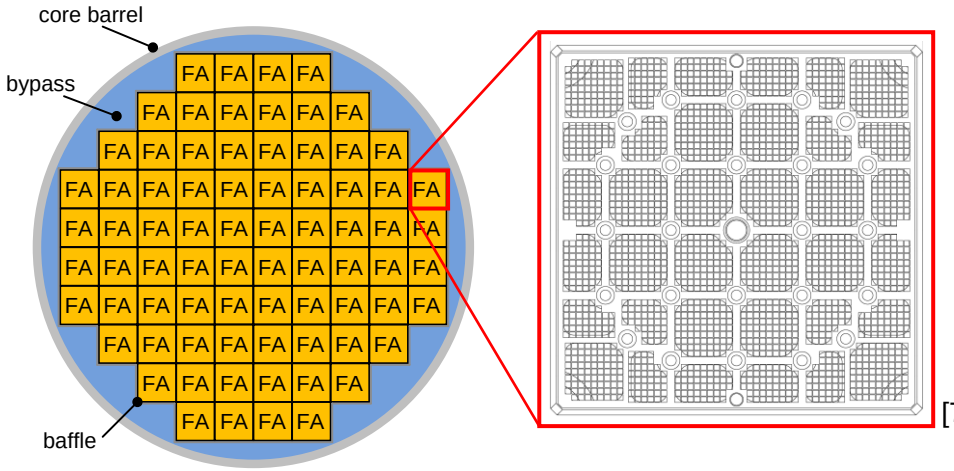
- DBA simulations with Apros:
  - Various ACC pressures at 60.0-15.0-7.5 bar
  - Voided and filled[2] CSG annuli (space surrounding the CSGs)
  - Decay heat curve: extended ANS94 3.a (conservative) with EOC axial profile [6]
  - Uniform radial profile
  - Fuel type: NuFuel-HTP2 (NuScale/AREVA 17x17 PWR assembly) [7]
  - Assumptions: 4.95 % enrichment, 95 % matrix density

- Loss Of Coolant Accident (LOCA)
  - ø40 mm double-ended guillotine break on AC01 injection line
  - AC(02,03,04) and PHRS available
  - LOCA1: voided CSG annuli, 15 bar ACC pressure
  - LOCA2: filled CSG annuli, 15 bar ACC pressure
  - LOCA3: filled CSG annuli, 7.5 bar ACC pressure

- Station Blackout (SBO)
  - Manual SBO trip
  - Four ACC vessels, PHRS available
  - SBO1: Voided CSG annuli, 15 bar ACC pressure
  - SBO2: Filled CSG annuli, 7.5 bar ACC pressure



[6]



[7]

[2]The 'voided' RPV design refers to a case with a large CSG annular volume omitting metallic structures while the 'filled' design describes a more realistic CSG annuli.

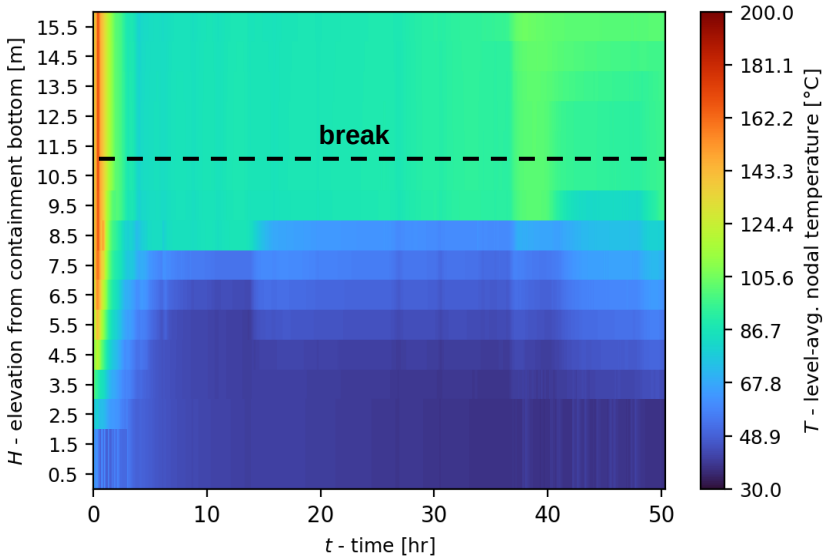
[6] United States Nuclear Regulatory Commission, Attachment 1: Appendix K Decay Heat Standards, URL: https://www.nrc.gov/docs/ML0217/ML021720702.pdf
[7] NuScale Power LLC, NuFuel-HTP™ Fuel and Control Rod Assembly Designs, Rev. 3, 01.2019, URL: https://www.nrc.gov/docs/ML1935/ML19353A719.pdf

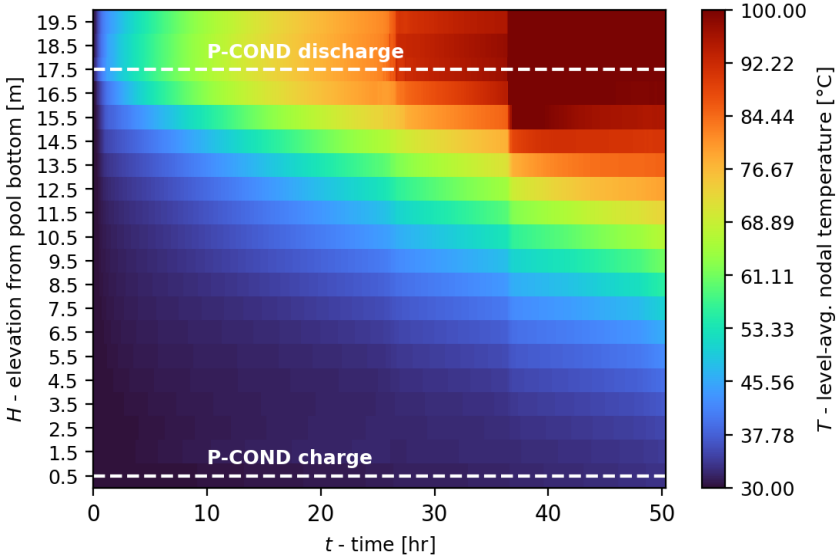
WP5: Example of application of safety case methodology (Apros results)

- LOCA1 & LOCA2 results:
  - 15+ bar ACC pressures were unnecessary as the makeup inventory left the RPV during the blowdown period.
  - The voided CSG annular region acted as a gas plug due to its flow restrictions, blocking the downflow of the cold water.
  - The remaining primary coolant inventory could sustain natural circulation for 3.0-3.5 hrs, afterwards the S-CSG would become unreachable.

- LOCA3 results:
  - The 7.5 bar ACC pressure enabled a far better makeup inventory utilization.
  - More balanced riser reflood, no excess flow rates via the break.
  - The slow feed-bleed regime facilitated primary natural circulation for ~36 hrs, thereafter the RPV collapsed water level started to decrease after ~48 hrs.
  - Conservatively a ~6-8 t coolant inventory could compensate the coolant losses of the 3rd day (~32-42 % of a single ACC).

- Key takeaways:
  - Lower ACC pressures are preferable due to better coolant inventory utilization.
  - The integrated P-COND power was multiple times (~x6.3) larger than the transferred heat via the containment vessel.
  - The maximum containment peak pressure was 5.55 bar, far below the 9 bar design pressure.
  - With additional makeup inventory core cooling could be ensured throughout the 3-day grace period.



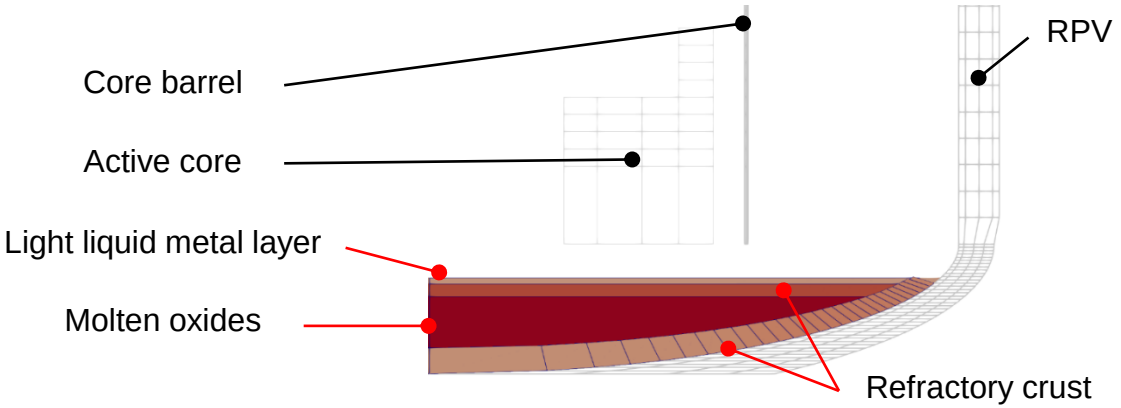


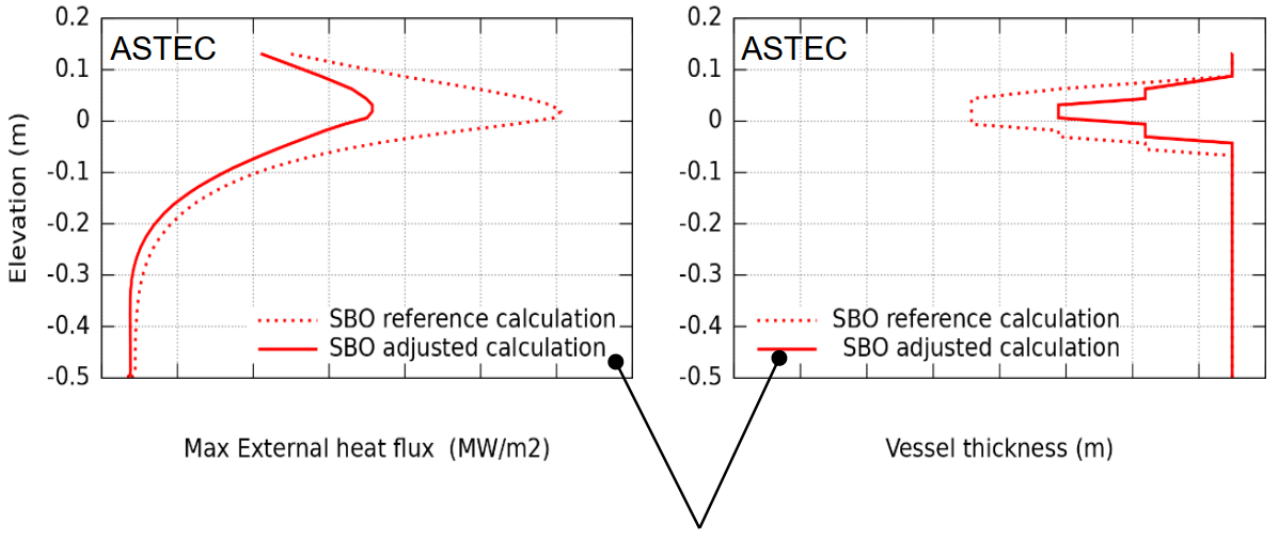
WP5: Example of application of safety case methodology

- Design Extension Condition (DEC) simulations with MAAP5.04 and ASTEC v3:
  - SBO and LOCA w/wo safety systems, 15-day runs
  - The models featured a rudimentary primary system (good performance compared to system codes e.g. CATHARE)
  - Safety systems: accumulators, injection from the water wall for ~12 hrs (assumed battery life), N_2 injection, RPV depressurization

- MAAP[4] results (EDF) w safety systems:
  - Evaluation of in-vessel retention strategy → core degradation was observed but no vessel ablation.
  - Assessment of H_2 combustion risks and potential mitigation strategies → burn limit reached yet far from detonation.
  - Using N_2 injection the burn limit could not be reached.

- ASTEC[5] results (IRSN) w safety systems:
  - Noticeable vessel ablation was observed in both transients.
  - Removing the fission products' (FP) contribution from the decay heat noticeably improved the ablation trends.
  - H_2 combustion risk – even the detonation limit was reached in both scenarios.
  - Once again applying N_2 injection the gas mixture was secured far from the burn limit.





'*adjusted*' – corrected decay heat

[4]Modular Accident Analysis Program
[5]Appropri Accident Source Term Evaluation Code

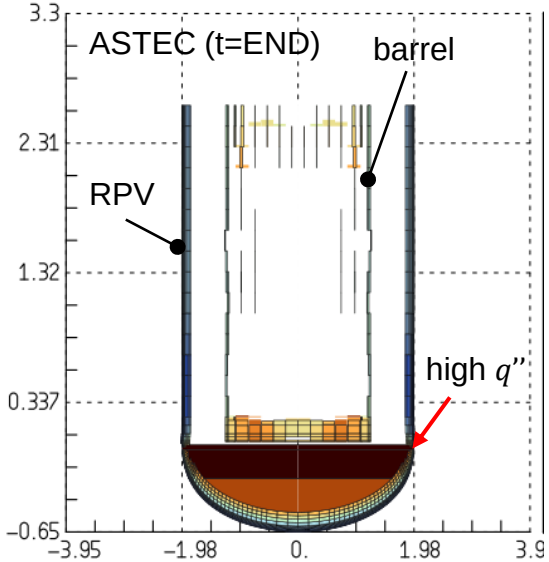
WP5: Example of application of safety case methodology

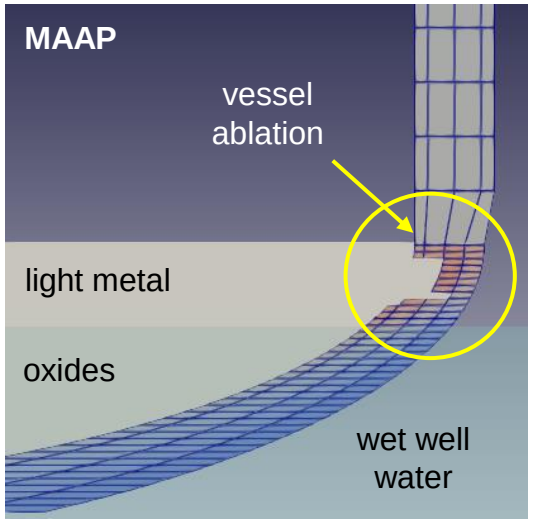
- MAAP SBO results (EDF) wo safety systems:
  - Cladding rupture in 5000 s after initiating event, the first corium to the lower head is registered at 13100 s.
  - Without safety system and external cooling the light metal layer induces ablation, vessel failure was observed in ~10.6 hrs.
  - High risk of H_2 combustion noted!

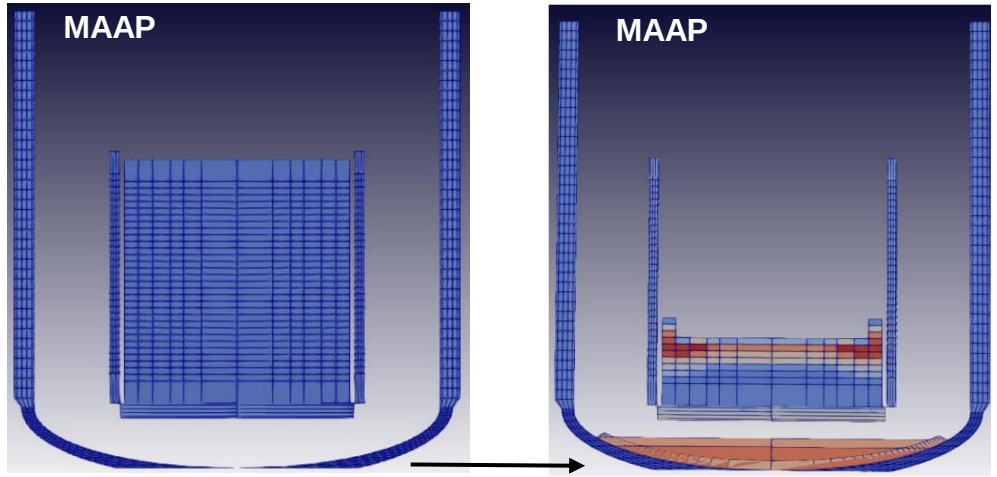
- ASTEC SBO results (IRSN) wo safety systems:
  - Cladding rupture in 4346 s, corium in lower head in 9658 s and vessel rupture in ~15000 s.
  - Due to the inversion of material layers the growing light metal layer remains relatively small → very strong focusing effect.

- Key takeaways:
  - The early stages of vessel degradation are quite similar for both codes but boundary conditions profoundly altered the later period.
  - Including the FP contribution in the decay heat and using a conservative steel heat conductivity in ASTEC

    → large differences in the timing of vessel failure.
  - Hydrogen burn/detonation limits could be reached but (1) no recombiners were considered and (2) N_2 injection was proven to be an effective preventive measure.







SBO progression without safety systems

WP6 & WP7: Dissemination & Education

- All the hereby referenced ELSMOR reports are available on the project's website.

- The consortium held three annual meetings (Espoo-FI, Milan-IT, Cadarache-FR) and co-organized the ELSMOR-TANDEM workshop in Brussels (6-7th December 2022), presentations of the joint workshop are available on the ELSMOR website (the password can be requested from VTT).

- In July 2022 Polimi organized the "International Summer School on early-deployable SMRs" with 63 students from 24 different countries (Lake of Lecco, Italy) involving M.Sc. and Ph.D. students. Lectures were given by international experts from IAEA, CNEA (Argentina), CNSC (Canada) and ELSMOR member organizations. The presentations of the Summer School are available on the website of the event, corresponding video materials can be found on the YouTube channel of ELSMOR here.

- The E-SMR dataset is planned to be made public in 2023, free of charge with adequate licensing (e.g. Creative Commons open-source license).

Synopsis & outlook

- The ELSMOR project investigated the licensing and safety demonstration aspects of LW SMRs.
- The extensive review of various regulatory frameworks highlighted no show-stopper legislation although SMR-specific guidelines are yet to be formulated.
- Anticipating such changes, a new safety case methodology was developed aiming to address SMR-relevant issues and shortcomings of current safety assessment practices.
- The ELSMOR test facility was designed, commissioned and operated by SIET in order to establish a robust V&V library focusing on a plate-type heat exchanger. The experimental campaign was completed during Q1 2023, providing data also on the global behavior of the given passive heat removal system.
- CFD activities explored the available experimental databases and the limitations of current computational methods with respect to a submerged containment vessel.
- The European SMR academic reactor design was conceived and tested against design basis accidents and design extension condition scenarios.
- A large array of reports, presentations and lecture materials was made publicly available by the consortium to instigate various stakeholders of the field to take initiative.

- Subsequent EU projects (e.g. TANDEM) will utilize and build on the outcomes of ELSMOR.

Thank you for your attention!

ELSMOR

Towards European Licensing of Small Modular Reactors

This project has received funding from the Euratom research and training programme 2014-2018 under Grant Agreement No. 847553.

2.10 ALFRED - The European Initiative Towards Lead-Cooled Fast Reactors, Giacomo Grasso, ENEA (Remote)

ALFRED

ALFRED: the European initiative towards Lead-cooled Fast Reactors

2nd HARMONISE Workshop

June 20-21, 2023

via Martiri di Monte Sole, 4

40129 Bologna – Italy

www.enea.it

Giacomo Grasso

Head of Laboratory for Core Design
Member of Expert Board, FALCON Consortium

Phone: +39 051 6098 438

giacomo.grasso@enea.it

ALFRED

More energy… of a new type

FALCON

9.7 billion people by 2050
2/3 of the world's people living in urban areas

25% global energy increase by 2040
2 times faster electricity demand increase

1.7% increase of CO_2 in 2018
70% higher than average increase since 2010

2.8% RES increase per year
RES will provide 31% of electricity generation by 2040

ALFRED

Facts and forecasts at worldwide level

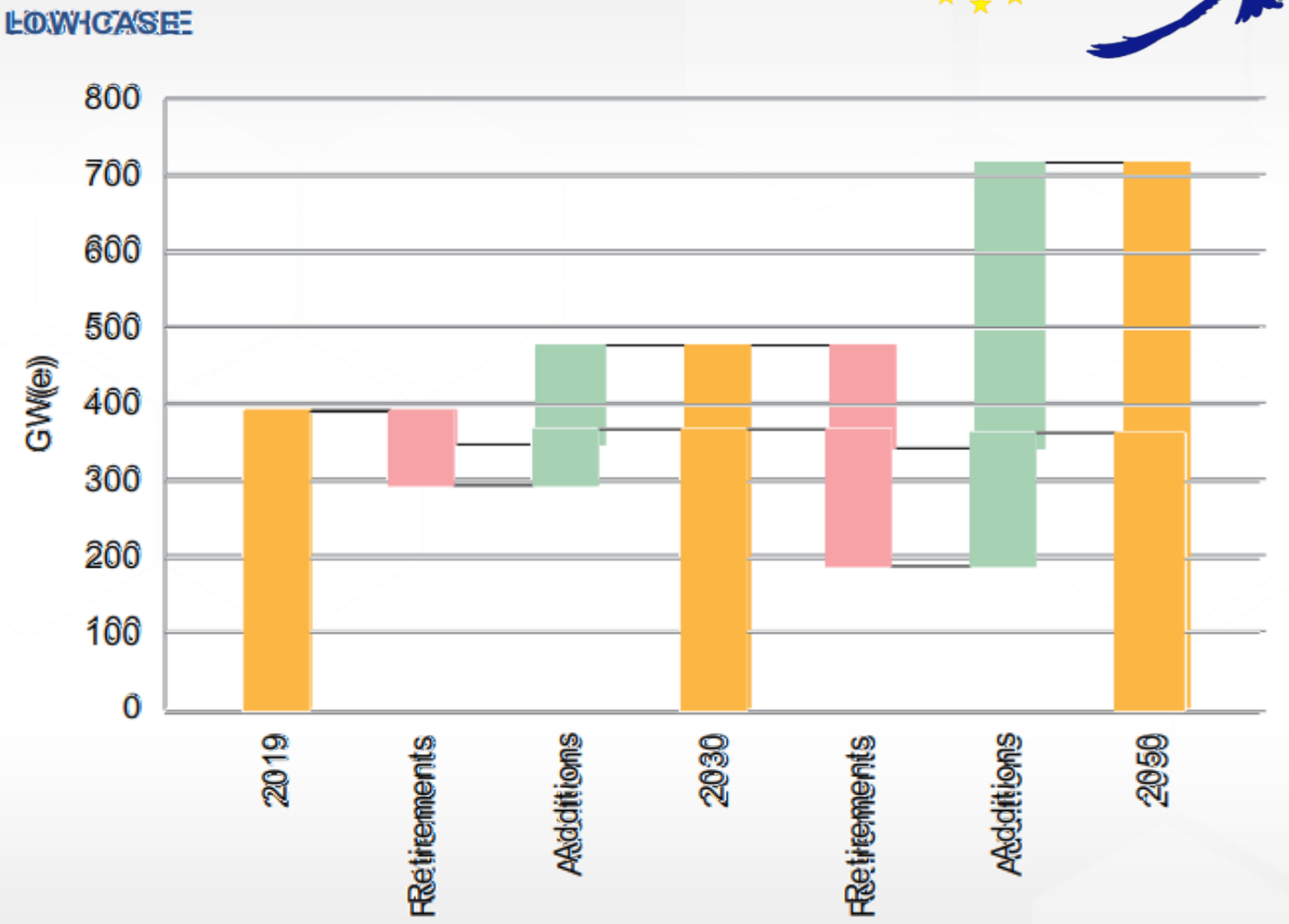
FALCON

7713
million people

25 602TWh
of electricity produced

10.4%
from nuclear

500-225 GWe
of new installed capacity by 2050



Energy, Electricity and Nuclear Power Estimates for the Period up to 2050, Reference Data Series No. 1, 2018 Edition – IAEA.

ALFRED

Facts and forecasts in Europe

FALCON

North/West/ Southern Europe

454
million people

2 989 TWh
of electricity produced

24.2%
from nuclear

Eastern Europe

293
million people

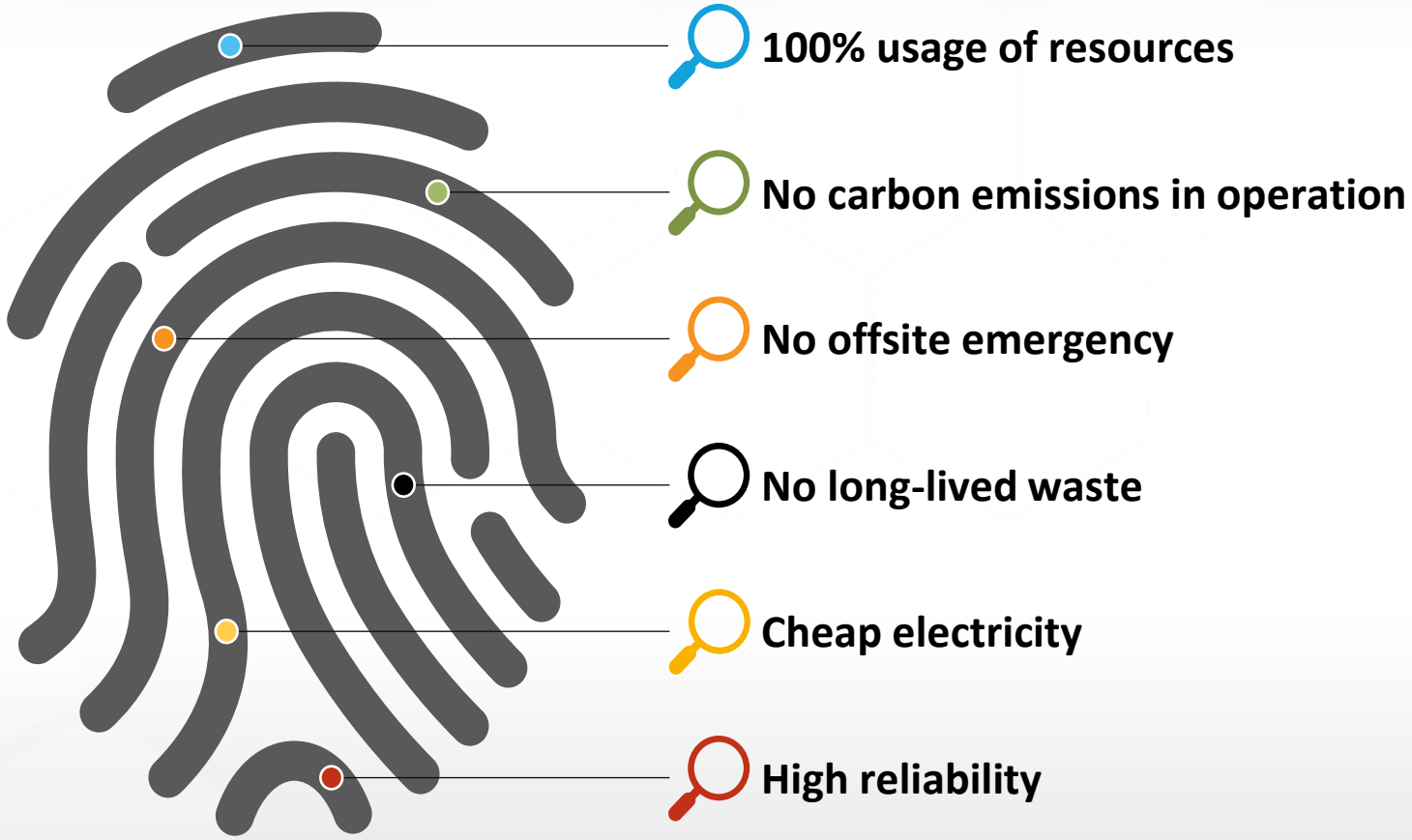
1 622TWh
of electricity produced

22.1%
from nuclear

130-75 GWe
of new installed capacity by 2050

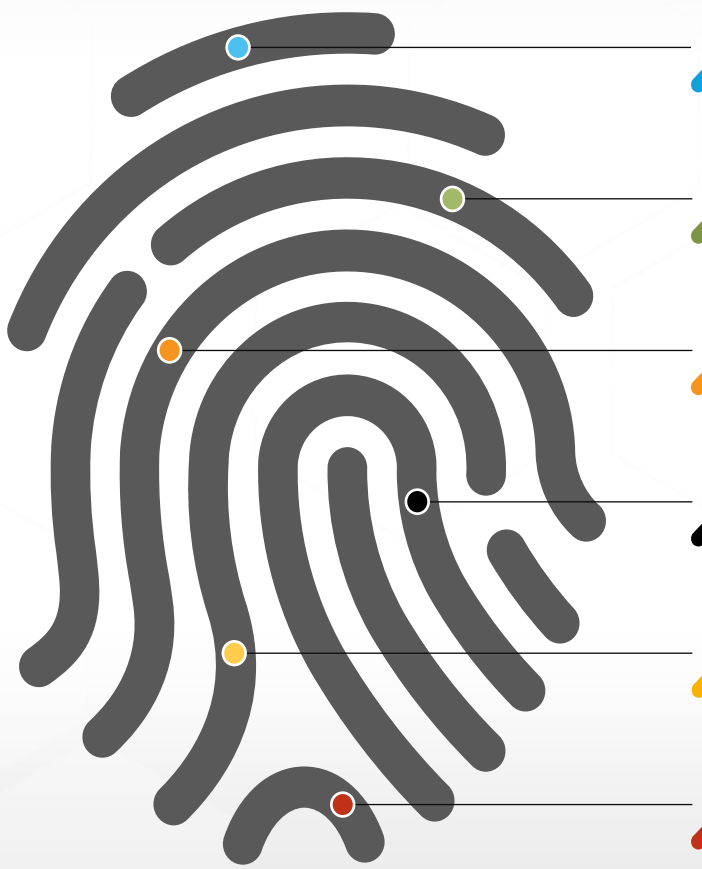
Energy, Electricity and Nuclear Power Estimates for the Period up to 2050, Reference Data Series No. 1, 2018 Edition – IAEA.

The «ideal» Nuclear Power Plant



ALFRED

Promises of Lead-cooled Fast Reactors



100% usage of resources	Closed fuel cycle
No carbon emissions in operation	(as any NPP)
No offsite emergency	Inherent & passive provisions
No long-lived waste	Closed fuel cycle
Cheap electricity	Design simplicity
High reliability	Safety + simplicity

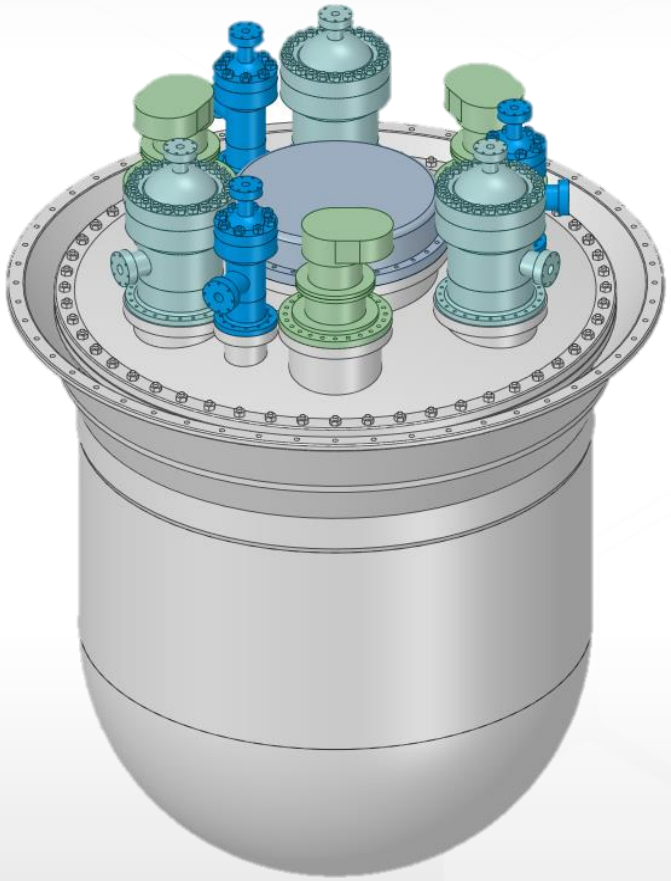
ALFRED

No other advanced reactor technology can feature the same unique aspects

One of the most promising technologies for deployment in the SMR segment

Steadily increasing attention by industry and utilities worldwide

Recognized by inclusion in the research agendas at international level (GIF, ESNII)

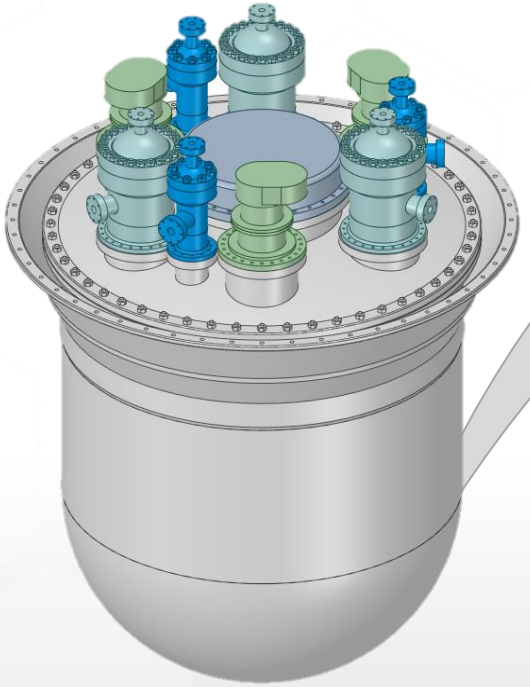


ALFRED, a **demonstration reactor**, also **prototypic of a Lead-based SMR**, to bridge the final gap between conducted research and industrial application

ALFRED

LFR demonstrator with SMR-oriented features

ALFRED
Advanced Lead-cooled
Fast Reactor European
Demonstrator



(Demonstrator)

(Prototype)

Pro-LFR
(Prototype)

ELFR
(FOAK)

Commercial
Deployment
Gen-IV

(European LFR
Roadmap)

SMFR
(FOAK)

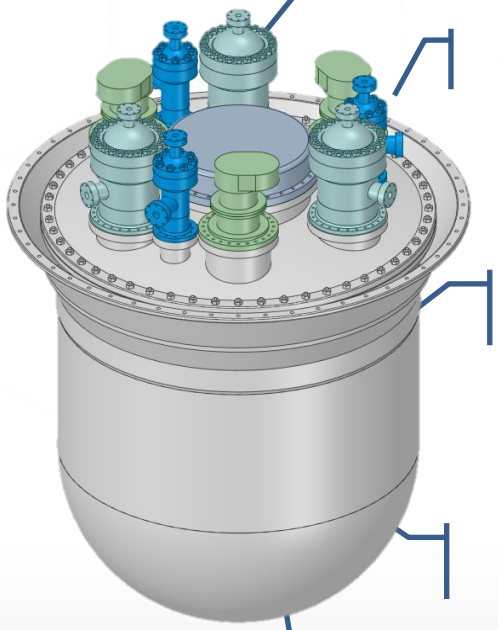
Anticipated SMFR
commercial deployment

(FALCON vision)

- Leverage on LFR features
  - Intrinsic and passive safety
  - Highest level of safety
  - Exclusion of domino effects
  - Optimum for multi-unit sites

ALFRED to address the challenges

Challenge	Demonstrator approach
Design	Design focusing on short-term R&D in parallel targeting longer-term
Safety	Reasonable power to address safety concerns/unknowns with margins
Licensing	Means to improve the regulatory framework to be used later
Operation	Gain operational experience Staged commissioning and operation
Financing	Shortened time-to-market Strengthening synergies and opportunities of PPP



Relatively low power

Compact design
- Removable components
- Proven technologies

Simple flow path
- Efficient natural circulation

Molten lead as coolant
- Excellent intrinsic properties
- Manageable negative properties

Pool type Primary System

A world-class Research Infrastructure

FALCON

The largest pool facility in the world, for large-scale components testing in representative conditions

ATHENA

A broad-scope laboratory on the chemistry of HLMs and materials science

ChemLab

A hot facility to characterize radioisotopes behavior in Lead under accident conditions

Meltin'Pot

ELF

A pool facility for long-term experiments, to characterize the components and systems

A loop facility for full-scale testing and complete thermal-hydraulic characterization of fuel and absorber assemblies

HELENA-2

Hands-ON

A facility devoted to the testing and qualification of systems and procedures for the handling of core elements

ALFRED

Research Infrastructure: Science and Technology development

FALCON

Consolidate the HLM science

Deploy a world-class research infrastructure

Pool the European research community

Demonstrate the LFR technology

Provide industrial qualification services

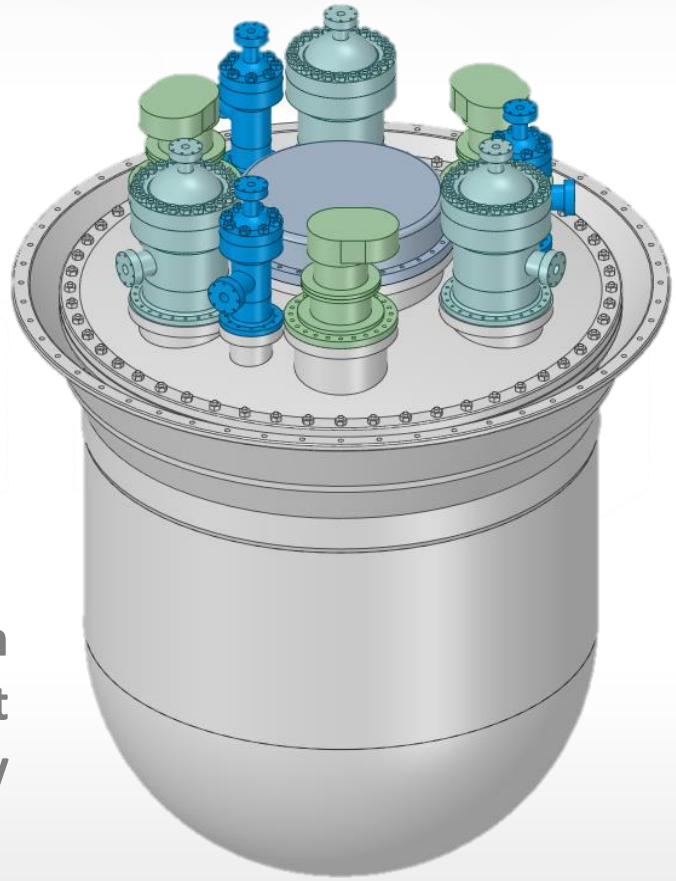
Support LFR safe and sustainable operation

ALFRED

Role of the Research Infrastructure

FALCON

To support the final design and licensing of the ALFRED reactor



To provide a comprehensive platform to master the LFR technology

To support a staged approach for the further advancement of the LFR technology

To continuously enhance the safety and sustainability performances of following commercial units

FALCON: A long-lasting collaboration endeavor

FALCON

- Fuel-coolant chemistry
- Engineering support
- CFD analysis
- Balance of Plant optimization
- Analysis and E&T

POLITECNICO DI TORINO
UNIVERSITÀ DEGLI STUDI DI PALERMO
SAPIENZA UNIVERSITÀ DI ROMA
POLITECNICO MILANO 1863
UNIVERSITÀ DI PISA
ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

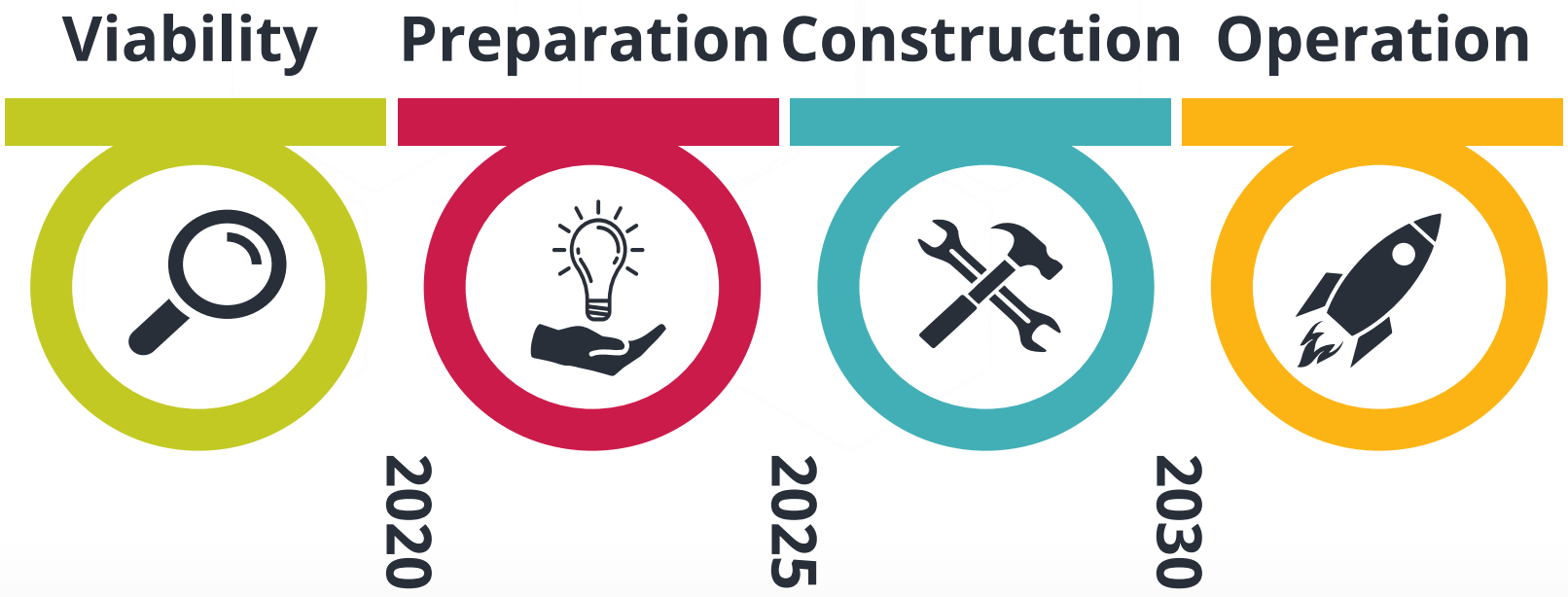
FALCON
ANSALDO NUCLEARE Ansaldo Energia Group
ENEA
RATEN ICN PITEŞTI

- Coatings development
- CFD analysis
- Operator's review
- Manufacturing feasibility

CESINA Partnership
IFIN-HH
CITON
ROMATOM FORUMUL ATOMIC ROMÂN

ALFRED

A challenging roadmap…



ALFRED

...on a solid basis

2011

Availability of **Romania** to **host** ALFRED

2015

ALFRED in **Smart Specialization Strategy** of South-Muntenia

2017

Romanian National Research and Innovation Plan

Jul.2020

Contract signed **ATHENA** and **ChemLab construction**

2019-2020 - **~2.5 M€** for **National R&I plan on ALFRED** (PRO-ALFRED)
2021-2023 - **22 M€** for **ATHENA** and **ChemLab** Infrastructure

2020, Jul. - Contract signed for **Athena** and **Chemlab construction**

2020, Apr. - **Integrated National Energy and Climate Change Plan** (**NECP**) for 2021-2030 Romania

2018 - **ESNII Exec Board** promoted **ALFRED** in the **Fast Track**

2017 - **National Strategy for RDI** (2015-2020)

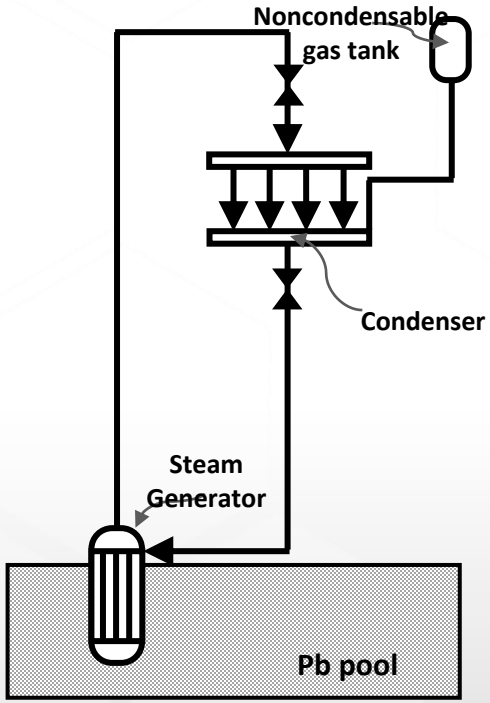
2017 - **Roadmap** for **Research Infrastructures** in Romania for 2017-2025, Ministry of Research and Innovation

2017 - **CESINA** (academia), **ROMATOM** (nuclear industry) **partnerships and NUCLEARELECTRICA agreement**

2017 - **ALFRED** included in the **Romania National Research and Innovation Plan 2015-2020**

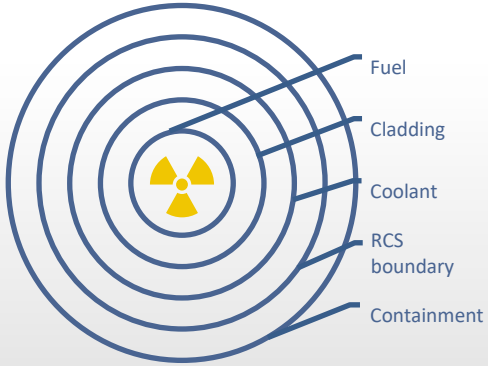
Recent and ongoing supporting projects

3.2 M€, 2019-2022 (G#847715)
piace.brasimone.enea.it/
In synergy with **SIRIO** facility at **SIET** funded by IT (1.4 M€)

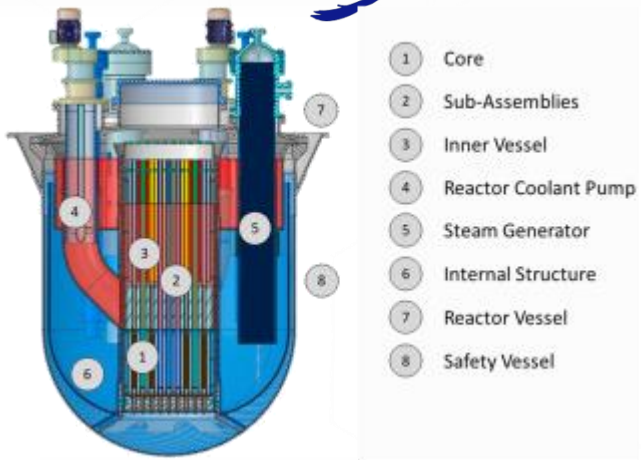


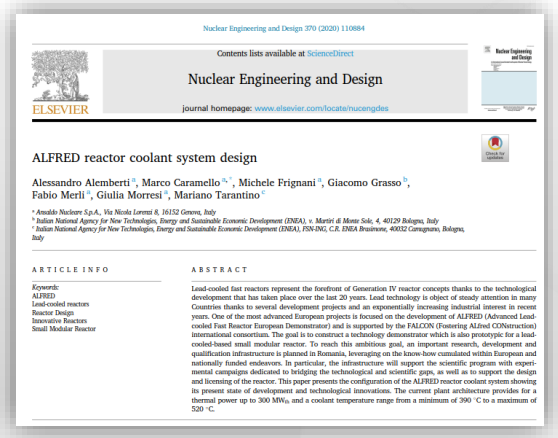
6.6 M€, 2017-2021 (G#755269)
In synergy with **EERA JPNM**
eera-jpnm.eu/gemma/

4.7 M€, 2020-2024 (G#945341)
Endorsed by **ESNII**, **EERA JPNM, FALCON**
pascalworkspace.eu



2.5 M€, 2019-2020
Funded by RO Gvt.
proalfred.nuclear.ro/
>20 del.s in 7 WPs
Licensing Basis Document
Workshop with CNCAN




Nuclear Engineering and Design 370 (2020) 110884

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journal homepage: www.elsevier.com/locate/nucengdes

ALFRED reactor coolant system design

Alessandro Alemberti [a], Marco Caramello [b, *], Michele Frignani [a], Giacomo Grasso [b], Fabio Merli [a], Giulia Morresi [a], Mariano Tarantino [c]

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ARTICLE INFO

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Lead-cooled reactors
Reactor Design
Innovative Reactors
Small Modular Reactor

ABSTRACT

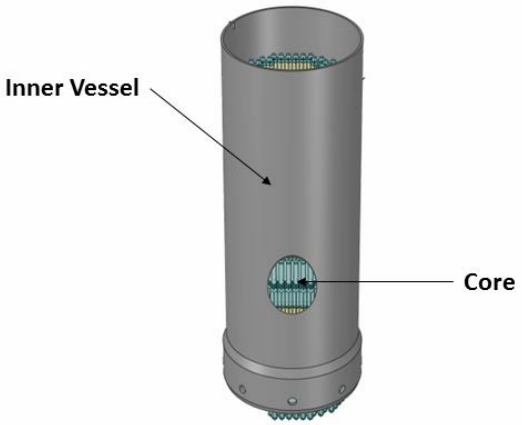
Lead-cooled fast reactors represent the forefront of Generation IV reactor concepts thanks to the technological development that has taken place over the last 20 years. Lead technology is object of steady attention in many Countries thanks to several development projects and an exponentially increasing industrial interest in recent years. One of the most advanced European projects is focused on the development of ALFRED (Advanced Lead-cooled Fast Reactor European Demonstrator) and is supported by the FALCON (Fostering ALfred CONstruction) international consortium. The goal is to construct a technology demonstrator which is also prototypic for a lead-cooled-based small modular reactor. To reach this ambitious goal, an important research, development and qualification infrastructure is planned in Romania, leveraging on the know-how cumulated within European and nationally funded endeavors. In particular, the infrastructure will support the scientific program with experimental campaigns dedicated to bridging the technological and scientific gaps, as well as to support the design and licensing of the reactor. This paper presents the configuration of the ALFRED reactor coolant system showing its present state of development and technological innovations. The current plant architecture provides for a thermal power up to 300 MW_{th}, and a coolant temperature range from a minimum of 390 °C to a maximum of 520 °C.

ALFRED

General overview

General design choices:

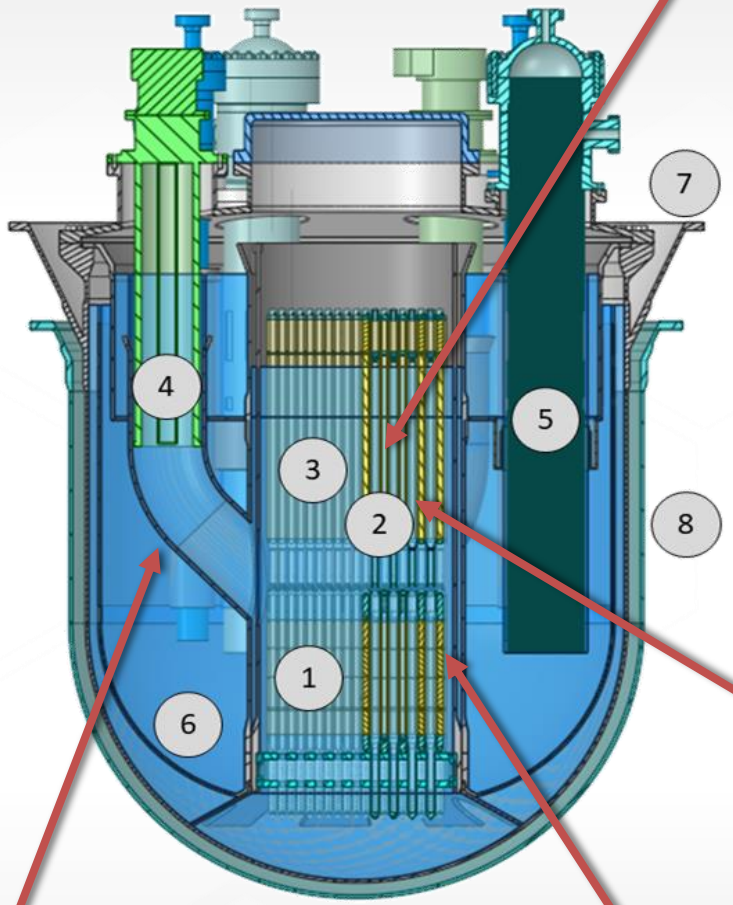
- Pool arrangement
- Loop flow
- Extractability
- Cover connection
- Upper support



ALFRED

General overview

Reactivity control: Two diverse and redundant systems, control and shutdown rods



1. Core
2. Sub-Assemblies
3. Inner Vessel
4. Reactor Coolant Pump
5. Steam Generator
6. Internal Structure
7. Reactor Vessel
8. Safety Vessel

Fuel assemblies: MOX fuel, grid-spaced, hexagonal, wrapped, extended stem

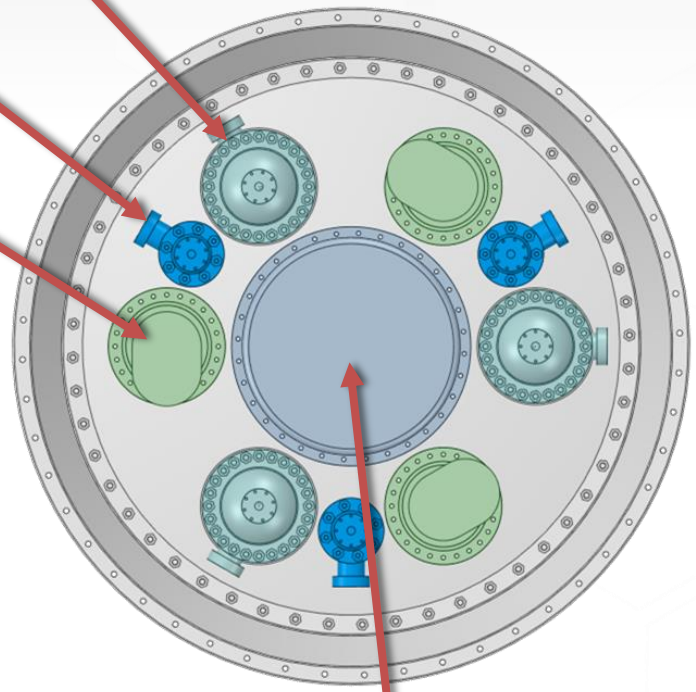
Internal Structure: no safety related, ensure pools separation and flow recirculation

Inner Vessel: safety-related, removable for out-of-vessel inspection

Steam Generator

Dip-cooler

Pump



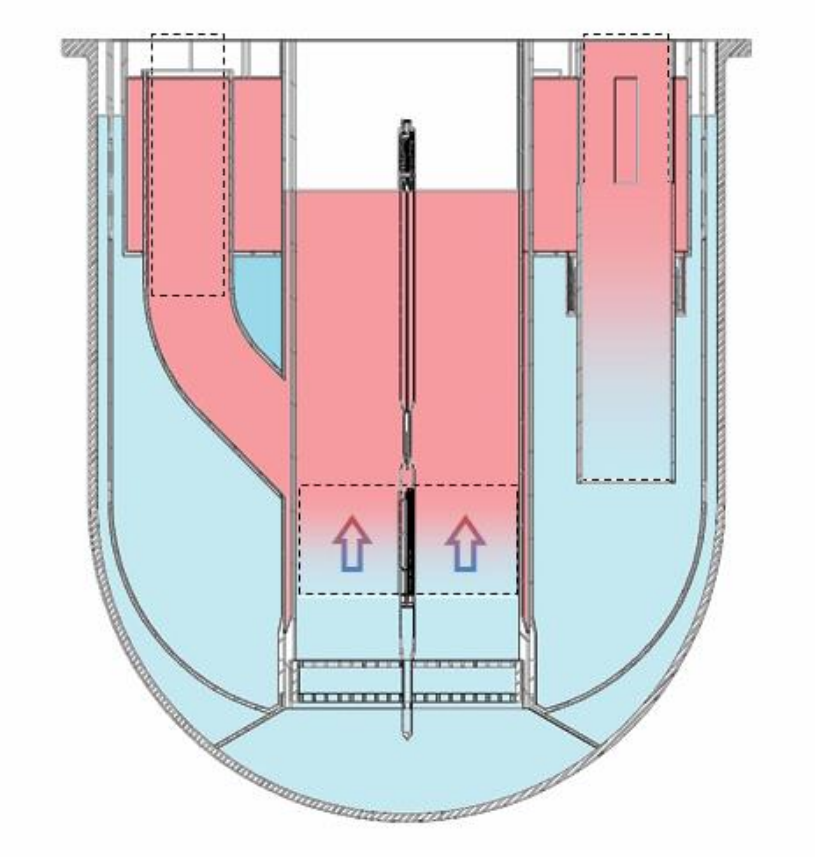
Design to ensure FA handling under lead during refueling operations

ALFRED

Primary system layout

The primary system layout has been developed to provide
a number of desirable features:

- elimination of thermal stratification in the pool
- elimination of direct SGs – core connection
  - elimination of double wall SGs
- simpler extractability of the inner vessel
- de-classification of the internal structure (no more safety-related)

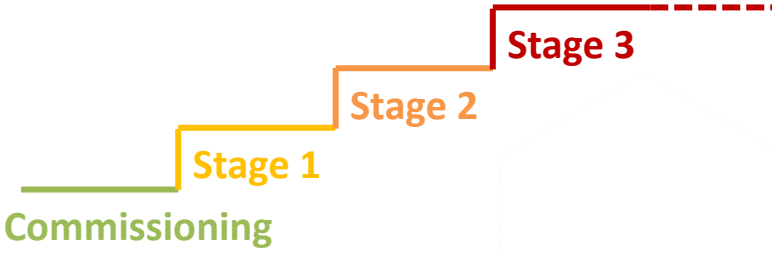


ALFRED

ALFRED Staged Approach

ALFRED operation has a stepwise approach:

- 1st stage: operation at low power & low-temperature range
  - Existing proven materials working in [O] controlled lead environment
- …
- 3rd stage: operation at full power & high-temperature range
  - Advanced materials or protective measures fully qualified during earlier stages



	1st stage	Final stage
Power	100 MW_{th}	300 MW_{th}
Thermal cycle	390-430°C	400-520°C
Coolant chemistry control	$10^{-6} \div 10^{-8}$ O_2 wt.%	Same, but not effective
Materials	316L, 15-15Ti	Relying on coating or innovative materials

ALFRED Staged Approach

Temperature distribution

Hot spot (HS):

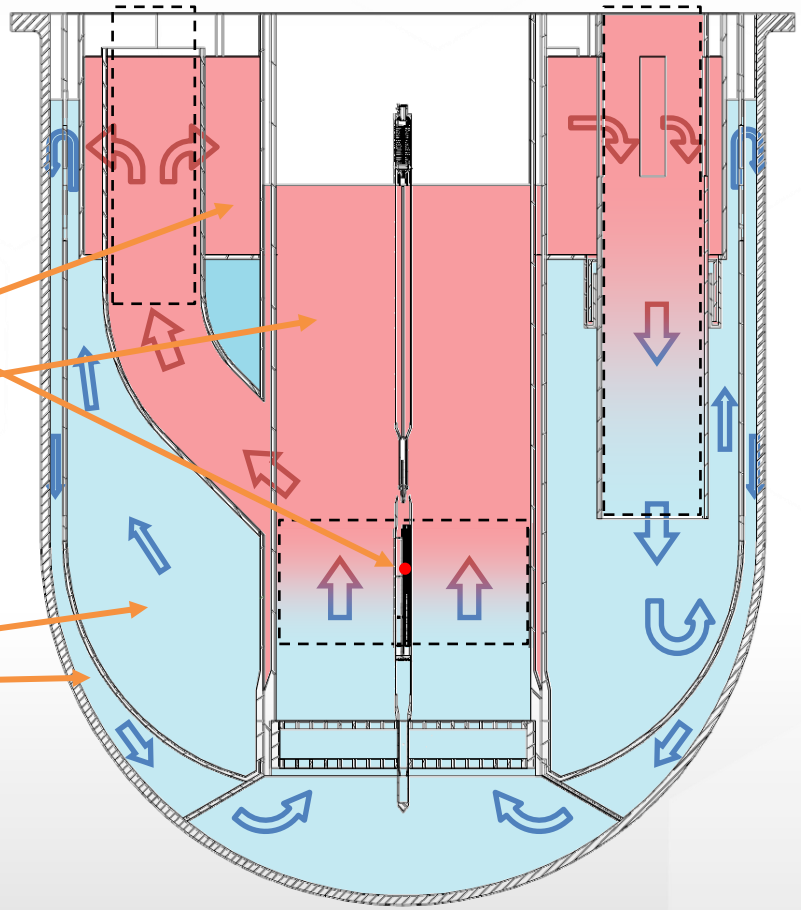
- Heated region
- Clad region at highest temperature

Hot pool (HP):

- Region at average core outlet temperature

Cold pool (CP):

- Region at average core inlet temperature

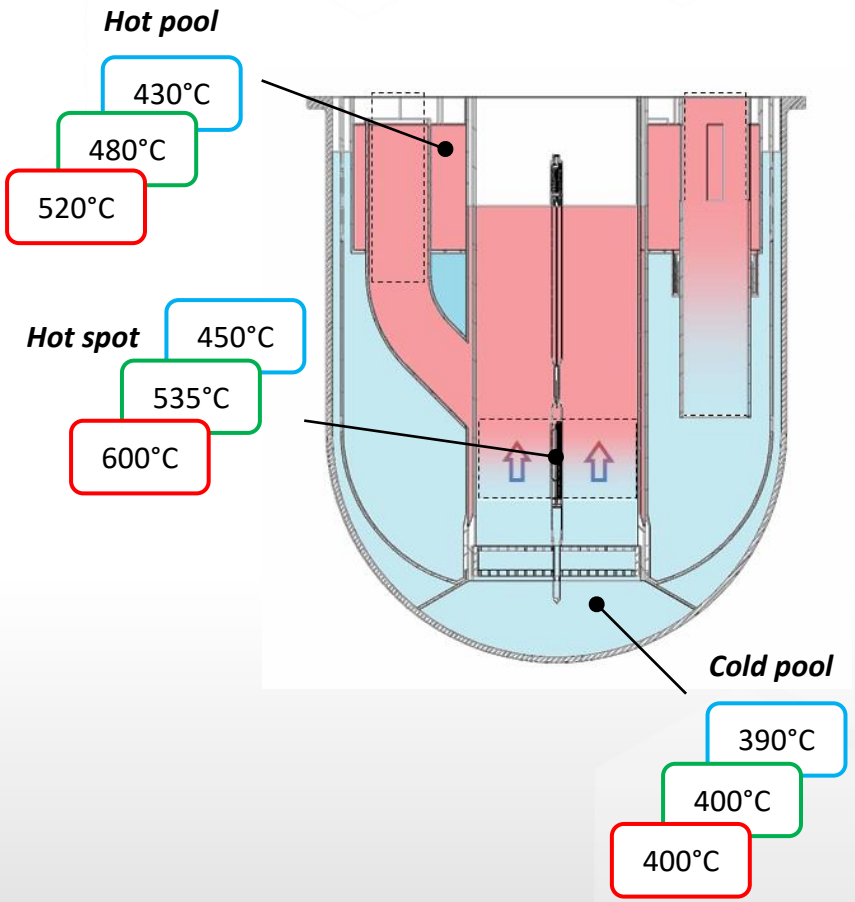


ALFRED Staged Approach

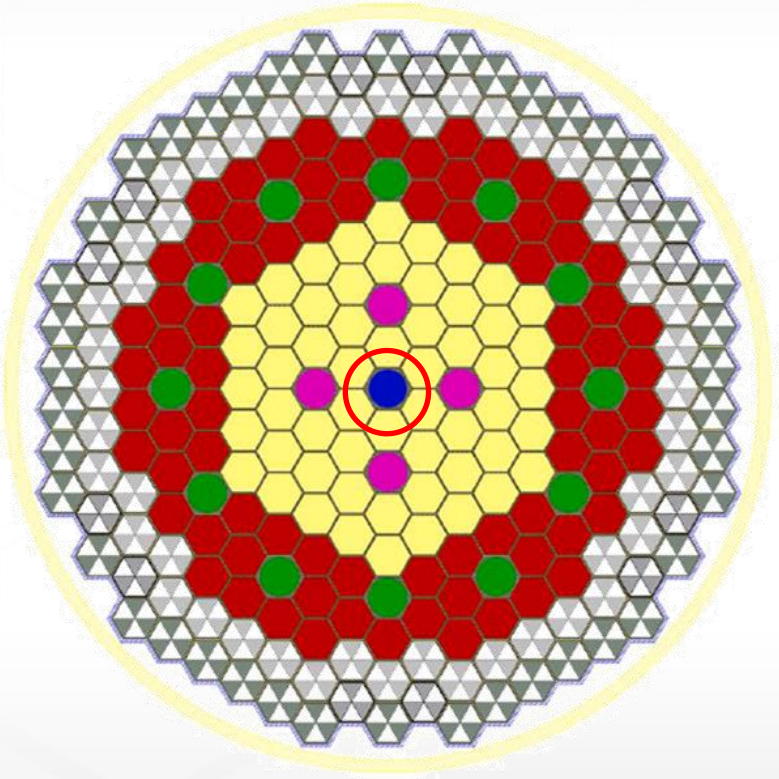
- ALFRED will facilitate licensing readiness and operational readiness for western LFR commercial reactors.

Increase in reactor coolant temperature

- **STAGE 1**
  - Proven technology, proven materials, oxygen control, low temperature
  - Aimed at in-core qualification of PLD Al_2O_3 coating for cladding
- **STAGE 2**
  - Need for FA replacement
  - Aimed at in-core qualification at higher temperature
- **STAGE 3**
  - Replacement of main components (SGs, PPs, dip coolers, ...)
  - Representative of FOAK conditions for LFR deployment



ALFRED Testing between stages

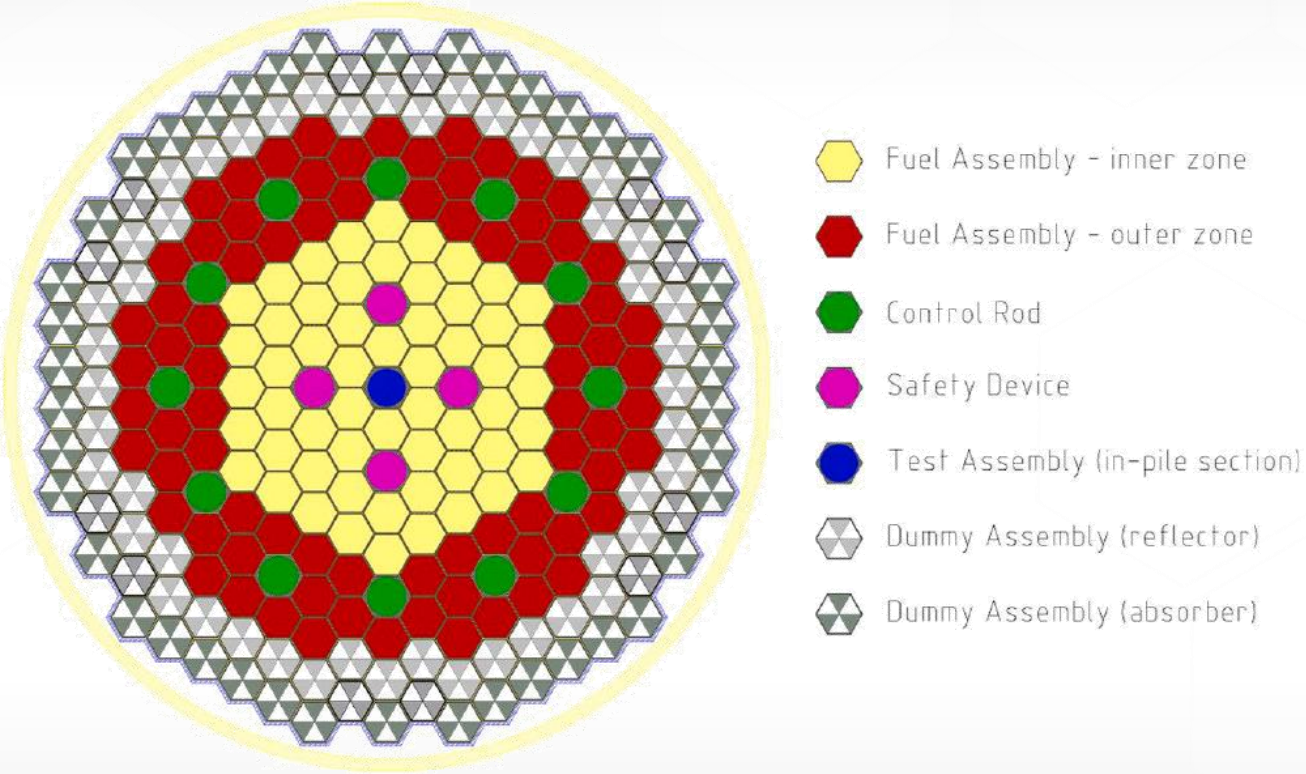


- Shifting between stages requires experimental demonstration
- Fuel assembly testing to be perfomed in ALFRED within the **In-Pile section**
- Fuel assemblies having orificed plate to be tested in core central position to assess performance to qualify the technology and extend it to the entire core for the following stage
- Lower flow, higher temperature

ALFRED

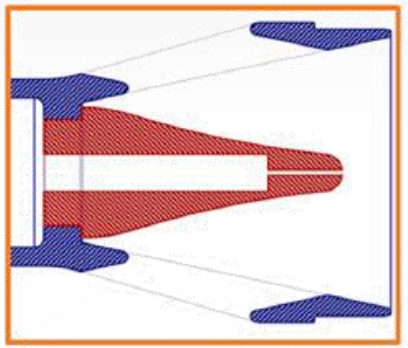
The Core

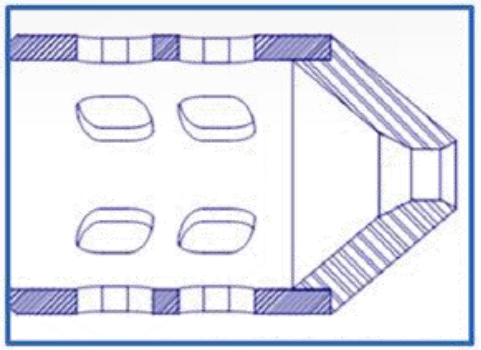
- 134 fuel assemblies (56 + 78)
- 102 dummy assemblies
- 12 control rods
- 4 safety devices (active + passive)
- 2 enrichment zones
- Fuel: MOX
- 5-batches refueling strategy
- Test assembly



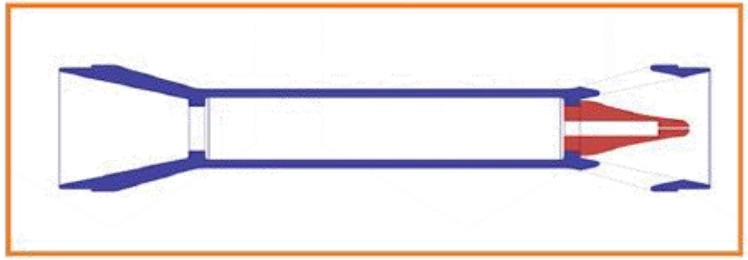
The Core

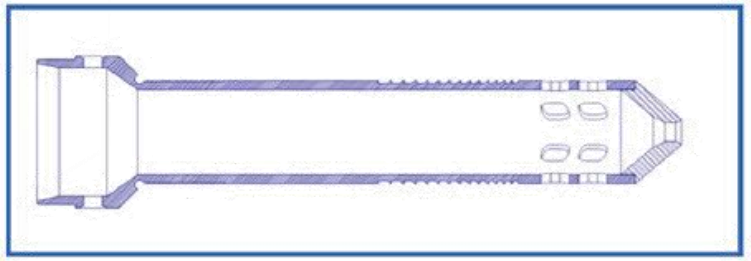
Outlet section allowing in-core instrumentation





Bottom section providing flow distribution





Top section extending above lead surface

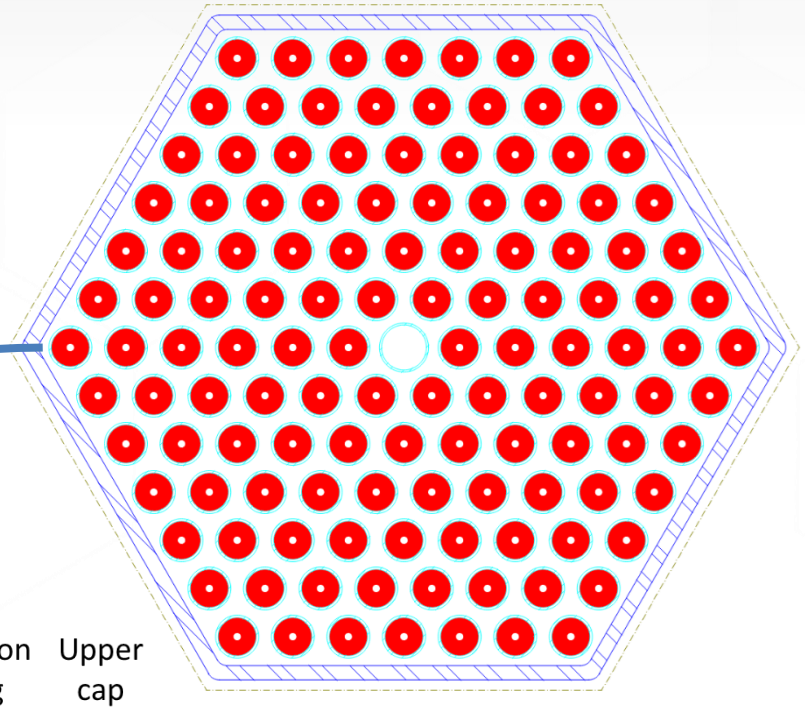
Active region

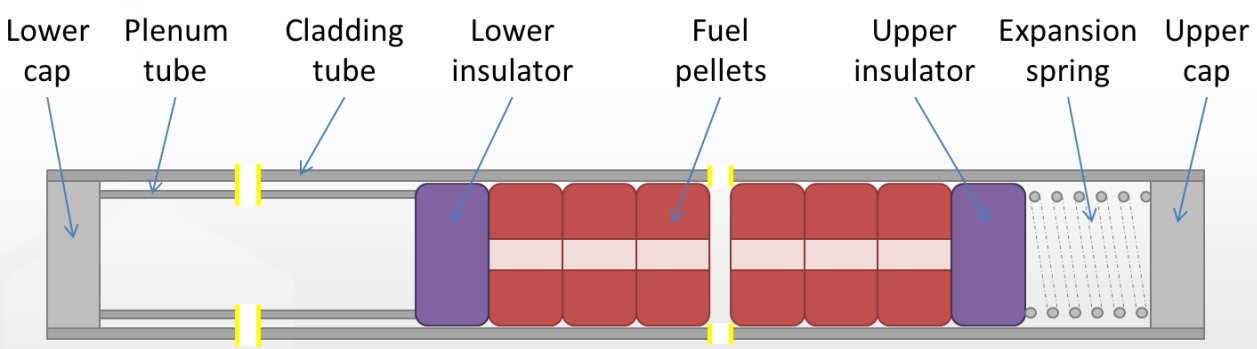
Bottom section matching lower core plate

ALFRED

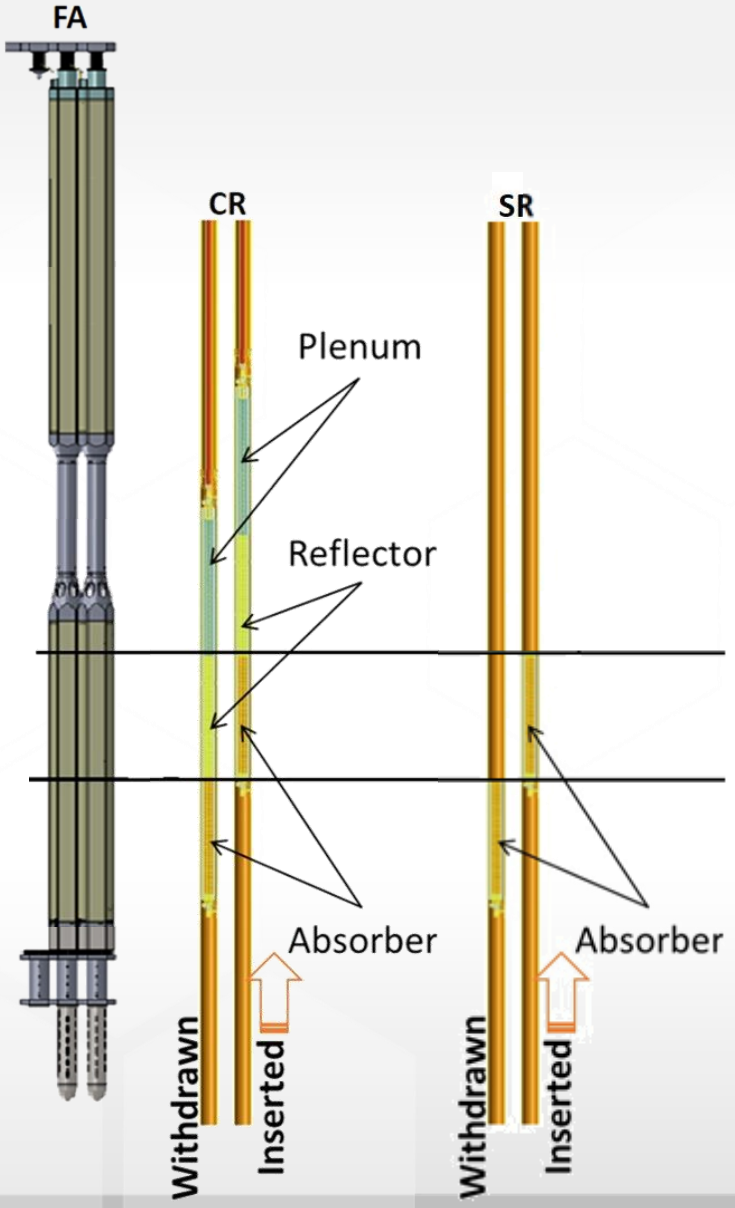
The Core

- Hexagonal cross-section
- 126 pins
- 1 dummy position
- 100 MWd/kgHM (peak)
- Cladding material AIM1





ALFRED Control rods & Safety devices

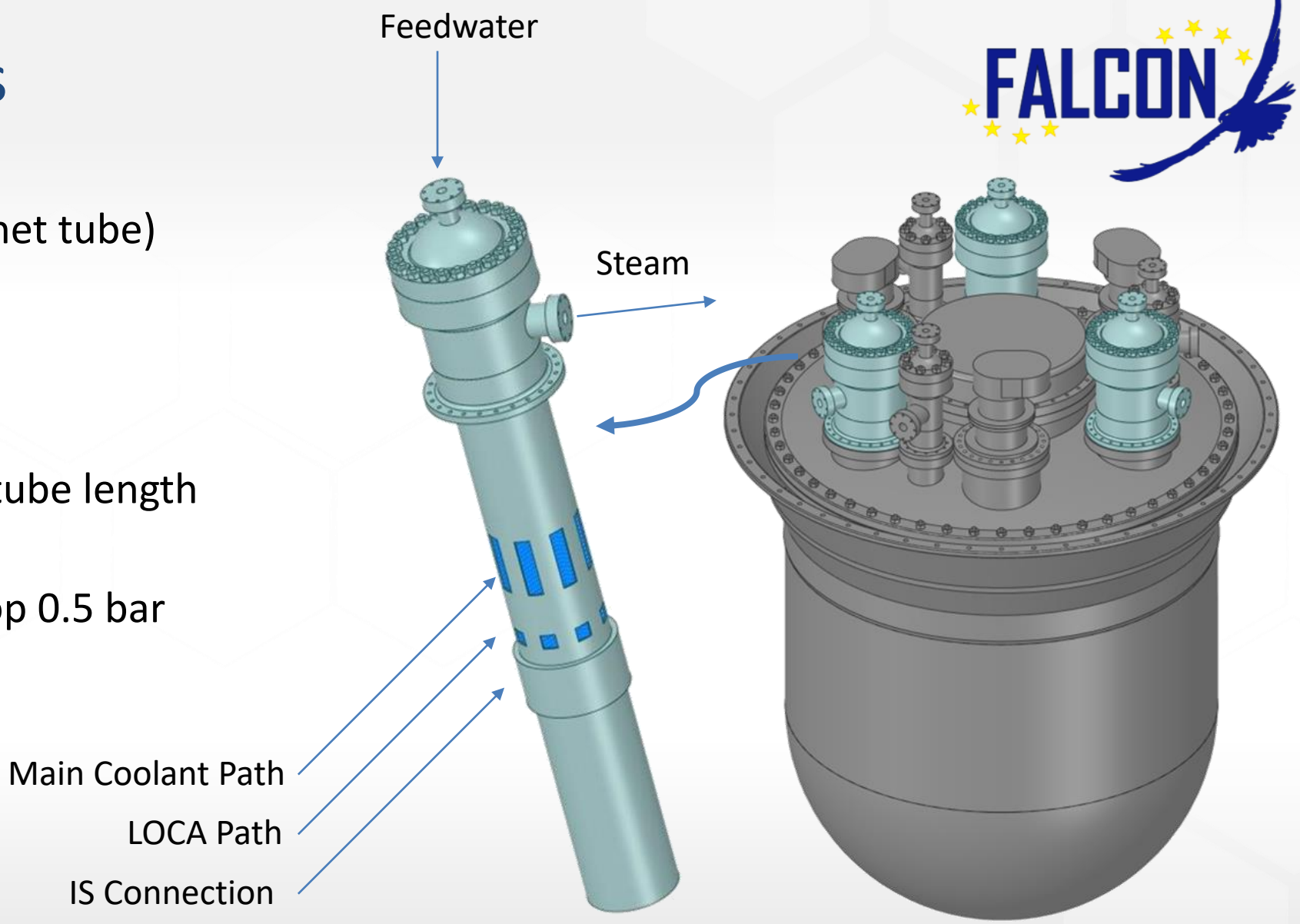


- Control rods (12)
  - bundle of absorber pins
  - B_4C with 42 and 90 at.% ^{10}B
  - actuation logics:
    - **withdrawn** below the core
    - moved by **motors** for control (CZP to HZP, reactivity swing, power transients, commanded shutdown)
    - **passively** inserted by buoyancy for SCRAM
- Safety rods (4)
  - innovative design with no bundle of pins (to withstand deformations)
  - B_4C with 90 at.% ^{10}B
  - actuation logic:
    - **withdrawn** below the core
    - only for SCRAM
    - **passively** inserted by buoyancy for SCRAM
    - actuated by a logics signal (commanded actuation) or by overtemperature (spontaneous actuation)

ALFRED

Steam Generators

- Shell & tube (single bayonet tube)
- Superheated steam SG
- Duty 67 MW*
- 880 1-inch tubes
- 5 spacer grids along 6 m tube length under lead
- Primary side pressure drop 0.5 bar

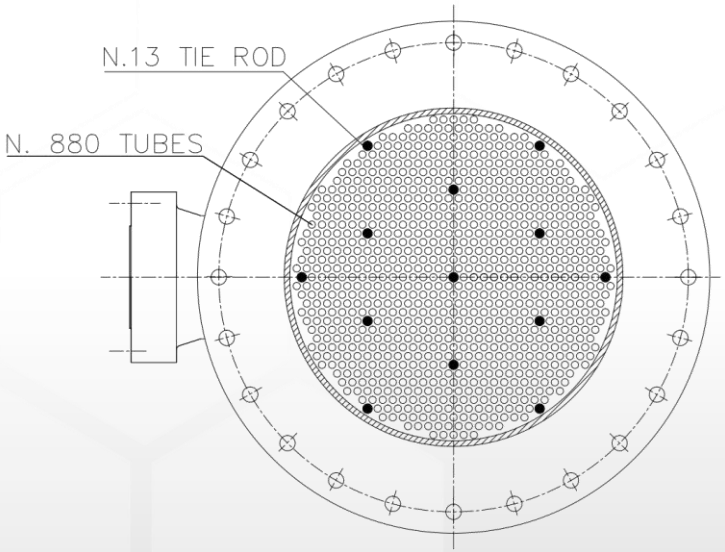


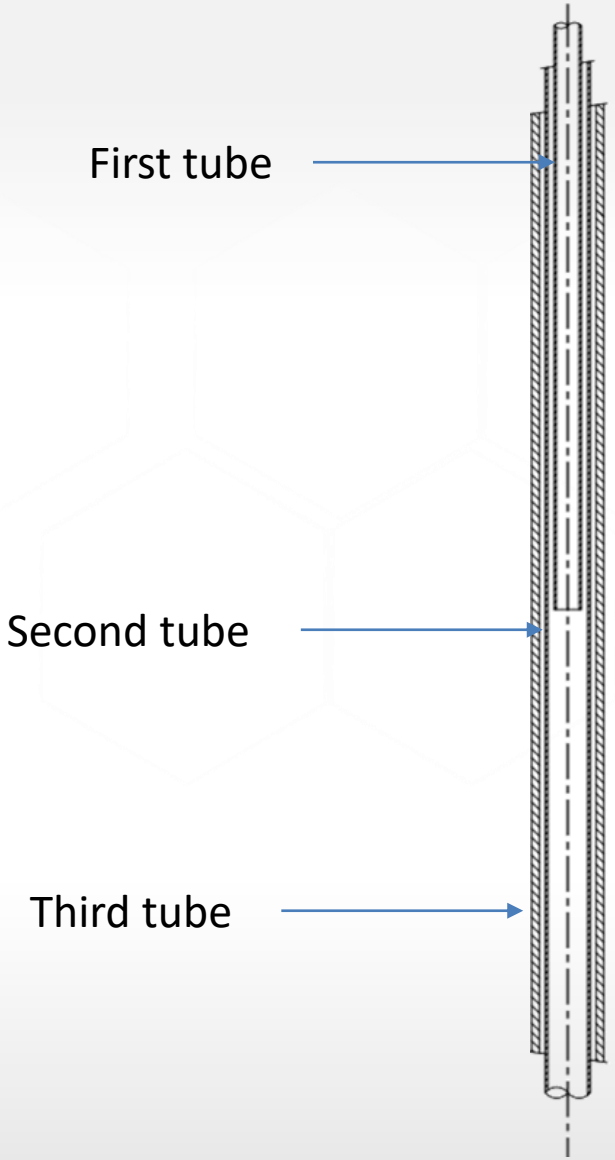
Stage 2 duty

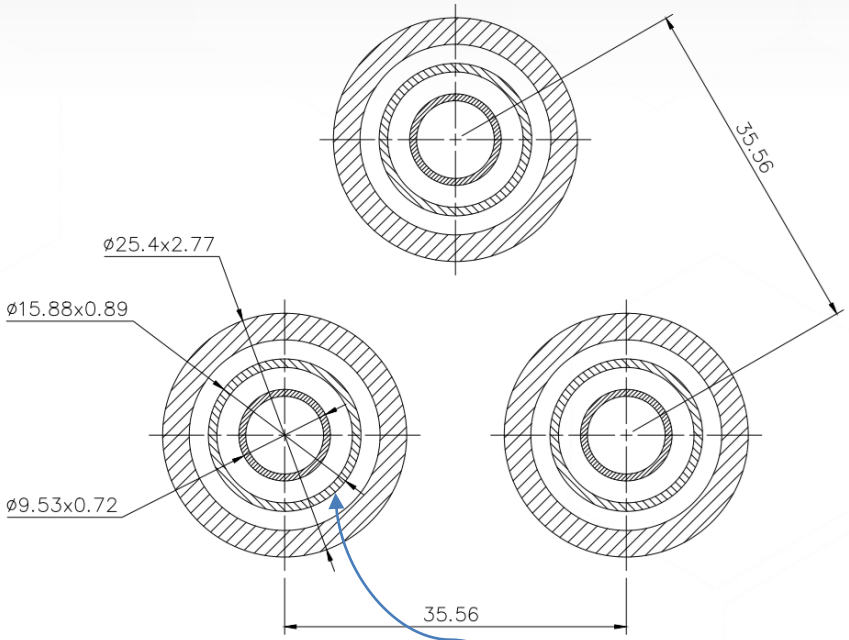
ALFRED

Steam Generators

- Triangular pitch array
- p/D 1.4
- 1” heat exchange tube
- 5/8” down-comer tube



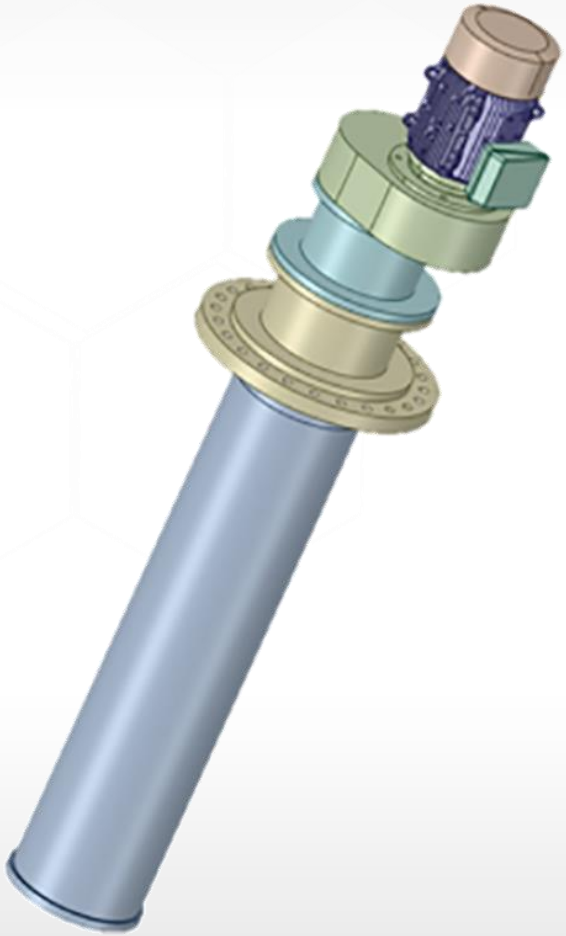


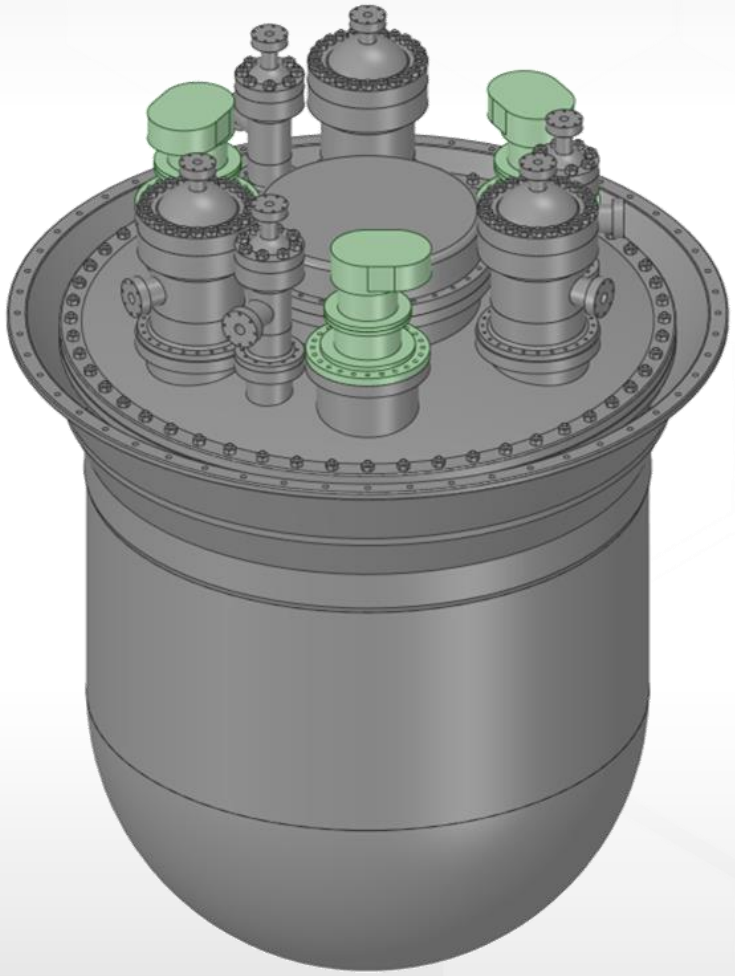


Minimum annular gap fixed at 2 mm to allow tube assembly, considering dimensional tolerances

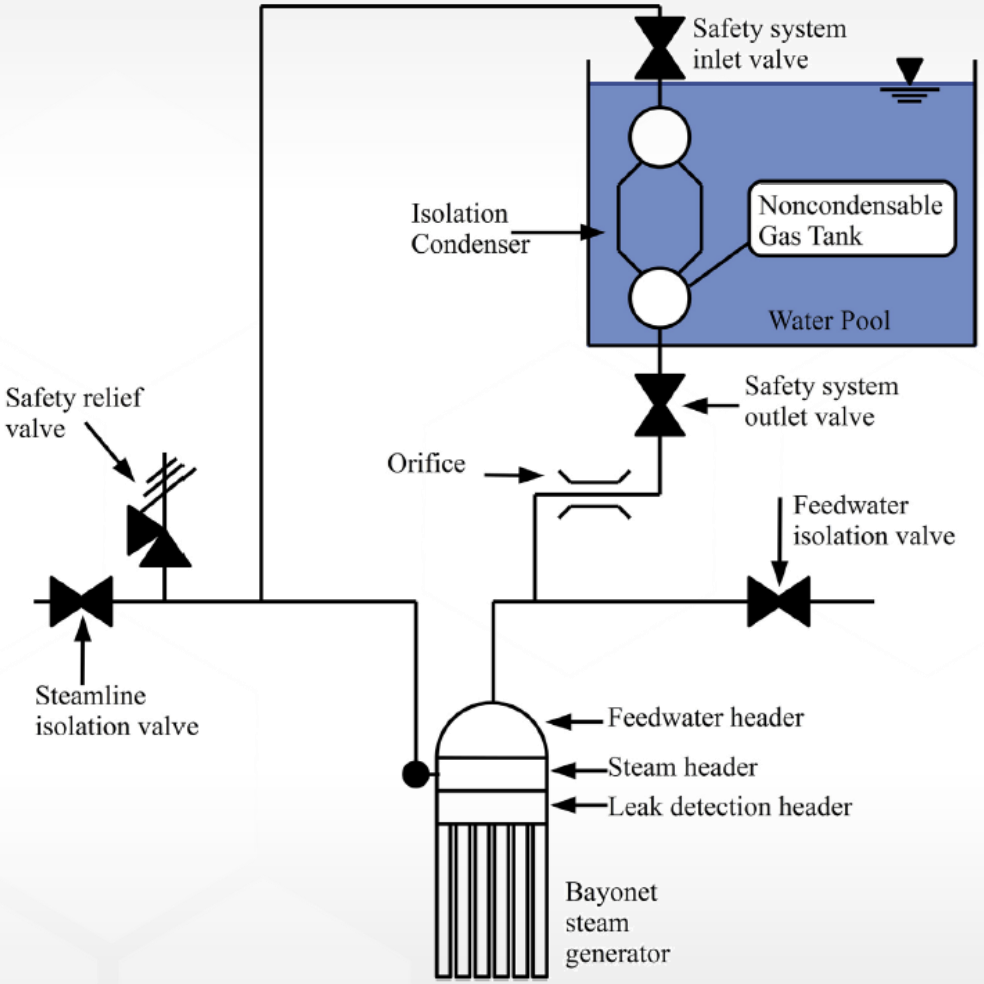
Reactor Coolant Pumps

- Axial impeller
- Nominal flow 0.53 m^3/s
- Nominal pressure head 0.15 MPa
- Rotational speed 289 RPM
- Hydraulic efficiency 73%
- Motor power 200 kW





ALFRED DHR (Isolation Condenser)



- Anti-freezing solution
  - based on the operation of the Isolation Condenser and of a tank of noncondensable gases
  - Non-condensable gases flooding the IC tubes will inhibit heat rejection to the water pool

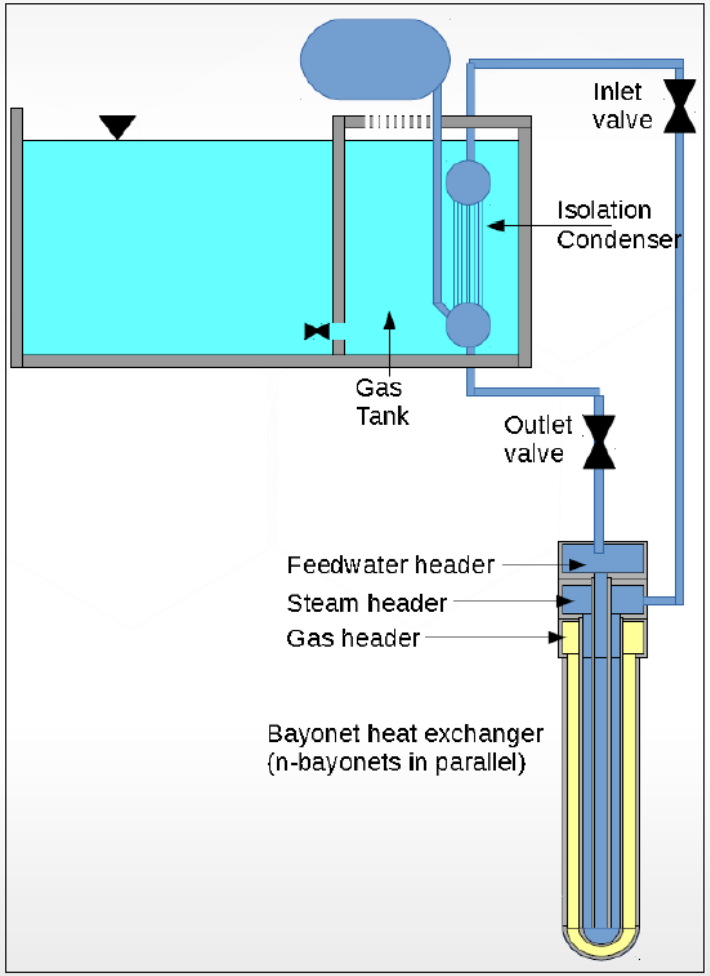
1 Loop each Steam Generator (3)

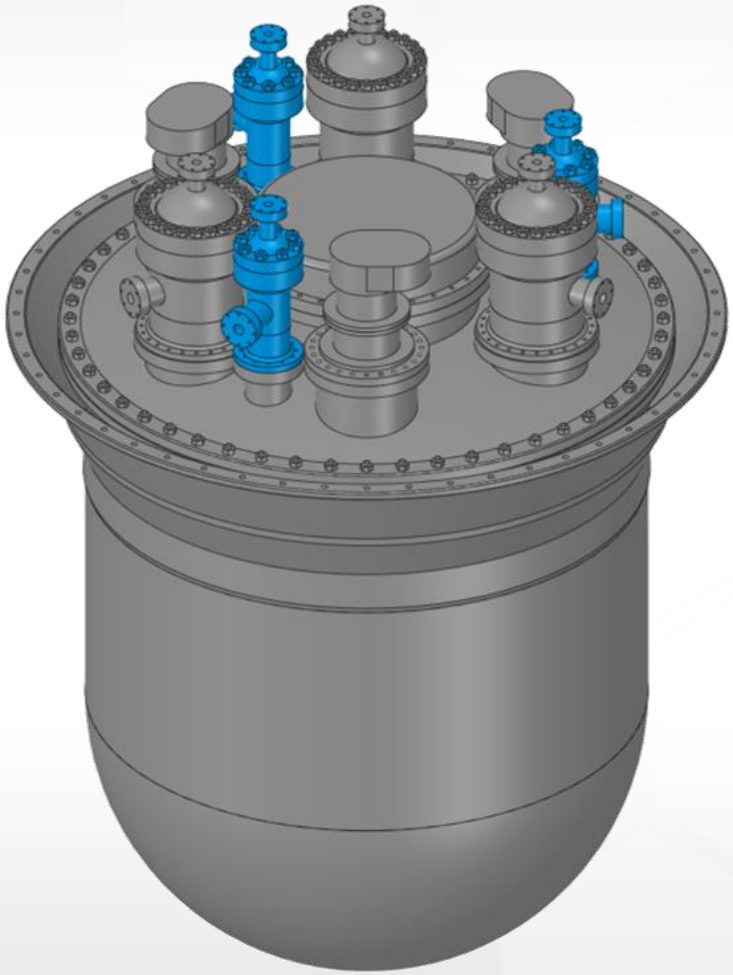
Each Isolation condenser in pool bay

Patented by Ansaldo Nucleare

Dip Coolers (under review)

- Actuation based on cold pool temperature
- Double tube bayonet heat exchanger
- Max. heat duty 1 MW
- Water loop





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2.11 McSAFER: High-Performance Advanced Methods and Experimental Investigations for the Safety Evaluation of Generic Small Modular Reactors, V. H. Sanchez-Espinoza, KIT (Remote)

The H2020 McSAFER: High-Performance Advanced Methods and Experimental Investigations for the Safety Evaluation of Generic Small Modular Reactors

Harmonise: Workshop on the Safety of Small Modular, Advanced and Fusion Reactors

V. H. Sanchez-Espinoza

H. Suikkanen, V. Valtavirta, M. Bencik, S. Kliem, C. Queral, S. Chochet, P. Smith, P. Van Uffelen, M. Seidl, Ch. Schneidesch, D. Grishchenko, H. Lestani

June 20-21, 2023, Celje, Slovenia

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

Content

- Goals and scientific approach
- Work packages, partners
- Challenges, solution approach, status
- Conclusions

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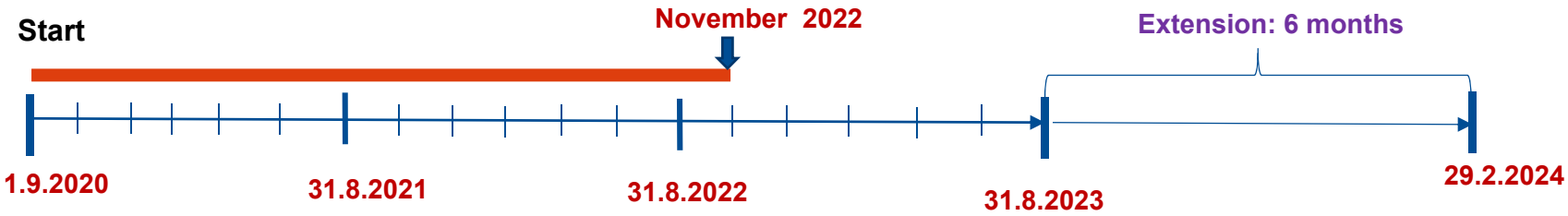
Technical Goals & Scientific approach

- Contribute to safety research for water cooled SMR
- Perform key thermal hydraulic experiments at three European facilities
- Develop and improve simulation tools for safety analysis of SMRs
- Validate thermal hydraulic tools using data generated in McSAFER
- Analyse the core and plant behaviour of selected SMR-designs under transient conditions
- Demonstrate advantages of multi-physics/-scale tools compared to industry-like tools

Scientific approach: Combine experimental investigations and numerical simulations

Project Timeline:



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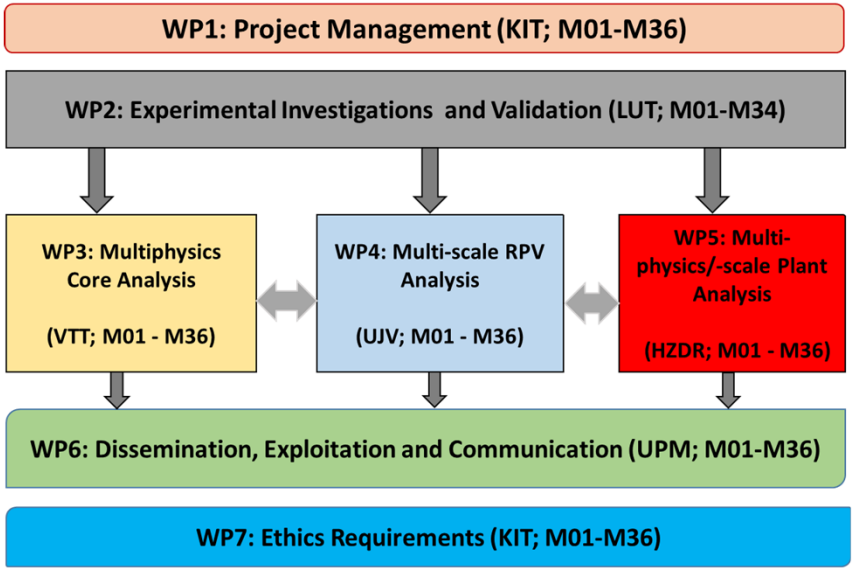
McSAFER: Work Packages, Partners



McSAFER: Work Package Structure

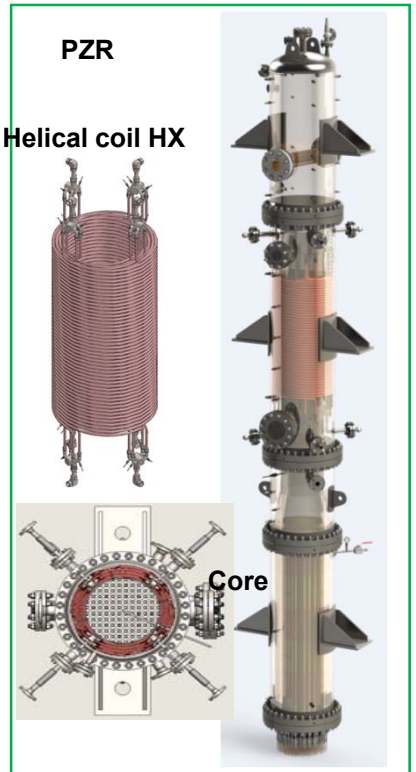
Universities

R&D, TSOs

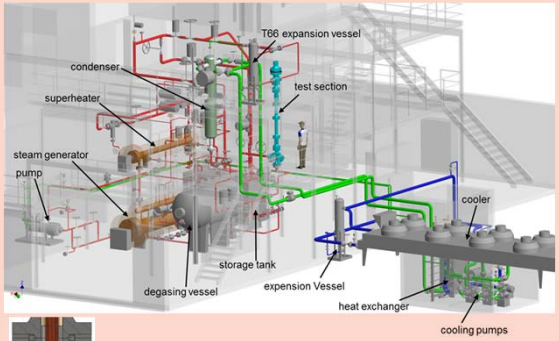
Industry

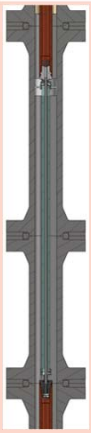
This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

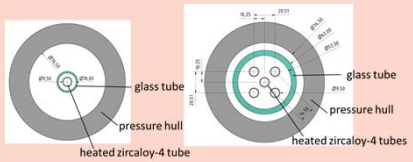
McSAFER Experimental Facilities: MOTEL, COSMOS-H, HWAT



MOTEL Nat. Circ. Loop

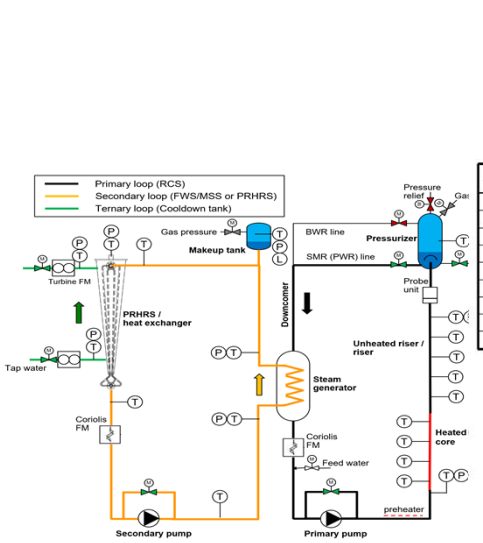




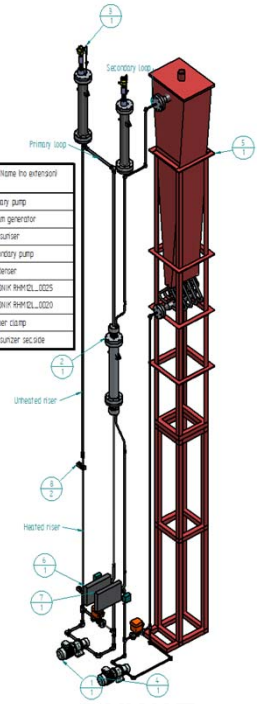


Serie-1 Serie-2

COSMOS-H: Test Section



HWAT Loop for forced and natural circulation (SS/TR)



HWAT Test Section

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McSAFER Experimental Facilities: Key Parameters and Features

Key-Parameters	COSMOS-H	MOTEL	HWAT
Focus	Fundametal HAT, Boiling, CHF	HX-performance, core crossflow	forced convection SS, transition to natural circulation, natural circulation
Power (MW)	2 (0.6)	0.99	1
Pressure (MPa)	5 to 17	4 MPa (PS) / 40 MPa (SS)	25
Max T_inlet (°C)	370	250 (PS) / 250 (SS)	350
Mass flow rate (kg/s)	0-1.4		1
Loop height (m)/D (m)	3.54 /0.08	7.4 / 0.711	8.8
Test section:			
Height (m)	1 to 2	1.830	3.7 (heated riser), 1.89 m diff between hot/cold sections
Heated rods /tubes	1 tube, 5 tubes	132 (heated) / 145 (dummy)	1
Instrumented rods	all	16	
Instrumentation:	Many TCs, p-sensors, high-speed cameras and LDA	340 TCs, 212 in the core, 5 p-sensors, 7 diff. pressure, Ultrasonic flowmeter	Multi-sensor probe at exit if heated riser to measure velocity, void and temperature, DP-transducers, Coriolis flow meter, TCs

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

Status of the McSAFER Experimental Program

- Tests at MOTEL successfully done, data available for code validations

- Tests at HWAT facility: delays due to COVID (Delivery problems) and component failure
  - Test series 1: June 2023
  - Test series 2: October 2023

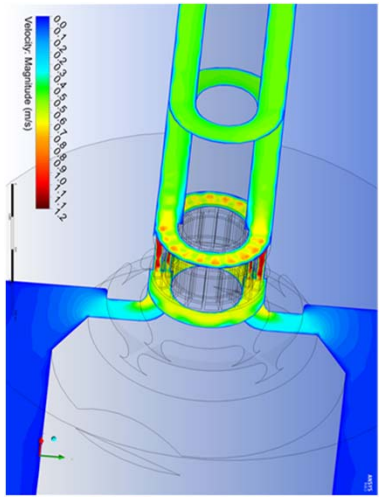
- Tests at COSMOS-H: delays due to COVID (Delivery problems) and leakage in SG at high pressure tests detected
  - Test series 1: June 2023
  - Test series 2: Mid-October/November 2023

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

Validation of Thermal Hydraulic Codes using McSAFER-Data

Status:

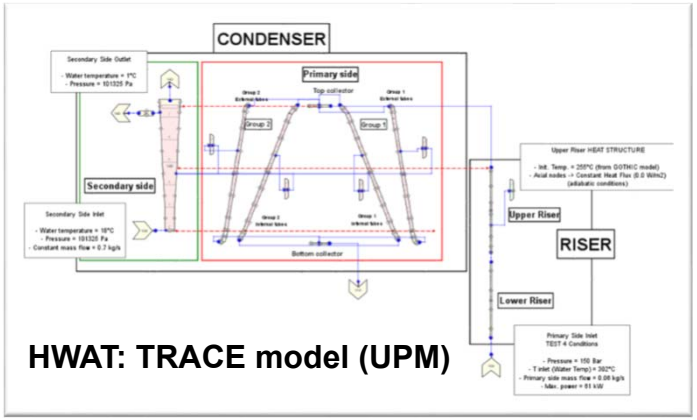
- COSMOS-H model under development
- HWAT pre-test calculations done
- First validation using MOTEL-data **done**



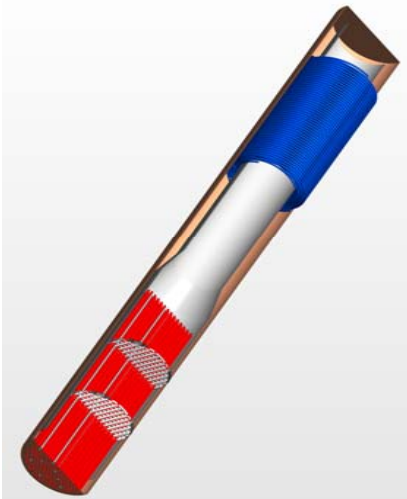
COSMOS-H: FLUENT Model (KIT)

Tests	CFD	Subchannel	System TH
COSMOS-H	KIT LUT UJV	KIT UJV	KIT UJV
MOTEL	KIT UJV	TBL UJV	LUT UPM
HWAT	KTH		KTH UPM

Validation Matrix



HWAT: TRACE model (UPM)



MOTEL CFX Core Model (KIT)

- Unstructured mesh
- Fully resolved geometry
- 150 millions cells

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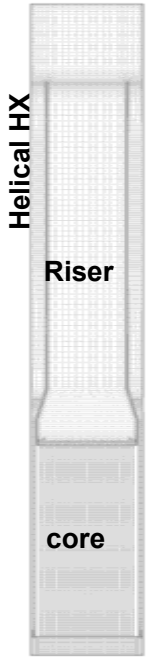
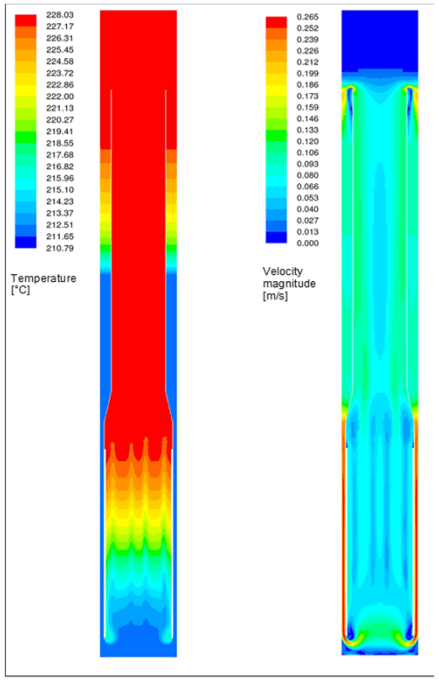
FLUENT Validation using MOTEL helical SG Data (UJV)

SG performance test:

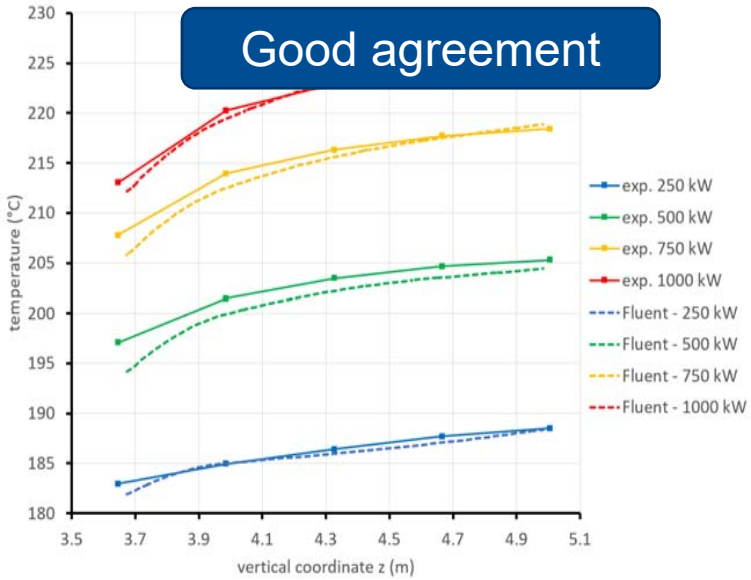
- Core: porous media with momentum losses and heat sources
- FA and probes as hexahedral block volumes
- SG as porous zone with momentum losses and heat sink
- Refined cells boundary layers to capture flow pressure losses



FLUENT: Motel mesh: 1.57 million cells



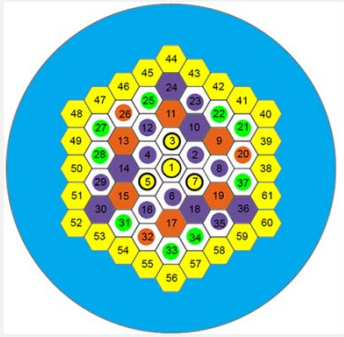
FLUENT: Temp. / velocity field in MOTEL facility (power 1000 kW)



Data-vs-Predictions: SG Primary axial temperature
(power 250, 500, 750 and 1000 kW
(Tests MS-SG01R, MS-SG01-A and MS-SG01-B)

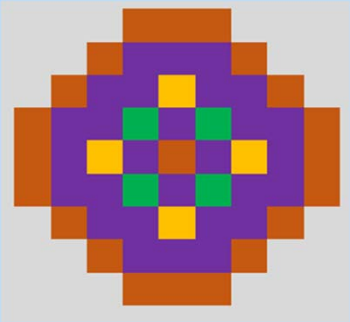
This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

WP3: Multi-physics Core Analysis of different SMR-cores



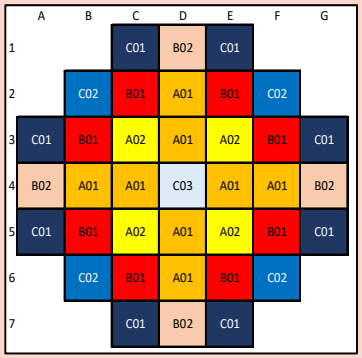
CAREM-Like core

- 61 HEX FA (1.4 m)
- Some FA with BP (6-12)
- 25 control FA
- U-235 enrichment: 1.8 to 3.1 %



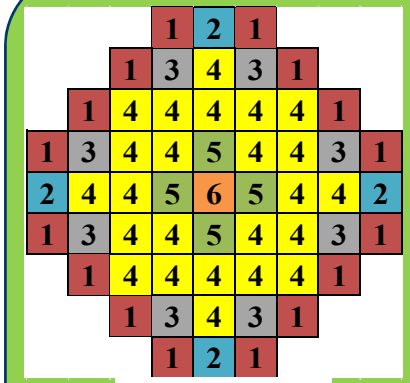
FSMR Core

- 57 FA 17x17-24-1 (1.6 m)
- All FA with AIC-rods
- Gd-rods (6-10 %)
- Heterogeneous FA-design
- Different enrich.3.5-4.95 %



NuSCALE-Like core

- 37 FA 17x17-24-1 (2m)
- GD-rods (16)
- U235 enrich: 1.5 -4.55 %
- Control rods design: Axial varying CR-materials: AIC, B4C



KSMR Core

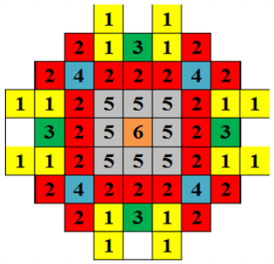
- 57 FA 17x17-24-1 (2 m)
- 6 FA designs, each with CRs (AIC, B4C, SS)
- U235 enrich: radial/axial (2-4%)
- 20-24 BP rods (B4C, Al_2O_3)

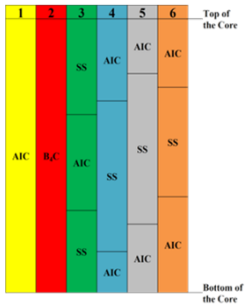
This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

Challenges of Water-cooled SMRs for Core Physics

- Compactness
- Small size (H and D)
- Heterogeneity (radial, axial)
- High leakage
- Harder spectrum
- Complex control rod designs
  - Different types
  - Axial heterogeneity
- Increased role of reflector

- Boron free cores:
  - Need innovative control rod design
  - Optimized shutdown reactivity
  - Reduced reactivity swing over the cycle
  - Etc.



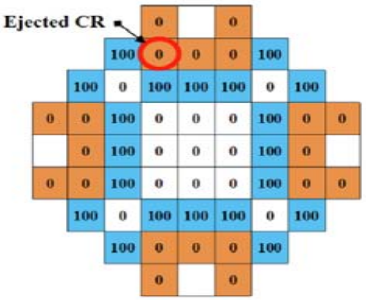


McSAFER Approach

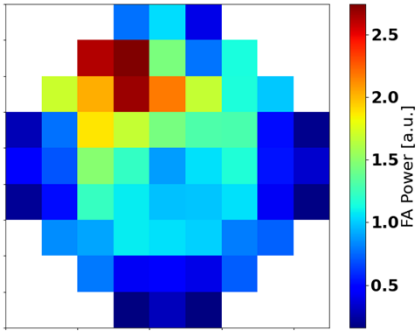
- Nodal diffusion /1D TH or Subchannel
- Pin-based transport / Subchannel
- Pin-based MC /Subchannel (SS, Transiet)

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

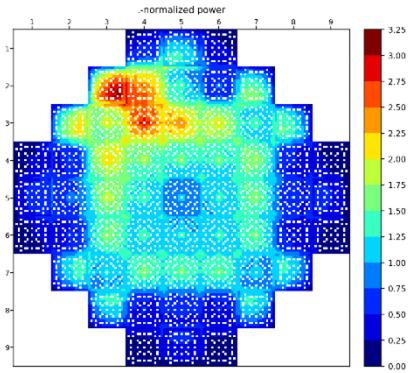
KSMR-Core: REA Analysis with Nodal and Pin Level Simulations



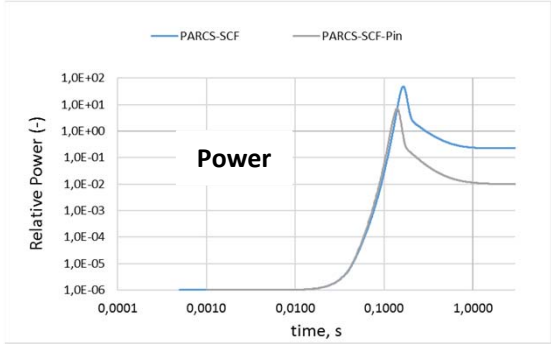
- Initial power: 1E-4 (HZP)
- Tcoolant: 296 °C, G: 2006 kg/s, CR-worth: 1.48 $
- Ejection time: 0.05 s, BOL

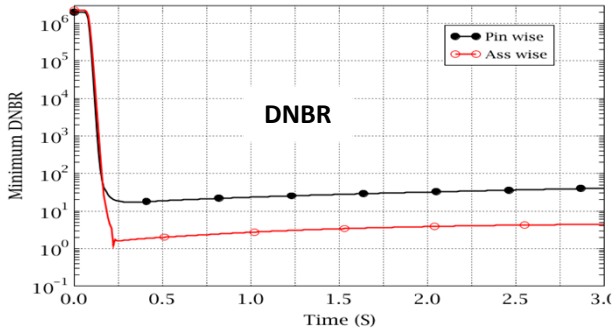


PARCS-SCF: Nodal /FA-level simulation: rel. rad. FA-power



PARCS-SCF: Pin/subchannel level simulation: rel. rad. Pin power





PARCS/SCF: Comparison of nodal and pin level solution

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

Challenges for integrated SMR for Thermal Hydraulics & Safety

- Selected TH-challenges of water-cooled SMR
  - Cross flow in the core
  - Helical HX
  - Transition from
    - Forced to natural convection
    - Natural to forced convection
  - Safety parameters like
    - CHF
  - 3D flow inside the RPV
  - Stability of natural convection flow
  - Effectiveness of passive systems e.g. PRHRS

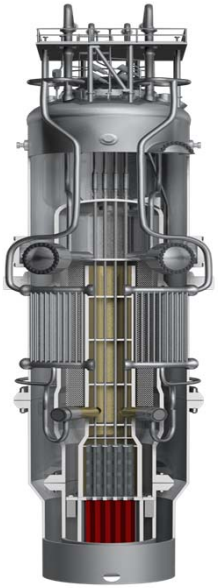
Experimental data exist but proprietary (SMR-designers)

McSAFER Approach

Extend data base for safety-relevant phenomena

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

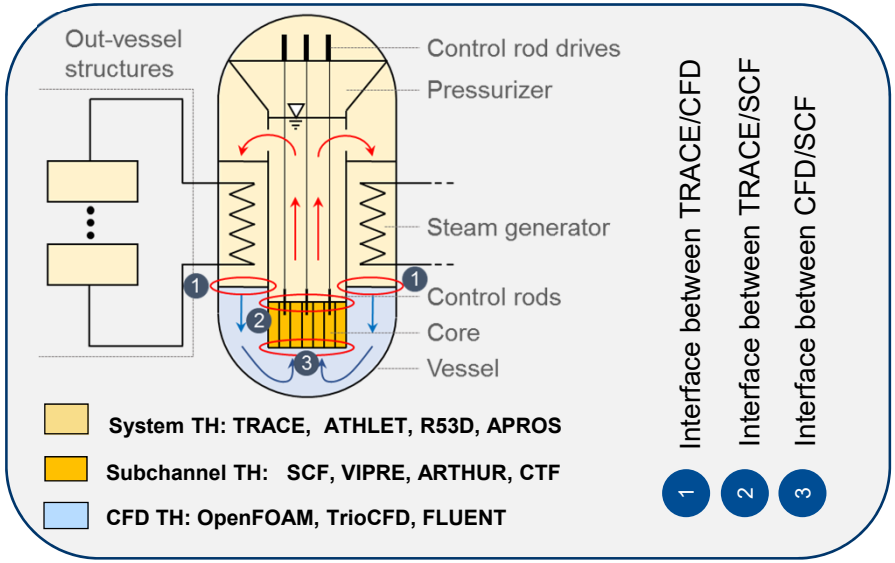
WP4 and WP5: Multiscale RPV Analysis Methodologies for SMR



NuScale (USA)

WP4: Boron dilution

WP5: SLB

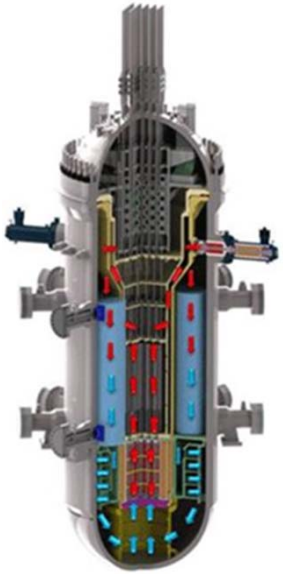


WP4: Multiscale coupling

- System TH/ Suchannel TH
- System TH/ CFD

WP5: Multi-scale /-physics coupling

- System TH/ Suchannel TH/3D NK
- System TH/ CFD / 3D NK



SMART (KAERI)

WP4: ATWS

WP5: SLB

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

WP4: Status of Multi-scale Analysis of the SMR RPV

SMART ATWS

Partners: KIT, TBL

- 1D/3D TH analysis: done

- System TH/Subchannel: done
  - TRACE/SCF/ICoCo (KIT)

- System TH/CFD: ongoing
  - TRACE/OpenFOAM/ICoCo (KIT)

NuScale Boron Dilution

Partners: HZDR, UJV, UPM, JACOBS, TBL, JRC

- 1D /3D TH analysis: done

- System TH/Subchannel: done
  - TRACE/SCF/ICoCo (UPM)
  - TRACE/ARTHUR (JACOBS)

- System TH/CFD: ongoing
  - ATHLET/FLUENT (UJV)
  - ATHLET/TrioCFD (HZDR)

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

WP5: Status of Multi-physics/-scale Plant Analysis

SMART Steam Line Break (SLB)

Partners: KIT, TBL

- 1D TH /3D Neutronics (N): done
  - TRACE/**PANTHER** (TBL)
  - TRACE/**PARCS** (KIT)

- System TH/ SubCh/ **3D N**: done
  - TRACE/**PARCS**/SCF/ICoCo (KIT)

- System TH/ **3D N** /CFD: ongoing
  - TRACE / **PARCS** / OpenFOAM / ICoCo (KIT)

NuScale Steam Line Break (SLB)

Partners: HZDR, UJV, UPM, JACOBS, TBL

- 1D TH/ **3D Neutronics**: done
  - ATHLET/DYN3D (HZDR)
  - TRACE/PANTHER (TBL)
  - ATHLET/DYN3D (UJV)
  - TRACE/PARCS (UPM)

- **System TH/ 3D N/ SubCh: done**
  - TRACE/PARCS/SCF/ICoCo (UPM)
  - TRACE/WIMS/ARTHUR (JACOBS)
  - TRACE/PANTHER/CTF4 (TBL)

- **System TH/ 3D N/ CFD: ongoing**
  - ATHLET/DYN3D/FLUENT (UJV)
  - ATHLET/DYN3D/TrioCFD (HZDR)
  - TRACE/ANTS/OpenFOAM (VTT)

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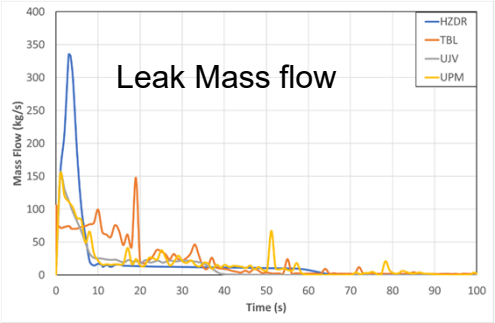
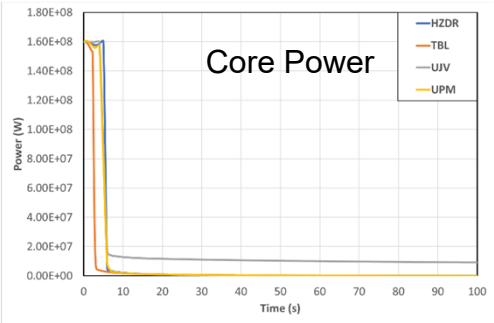
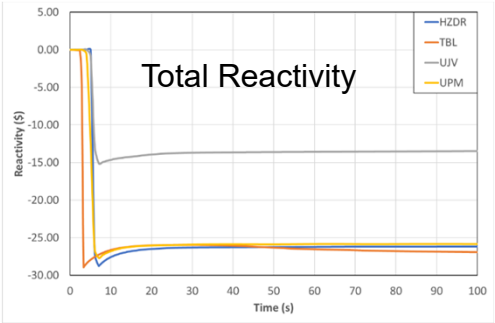
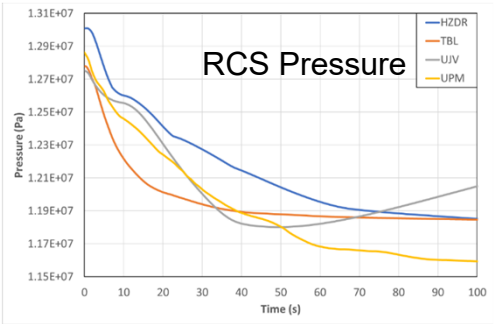
NuScale SLB: Preliminary Results with system TH /3D NK









Remarks:

- Similar trends of key parameters BUT
- Different timing
- NuScale models are under revision by the partners

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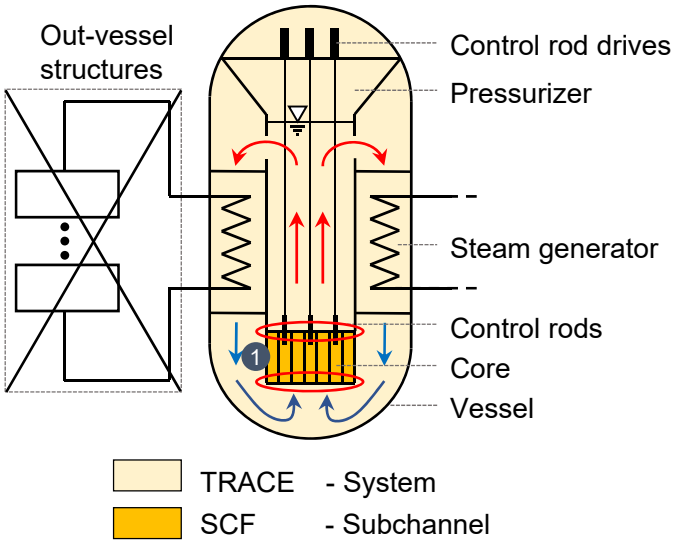
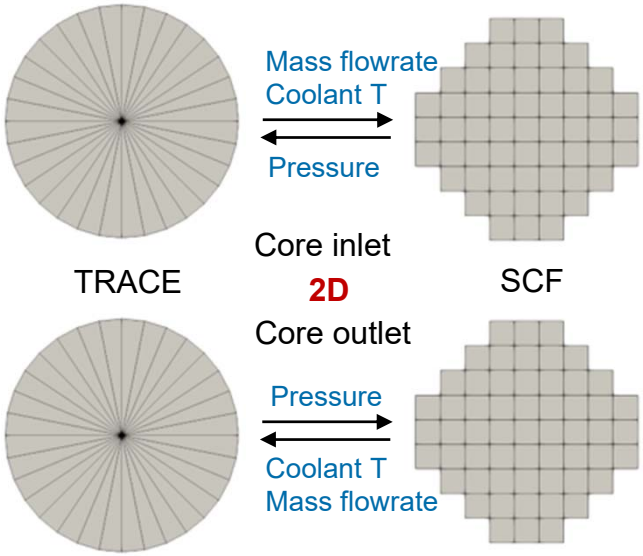
Multiscale coupling methods: TRACE/SCF/ICoCo (WP4)





1 Interface between TRACE and SCF

The field mapping between codes are by MEDCoupling

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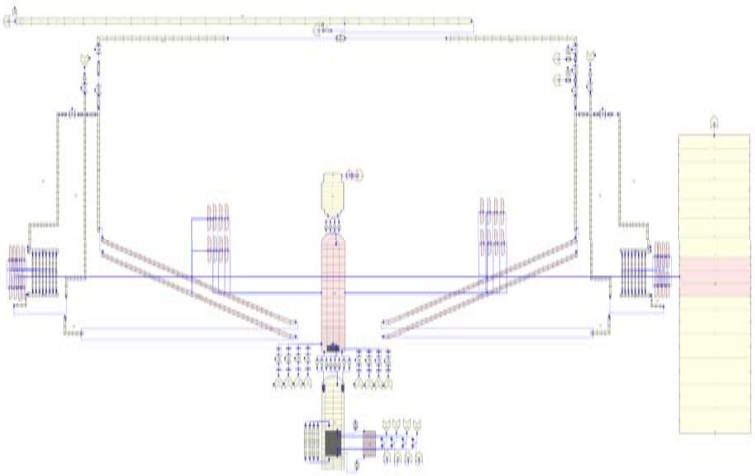
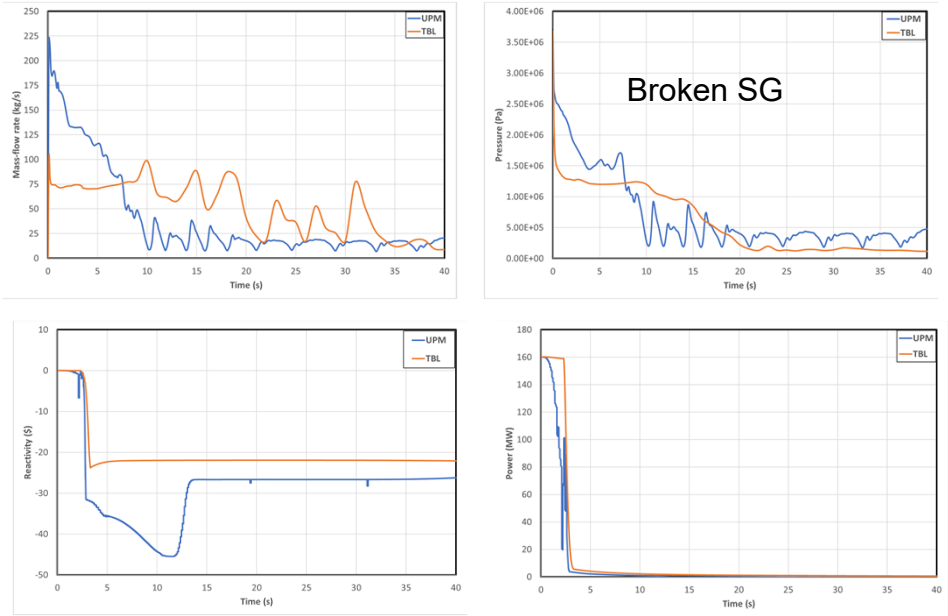
NuScale MSLB Analysis with different Approaches (WP5)

- Codes:
  - UPM: TRACE/PARCS/SCF (3D TH)
  - TBL: TRACE/PANTHER (1D TH)

- NuScale: Multiscale model (UPM)



- NuScale: Steam Line Break
  - Initial event: at 0 s, SCRAM: Psl < 2.068 MPa, CR-insertion, Signal for MSIV, FWIV, MSIV (SG1 and SG2) close, DHRS start



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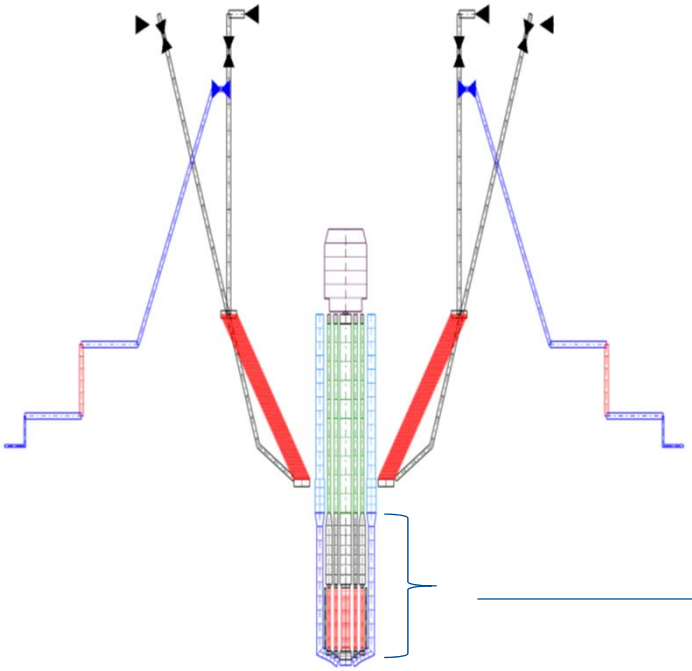
NuScale: Multiscale analysis using ATHLET/DYN3D/TrioCFD



NuScale 1D/3D Thermal Hydraulics Model (HZDR)

TrioCFD Model of Downcomer and lower plenum (HZDR)

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

Conclusions

- Experimental program will provide key-data for code validation regarding
  - Behavior of helical coil HX
  - Cross flow in the core, CHF
  - Transition from forced to natural circulation

- Multi-physics core analysis will allow to identify which kind of tools are needed to assess complex, small, heterogeneous SMR-cores

- Multiscale/-physics analysis of SMR-transients will demonstrate which numerical tools are most appropriate for safety evaluations of integrated SMRs
  - Reduce conservatism
  - Enhance operational flexibility
  - Improve economics

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McSAFER: Dissemination of Main results

McSAFER Zenodo Open Repository:

https://zenodo.org/communities/mcsafer/

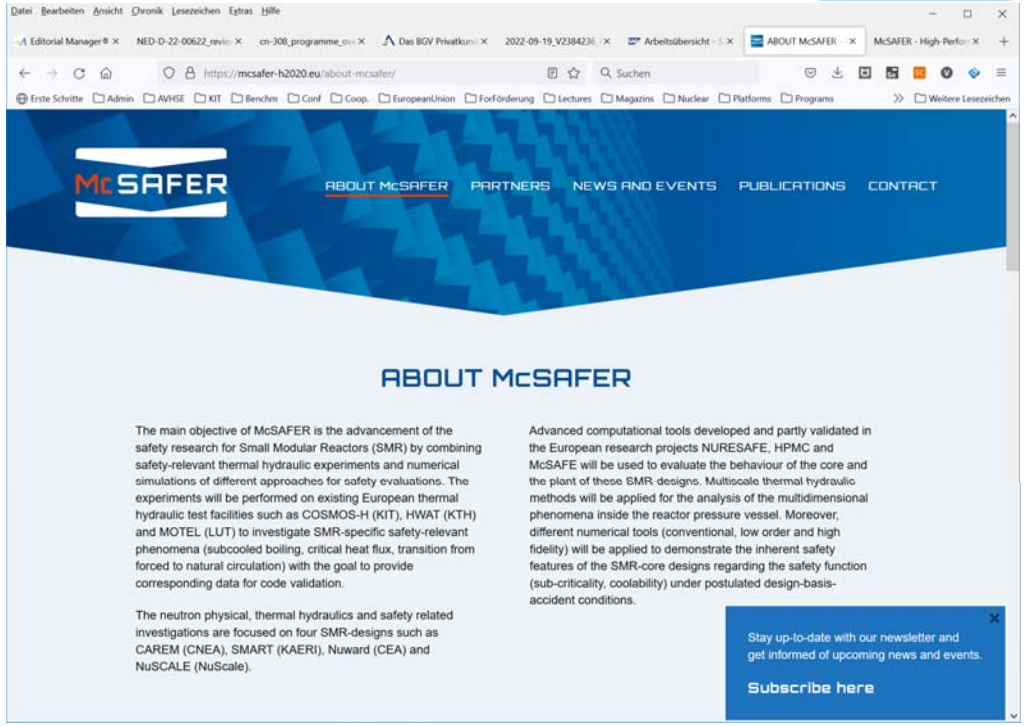
User group members:
NRG, IRSN, ININ, BME, FRAMATOME GmbH

Contact:

Victor.sanchez@kit.edu

Handy: +49 15201547532

KIT CN Karlsruhe



Visit public website: www.mcsafer-h2020.eu

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

2.12 Safety Systems Required for a Supercritical Water-Cooled Reactor, Thomas Schulenberg, KIT (In person)

Safety Systems Required for a Supercritical Water-Cooled Reactor

Thomas Schulenberg

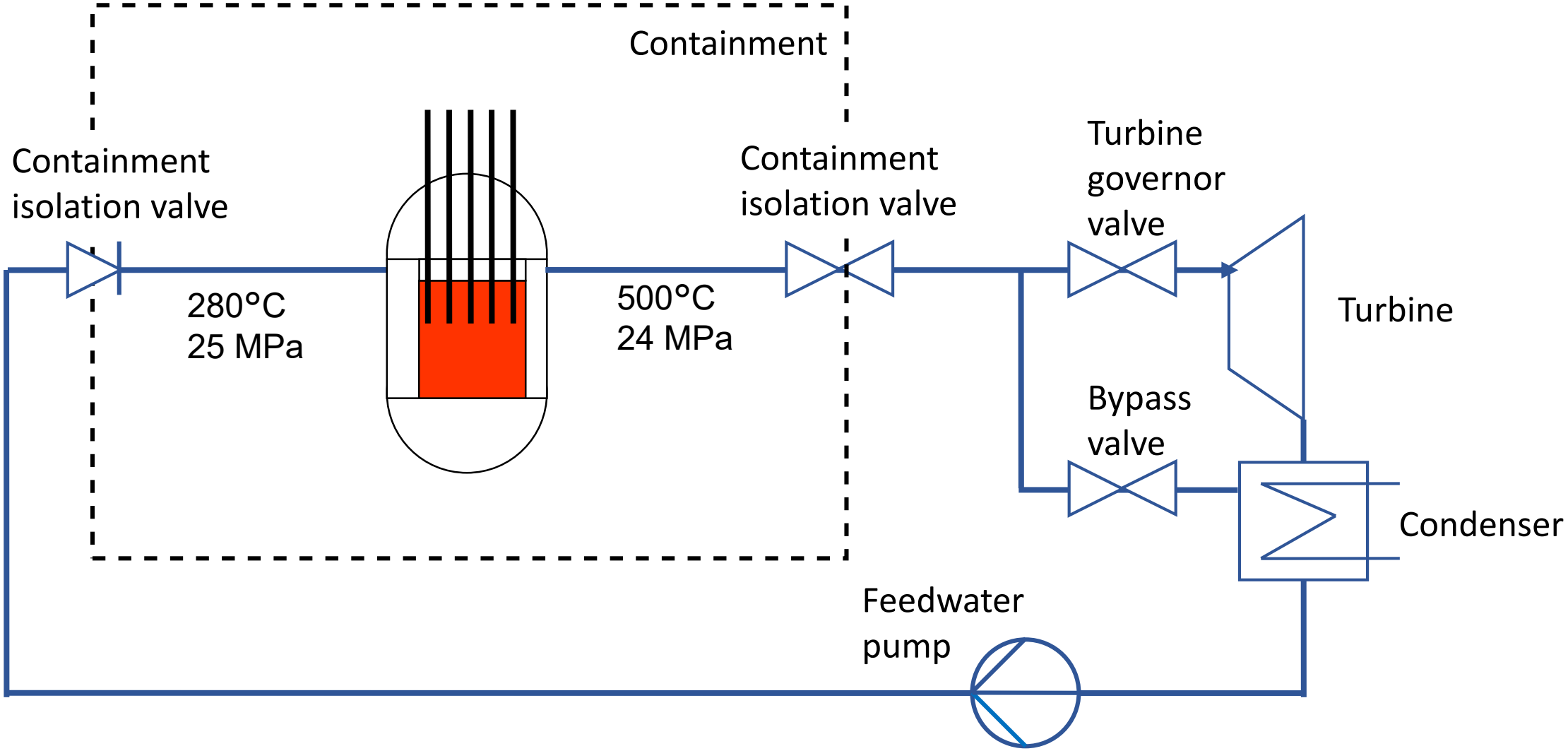
Workshop on Safety of Small and Modular Reactors

Celje, Slovenia, June 20-22, 2023

General safety requirements for innovative reactors

- Nobody shall be exposed to any serious radiation damage, neither during normal operation nor during any conceivable accident
- Neutron and gamma radiation must be shielded, e.g. by lead, concrete, or water
- Radioactive material must be locked like in a high security prison:
  - First barrier: Fuel claddings
  - Second barrier: Primary system
  - Third barrier: Containment

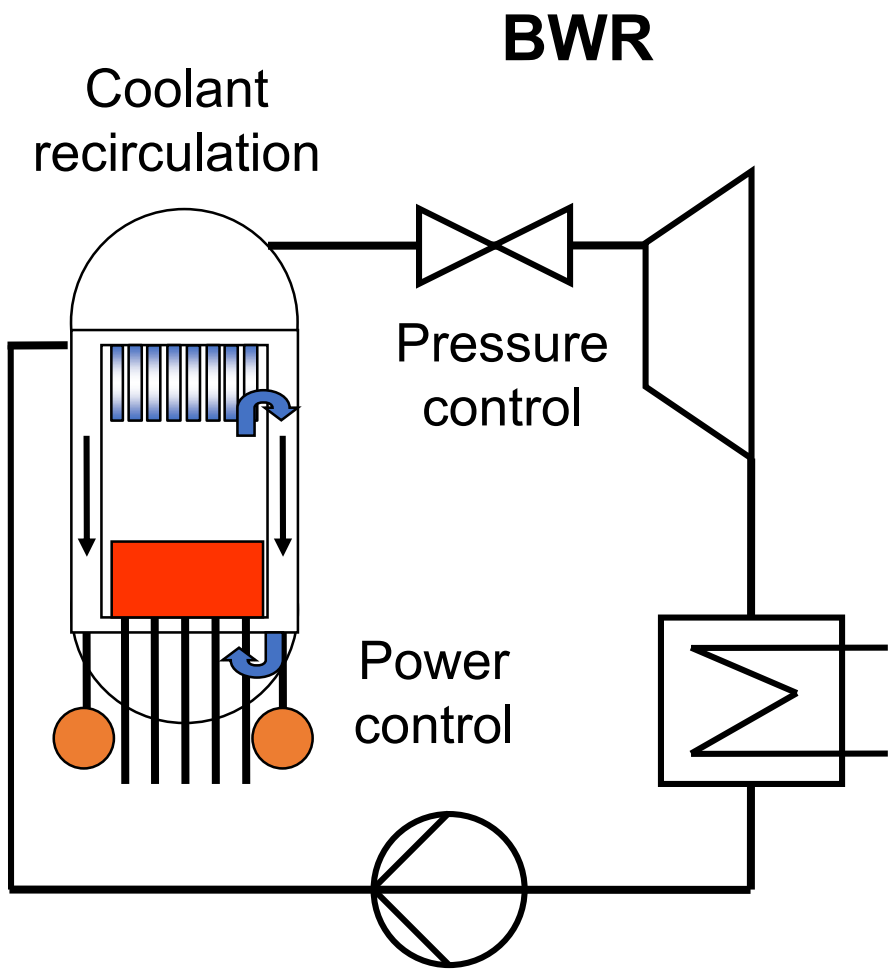
Once-through steam cycle of a SCWR



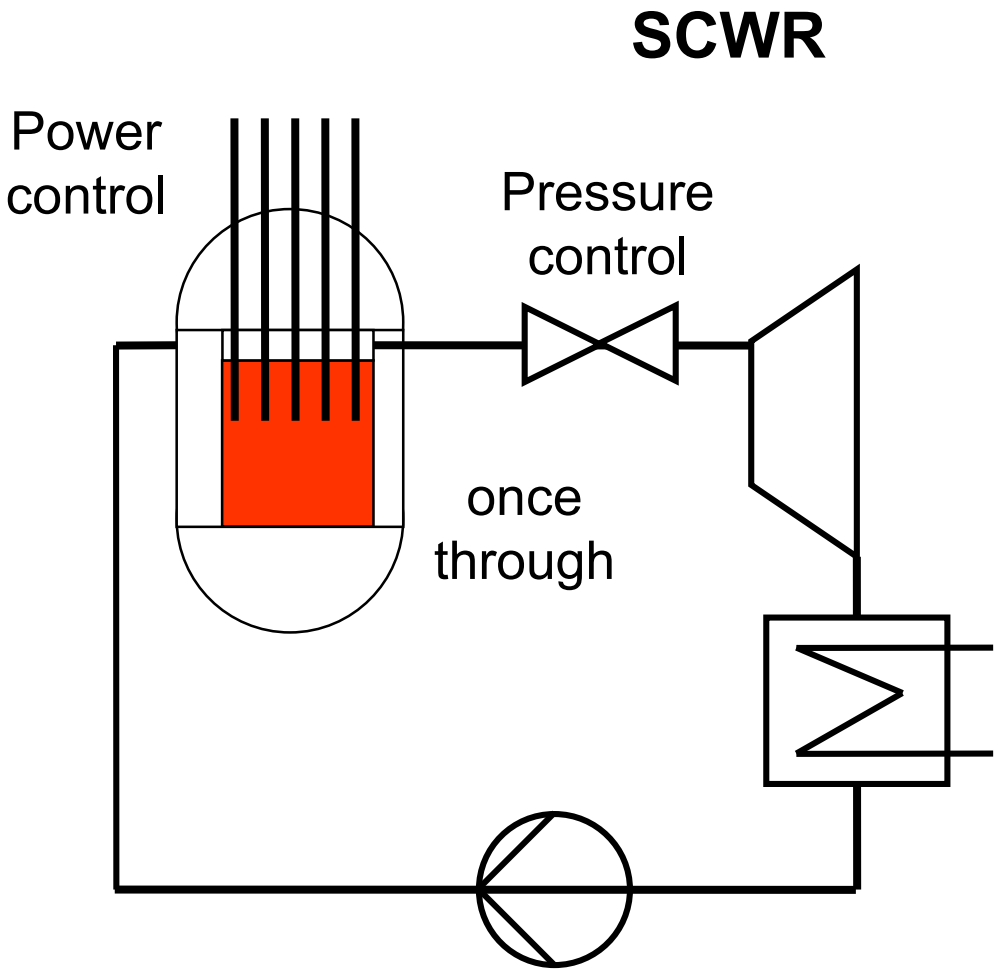
The second barrier of a SCWR

- The reactor and the entire steam cycle are forming the second barrier, like in a BWR
  - Radioactive material (e.g. N-16) is transported to the steam turbine even during normal operation.
  - The turbine building may only be entered with protective measures.
- The second barrier is penetrating the containment, the third barrier.
  - Containment isolation valves are needed to close these penetrations in case of an accident.

Comparison of BWR with SCWR



Liquid level control



Steam temperature control

Different Safety System Requirements

Karlsruhe Institute of Technology

BWR

- Closed coolant loop inside reactor
- Residual heat removal by natural convection driven by rising steam
- ⇨ Maintain coolant inventory

SCWR

- Only a single coolant loop through the turbine (once-through)
- Residual heat removal by forced convection through the reactor
- ⇨ Maintain coolant mass flow

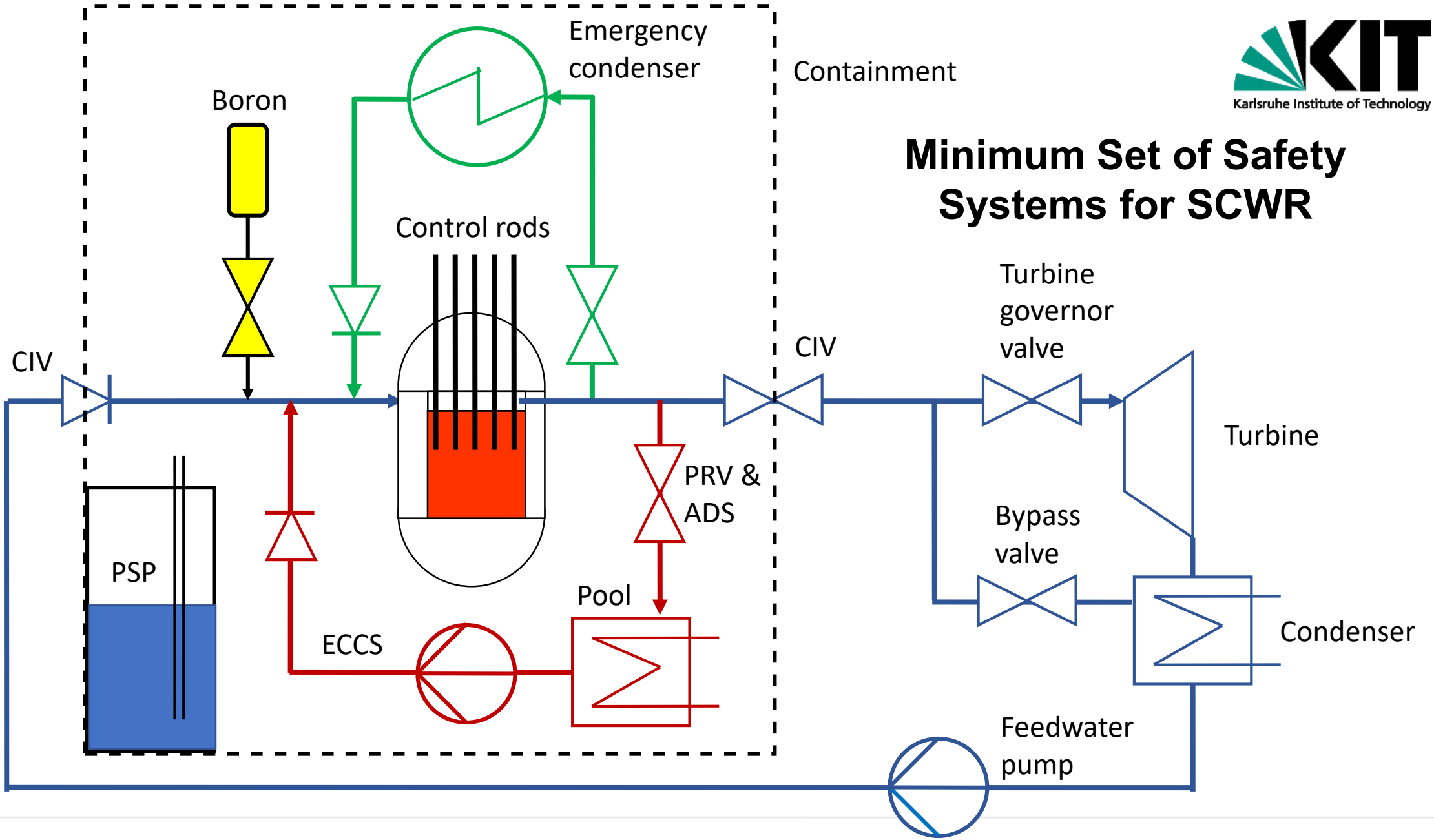
General Safety System Requirements

Karlsruhe Institute of Technology

Common requirements for BWR and SCWR in case of accidents

- Reactor SCRAM by control rods or boron injection
- Containment isolation, closing the 3rd barrier
- Close the coolant loop inside containment:
  - Depressurize steam into containment pool
  - Refill reactor with condensate
- Limit pressure increase inside containment by pressure suppression pool

Minimum Set of Safety Systems for SCWR



Options for residual heat removal

- Normal operation without containment isolation:
  - Reactor SCRAM and turbine trip
  - Turbine bypass valve opens, keeping reactor pressure at 25 MPa
  - Feedwater pump is providing mass flow rate needed to cool the reactor core.
- Active emergency core cooling system after containment isolation
  - Reactor SCRAM and turbine trip
  - Containment isolation valves close
  - Pressure relief valves open, decreasing the pressure but maintaining a coolant mass flow rate
  - Lost coolant is re-injected by active coolant pump

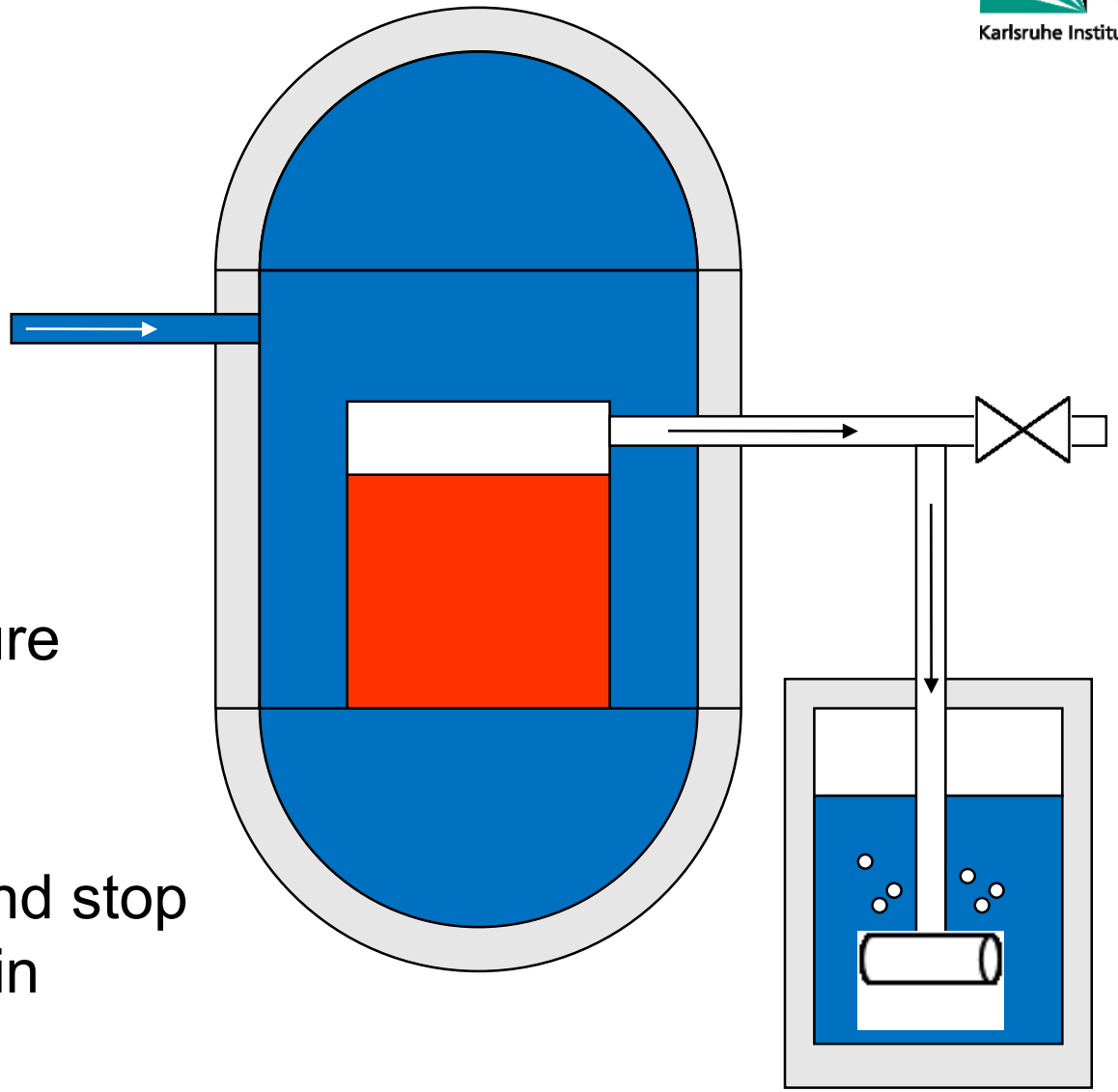
How fast would we need the active emergency core cooling pump?

Early coolant injection: < 20 s

- Coolant injection system will continue to drive coolant flow
- Well-cooled for long term

Late coolant injection: ~10 min

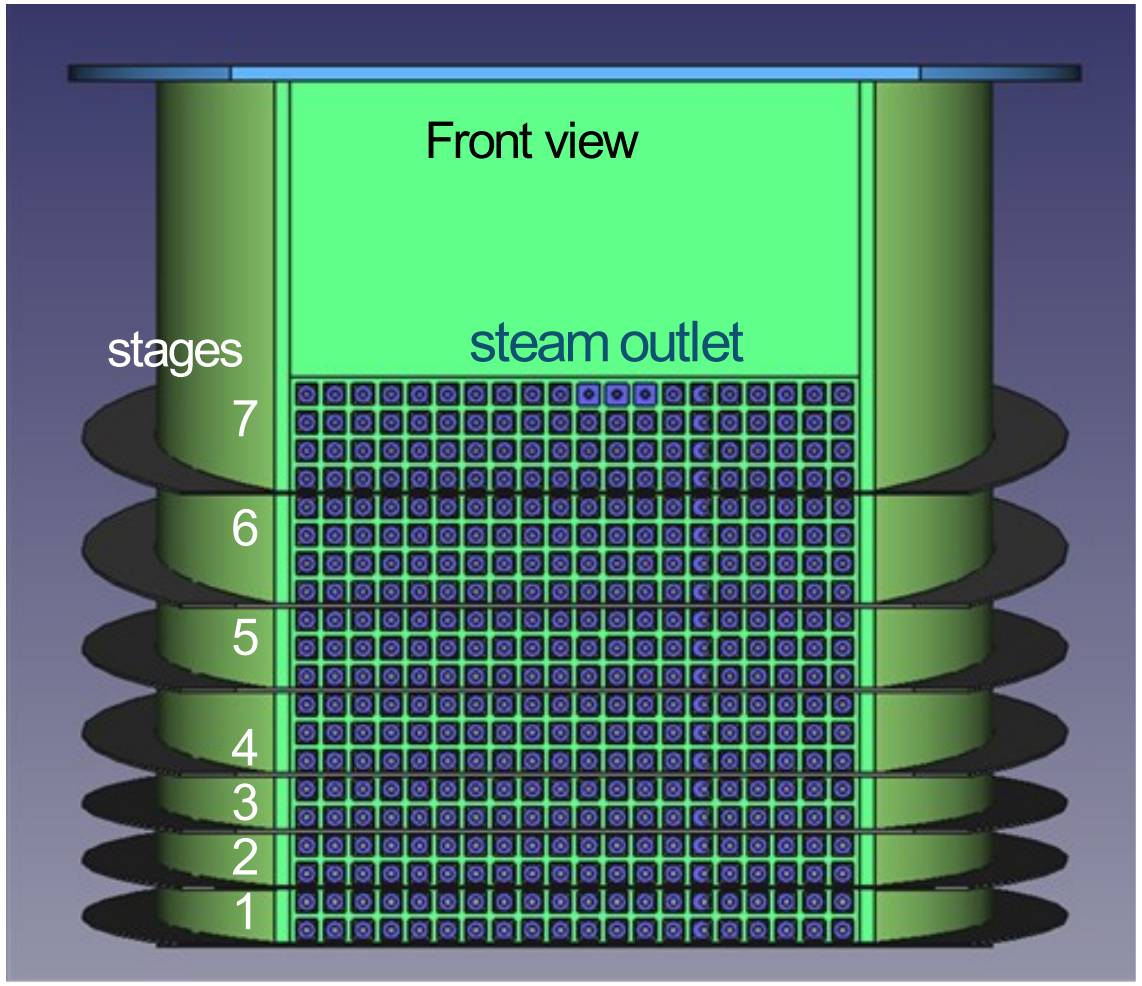
- Coolant is driven by steam pressure inside reactor
- Cold coolant injection would depressurize the feedwater side and stop core flow until RPV is filled up again

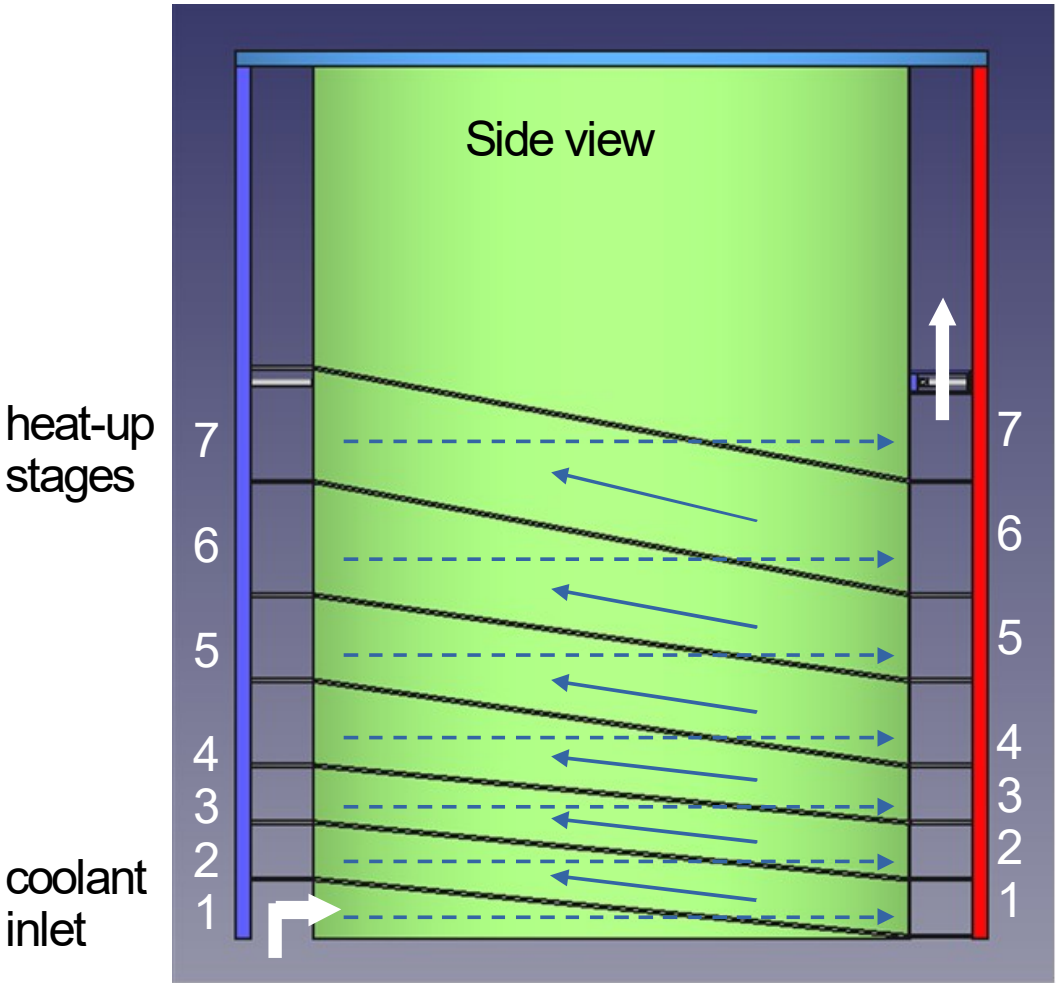


Passive residual heat removal

- In case of loss of offsite power:
  - Reactor SCRAM and turbine trip
  - Containment isolation valves close
  - Pressure relief valves open, decreasing the pressure and maintaining a coolant mass flow rate
  - Riser to an emergency condenser opens
  - Condensate is returning driven by gravity, replacing the evaporated coolant
  - Pressure relief valves are closing again.

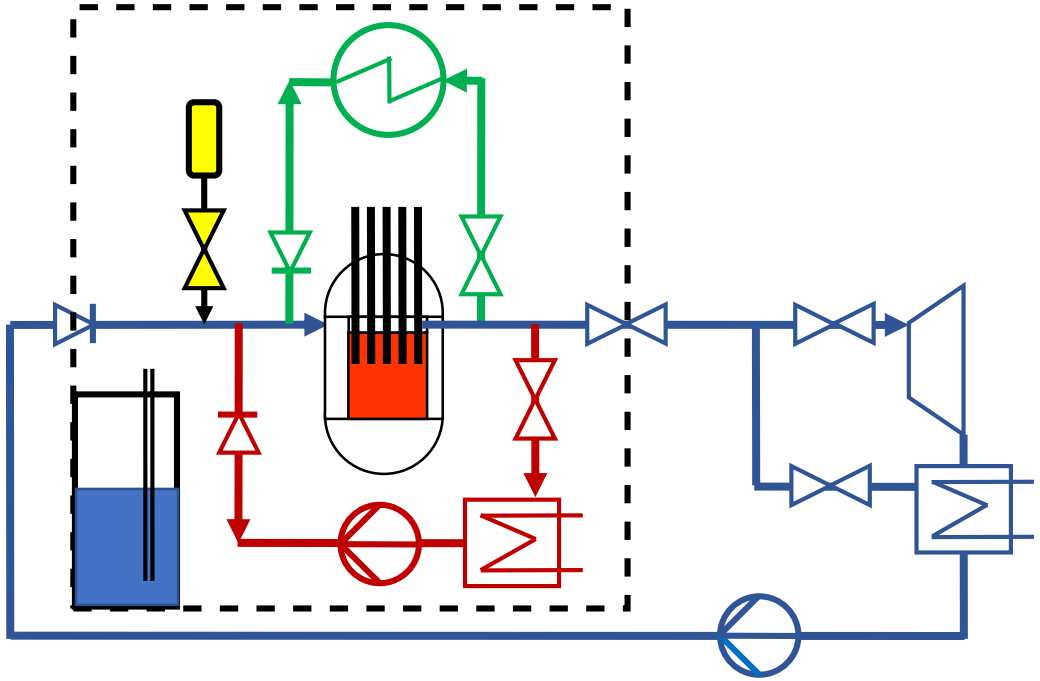
The reactor core must be designed such that it enables natural convection: upward flow only





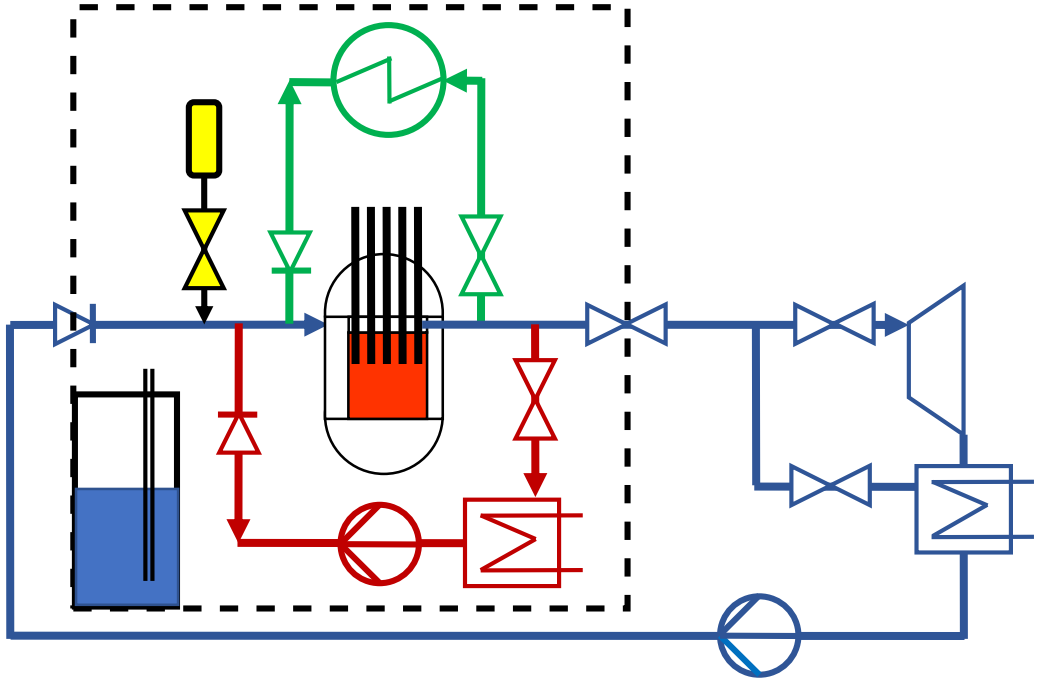
Load rejection of the generator

- Reactor SCRAM and turbine trip
- Turbine bypass valve opens passively
- Containment isolation valves stay open
- Reactor may stay at supercritical pressure
- Feedwater pumps provide coolant mass to keep the cladding temperatures below their limits



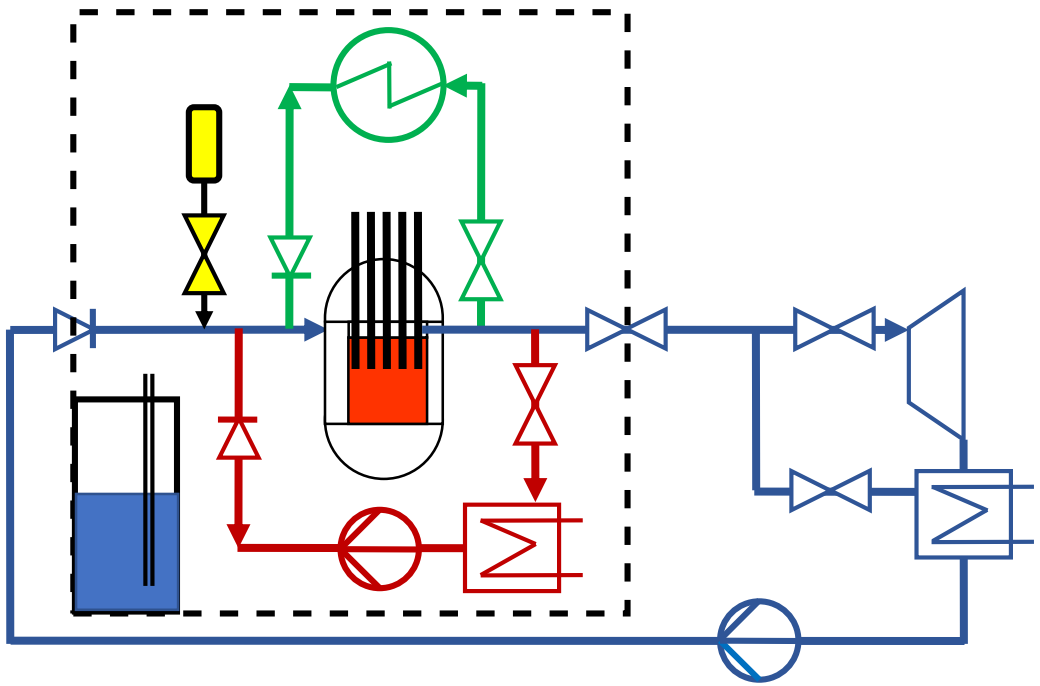
Station black-out

- Reactor SCRAM and turbine trip
- Turbine bypass valve opens passively
- Containment isolation valves close
- Pressure relief valves open temporarily
- Lines to the emergency condenser are opened



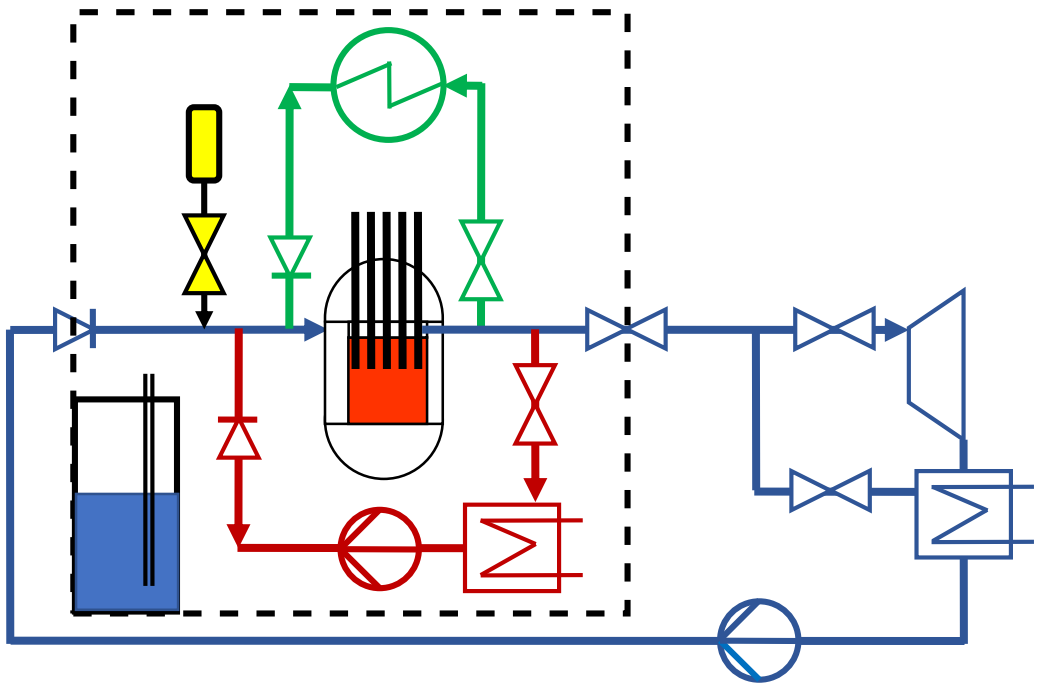
Break of a steam/feedwater line outside the containment

- Reactor SCRAM and turbine trip
- Turbine bypass valve opens passively
- Containment isolation valves close
- Pressure relief valves open temporarily
- Lines to the emergency condenser are opened



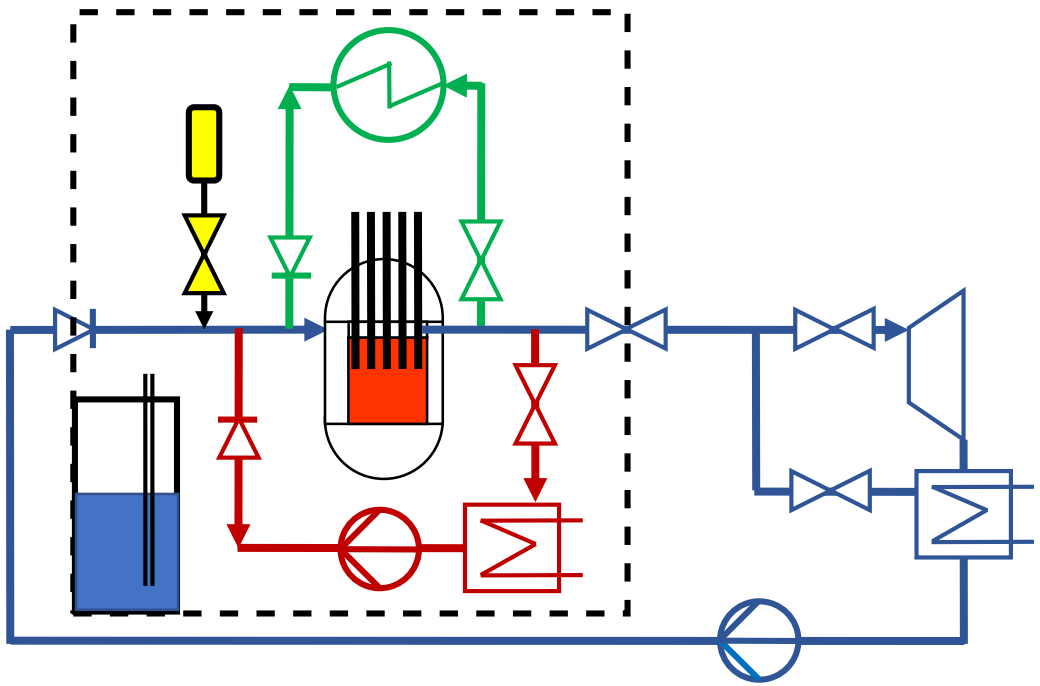
Break of a steam/feedwater line inside the containment

- Reactor SCRAM and turbine trip
- Turbine bypass valve opens passively
- Containment isolation valves close
- Pressure relief valves open
- Active emergency core cooling system is refilling lost water
- Pressure suppression pool is keeping containment pressure below its limit



Core melts, e.g. due missing coolant injection

- Depressurization to low pressure
- Boron injection
- Reactor is refilled from a core flooding pool?
- Need of RPV cooling from outside or a core catcher underneath the reactor?



Conclusions

- Safety systems required for a SCWR have much in common with those of BWRs
- The main difference is the missing coolant recirculation inside the RPV, which may be replaced by a passive emergency condenser system outside the RPV
- The reactor core should be designed such that it can be cooled by natural circulation
- The safety systems of the ECC-smart concept still need to be designed, analyzed with system codes and optimized to keep the maximum cladding temperature below its limits.

2.13 Thermal Hydraulics safety considerations in ECC-SMART, Ivan Otic, KIT (In person)

JOINT EUROPEAN CANADIAN CHINESE
DEVELOPMENT OF SMALL MODULAR REACTOR TECHNOLOGY

Thermal hydraulics safety considerations in ECC-SMART

I. Otic

Karlsruhe Institute for Technology (KIT), Germany

ivan.otic@kit.edu

This project has received funding from the Euratom Research and Training programme 2019-2020 under Grant Agreement No 945234.

Introduction; ECC-SMART Project

Thermal-hydraulic R&D activities for SMR-SCWR in EURATOM are currently within the ECC-SMART Project

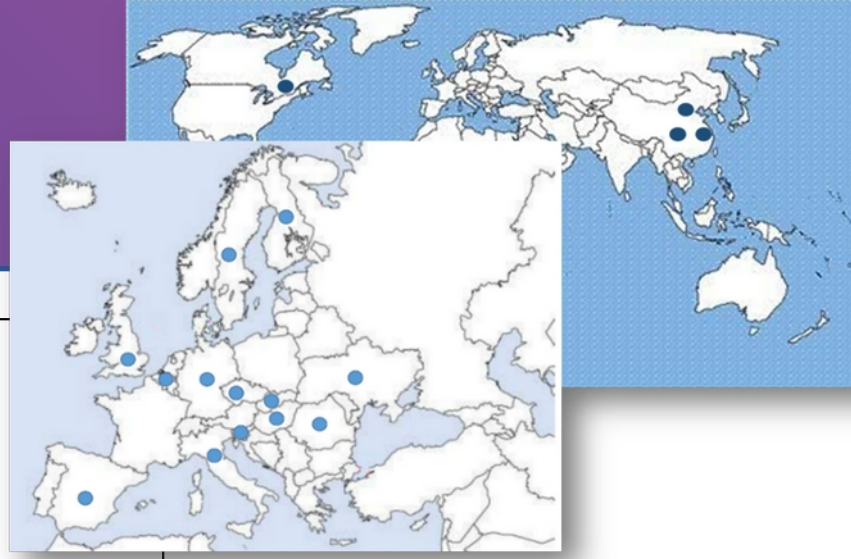
Joint European Canadian Chinese development of Small Modular Reactor Technology

- Duration: September 2020 – August 2024 (48 months)
- Total budget: 8 911 950 €
- EC contribution: 3 997 237 €
- Total effort: 958 PM

- Consortium: 20 partners

  15 European, 3 Chinese, 1 Canadian and 1 Ukrainian partner
- Cordis: https://cordis.europa.eu/project/id/945234
- Website: https://ecc-smart.eu/

ECC-SMART Consortium



CVŘ	*CZ*	CVŘ Research Centre Řež	RATEN	*RO*	RATEN
JRC	*BE*	European Commission	IPP	*UA*	IPP CENTRE Intelligent Practical Profound
CIEMAT	*ES*	Gobierno de España, Ministerio de Ciencia e Innovación, Ciemat	VTT	*FI*	VTT
JSI	*SLO*	Jožef Stefan Institute, R4 Reactor Engineering Division	CNL	*CA*	Canadian Nuclear Laboratories / Laboratoires Nucléaires Canadiens
UNIPI	*IT*	Università di Pisa	SJTU	*CN*	Shanghai Jiao Tong University
USFD	*UK*	The University Of Sheffield.	KIT	*DE*	KIT Karlsruher Institut für Technologie
STUBA	*SK*	STU FEI Slovak University of Technology in Bratislava, Faculty of Electrical Engineering and Information Technology	KTH	*SE*	KTH Vetenskap och Konst
ENEN	*BE*	enen	VŠCHT	*CZ*	University of Chemistry and Technology Prague
BME	*HU*	Műegyetem 1782	USTB	*CN*	
UON	*UK*	The University of Nottingham, United Kingdom · China · Malaysia	NPIC	*CN*	中核集团 CNNC

20 partners in the ECC-SMART consortium:

- 15 European
- 3 Chinese
- 1 Canadian
- 1 Ukrainian partners

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ECC-SMART SMR Design Targets

Main Goal: Derivation of European-Canadian-Chinese (ECC) design requirements for a ECC SCW-SMR design concept

Design Targets

- The electric power output of the SMR should be around 200 to 300 MW.
- The specific plant erection costs (€/kW installed electric power) should be less 20% compared with SMR concepts based on a PWR.
- The power plant shall remove the residual heat without the need of electric power at least within a time period of 3 days.
- The specific fuel cost (€/MWh electric power) shall be smaller than those of SMR concepts based on a PWR, which may be accomplished by a higher efficiency compensating higher fuel production costs.

ECC-SMART: List of work packages

1.3.1. WT1 List of work packages

WP Number[9]	WP Title	Lead beneficiary[10]	Person-months[11]	Start month[12]	End month[13]
WP1	Project Coordination	1 - CVR	21.00	1	48
WP2	Materials Testing	3 - CIEMAT	430.20	1	48
WP3	Thermal Hydraulics and Safety of the SCW-SMR	17 - KIT	364.70	1	48
WP4	Neutron physics of SCW-SMR	9 - BME	87.90	1	48
WP5	Synthesis and Guidelines for Safety Standards	4 - JSI	34.40	1	48
WP6	Dissemination and communication	8 - ENEN	26.00	1	48
WP7	Ethics requirements	1 - CVR	N/A	1	48
		Total	964.20		

WP3 Leader: KIT – Ivan Otic

Objectives of TH and Safety Work Package (WP3)

- To provide a database using experimental and numerical data
- Improvement, implementation and validation of engineering CFD models for turbulent heat and mass transfer at SC conditions
- Development and validation of heat transfer correlations and models for applications in sub-channel and system codes at SC conditions
- Safety and design analysis of the SCW-SMR concept
- **Derivation of European-Canadian-Chinese (ECC) design requirements for a ECC SCW-SMR design concept;**
- **This design requirement document is also the main goal of the entire ECC-SMART project.**

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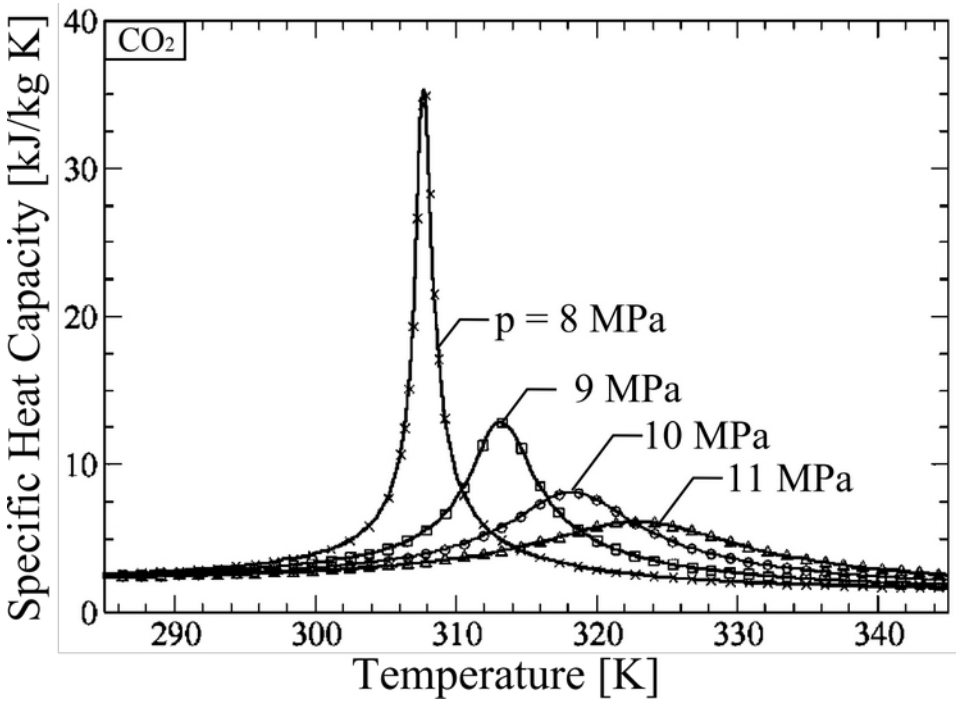
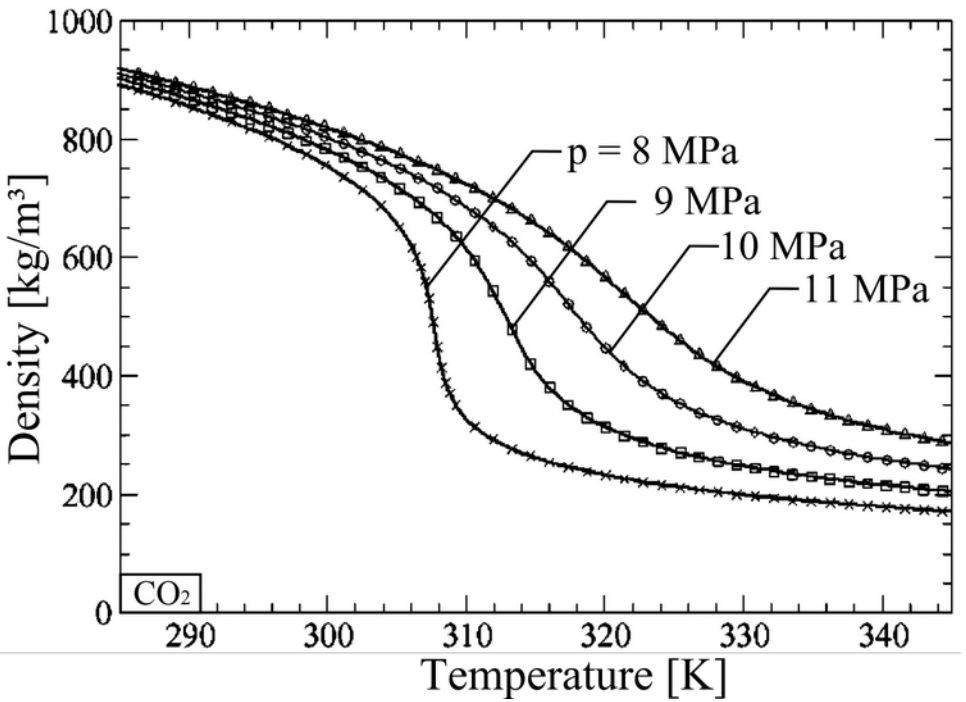
Heat transfer under supercritical pressure conditions

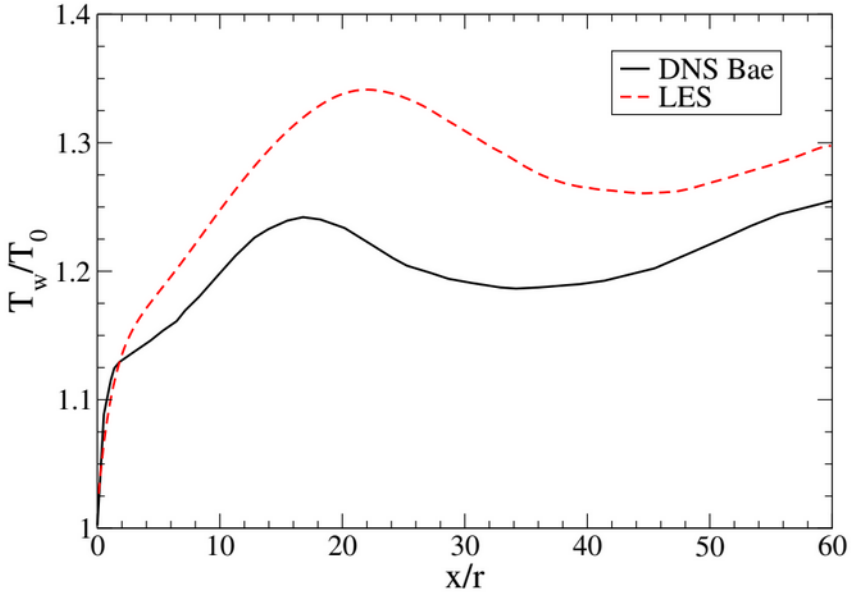
Fluid properties variation



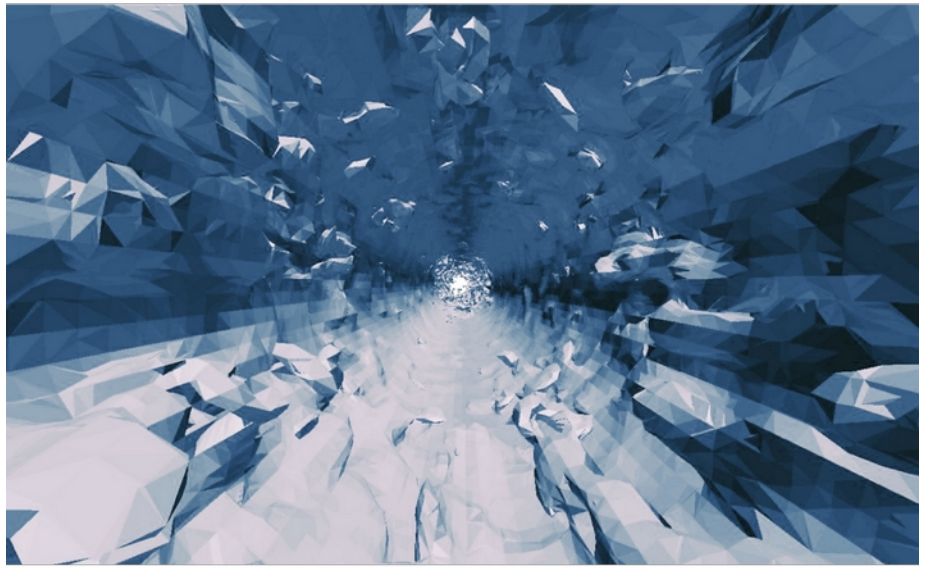


Heat transfer under supercritical pressure conditions

Flow properties: Strong localized deterioration of heat transfer



Wall temperature. Along heated a pipe.



Vorticity. View through a pipe.

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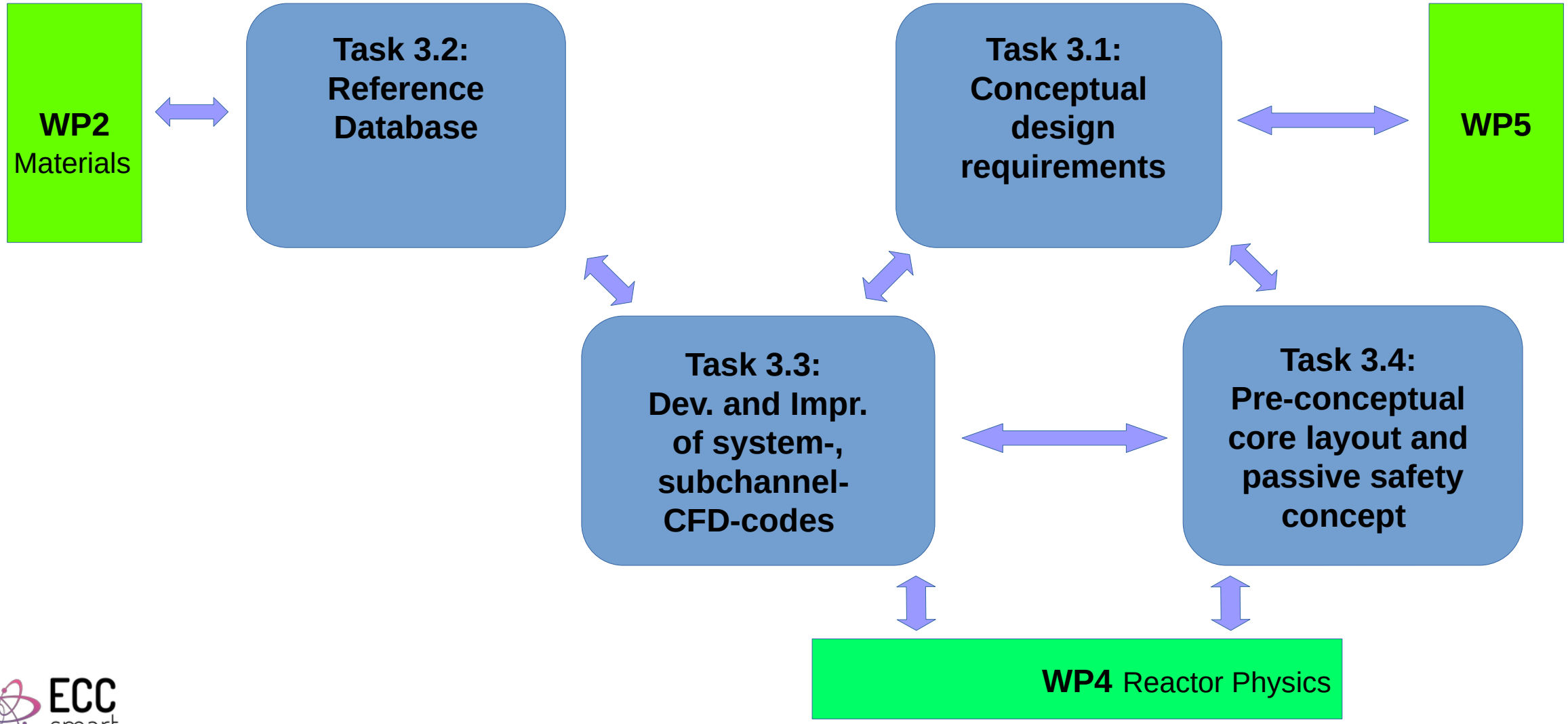
Thermal Hydraulics WP3; Structure



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WP3 Task 3.1: Conceptual design requirements

Task Leaders: KIT – Ivan Otic, CNL- Armando Nava-Dominiquez,
Contributors: KIT, CNL, CVR, NPIC, UNIPI, BME

Task 3.1:
Based on (HPLWR), an ECC SMART design concept of a small modular reactor is in the iterative development procedure: materials, reactor physics and thermal hydraulic analysis.

The first development of the concept is published (Journal of Nuclear Engineering and Radiation Science https://doi.org/10.1115/1.4052191)

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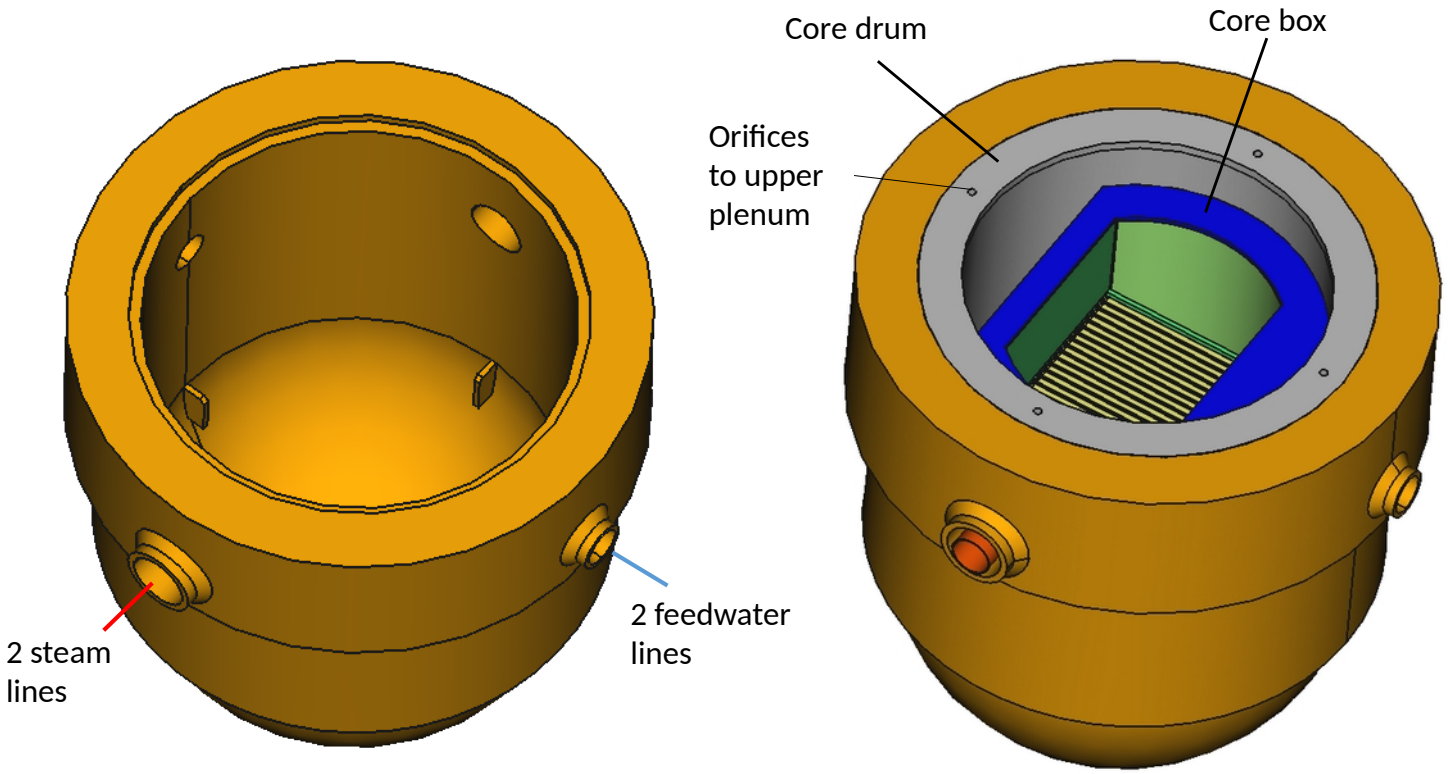
WP3 Task 3.1: Conceptual design requirements

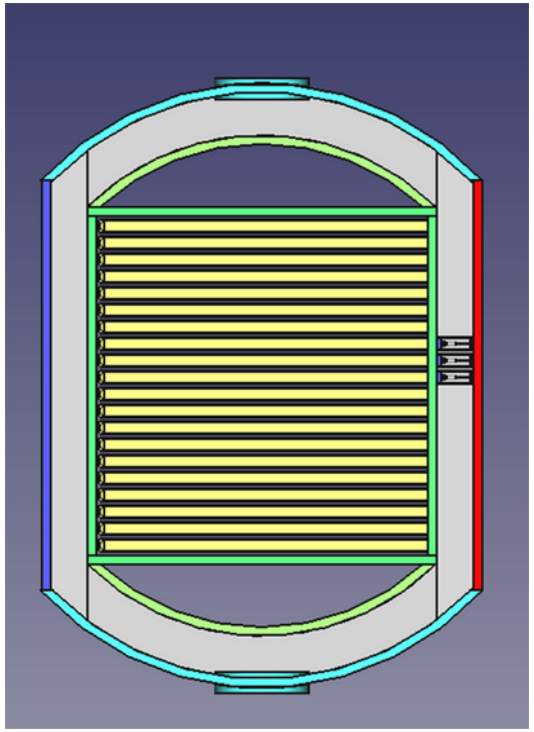
ECC-SMART Design based on HPLWR



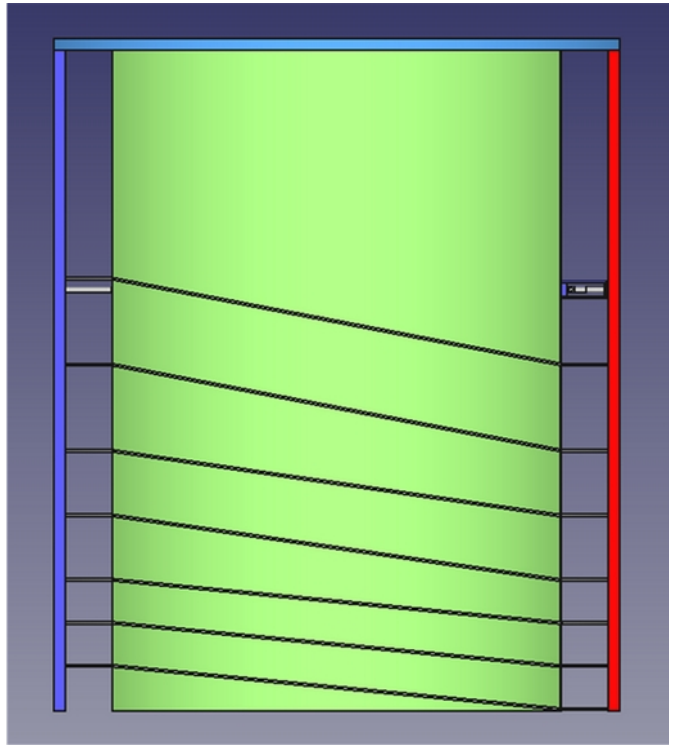
Reactor pressure vessel, empty (left) and with core drum and core box inserted (right). Reactor closure head removed.

WP3 Task 3.1: Conceptual design requirements

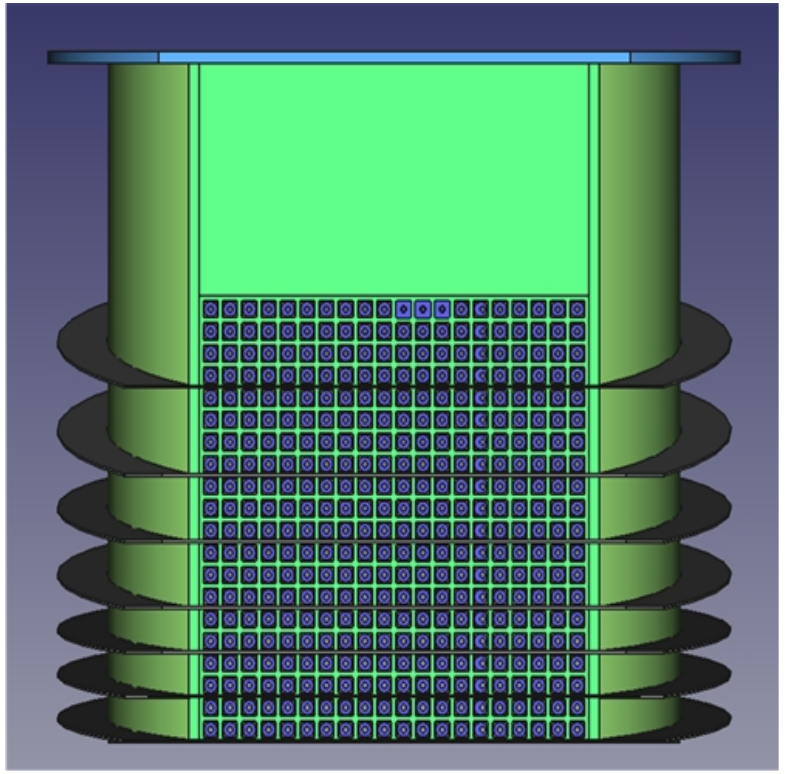
ECC-SMART Design based on HPLWR; Reactor core



Top view of the reactor core.



Side view of the reactor core.



Side view of the reactor core.

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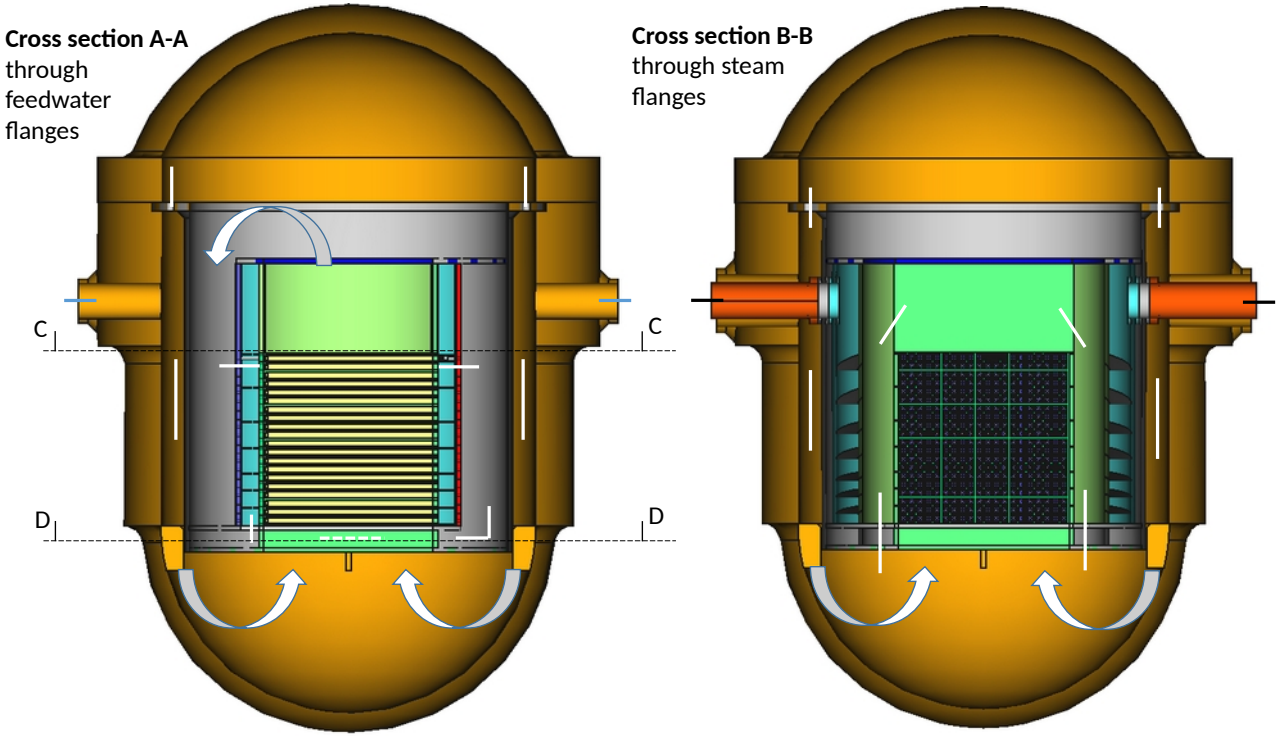
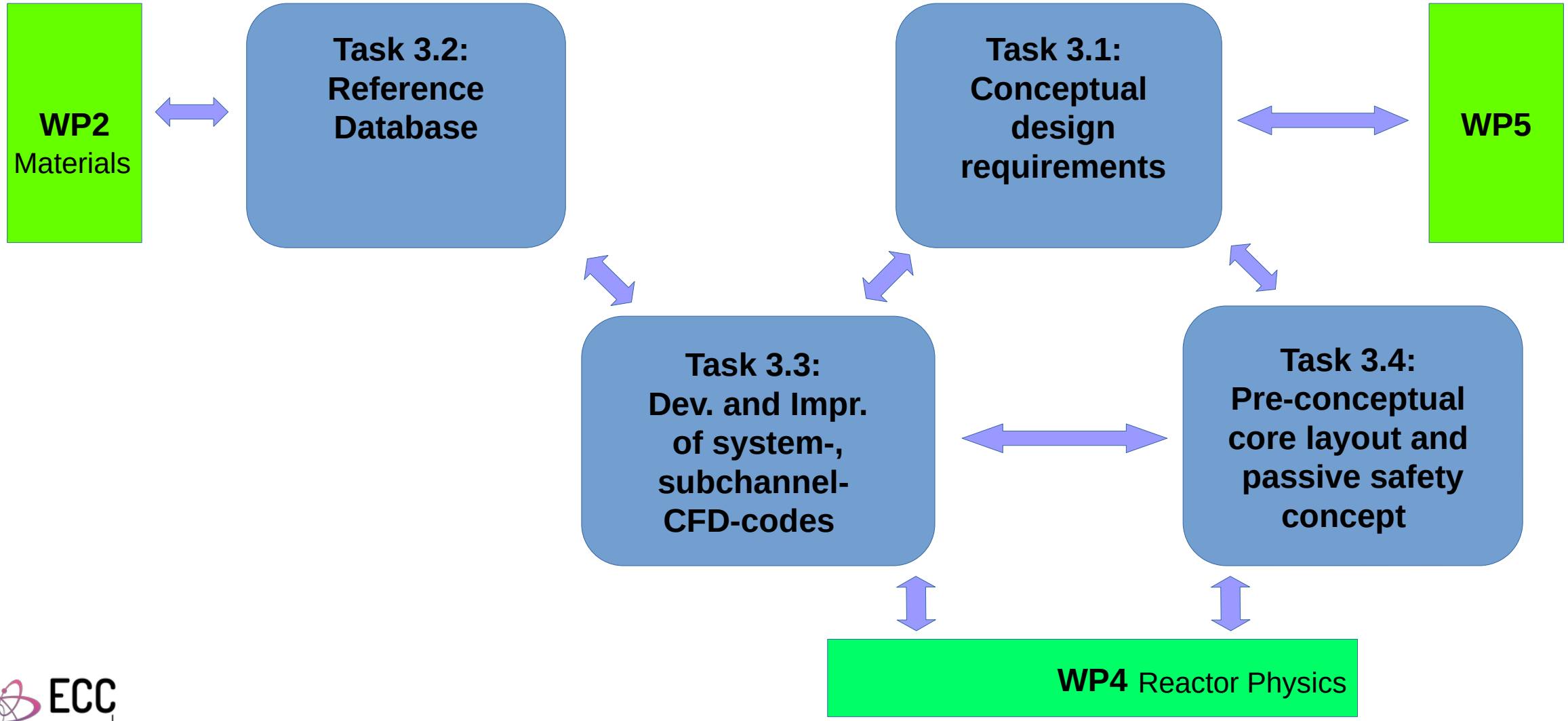
WP3 Task 3.1: Conceptual design requirements

ECC-SMART Design based on HPLWR



Vertical cross sections through the reactor

WP3; Task 3.2: Reference database



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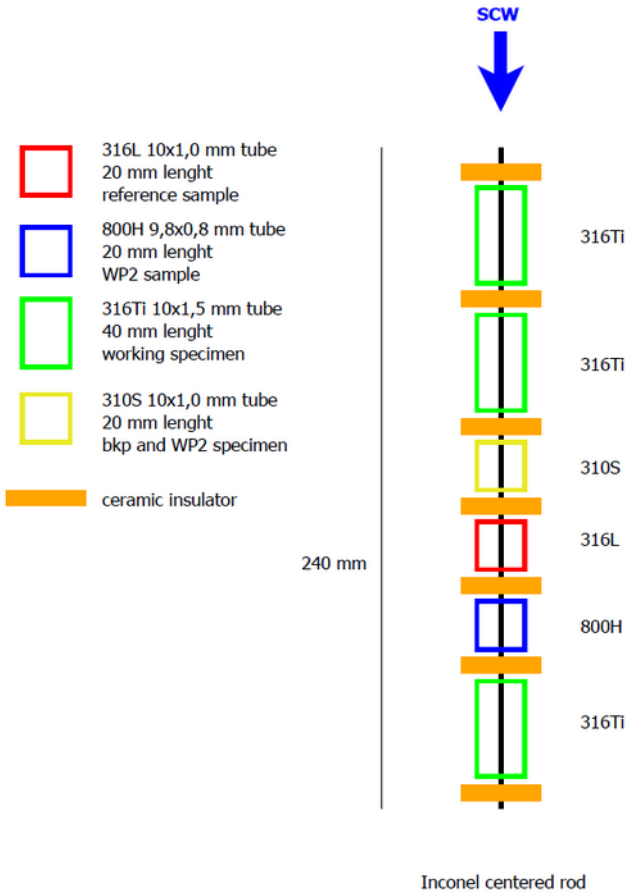
Task 3.2: Reference database

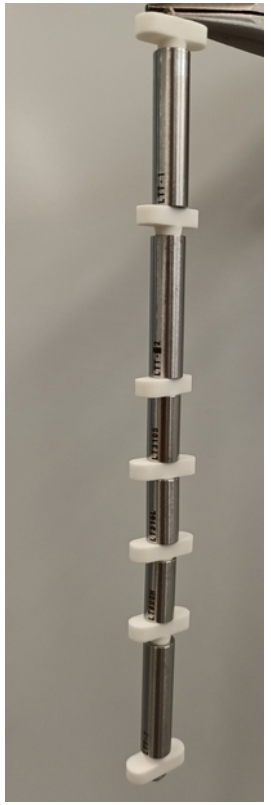
Task Leaders: KIT – Ivan Otic
Contributors: KIT, CNL, CVR, USFD, IPP

Subtask 3.2.1. Experimental investigations of turbulent heat transfer along corroded surfaces (Subtask Leader: KIT – Ivan Otic)
Subtask 3.2.2. Experimental investigations of turbulent flows along corroded surface (Subtask Leader: CNL – Armando Nava-Dominiquez)
Subtask 3.2.3. Exposition of experimental specimens (Subtask Leader: CVR – Jan Vít)
Subtask 3.2.4. Direct numerical simulations of flow over rough surfaces. (Subtask Leader: USFD – Shuisheng He)
Subtask 3.2.5. Direct numerical simulations with CHT (Subtask Leader: KIT – Ivan Otic)
Subtask 3.2.6. Assembling the existing experimental data base (Subtask Leader: IPP – Vladyslav Filonov)

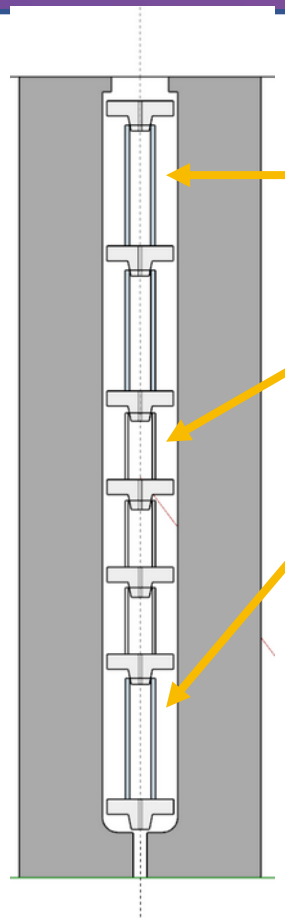
Experimental investigations of turbulent heat transfer along corroded surfaces (CVR*)



PLAN

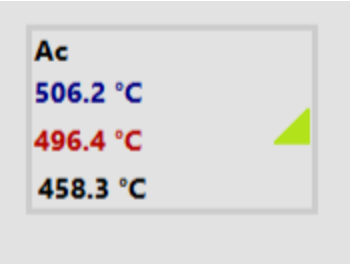


REAL SETUP



SETUP IN VESSEL

Real T values

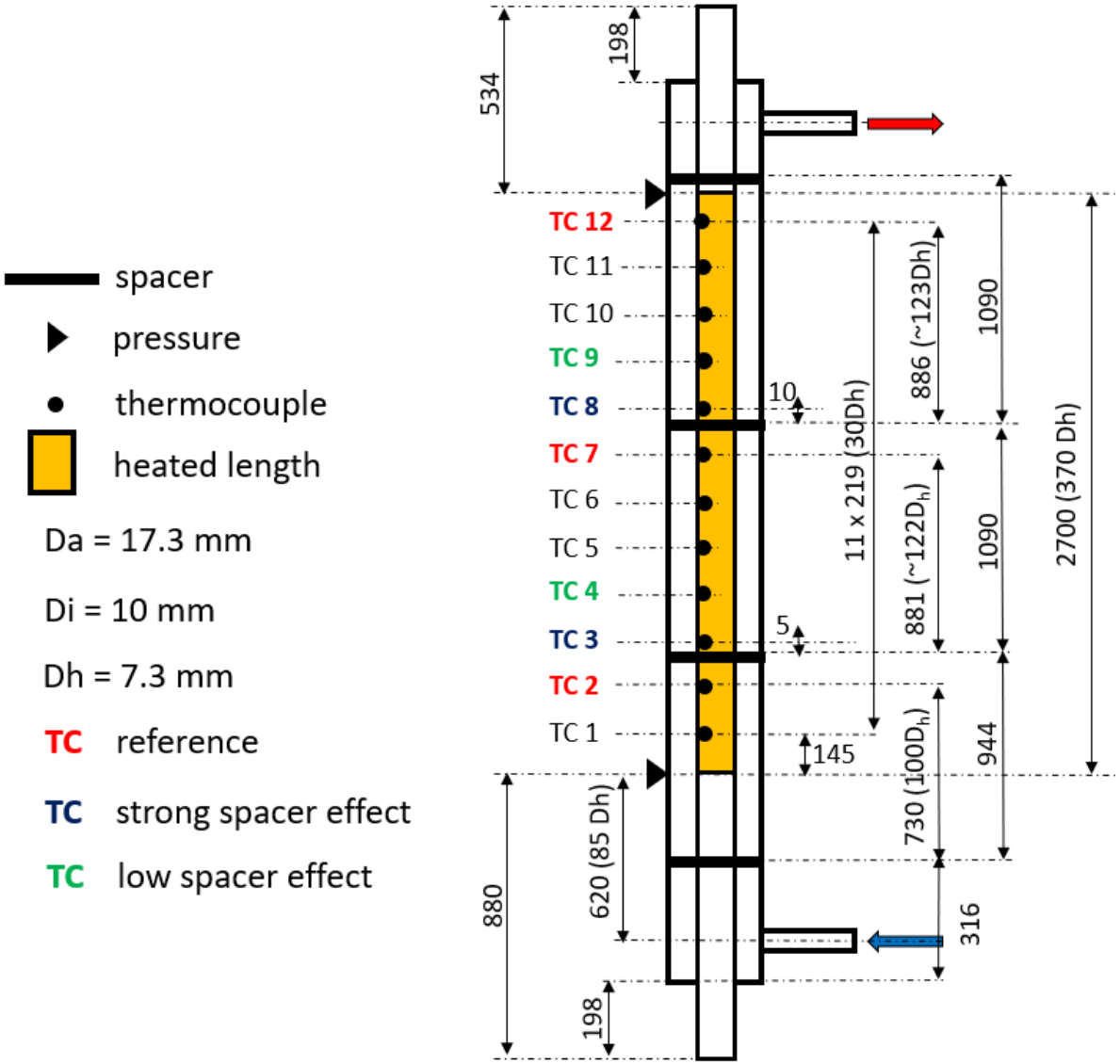


TEMPERATURE DISTRIBUTION

*M. Sipova, J. Vit, CVR, Czech Republic

Experimental investigations of turbulent heat transfer along corroded surfaces (KIT)

- Oxidized rough surface rod
- introduced to TH experiment
- Heated Rod Length: 2.7m
- annular geometry
- 12 thermocouples
- Working fluid R134a



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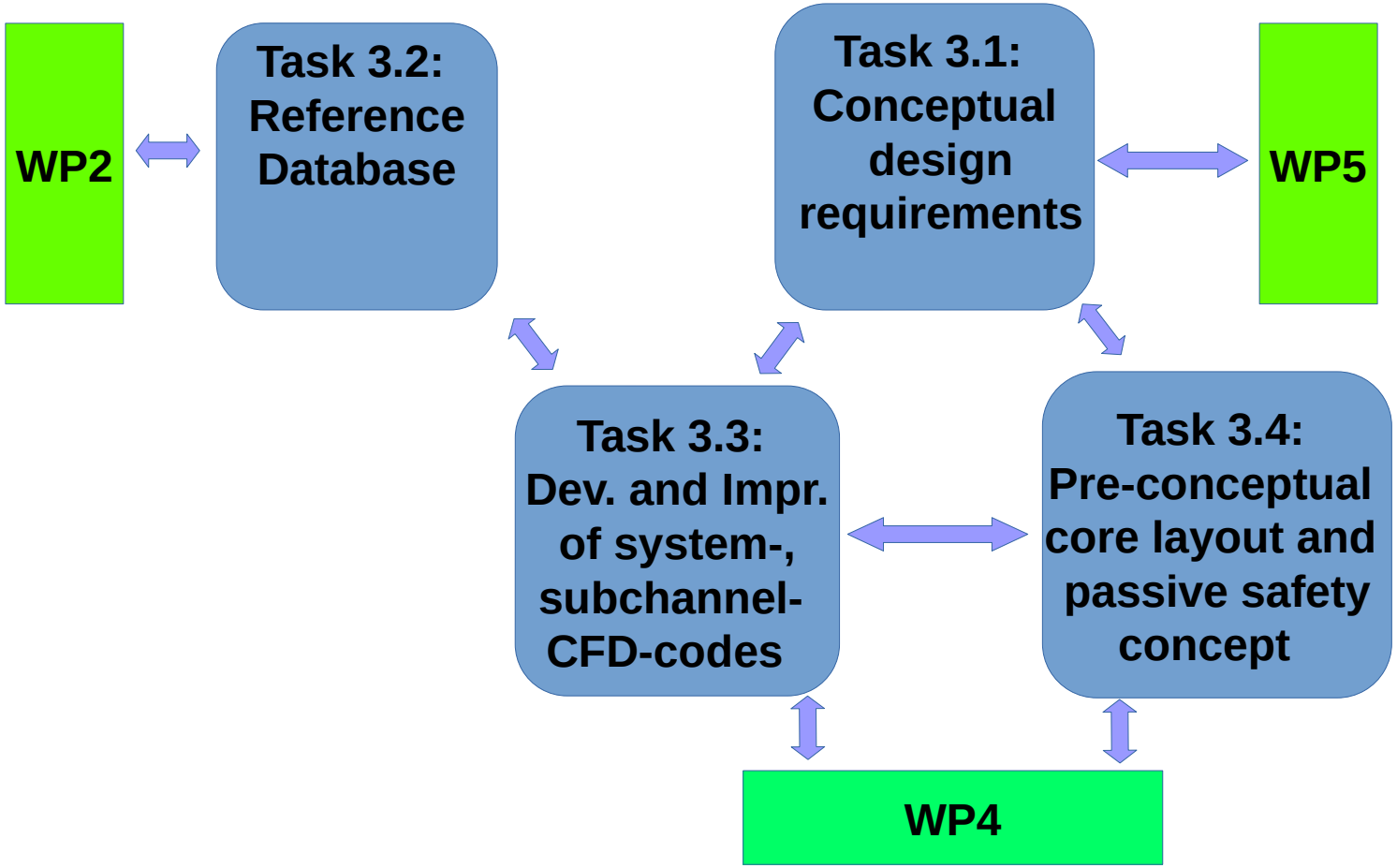
WP3; Task 3.3: Development and improvement of system-, subchannel- and CFD-codes for SCW-SMR



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Task 3.3: Development and improvement of system-, subchannel- and CFD-codes for SCW-SMR

Task Leaders: UNIPI Walter Ambrosini
Contributors: UNIPI, BME, CNL, IPP, KTH, UoN, NPIC

Subtask 3.3.1. Contribution to establish heat transfer correlations and CFD models appropriate for postulated operating conditions. (Subtask Leader: UNIPI - Walter Ambrosini)

Contributors: (UNIPI, BME, CNL, IPP, UoN, NPIC)

Subtask 3.3.2. Benchmarking of system codes under SCW-SMR conditions. (Subtask Leader: BME – Attila Kiss)
Contributors: (BME, CNL, IPP, UoN, UNIPI, NPIC)

Subtask 3.3.3. Investigation and implementation of heat transfer correlations. (Subtask Leader: CNL – Armando Nava- Dominiquez)
Contributors: (CNL)

Subtask 3.3.4. Improvement, implementation and validation of engineering models for turbulent heat transfer under supercritical conditions. (Subtask Leader: IPP – Vladyslav Filonov);
Contributors: (IPP)

Subtask 3.3.5. CFD modeling and validation of supercritical water heat transfer along corroded rough surfaces. (Subtask Leader: KTH – Henrik Anglart);
Contributors: (KTH, UNIPI)

Subtask 3.3.6. Two and more equation RANS modelling of turbulent heat and mass transfer along corroded surfaces (Subtask Leader: UoN – Jie Zhu) ;
Contributors: (UoN, UNIPI)

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Heat transfer correlations for system codes

Table 1. List of the Nusselt number correlation for supercritical fluids

Author	Equations	
Dittus-Boelter (1930)	$Nu_b = 0.023 Re_b^{0.8} Pr_b^n$ $n = 0.3$ for cooling, $n = 0.4$ for heating	(1)
Krasnochekov and Protopopov (1959)	$Nu_b = Nu_{0,b} \left(\frac{\bar{c}_p}{c_{p,b}}\right)^{0,35} \left(\frac{k_b}{k_w}\right)^{-0,33} \left(\frac{\mu_b}{\mu_w}\right)^{0,11}$ $Nu_{0,b} = \left(\frac{\frac{f_b}{8} Re_b \overline{Pr}}{12.7 \left(\frac{f_b}{8}\right)^{0.5} \left(\overline{Pr}^{\frac{2}{3}} - 1\right) + 1.07}\right)$ $f = (1.82 \log_{10}(Re_b) - 1.64)^{-2}$	(2)
Gnielinski (1976)	$Nu = \frac{(f/8)(Re - 1000)Pr}{1 + 12.7(f/8)^{0.5}(Pr^{2/3} - 1)}$ *For smooth tubes:* $f = (0.790 \ln(Re) - 1.64)^{-2}$, $10^4 < Re < 10^6$	(3)

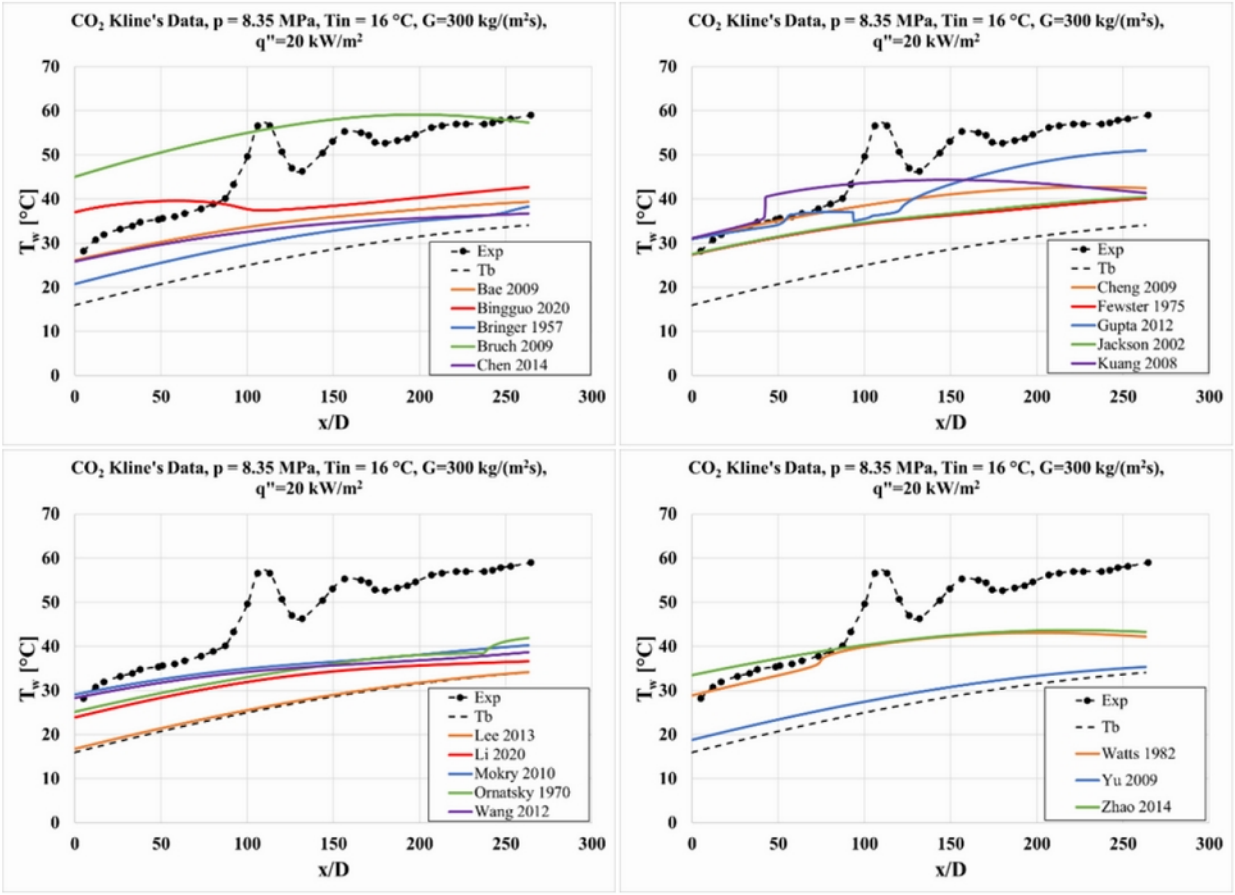

Figure 22.Wall temperature trends obtained in the prediction mode by different heat transfer correlation and compared to the case of CO2 Kline's Data at p = 8.35 MPa, Tin = 16 °C, G=300 kg/(m2s) and q"=20 kW/m2.

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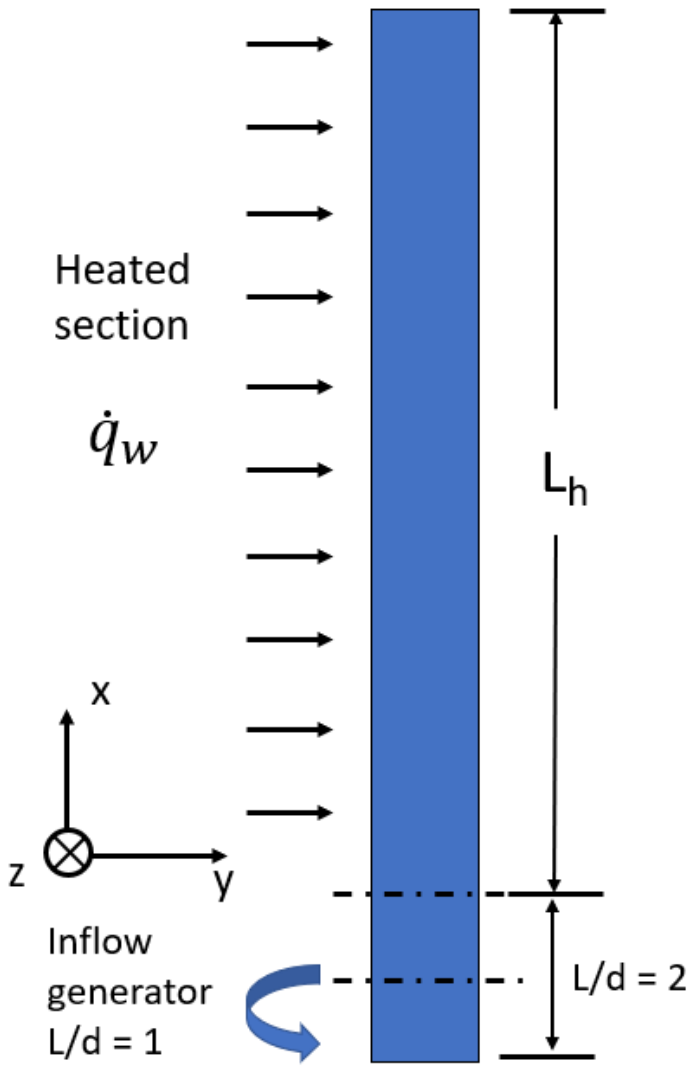
CFD

CO2 DNS - RANS

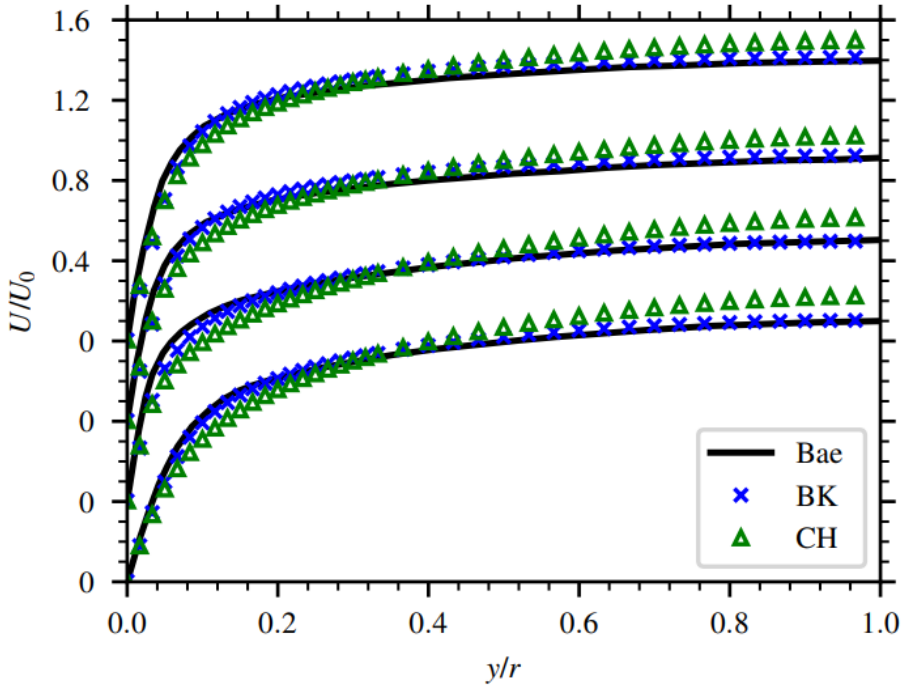
- Inflow generator
- Constant heat flux on the wall of the heated section:
- Adiabatic walls in the inlet section.
- Outlet is defined as uniform pressure.
- Initial velocity uniform value.
- Initial values for k and epsilon calculated as:

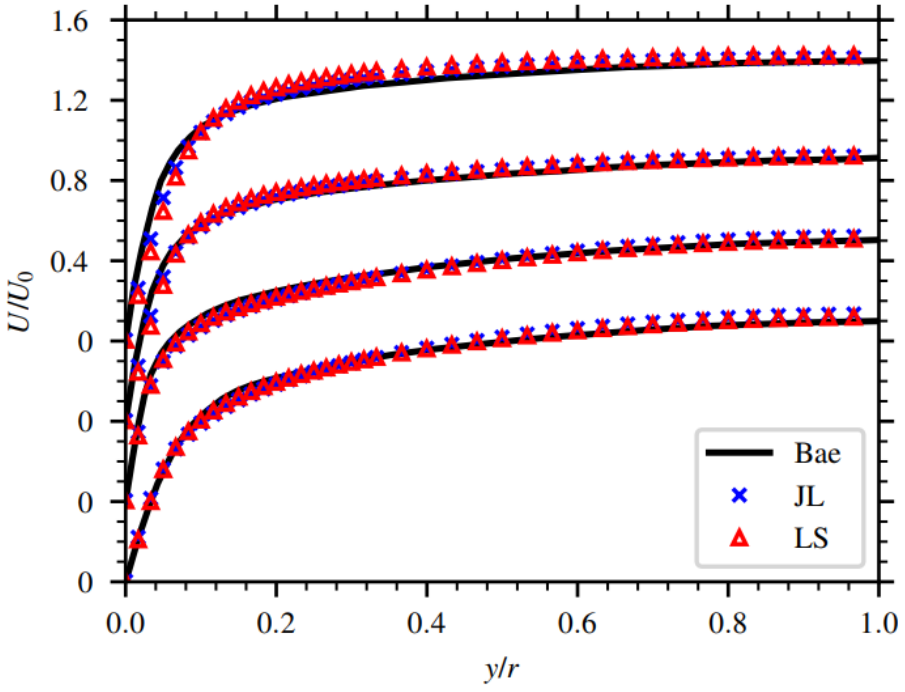


CFD Velocity profiles

CO2 forced convection DNS vs RANS - vertical pipe flow

- Axial locations of x/D = 0, 5, 15 and 30.

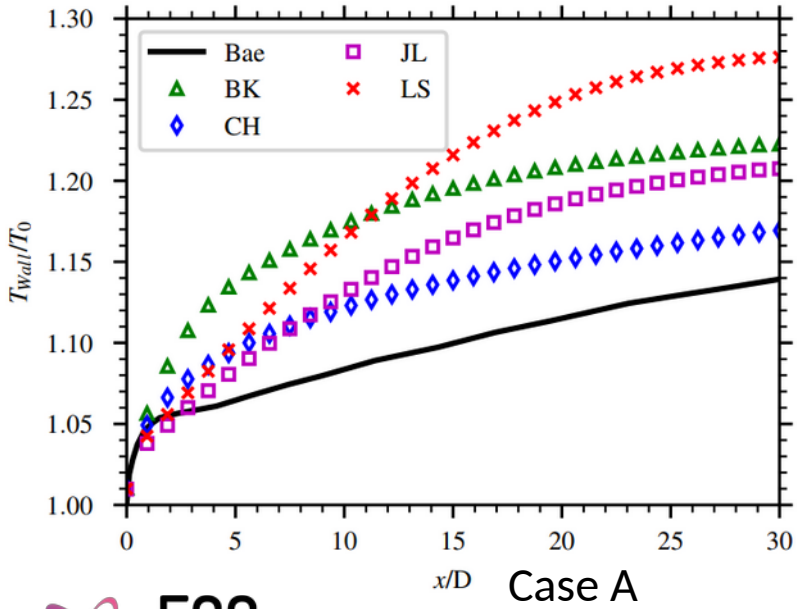




CFD wall temperatures

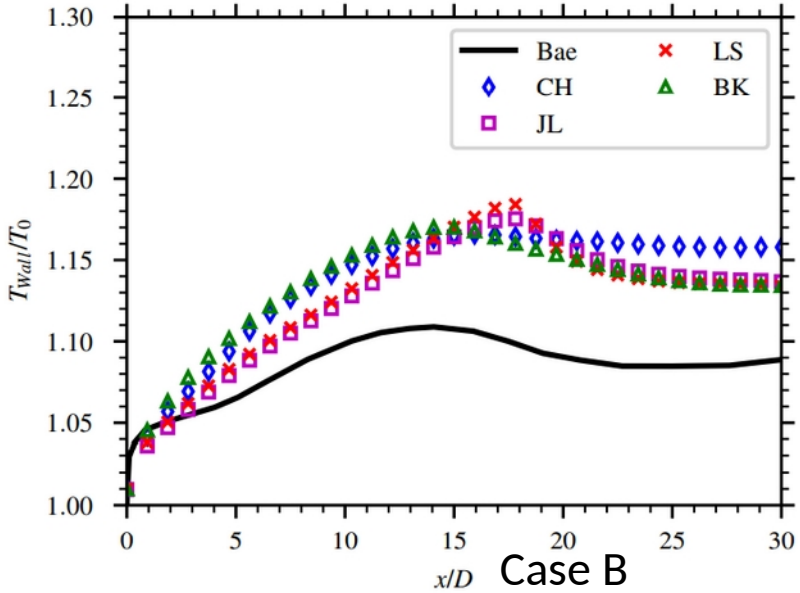
CO2 forced convection DNS vs RANS - vertical pipe flow

forced convection



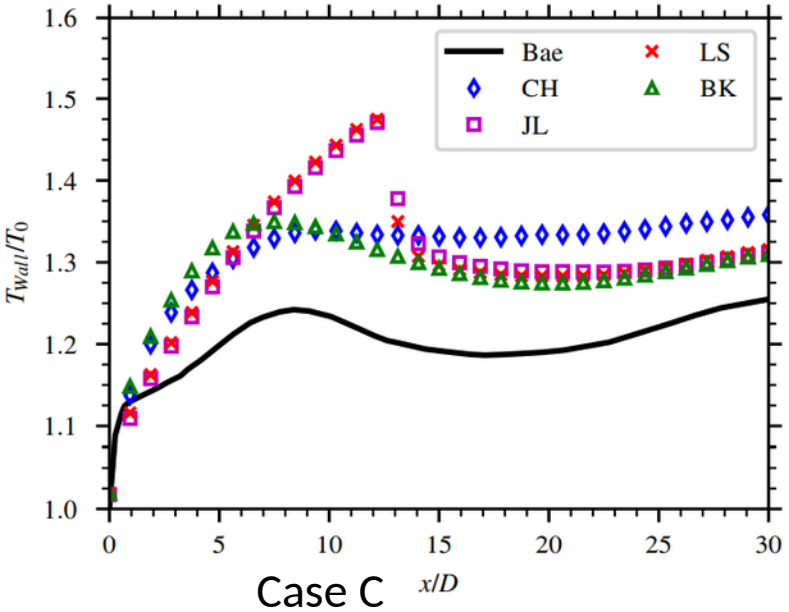
Case A

mixed convection



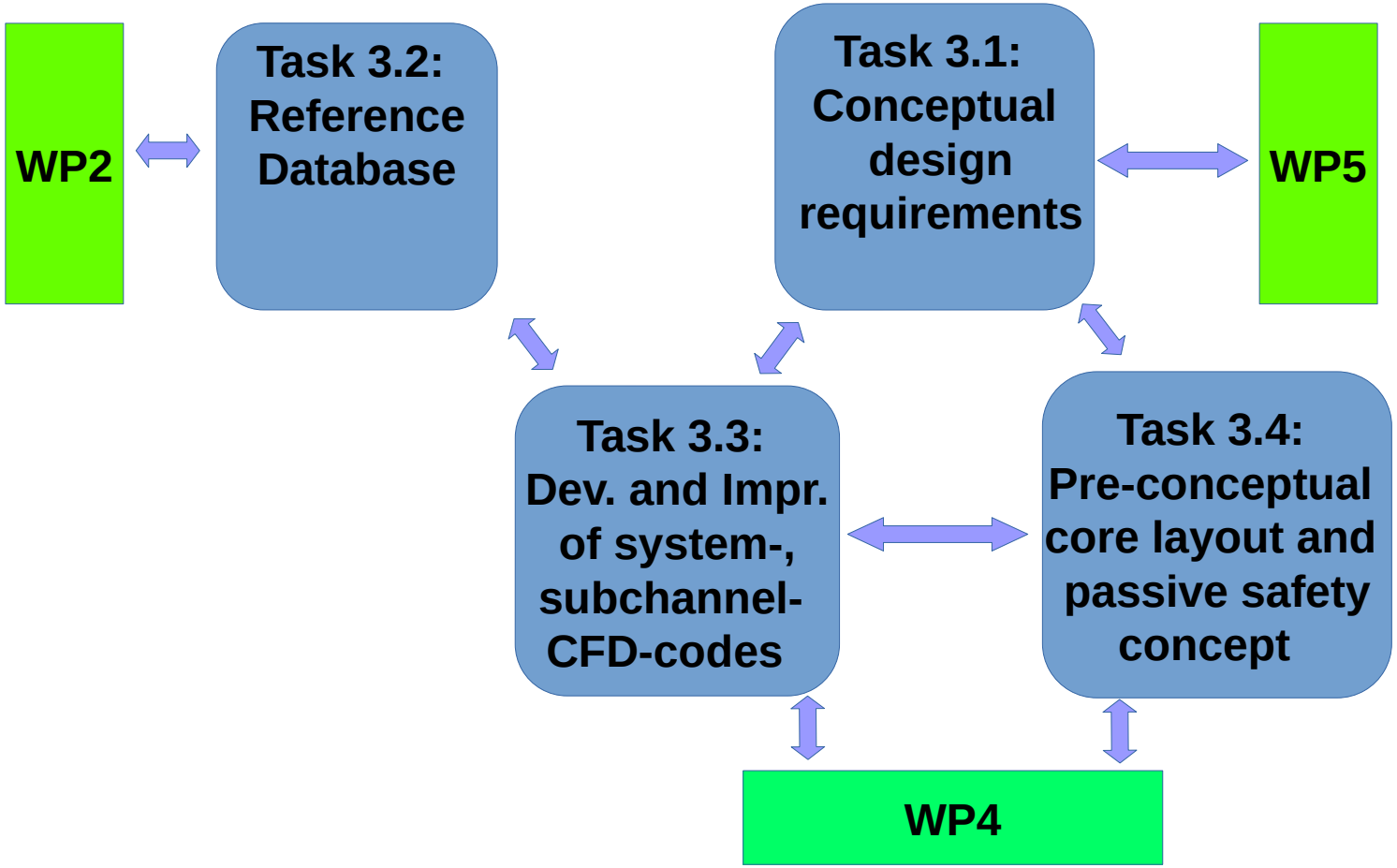
Case B

mixed convection



Case C

WP3; Task 3.4: Pre-conceptual core layout and passive safety concept for SCW-SMR.



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Task 3.4: Pre-conceptual core layout and passive safety concept for SCW-SMR.

Task Leaders: UNIPI Walter Ambrosini
Contributors: UNIPI, BME, CNL, IPP, KTH, UoN

- **Subtask 3.4.1. Thermalhydraulics safety assessment of a proposed SCW-SMR for supporting the design requirements matrix.** (Subtask Leader: CNL – Armando Nava-Dominiquez)
- **Subtask 3.4.2. Safety and design analysis of the SCW-SMR concept.** (Subtask Leader: IPP – Vladyslav Filonov)
- **Subtask 3.4.3. Analysis of pre-conceptual core layout and passive safety concept for SCW-SMR.** (Subtask Leader: BME – Attila Kiss)
- **Subtask 3.4.4. Analysis of passive safety aspects** (Subtask Leader: UNIPI – Walter Ambrosini)

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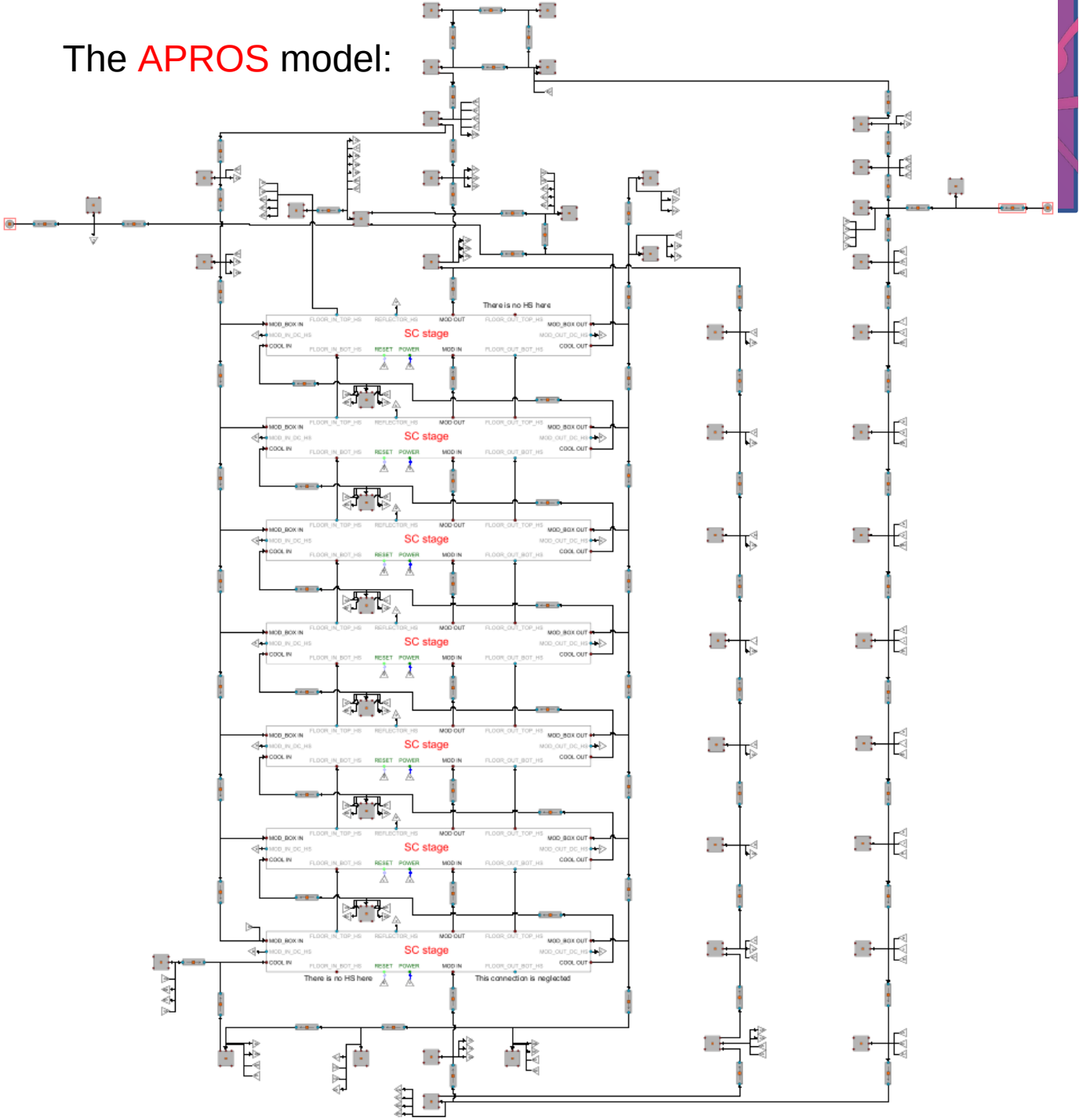
Analysis of pre-conceptual core layout APROS model (BME*)

- BME NTI is building an APROS model of the SCW-SMR reactor concept, based on the CAD model and design documents. APROS version 6.11.32.02 is currently used.
- The reactor vessel model has been finished, including the whole moderator and coolant flow path, and all of the active and passive heat structures.
- At each stage, the horizontal moderator and coolant channels within the fuel assemblies are modelled by 3-3 (cold, average, hot) parallel channels. The active part of these channels has 20 axial nodes.
- The power profiles can be set separately for each stage and each subchannel (total of 21 profiles).

*B. Babcsány, T.Varju, A. Kiss; BME, Hungary

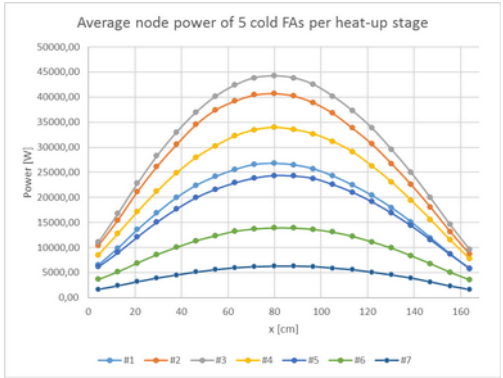
The APROS model:

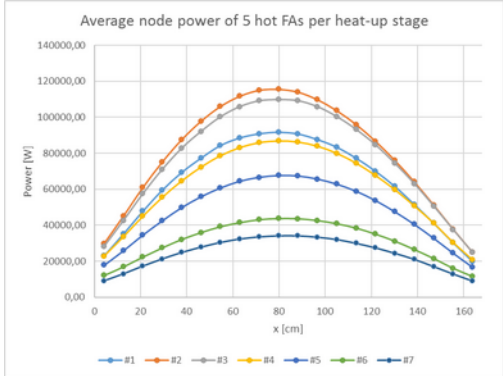


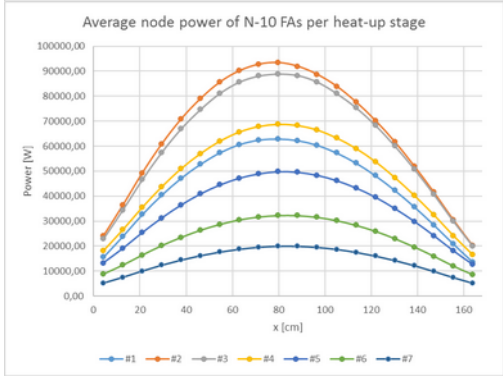
APROS-Serpent coupling (BME*)

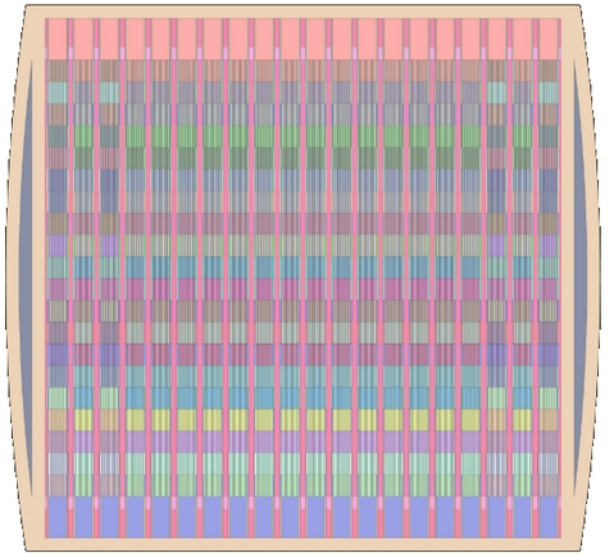
- Serpent 2 full core SCW-SMR model is developed that is able to take into account the moderator, coolant and fuel temperature and density distributions at 20 axial layers in each FA
- iteration is partially automated; the data communication is performed using template Excel-files
- from the Apros cold, hot and average channel TH data, the temperature and density distributions to be taken into account in the Serpent 2 model are determined for each FA node (200 x 20) using a quadratic interpolation scheme based on the power distribution map obtained from the previous power iteration step

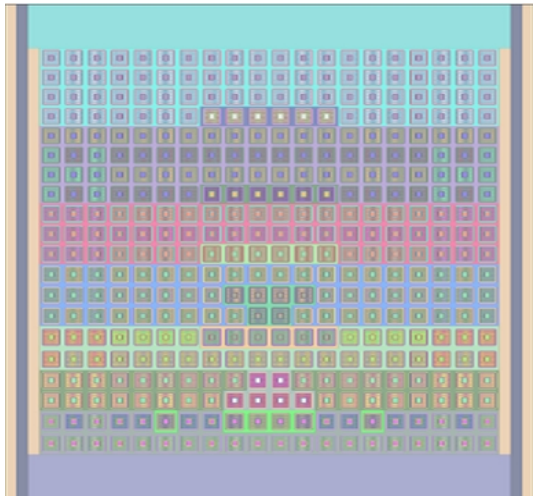
- *B. Babcsány, T.Varju, A. Kiss; BME, Hungary











Thank you!

2.14 ECC-SMART Cladding Material, Alberto Sáez-Maderuelo, CIEMAT (In person)

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JOINT EUROPEAN CANADIAN CHINESE
DEVELOPMENT OF SMALL MODULAR REACTOR TECHNOLOGY

ECC-SMART: Material cladding selection "the first reactor safety barrier"

Alberto Sáez-Maderuelo

21 June 2023 (Celje; Slovenia)

This project has received funding from the Euratom Research and Training programme 2019-2020 under Grant Agreement No 945234.

Index

1. Introduction

2. Cladding for Light Water Reactors

3. Supercritical Water Reactor (SCWR) and Small Modular Reactors (SMR)

4. Cladding materials for SCWR and SCW-SMR

5. ECC-SMART: Materials Testing Workpackage

Index

Reactors

H_2O

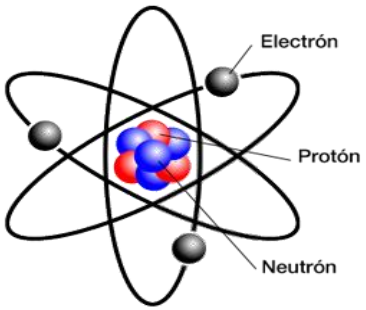
Cladding

ECC smart

Introduction

Nuclear fission: subdivision of a heavy atomic nucleus, such as that of uranium or plutonium, into two fragments of roughly equal mass. The process is accompanied by the release of a large amount of energy.

Energy: the capacity for doing work; technological development of the society.



ATOM: Energy storage.

3 Stages

- 1896-1940: First nuclear fission achieved by Fermi (1934); 1938: Bohr proposed the U^{235} as a fissionable isotope better than U^{238} and Slizard and Fermi proposed the use of a moderator to slow down the emitted neutrons to sustain the chain reaction; Perrin demonstrated that chain reaction could be sustained in a U-H_2O mixture.
- 1939-1950: The military years: the aim was to build the firdt atomic bomb; 1942 the first nuclear reactor was built (Chicago Pile-1).
- 1951-2023: Civilian Energy Generation: 1957 the USA began the operation of a PWR (Shippingport, 60 MWe) using Zr alloy as **cladding material** and H_2O as coolant and moderator material and enriched U as fuel.

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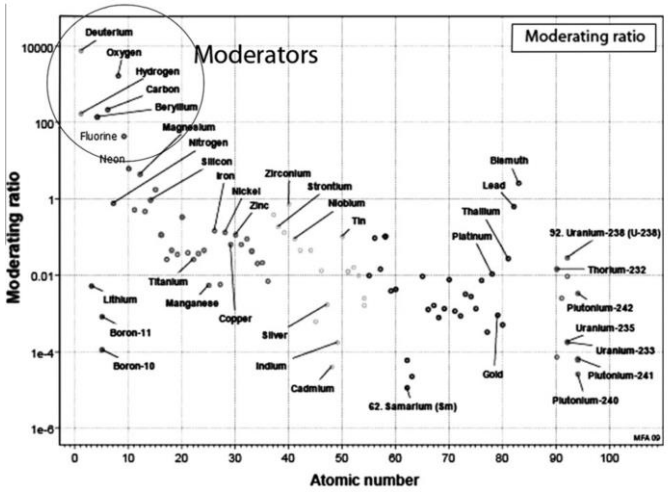
Introduction: coolant/moderator

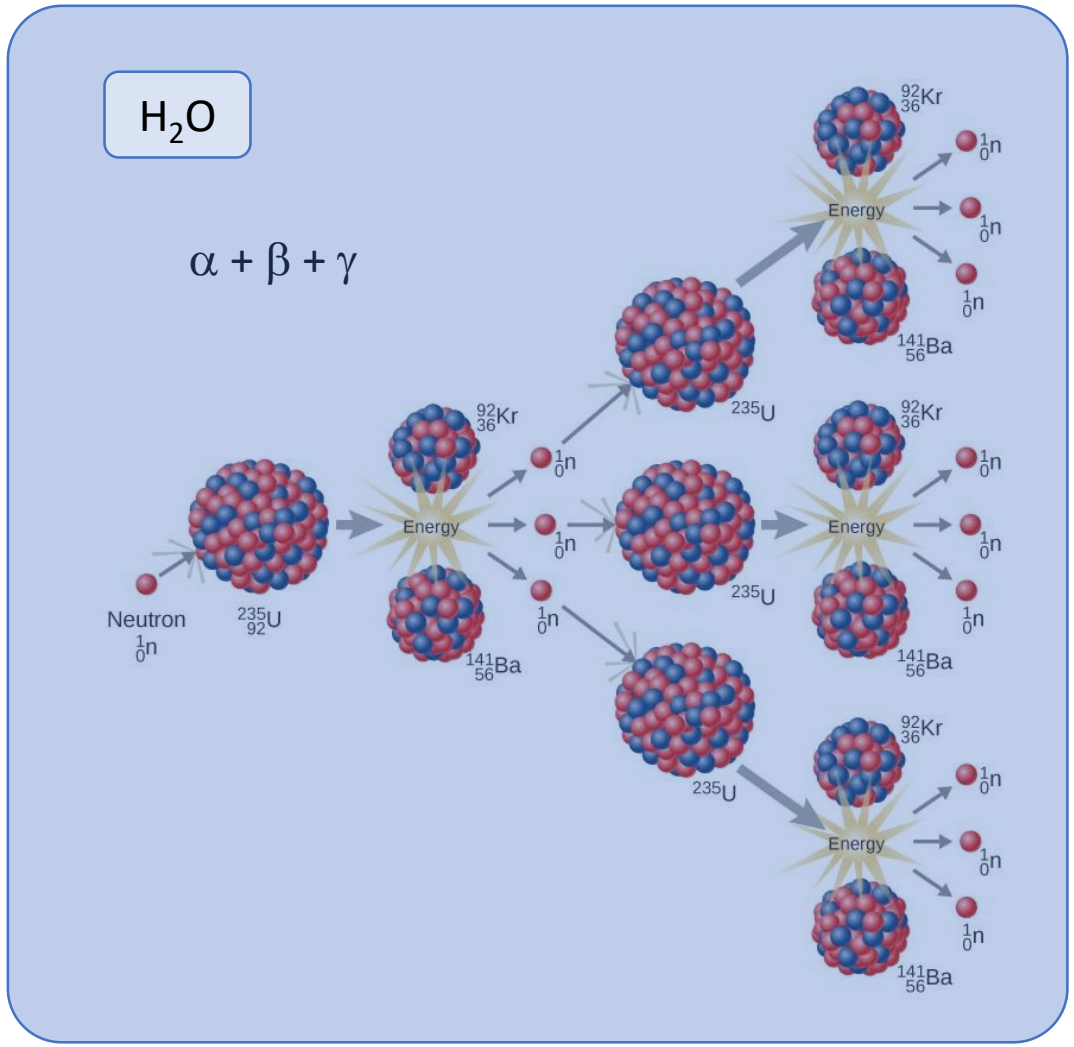
COOLANT/MODERATOR:

- High neutron scattering
- Low neutron absorption
- Good moderator: fast neutrons into thermal neutrons (high effective neutron absorption; increase fision reactions)
- Chemical stability
- Price
- Availability
- High heat Exchange.

H_2O



Azevedo Engineering Failure Analysis (2011) 18 (1943-1962)



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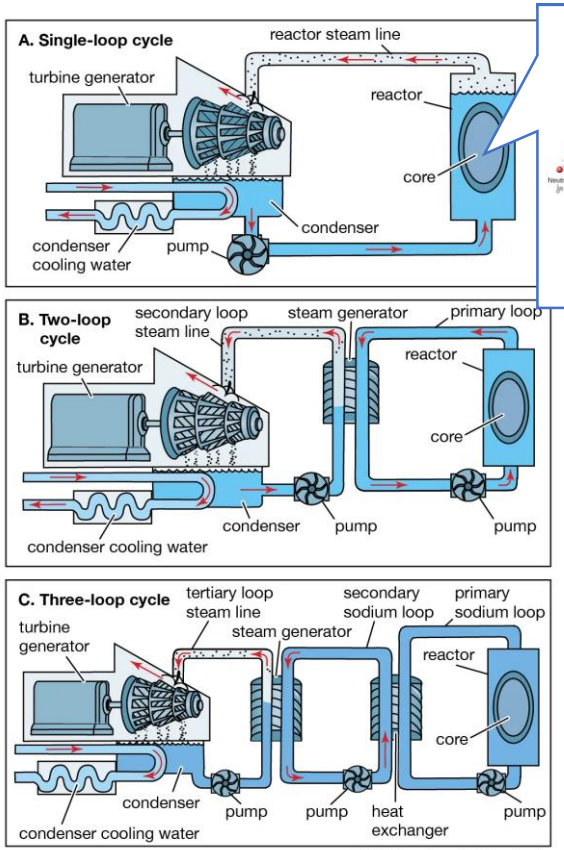
Introduction: nuclear reactor

Nuclear Reactor: device that aims to use the energy produced in the fission reaction to produce electricity in a controlled and safe way.



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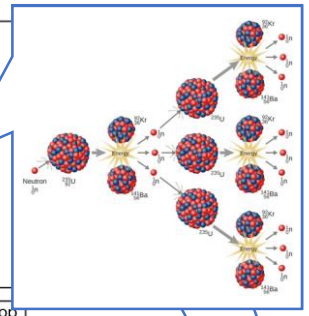


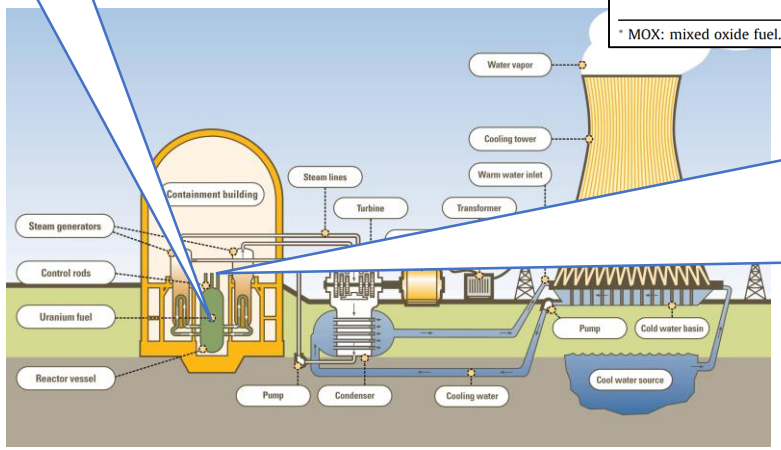
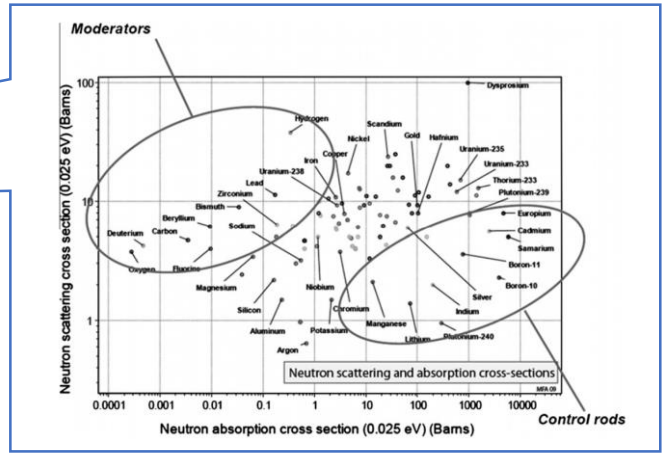


Table 4
Common design of nuclear fission reactors (GI and GII), showing the variety of operating conditions and materials used for fuel, moderator, coolant and fuel cladding [1,34,68].

Name of the reactor	Fuel material	Moderator material	Primary coolant material	Fuel cladding material	Operation parameters
GCR, Gas-cooled reactor (GI)	Natural UO_2	Graphite	CO_2	Magnesium alloys	P: 2.7 MPa T_{inlet}: 250 °C T_{outlet}: 400 °C
PWR, Pressurised water reactors (GII)	Enriched UO_2 MOX	H_2O	H_2O	Zirconium alloys	P: 15 MPa T_{inlet}: 290 °C T_{outlet}: 325 °C
BWR, Boiling water reactor (GII)	Enriched UO_2 MOX	H_2O	H_2O	Zirconium alloys	P: 7 MPa T_{inlet}: 280 °C T_{outlet}: 330 °C
PHWR, Pressurised heavy water reactor (GII)	Natural UO_2	D_2O	D_2O	Zirconium alloys	P: 10 MPa T_{inlet}: 270 °C T_{outlet}: 310
AGR, Advanced gas-cooled reactor (GII)	Enriched UO_2	Graphite	CO_2	Austenitic stainless steel	P: 4 MPa T_{inlet}: 340 °C T_{outlet}: 635 °C
RBMK, High power channel-type reactor (GII)	Enriched UO_2	Graphite	H_2O	Zirconium alloys	P: 8 MPa T_{inlet}: 260 °C T_{outlet}: 290 °C

* MOX: mixed oxide fuel.



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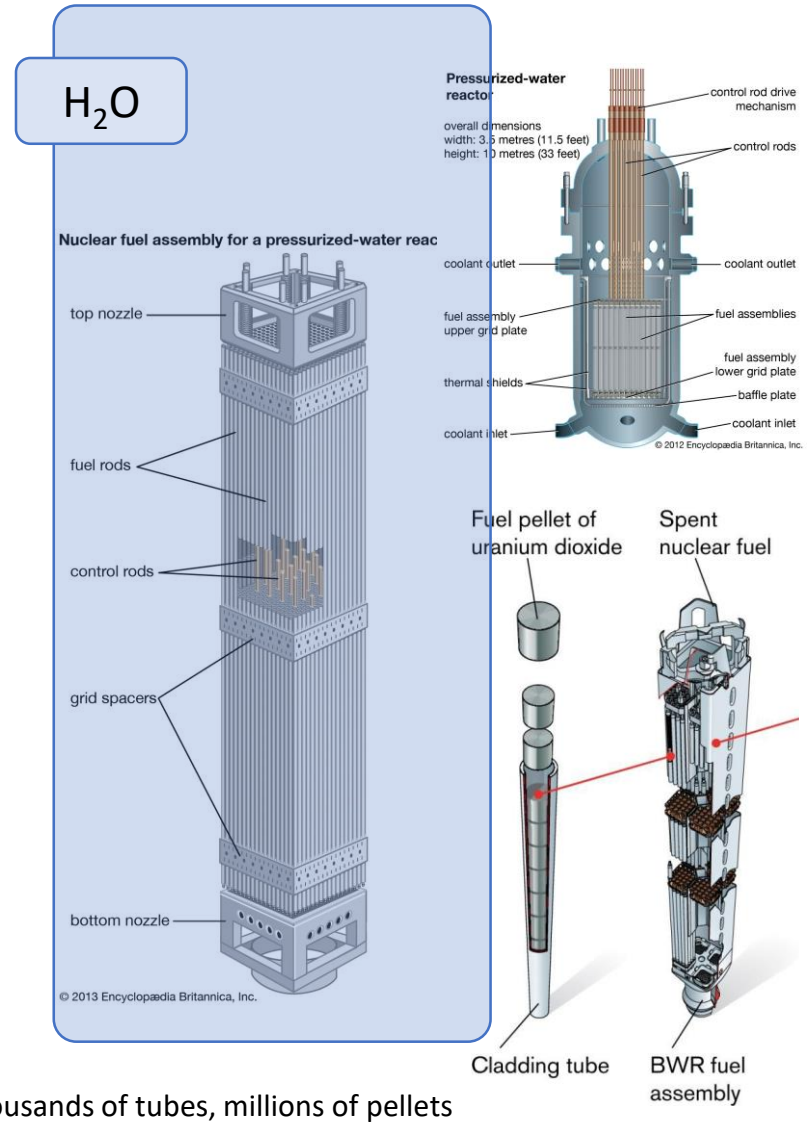
Cladding Materials for LWR

> ***Fuel cladding*** *is the outer layer of the fuel rods, standing between the* ***reactor coolant*** *and the* ***nuclear fuel*** *(i.e.,* ***fuel pellets****). It is a corrosion-resistant material with a low absorption cross section for thermal neutrons (~ 0.18 × 10^{-24} cm^2), usually* ***zirconium alloy****.* ***Cladding*** *prevents radioactive fission products from escaping the fuel matrix into the reactor coolant and contaminating it. Cladding constitutes one of the barriers in the '****defense-in-depth*** *'approach. Therefore its* ***coolability*** *is one of the key safety aspects.*
>
> Nuclear-Power.com

CLADDING

- Prevents radioactive fission products from escaping the fuel matrix into the reactor coolant and contaminating it.
- Maintains the geometry and structure of the fuel preventing it from disintegrating or dispersing.



Thousands of tubes, millions of pellets

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Selection of Cladding Materials

Nuclear Fuel

Moderator

Coolant

SELECTION of CLADDING MATERIAL

ITERATIVE PROCESS

MATERIAL SELECTION

Mechanically resistant at high temperatures (normal and accident)

Mechanical interaction between fuel and cladding:
-Cladding creep
-Fission gases/swelling

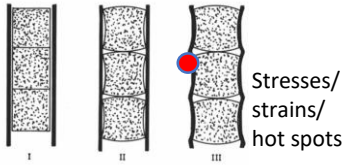
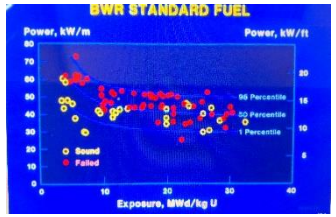


Fig. 2. Interaction between fuel and cladding [20].

Steinar Nuclear Engineering and Design 21 (1972) 237-256.



PCI failures (red) ocurred with an increasing probability as the maximum ramp power increased, (Armijo/Abdullahi, 2009)

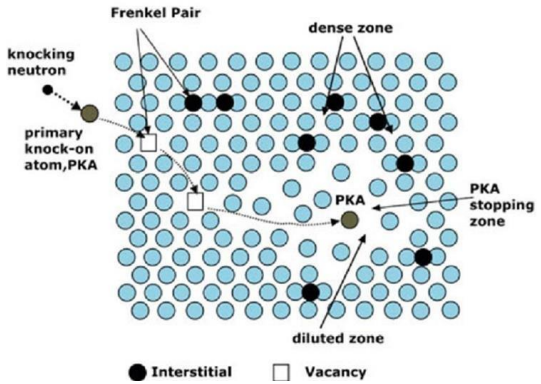
Corrosion resistance

Oxidation of cladding (0,17 times the cladding thickness; 0,6 mm)

Release of corrosion products/Thermal cond.

Stress corrosion Cracking (SCC)

Neutron resistance (defects tan modifies corrosion res., mechanical properties, difussion,…) and high neutron transparency



Thermal expansion/Thermal conductivity

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Selection of Cladding Materials (LWR)

Calculated effective neutron absorption cross section (neutron absorption cross section per unit of yield strength) for pure elements in comparison to Zr [31,34].

Elements	Neutron absorption cross section (Barns)	Yield strength (MPa)*	Relative effective neutron absorption cross section in relation to Zr
Be	0.009	200–350	0.04
C	0.004	24–28	0.2
Mg	0.063	65–100	1
Si	0.160	165–180	1
Zr	0.185	135–310	1
Al	0.231	30–40	8
Mo	2.480	170–350	10
Cr	3.050	185–280	15
Nb	1.150	75–95	15
Fe	2.550	110–165	20
Ni	4.430	80–280	30
V	5.040	125–180	40
Sn	0.630	7–15	70

* Values for pure commercial alloys in the annealed condition.

Zirconium alloys used for fuel cladding [55].

Elements	Zircaloy 2	Zircaloy 4	Zr–Nb	Zirlo	M5	MDA	E 365	HANA 4
Sn	1.2–1.7	1.2–1.7	–	0.96	–	0.8	1.2	0.4
Fe	0.07–0.2	0.18–0.24	–	0.1	–	0.2	0.35	0.2
Cr	0.05–0.15	0.07–0.13	–	–	–	0.1	–	0.1
Ni	0.03–0.08	–	–	–	–	–	–	–
Nb	–	–	2.4–2.8	0.99	1.0	0.5	1.0	1.5
O	1400 ppm	1400 ppm	0.13	1430 ppm	1250 ppm	–	–	–

C.R.F. Azevedo Engineering Failure Analysis (2011) 18 (1943-1962)

Zr MAIN MATERIAL FOR CLADDING IN BWR/PWR

Low neutron absorption
Good mechanical properties
High service temperature
High corrosion resistance/irradiation

$Zr + 2H_2O \rightarrow ZrO_2 + 2H_2$ 340 ºC; delayed hydride crack

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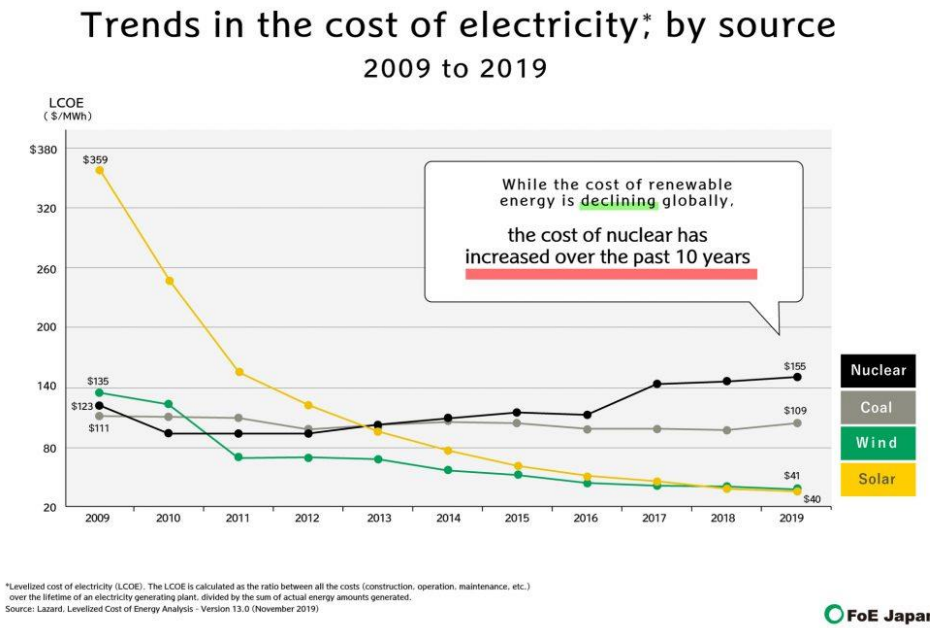
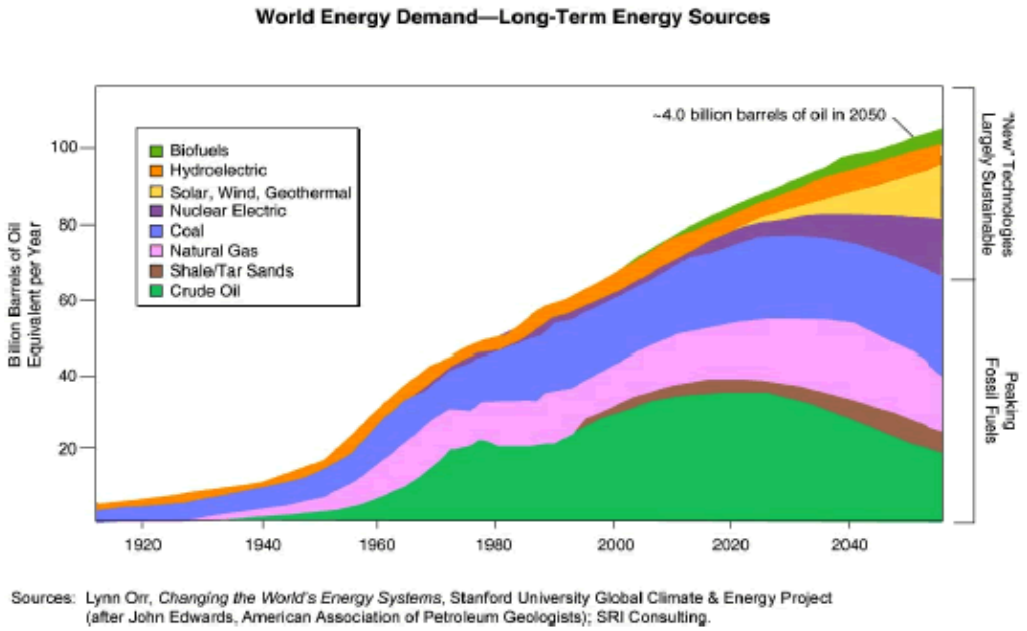
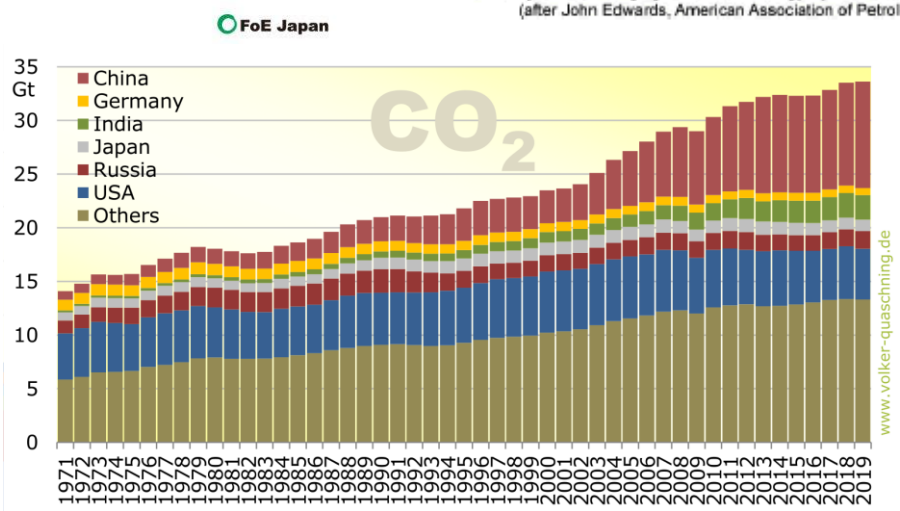
Supercritical Water Reactor (SCWR)







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Generation IV Reactors

Nuclear industry is trying to solve or helping to solve them by Gen IV Reactors

Main characteristics of GIV nuclear fission reactor systems [66–75].

Reactor type	Fuel	Coolant	Moderator	Neutron spectrum	Core outlet temperature (°C)	Dose (dpa)	Candidate cladding material
Super critical water-cooled reactor (SCWR)	UO_2 (thermal) MOX (fast)	Water	Water	Thermal or Fast	~ 550	10–40	Zr alloys Austenitic stainless steel F/M steels Ni–based superalloys ODS alloys
Sodium-cooled fast reactor (SFR)	UPuC/SiC U–Pu–Zr MOX	Liquid Na	–	Fast	~ 550	90–160	F/M steels ODS alloys
Lead-cooled reactor (LFR)	Nitrides, MOX	Liquid Pb alloys	–	Fast	550–800	50–130	Austenitic stainless steel F/M steels ODS alloys SiC Refractory alloys
Gas-cooled fast reactor (GFR)	$(U, Pu)O_2$ Carbide fuel (U, Pu)	He	–	Fast	~ 850	50–90	ODS alloys Refractory alloys SiC
Molten salt reactor (MSR)	Salt	Molten salt	Graphite	Thermal	700–800	100–180	No cladding
Very high temperature reactor (VHTR)	TRISO UOC	He	Graphite (thermal)	Thermal or Fast	1000	7–30	ZrC coating SiC coating

* TRISO: Tristructural isotropic fuel, a type of micro fuel particle consisting of a fuel kernel composed of uranium oxide (sometimes uranium carbide) in the centre, coated with four layers of three isotropic materials.

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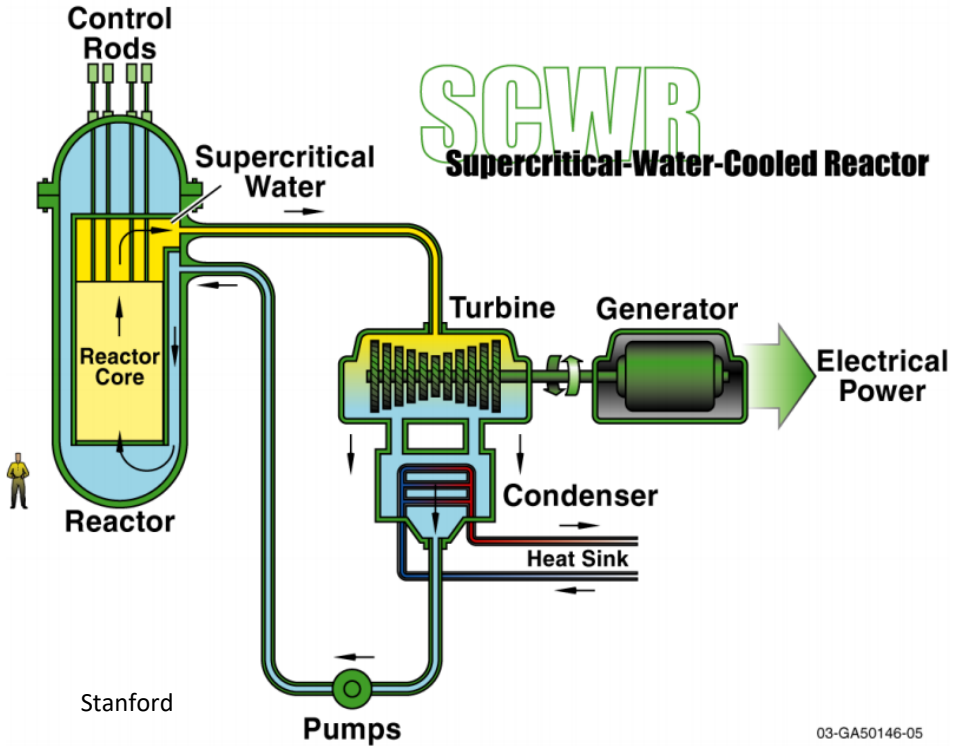
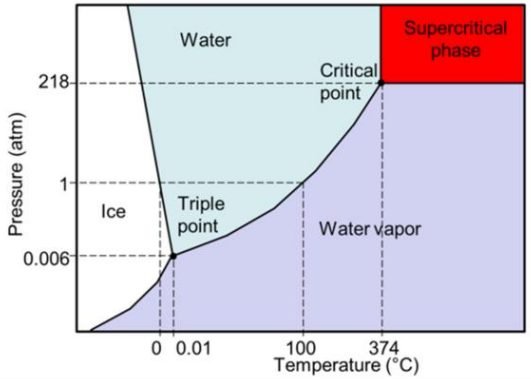
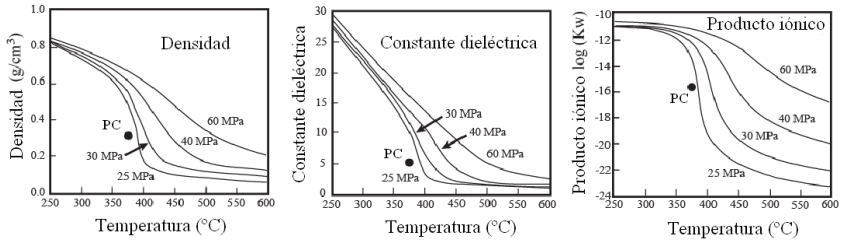
Supercritical Water Reactor (SCWR)

Supercritical water reactors (SCWR) base their design on light water reactors. Existing LWRs: Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWR)







ADVANTAGES

Increase the efficiency over LWR (45%)
Decrease capital costs
Decrease operational costs
Decrease electrical energy costs
Water is familiar and relatively safe médium
High enthalpy

DISADVANTAGES

The behavior of water with P and T within the supercritical region is not well known: It can affect the behavior of materials. Radiolysis.

Current SCWR design: direct cycle system (like BWR but without phase separation) operating at 25 MPa; average 500 °C.

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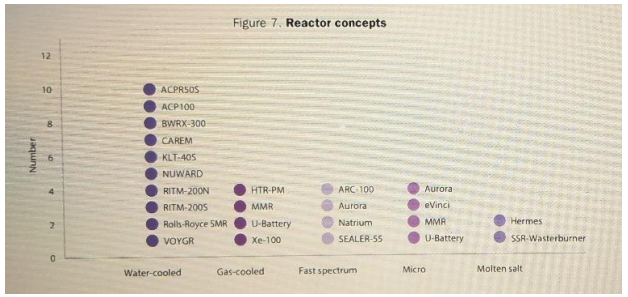
Small Modular Reactors (SMRs)

Small modular reactors (SMRs) are a proposed class of nuclear fission reactors that are **smaller** than conventional nuclear **reactors** and can be built in one location (such as a factory), then shipped, commissioned, and operated at a separate site. SMRs have a **power** capacity of up to **300 MW(e)** per unit. Many SMRs, which can be **factory-assembled and transported to a location for** installation, are envisioned for markets such as industrial applications or remote areas with limited grid capacity. SMRs offer the possibility to combine nuclear with alternative energy sources, including renewables and to bring reliable energy to remote and poor areas.



The NEA SMR Dashboard

ADVANTAGES

Modularity

As was written, the term "**modular**" in SMRs refers to its **scalability** and the ability to fabricate major components of the nuclear steam supply system (NSSS) **in a factory environmen**t and then transport them to the site.

Enhanced safety and security

Lower thermal power of the reactor core, compact architecture, and employment of passive concepts have the potential for enhanced safety and security compared to earlier designs and large commercial reactors.
The **passive safety systems** are a very important safety feature in the SMR.

Construction time and financing

DISADVANTAGES

Large-scale Production

Most economic benefits (especially lower capital cost) stated are valid for **n-th unit** produced. Large-scale production of SMRs and initial orders for tens of units is required to achieve these economic benefits.

Licensing

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ECC-SMART: SCW-SMR

SCWR + SMR

ECC smart

ECC-SMART: SCW-SMR

Reactors

H_2O

Cladding

ECC-SMART: SCW-SMR

Reactors

H_2O

Cladding

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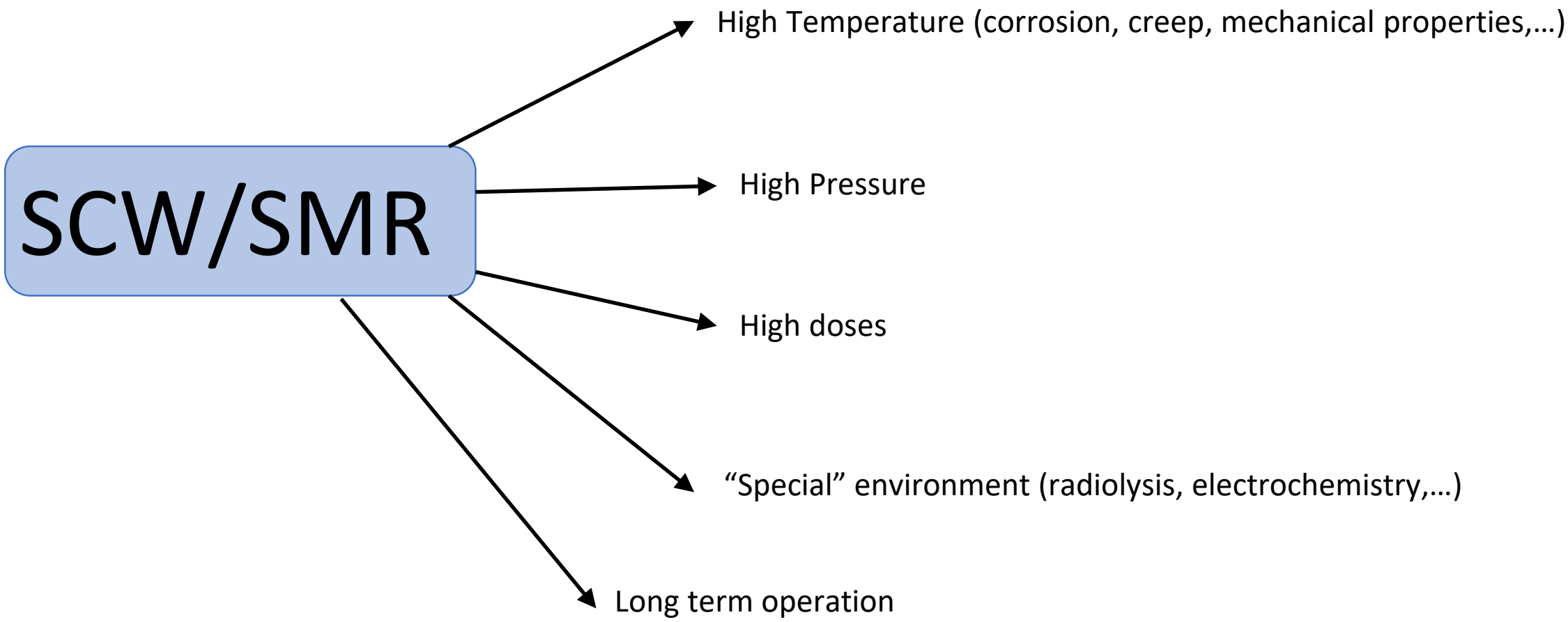
ECC-SMART: materials



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ECC-SMART: Selection of materials

Materials previously used in LWR with optimal behaviour/in codes: Zr alloys, Ni alloys, Stainless Steels

(SCC)

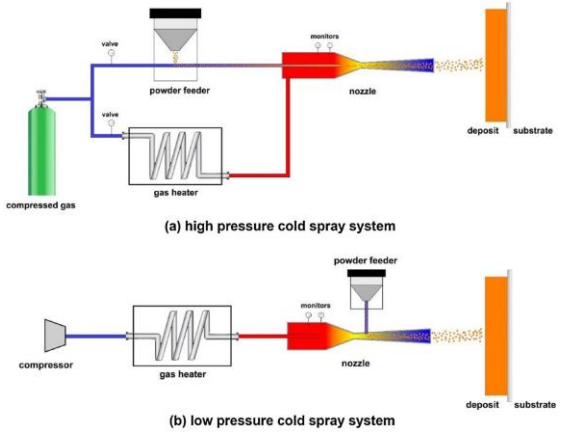
Alloy	Fe	Cr	Ni	Mo	Mn	Si	Al	Zr	C	Ti	Others
310	bal	24.5	20.2	0.29	1.17	0.33	-		0.048		
310S +Zr	bal	25.04	20.82	0.51		0.51		0.59	0.034		P:0.016
310S FG	bal	24.74	21.92	-	-	0.25	-	-	0.099	0.81	N:0.0006 P: <0.005
310S FG	bal	25.03	22.81	2.38						0.41	Nb: 0.26 N: 0.002 P: <
347	bal	18.0	11.0	-	2.0	1.0	-	-	0.08	-	Nb:10xC*
800H	bal	22.5	34.8	-	1.59	0.95	0.45	-	0.08	-	
625	4.9	22.6	bal	9.8	0.43	0.47	0.47	-	0.09	0.45	Nb: 3.7 Cu: 0.68
214	3	16	75	-	0.5	0.2	4.5	0.1	0.05	-	Y: 0.01 B: 0.01
1.4970	bal	15	15.3	1.18	1.68	0.53			0.095	0.45	
ODS PM2000	bal	19					5.5			0.5	Y_2O_3: 0.5
316L	bal	16.6	10	2.0-3.0	1.9	0.65			0.022		
316L(N)	bal	18	12	2.0-3.0	2.0	1.0			0.030		N: 0.16
316Ti	bal	16.6	12.1	2.03	1.15	0.45			0.032	0.38	
316L + Zr	bal	16.54	10.71	2.22		0.46		0.56	0.006		P: 0.016

- Zr alloys suffer from severe oxidation in SCWR simulated conditions

- Ni alloys: these are not the best option due to their low neutron transparency (15 times lower than Zr) and the production of He that produces embrittlement.

- Stainless steels with more than 20% Cr, good candidates high corrosion resistance in SCW, good creep resistance in spite of their low neutron transparency and swelling problems.

▶ 3 cladding candidate materials were selected: SS 310S, A 800H and AFA based on SS 310



316 L Cold Sprayed: Additive Manufacturing process (EDF)

ECC-SMART: Selection of materials

Tab. 4 The chemical composition of tubes from 800H according to the producer (material sheets[1]).

Element	C	Mn	S	Si	Ni	Cr	Mo
Longitudinal cut **%wt.**	**0.08**	**0.7**	**0.0005**	**0.2**	**30.7**	**19.7**	**0.18**
Perpendicular cut **%wt.**	**0.08**	**0.7**	**0.00001**	**0.2**	**30.8**	**19.8**	**0.18**

Element	Ti	N	Fe	Cu	Al	Co
Longitudinal cut **%wt.**	**0.58**	**0.01**	**46.7**	**0.45**	**0.40**	**0.11**
Perpendicular cut **%wt.**	**0.54**	**0.01**	**46.5**	**0.46**	**0.43**	**0.11**

Tab. 1 The chemical composition of tubes from SS 310S tested in this project according to the producer (material sheets[1]).

Element	C	Mn	Si	P	S	Ni	Cr	Mo	Fe
min	-	-	-	-	-	18.00	24.00	-	Bal.
max	0.08	2.00	1.00	0.045	0.03	22.00	26.00	0.75	Bal.
%wt.	**0.060**	**1.190**	**0.39**	**0.024**	**0.0006**	**21.450**	**25.270**	**0.250**	**Bal.**

ECC smart

WP 2: Materials Testing

Vallecitos

GEN IV International Forum

HPLWR-I & II, …

Laurence Leung: Supercrital Water Reactors. Laurence Leung. SCWR System Steering Committee, march 2017.

Guzonas, D., Svishchev, I. Journal of Supercritical Fluids, 60, pp. 121-126

FFP and SCWO

Based on previous activities and projects we selected some open points to be studied:

NEW

- Corrosion behavior of candidate alloys for cladding during long exposures in SCW.
- "Real" components (tubes); effect of shapping.
- Corrosion tests at operation conditions and under simulated accident conditions.
- Effect of neutron irradiation
- Radiolysis processes in SCW (supress at 400 ºC?)
- Changes in the physicochemical properties of water with P and T; electropchemistry.

WP 3: roughness and conductivity of oxides

WP 4: oxides composition; corrosion rates

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WP 2: Materials Testing (sub-tasks)

WP2: MATERIALS TESTING (sub-tasks)

→ WP 2.1 (M1-48): Selection and characterization of materials.
Task Leader: CVR – Daniela Marušáková

→ WP 2.2 (M1-48): Study of the corrosion and EAC behaviour of Selected alloys out-of-pile.
Task Leader: JRC – Radek Novotný

→ WP 2.3 (M1-48): Study of the corrosion and EAC behaviour of selected pre-irradiated alloys in SCW.
Task Leader: CVR – Monika Šípová

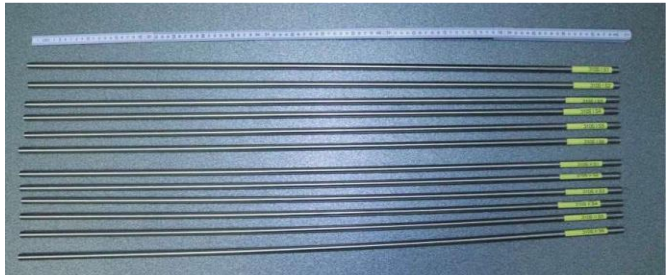
→ WP 2.4 (M1-48): Study of the effect of SMR-SCW chemistry and changes in the chemical properties of SCW in the behaviour of candidate materials.
Task Leader: CNL – Matt Edwards/Armando Nava-Dominiquez

Sub-task 2.1: Selection and characterization of materials

- 3 cladding candidate materials were selected: SS 310S, A 800H and AFA based on SS 310

- SS 310S, A 800H were bought in tube and rod shape to UnionOcel
  - They had all materials available
  - Located in CZ Rep
  - CVR had worked with them

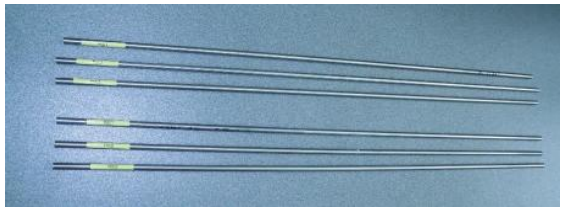
TUBES | OXIDATION & SSRT TESTS



2x 310S Tubes of 6 m cut into 1m tubes (12 TUBES)

2x 800H Tubes of 6 m cut into 1m tubes (12 TUBES)

RODS | ELECTROCHEMISTRY

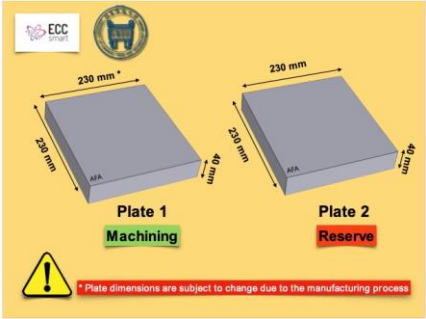


1 Rod of A800H of 3m cut into 1 m rods (3 rods)

1 Rod of 310 SS of 3m cut into 1 m rods (3 rods)

Not for Irradiation

AFA



1 AFA Plate was received at CVR in June (the 2nd one is at SJTU)

Problem: it is too brittle

Pt

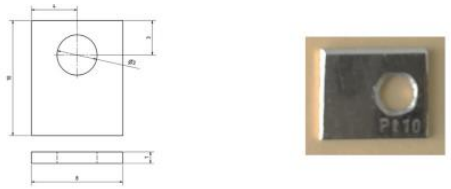


Fig. 19 The dimensions in mm (left) and real example (right) of coupon from Pt.

ECC smart

Sub-task 2.1: Selection and characterization of materials

316 L Cold Spray

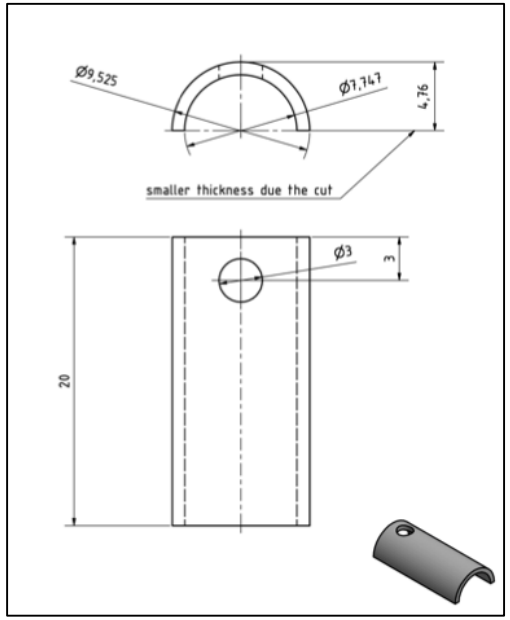
ECC smart

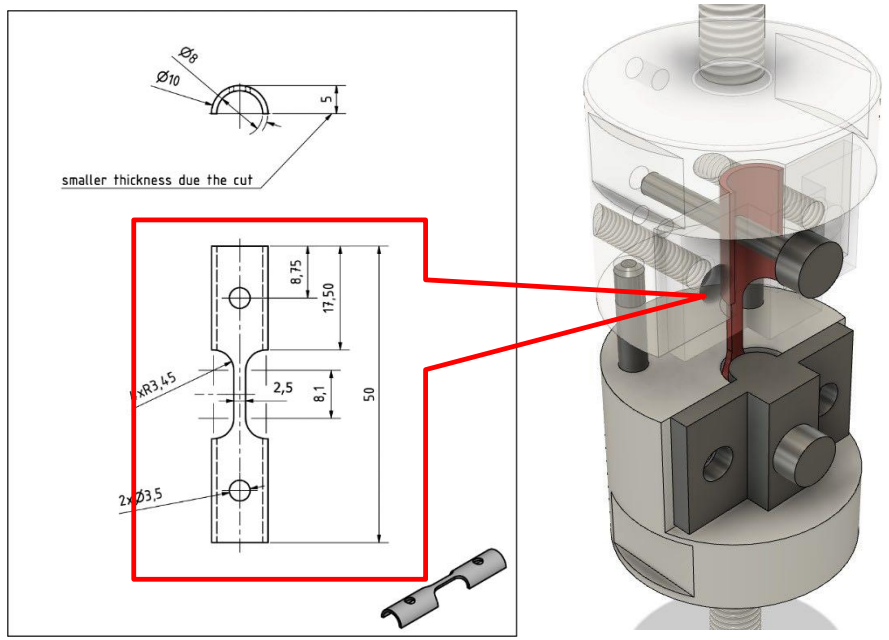
Sub-task 2.2: Study of the corrosion and EAC behaviour of Selected alloys out-of-pile.

MATERIAL	TEST CONDITIONS	CORROSION TEST	TEST TIME
310S	380 ºC/23 & 25 MPa/150 ppb O2	OXIDATION & SSRT	1000h and 7000 h
310S	500 ºC/23 & 25 MPa/150 ppb O2	OXIDATION & SSRT	1000h and 7000 h
310S	1200 ºC	OXIDATION	Several hours
800H	380 ºC/23 & 25 MPa/150 ppb O2	OXIDATION & SSRT	1000h and 7000 h
800H	500 ºC/23 & 25 MPa/150 ppb O2	OXIDATION & SSRT	1000h and 7000 h
800H	1200 ºC	OXIDATION	Several hours
AFA	380 ºC/23 & 25 MPa/150 ppb O2	OXIDATION & SSRT	1000h
AFA	500 ºC/23 & 25 MPa/150 ppb O2	OXIDATION & SSRT	1000h
316 L CS	380 ºC/23 MPa/150 ppb O2	OXIDATION	1000h
316 L CS	500 ºC/23 MPa/150 ppb O2	OXIDATION	1000h

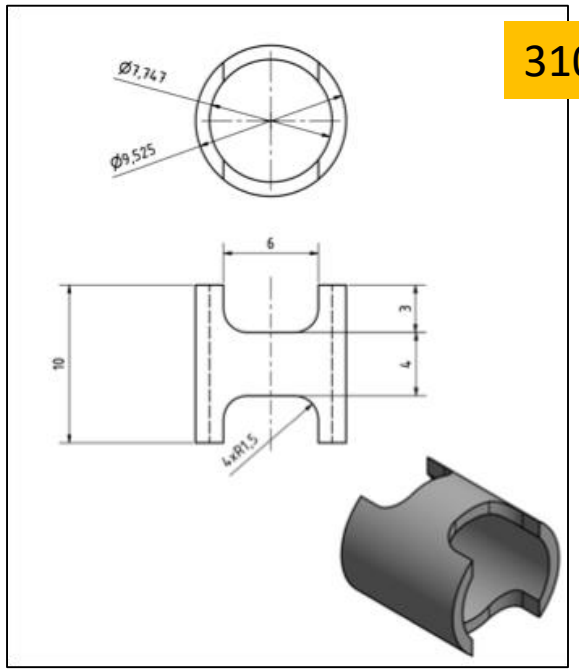
ECC smart

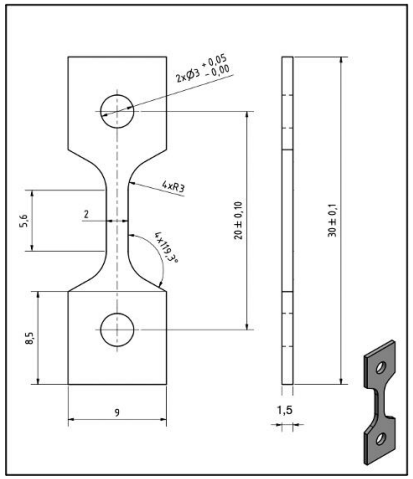
Sub-task 2.2: Study of the corrosion and EAC behaviour of Selected alloys out-of-pile.

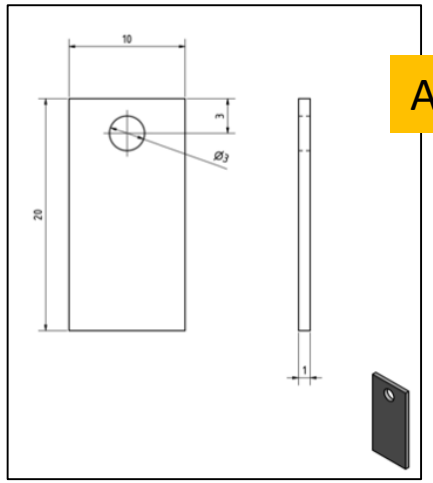




310 S/A 800H





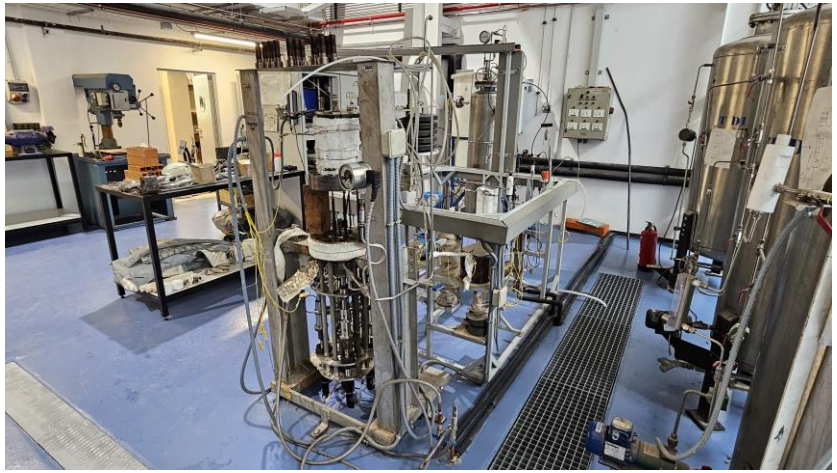


AFA

Interesting option to study anisotropic materials like Zr or materials that have lost their anisotropic behavior due to the effect of irradiation. Need less Material than for axial specimens.

ECC smart

Sub-task 2.2: Study of the corrosion and EAC behaviour of Selected alloys out-of-pile.

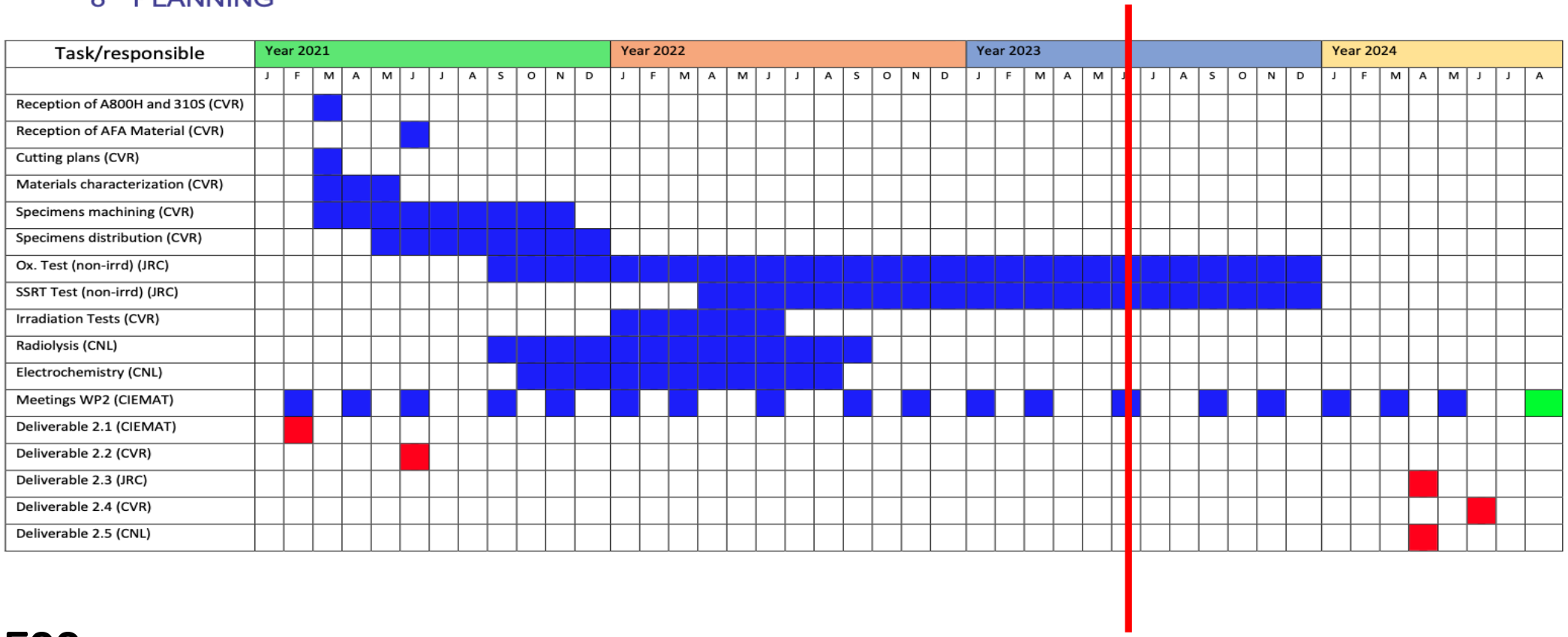


	ECC-SMART WORK PACKAGE 2 FACILITIES							
	TESTS PARAMETERS							
INSTITUTION	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CEMAT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
CNL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CNL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CNL (Van de Graaff) 4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
CVR	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ENEA	NO SCW FACILITY (PRESENT IN THE TECHNICAL MEETINGS AS LEADER OF WP 4)							
JRC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]
KALTEN	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SJTU	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
STUBA	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
USTB	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VSCHT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VTT	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

ECC smart

Sub-task 2.2: Study of the corrosion and EAC behaviour of Selected alloys out-of-pile.

8 PLANNING



Sub-task 2.1: Selection and characterization of materials

310 S cross-section of the tube

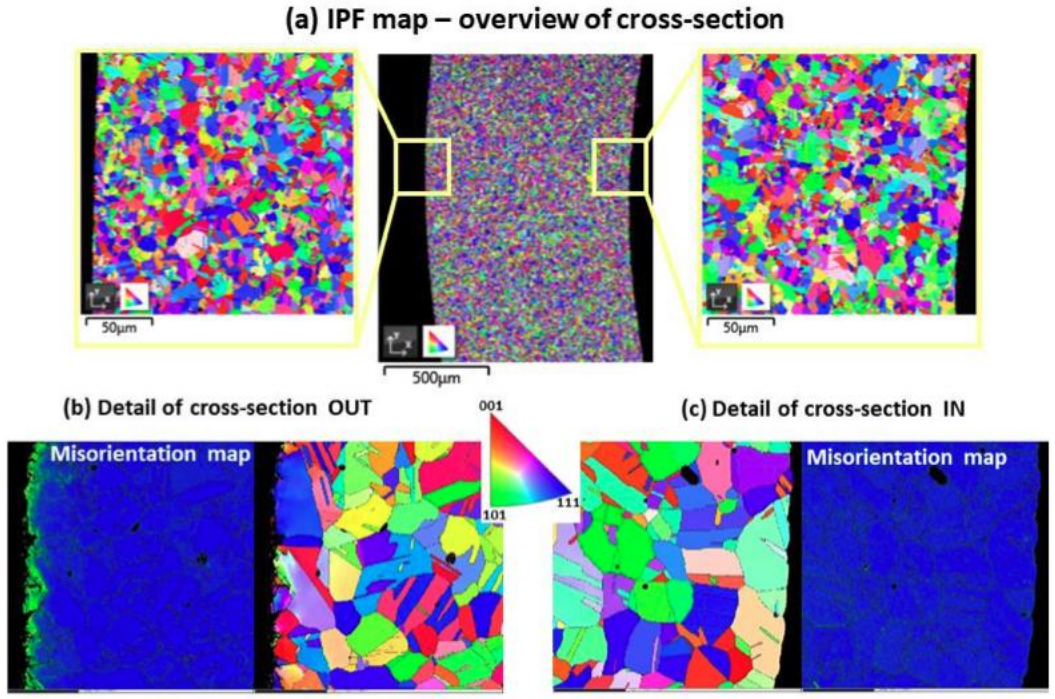


Fig. 41 (a) Inverse pole figure (IPF) map with a step size of 2.5 µm shows the initial microstructure in cross-section of 310S at MG 140x (on left and right, there are IPF maps at MG 1000x with a step size of 0.6 µm). The two detailed IPF maps are at MG 6000x, with a step size of 0.1 µm and they are accompanied with the highlighting of the misorientation (b) close to outside and (c) close to inside of the tube.

800 H cross-section of the tube

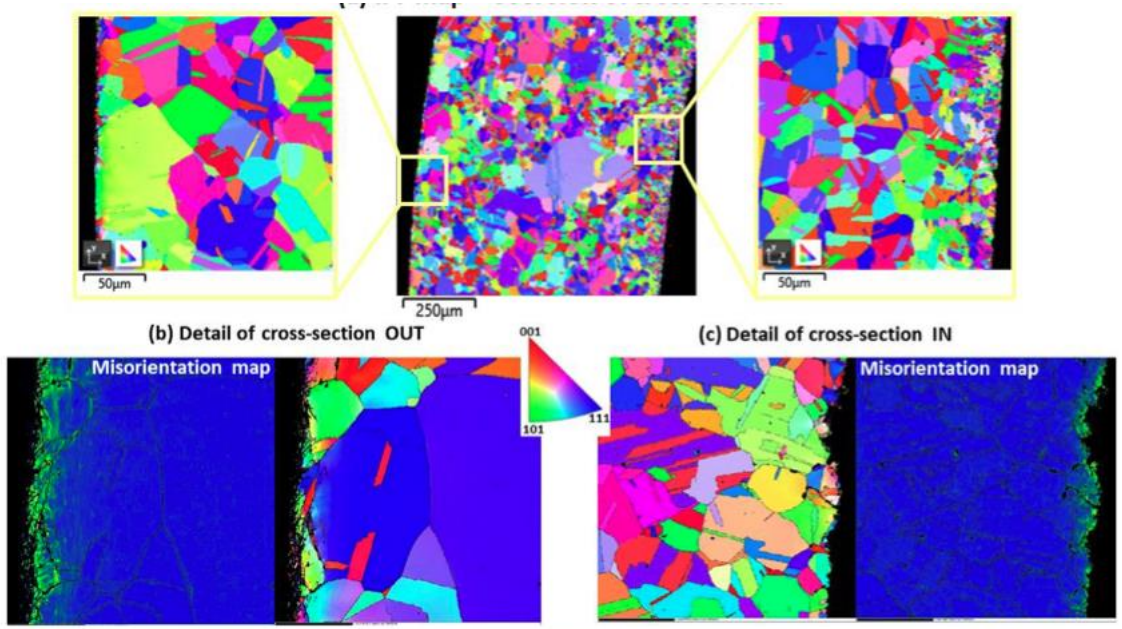
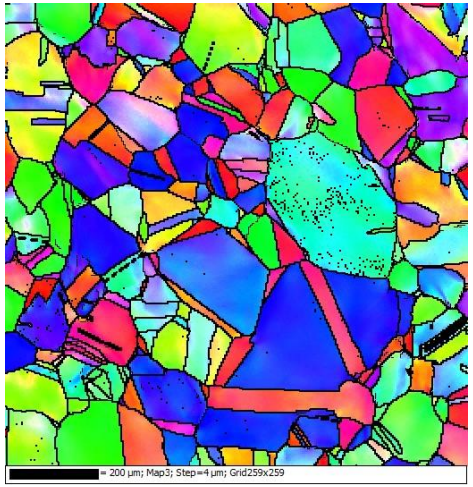
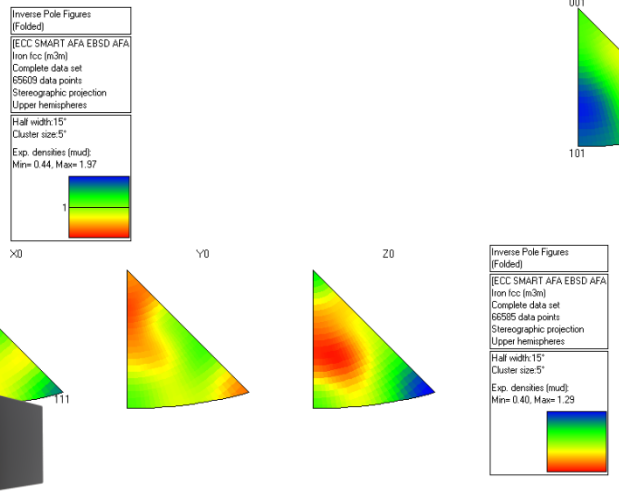


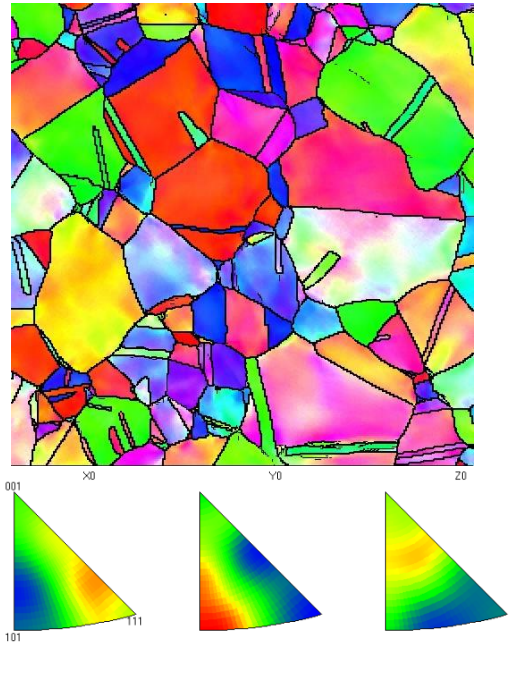
*Fig. 52 (a) Inverse pole figure (IPF) map with a step size of 2.5 µm shows the initial microstructure in **cross-section** of 800H at MG 140x (on left and right, there are IPF maps at MG 1000x with a step size of 0.6 µm). The two detailed IPF maps are at MG 6000x, with a step size of 0.1 µm and they are accompanied with the highlighting of the misorientation (b) close to outside and (c) close to inside of the tube.*

Sub-task 2.1: Selection and characterization of materials

AFA 310 S







UP

CROSS

SIDE

Grain size:

UP – 14-430 µm (N=200)

CROSS – 14-304 µm (N=120)

SIDE – 14-449 µm (N=244)

More homogeneous size of grains in CROSS-sectional cut.

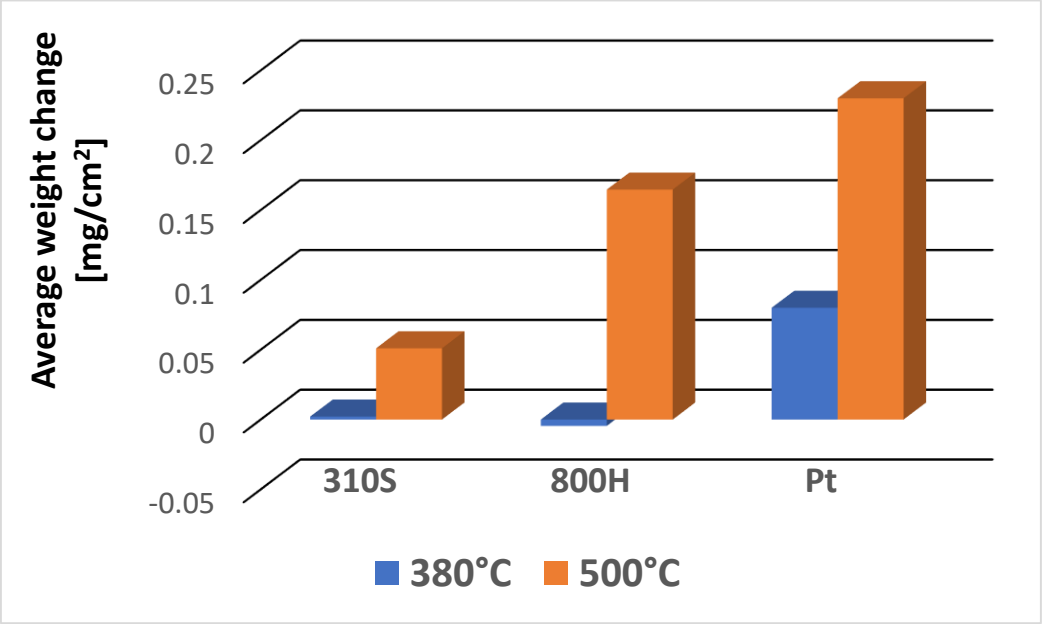
Chemical composition of AFA 310S:

Fe	Ni	Cr	Al	Mo	Nb	V	Si	W	O	C
48,7	24,8	20,0	2,0	0,6	0,5	0,4	0,4	1,4	0,2	1,2

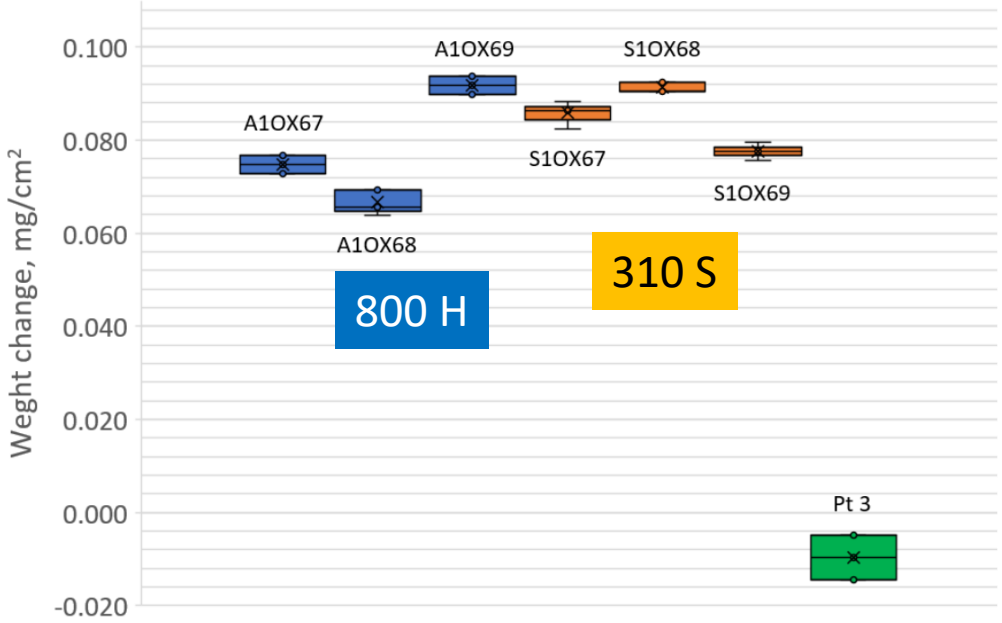
ECC smart

Sub-task 2.2: Study of the corrosion and EAC behaviour of Selected alloys out-of-pile

Static autoclave (380-500 ºC 1000 h)



Refreshed autoclave (380ºC, 1000h)



After oxidation, the microhardness for the 310S sample decreased on the outer surface but in the case of alloy 800H sample, it increased.

Sub-task 2.3: Study of the corrosion and EAC behaviour of selected pre-irradiated alloys in SCW.

Irradiation LVR-15

Inert.atm. He
T ~ 80°C
0.3 dpa

HMG 2022

Irradiated specimens

AIM: Degree of radiation dpa 0.3

Basic char.–TEM (degree of radiation damage)
Mechanical prop. – NI, TT (2 tensile sp./alloy, RT, 10^{-3},s^{-1})

HMG 2023

Exposure in SCW

Irradiated specimens

As-received specimens

SCW-autoclave

500 °C/25MPa, 1000 h, DO 150 ppb
May 2023

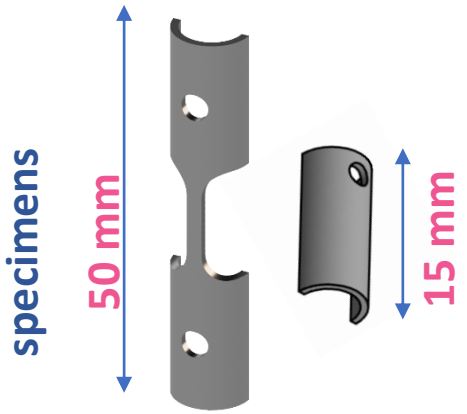
AIM: effect of n-radiation on corrosion behaviour.

Basic characterization:

- weight change (3 sp./alloy);
- comparison of irradiated and as-received sp.;
- description of ox.layer (SEM, NI)

BUT- limit of dose rate for SEM and NI

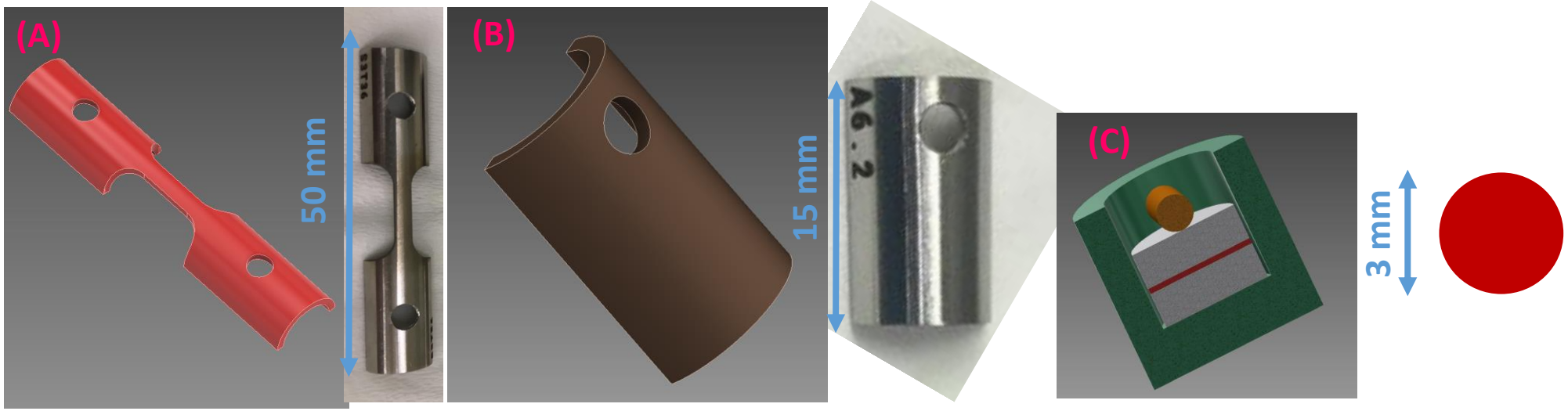
Mechanical prop. – TT (3 sp./alloy)



ECC smart

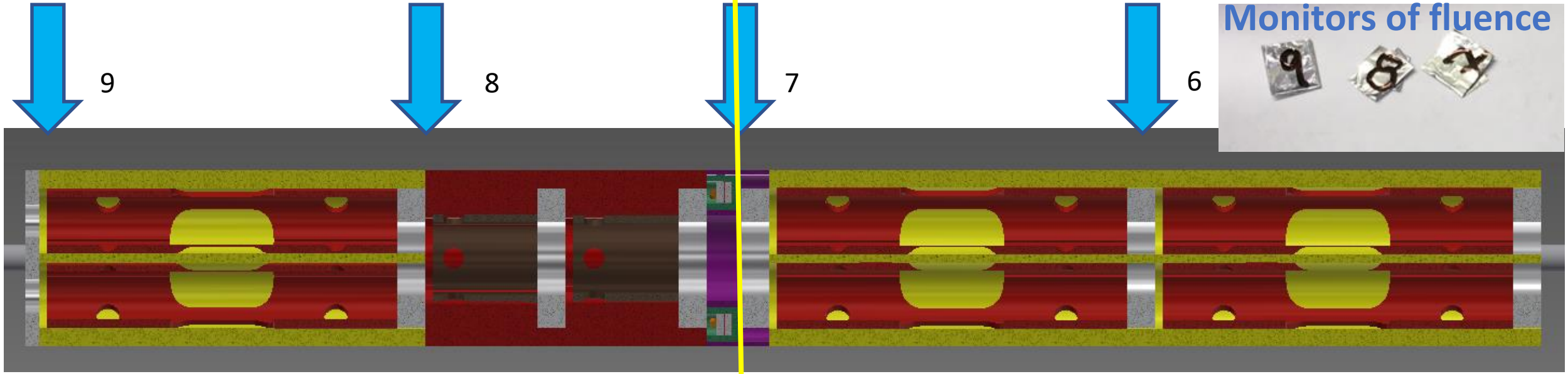
Sub-task 2.3: Study of the corrosion and EAC behaviour of selected pre-irradiated alloys in SCW.

- **3 types of specimens**: (A) tensile, (B) coupons, (C) specimens for TEM
- **3 materials**: 310S, 800H, 316L
- 0,3 dpa (6 months)



CNL: proton irradiation

Sub-task 2.3: Study of the corrosion and EAC behaviour of selected pre-irradiated alloys in SCW.



316L 8x
Tensile sp.

800H 4x
316L 2x

310S 4x
316L 2x

TEM foil
8x
S, A, L

Oxidation coupons

310S 8x
Tensile sp.

800H 8x
Tensile sp.

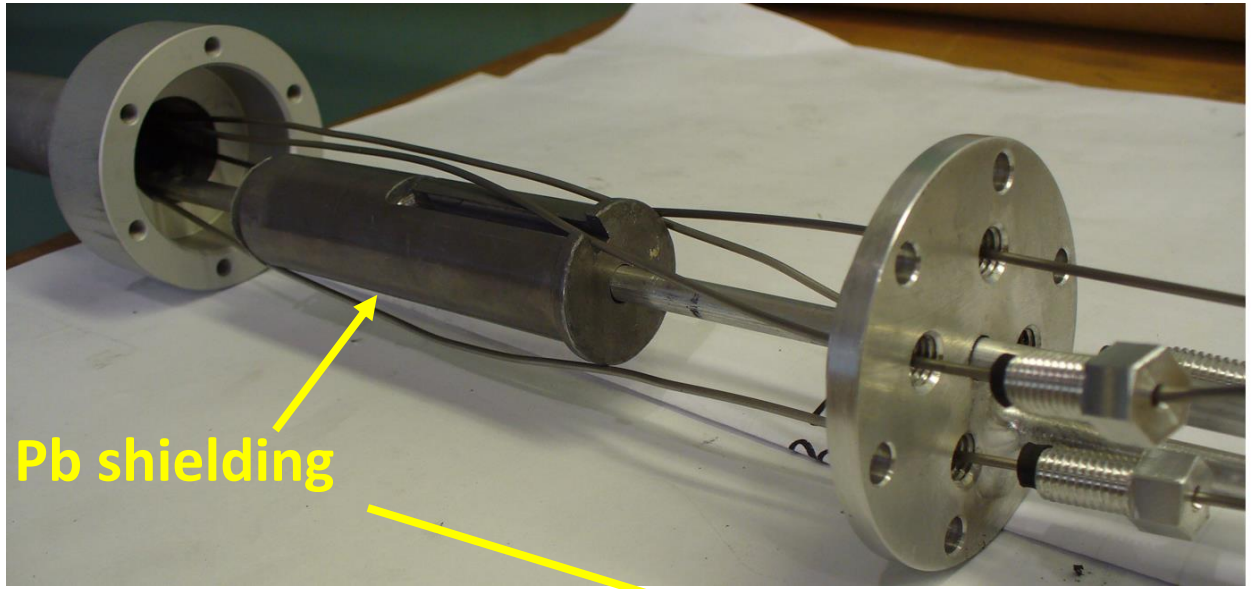
220 mm

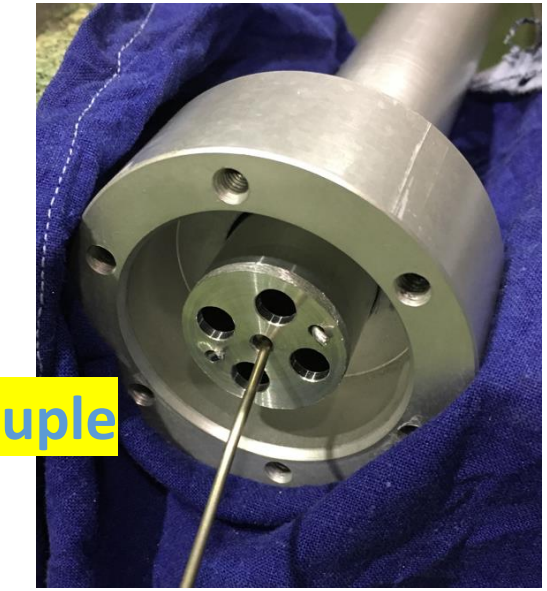
M=0,2 kg

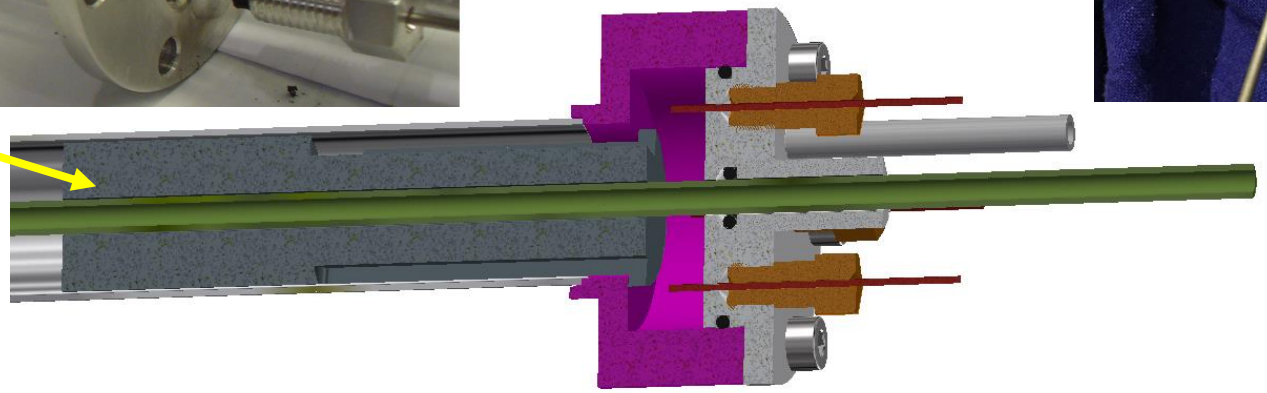
Midle of active zone

Rig

Upper part







Sub-task 2.4: Study of the effect of SMR-SCW chemistry and changes in the chemical properties of SCW in the behaviour of candidate materials.

Study of the effect of SMR-SCW chemistry and changes in the chemical properties of SCW in the behaviour of candidate materials. (CNL)

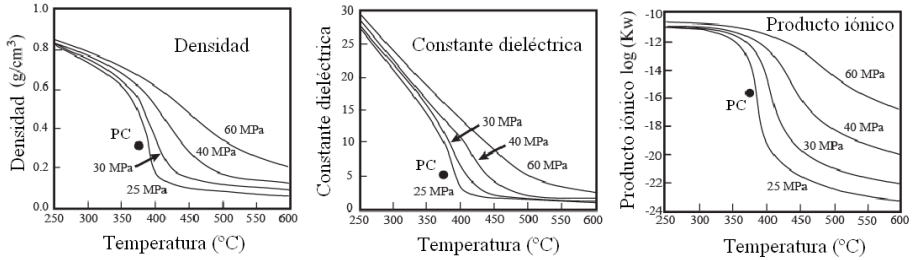
Proposed test matrix for radiolysis tests

Trial	T (°C)	P MPa	Ω (s^{-1})	[H_2] (mL/kg)	[NH_3] (mL/kg)
1	300	10	1	0	0
2	300	10	4	0	0
3	300	10	4	10	0
4	300	10	4	5	25
5	300	10	4	5	12.5
6	380	25	1	0	0
7	380	25	4	0	0
8	380	25	4	10	0
9	380	25	4	5	25
10	380	25	4	5	12.5
11	425	26.5	1	0	0
12	425	26.5	4	0	0
13	425	23.5	1	0	0
14	425	23.5	4	0	0
15	425	25	4	10	0
16	425	25	4	20	0
17	425	25	4	50	0
18	425	25	4	100	0
19	425	25	4	10	12.5
20	425	25	4	20	12.5
21	425	25	4	20	25
22	425	25	4	100	25
23	500	26.5	1	0	0
24	500	26.5	4	0	0
25	500	23.5	1	0	0
26	500	23.5	4	0	0
27	500	25	4	10	0
28	500	25	4	20	0
29	500	25	4	50	0
30	500	25	4	100	0
31	500	25	4	10	12.5
32	500	25	4	20	12.5
33	500	25	4	20	25
34	500	25	4	50	25

Canadian Nuclear Laboratories
Laboratoires Nucléaires Canadiens

Radiolysis

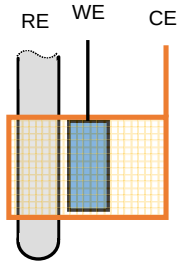
Sub-task 2.4: Study of the effect of SMR-SCW chemistry and changes in the chemical properties of SCW in the behaviour of candidate materials.



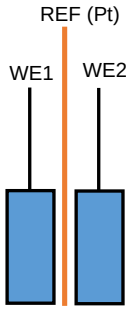
ECC smart

JRC

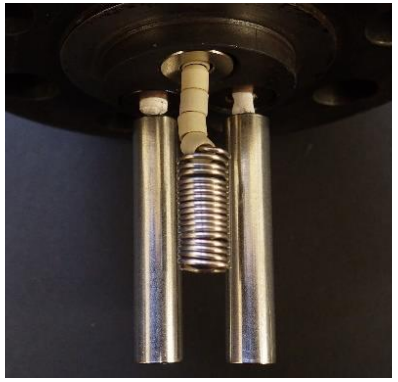
UCT PRAGUE



3- electrode setup - coaxial cell
EIS, E(t) measurements:
WE - 310S or 800H cylinder
CE - coaxial Pt mesh
REF - YSZ - Fe/Fe_3O_4 or Pt wire



3- electrode symmetrical setup:
EIS, EN in ZRA mode
WE1/2 – 310S or 800H cylinders
CE - Pt wire



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Thank you for your attention!

JOINT EUROPEAN CANADIAN CHINESE

DEVELOPMENT OF SMALL MODULAR REACTOR TECHNOLOGY

This project has received funding from the Euratom Research and Training programme 2019-2020 under Grant Agreement No 945234.

2.15 ECC-SMART Neutronics, Szabolcs Czifrus, BME (Remote)

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JOINT EUROPEAN CANADIAN CHINESE
DEVELOPMENT OF SMALL MODULAR REACTOR TECHNOLOGY

Neutron physics of SCW-SMR

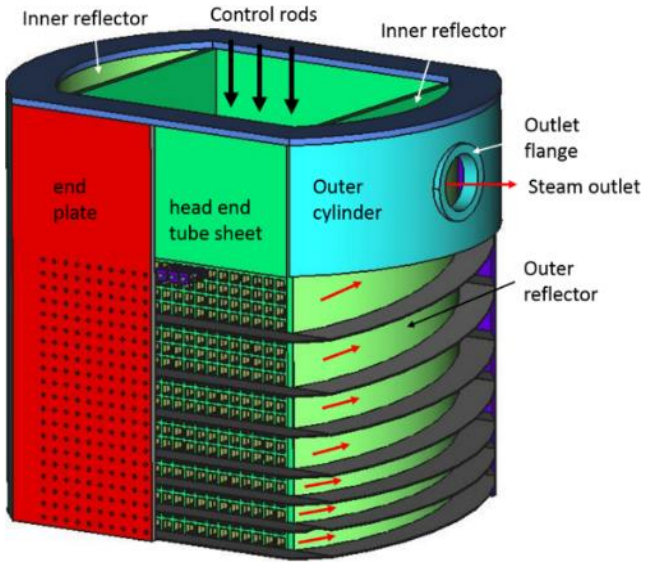
Workshop on the Safety of Small Modular, Advanced and Fusion Reactors

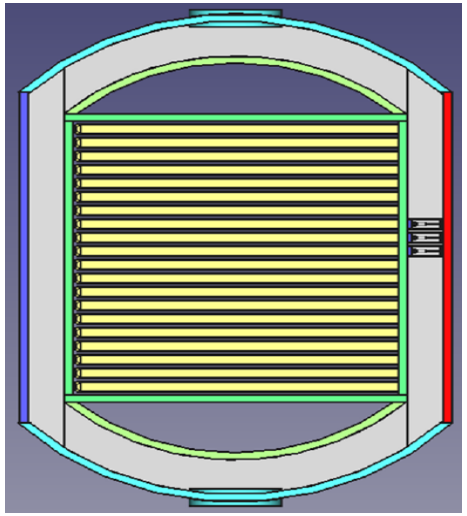
Hotel Evropa, Celje, Slovenia

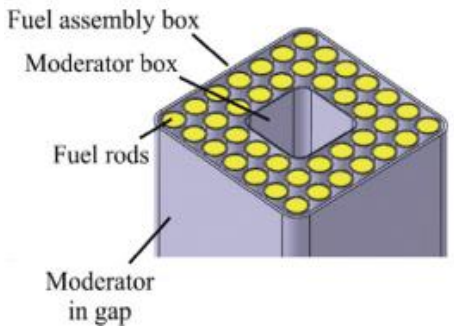
June 20-21, 2023

This project has received funding from the Euratom Research and Training programme 2019-2020 under Grant Agreement No 945234.

Neutronics modelling of the core



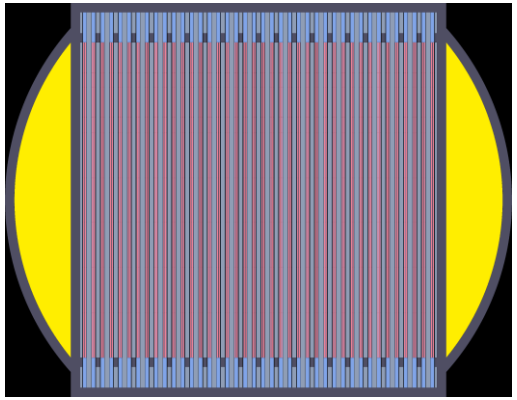


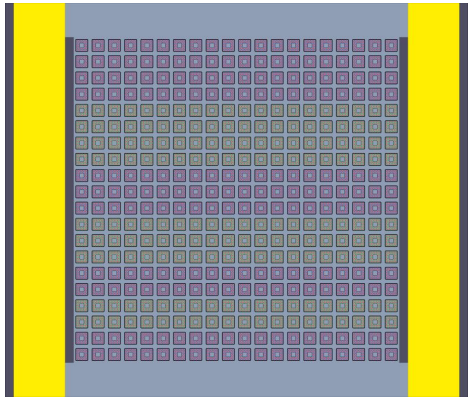


A core model was built with the Serpent 2 and MCNP Monte Carlo codes.

The starting model included UO_2 fuel assemblies with a uniform 5% U^{235} enrichment.

This model evolved to more elaborate core maps. The model is based on the conceptual design.





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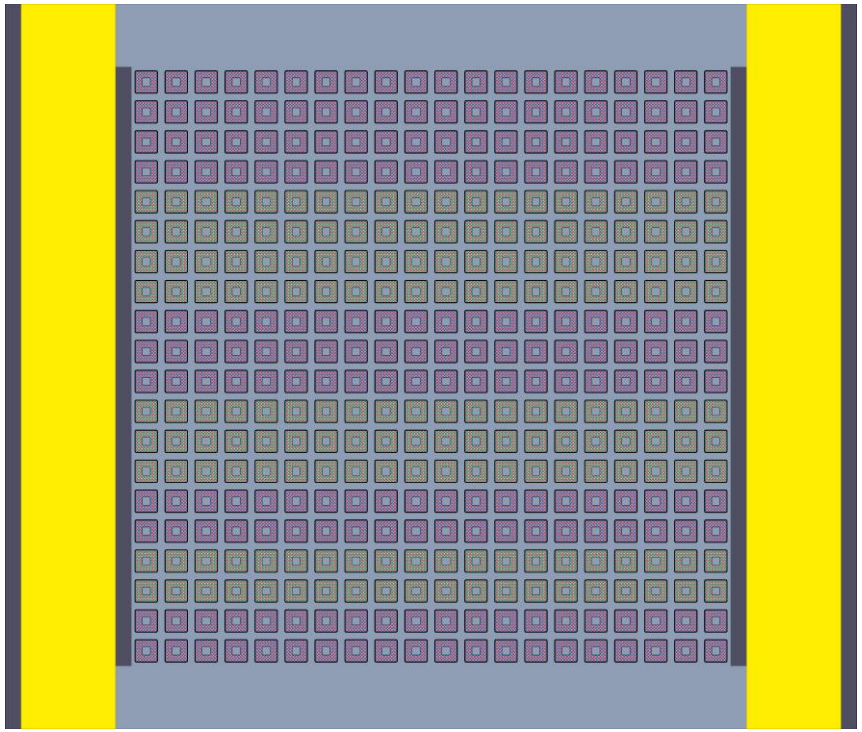
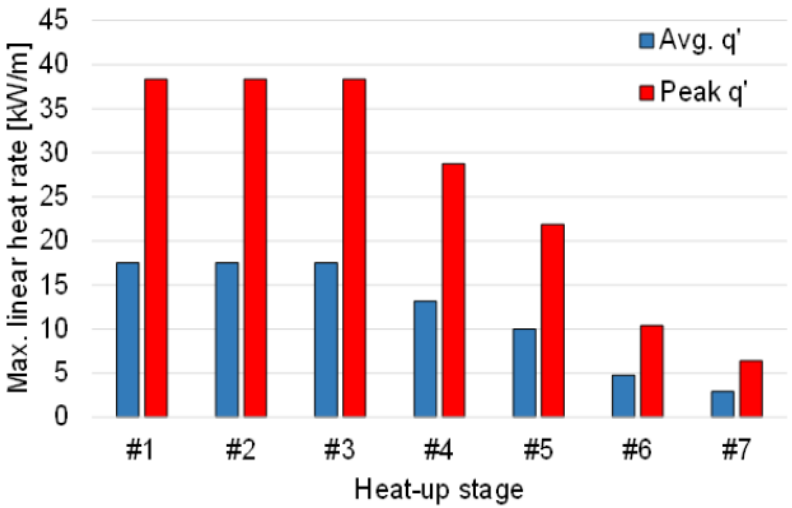
Neutronics modelling of the core

Heat-up stages



Main criteria and goal:

- to reach a burnup cycle length of 2- 3 years
  - → high enough reactivity reserve
  - → slow decrease of reactivity during burnup
- to achieve the necessary power profiles
  - → horizontally: (reasonably) flat profile
  - → vertically: target max. lin. heat rate profile from WP3



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Challenges in core design

- How to achieve sufficiently long burnup cycle?
- How to achieve a close-to-target power profile?
- How does power density distribution influence core temperature map?
- How to deal with the large exess reactivity?
- Negative reactivity feedback coefficients

- Use of higher than 5% enrichments
- Enrichment map and more

- Needs coupled neutronics-thermal-hydraulics calculations down to pin level
- Poisons and more – plus a good reactivity control system – no boron!
- Meaning – local or global? How negative should they be?

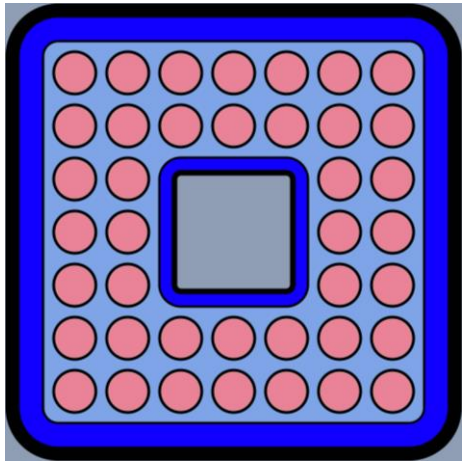
All in a very strongly coupled neutronic system

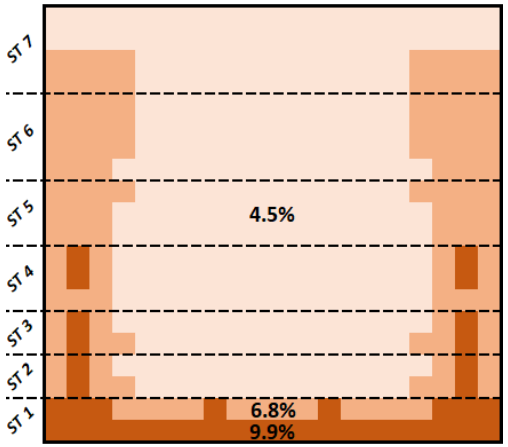
Reserve reactivity

Reserve reactivity of core would be really low using max. 5% enrichment

What makes it possible to achieve a 2-year-long cycle?

- FA structure
  → layered walls with SS 310S and Zircaloy-4
- moderation improvement
  → FA gap increased and moderator temperature reduced
- adjusted, non-uniform enrichment map
  → high reserve reactivity: average uranium enrichment well above 5%
  → power profiles: large difference between enrichments
  → highest enrichment used in the adjusted map: 9.9%
- neutron leakage decrease
  → Be reflectors added

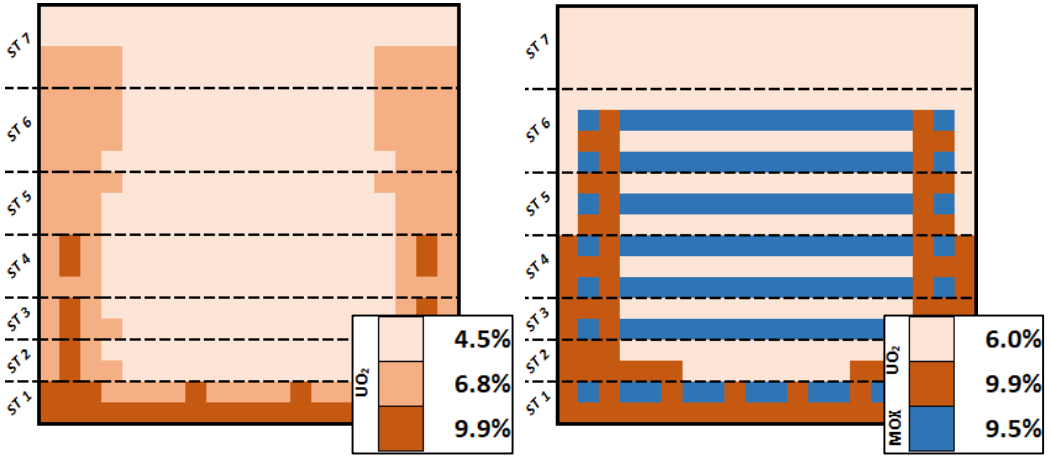


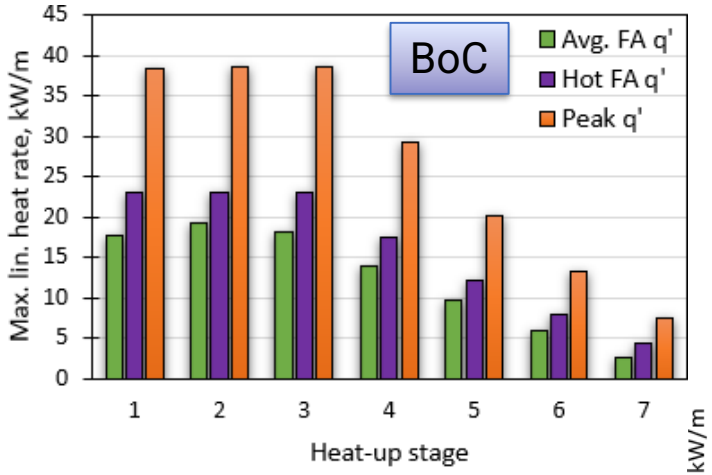


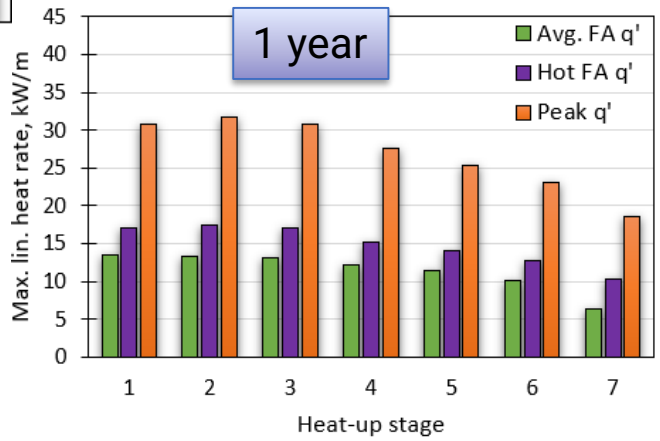
How to achieve proper power profile?

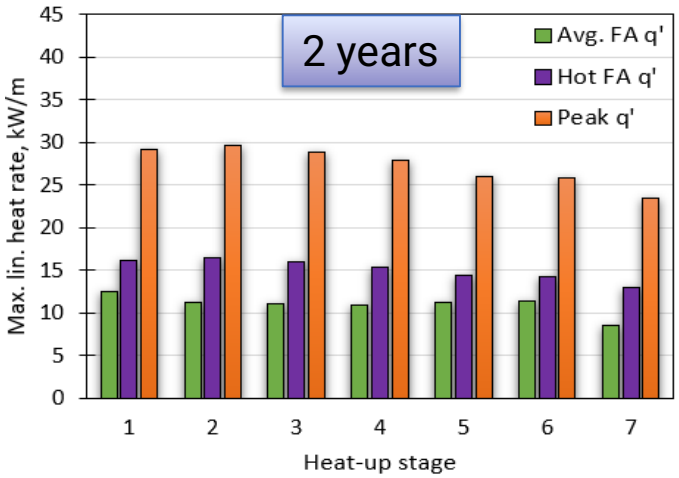
Core map design with 3 cores

- Homogeneous 5% U enrichment in UO_2 core
- UO_2 core with 4.5 … 9.9% enrichment
- Mixed core with UO_2 (6.0% and 9.9% enrichment) and MOX (with 6.5% Pu content)









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Pin level calculations

Aim of pin level calculations:

- Analysis of pin-power distribution, determination of hot pin power to average pin power ratio (pin-power-peaking factor)
- Investigation on how pin-power-peaking factor could be reduced using application of enrichment profiling / burnable absorbers of various types
- Analysis of effect of burnable absorbers on BoC reserve reactivity, EoC reserve reactivity

Pin level calculations

Three different types of assemblies were analyzed:

- two UO_2 assemblies: **7.5%** and **9%** of ^{235}U enrichment;
- one MOX assembly: **9.5%** Pu content.

1.32	1.10	1.02	0.99	1.01	1.10	1.32
1.10	0.89	0.86	0.87	0.86	0.88	1.10
1.02	0.86				0.86	1.02
0.99	0.87		7.5% UO_2		0.86	1.00
1.01	0.86				0.86	1.02
1.09	0.88	0.86	0.87	0.86	0.88	1.09
1.32	1.10	1.01	1.00	1.01	1.09	1.32

1.36	1.10	1.02	1.00	1.02	1.10	1.35
1.10	0.87	0.84	0.85	0.84	0.87	1.10
1.02	0.84				0.84	1.02
1.00	0.85		9% UO_2		0.85	1.00
1.02	0.84				0.84	1.02
1.11	0.87	0.84	0.85	0.84	0.87	1.10
1.35	1.10	1.02	1.00	1.02	1.10	1.35

1.61	1.17	1.05	1.02	1.05	1.17	1.60
1.17	0.75	0.72	0.73	0.72	0.75	1.17
1.05	0.72				0.72	1.05
1.02	0.73		9.5% $(U,Pu)O_2$		0.73	1.02
1.05	0.72				0.72	1.05
1.18	0.75	0.72	0.73	0.72	0.75	1.17
1.61	1.17	1.05	1.02	1.05	1.17	1.61

To flatten the pin power distribution, enrichment profiling and different types of burnable poisons were investigated.

Coupled neutronics - thermal-hydraulics calculations

Four different cooperation routes (for now, with the aim of equilibrium state determinations):

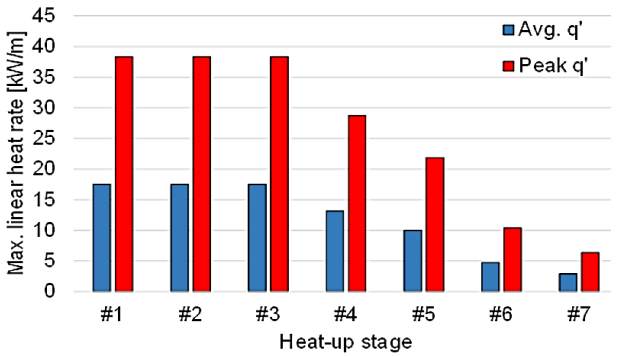
1. RELAP5 and Serpent 2 (Monte Carlo) weakly coupled thermal hydraulics and reactor physics calculations
2. Apros and Serpent 2 (Monte Carlo) weakly coupled thermal hydraulics and reactor physics calculations
3. Apros and SPNDYN (diffusion) coupled thermal hydraulics and reactor physics calculations
4. Ansys CFX and Serpent 2 weakly coupled thermal hydraulics and reactor physics calculations

Peak cladding temperature vs. reactor physics

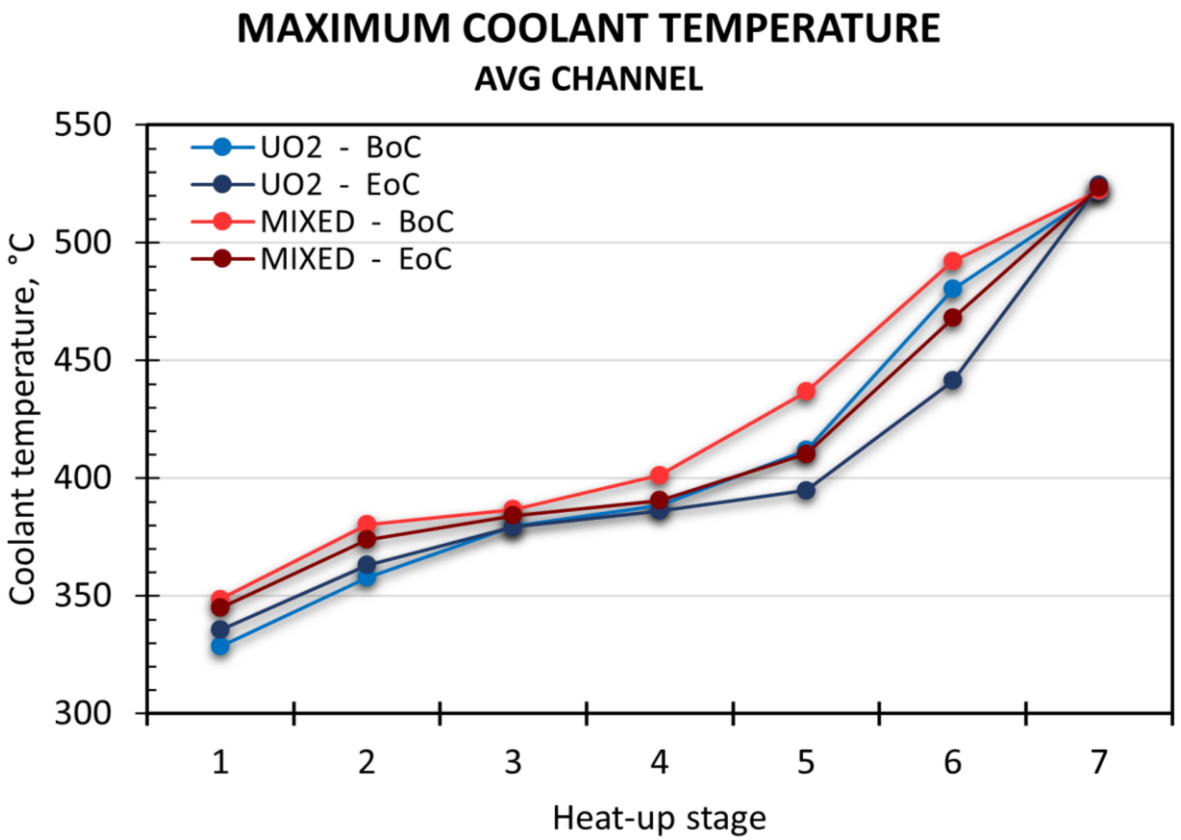
- The PCT is important to understand basis for material choice
- Initial estimate: 550 °C (for normal operation).

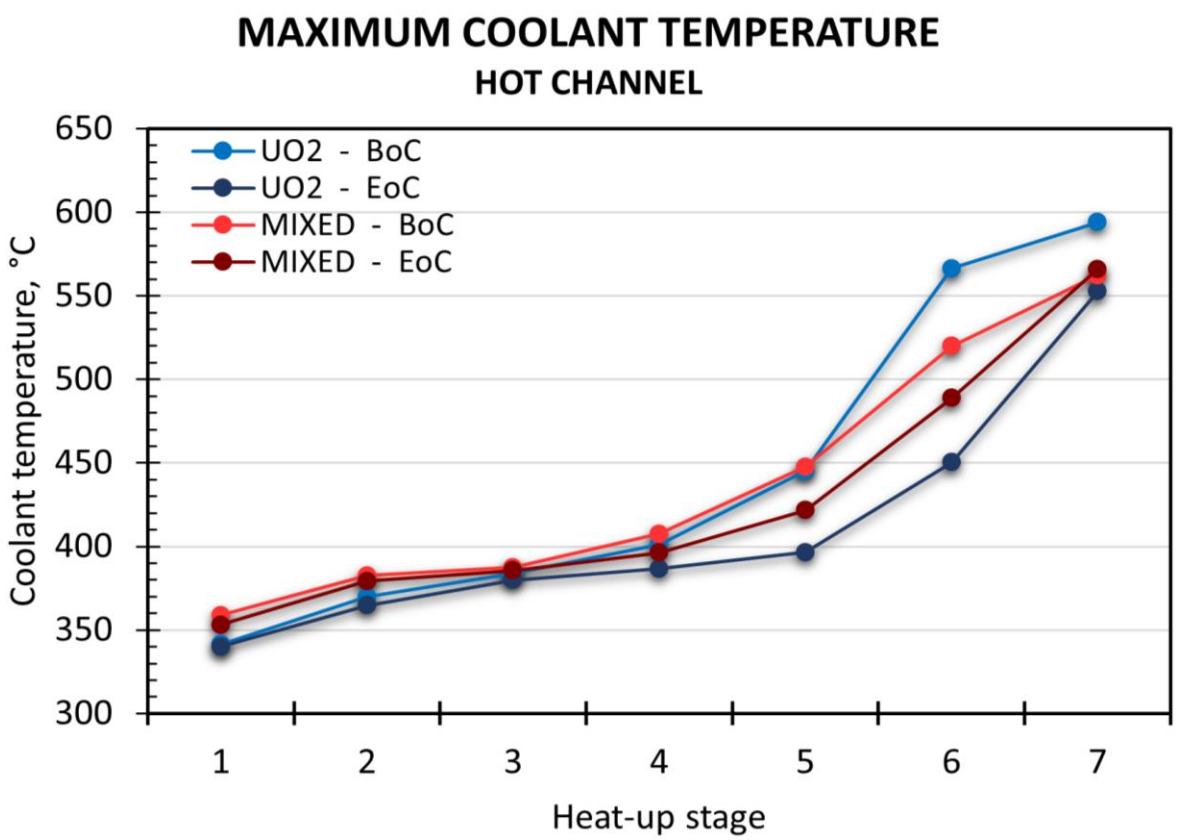
The coolant outlet temperature is around 500 °C.

Can this limit be kept with such a small temperature margin?
How does the target linear heat rate profile affect these temperatures?

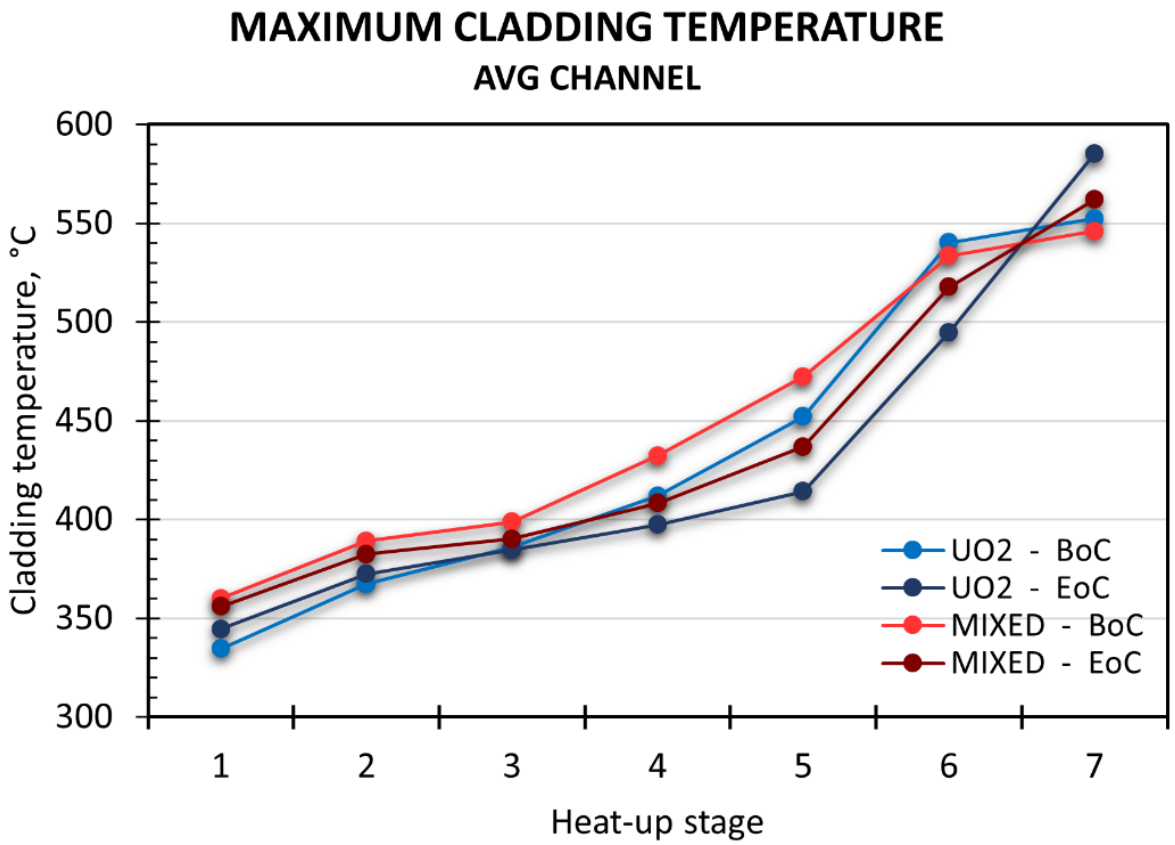


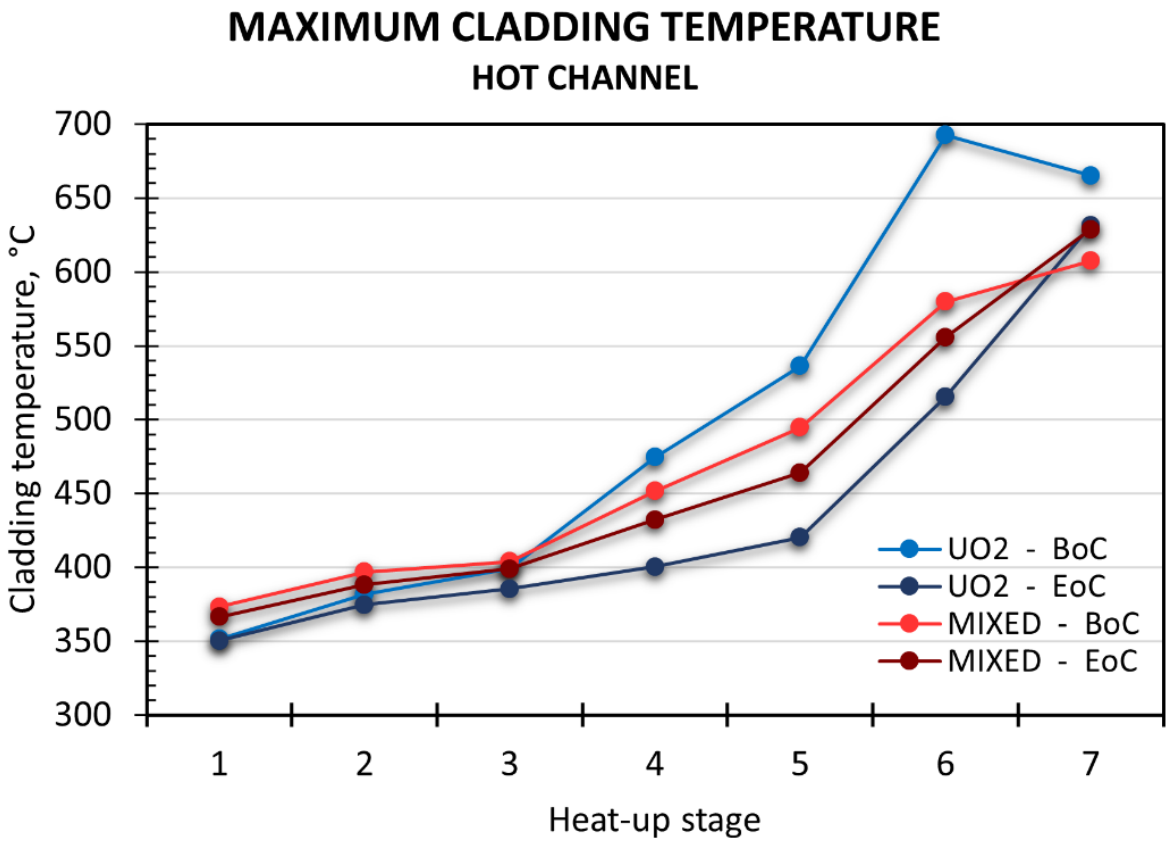
Coolant temperature - results of coupled calculations





Cladding temperature - results of coupled calculations





From coolant to cladding temperature

What is the relationship between cladding temperature and coolant temperature?

Hint: innovative materials for cladding – importance of understanding of cladding temperature

Coupled calculations can tell answer. A rough estimate is obtained for PCT:

$$T_{clad,peak,hot} = f_1 \cdot f_2 \cdot f_3 \cdot f_4 \cdot T_{cool,out,ave,80} + f_5 = (1.20 \ldots 1.28) \cdot T_{cool,out,ave,80} + (15 \ldots 30)$$

The assumed 500 °C average outlet coolant temperature would result in a requirement of 615 to 670 °C peak cladding temperature.

Reactivity control – first ideas

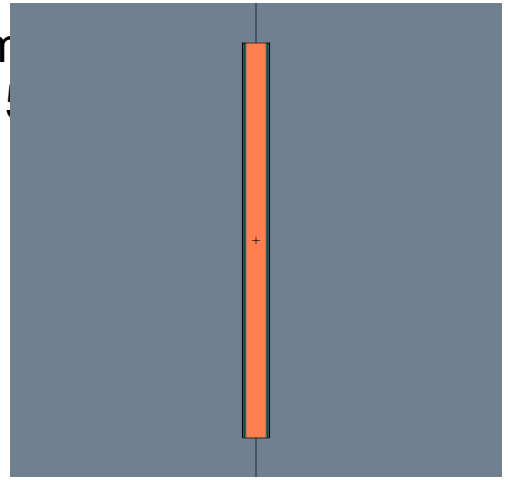
Plates (40) with B_4C, from top to bottom

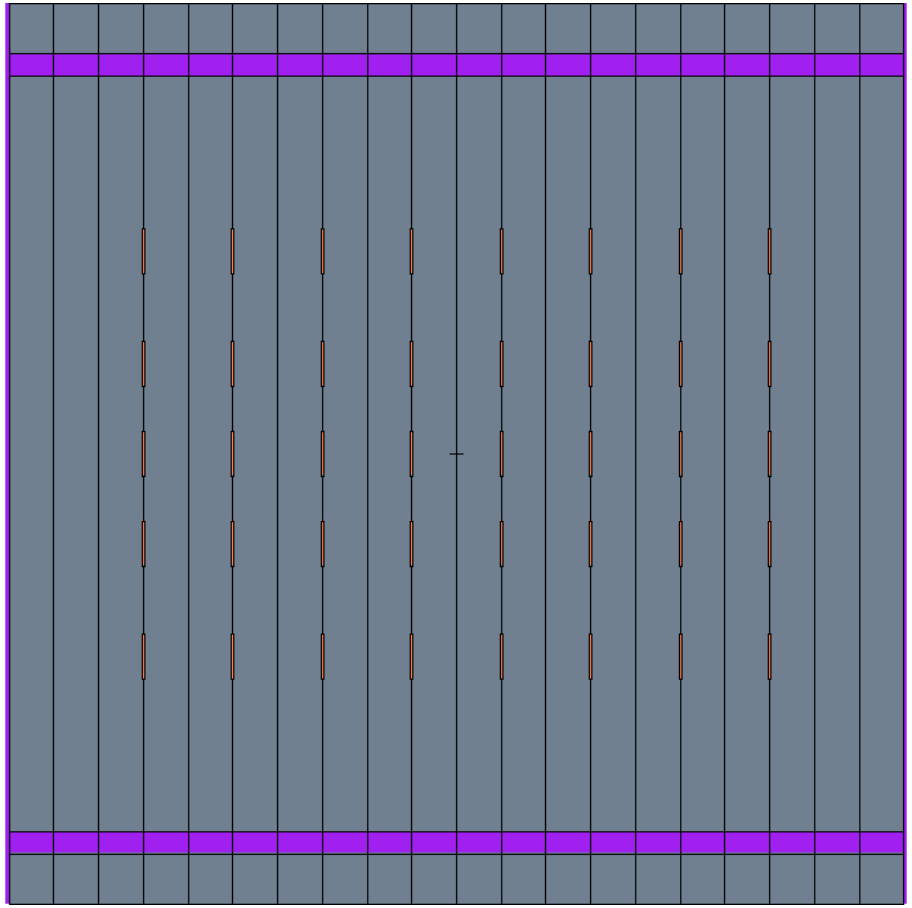
BWR rod drives, upside-down

Plate dimensions:

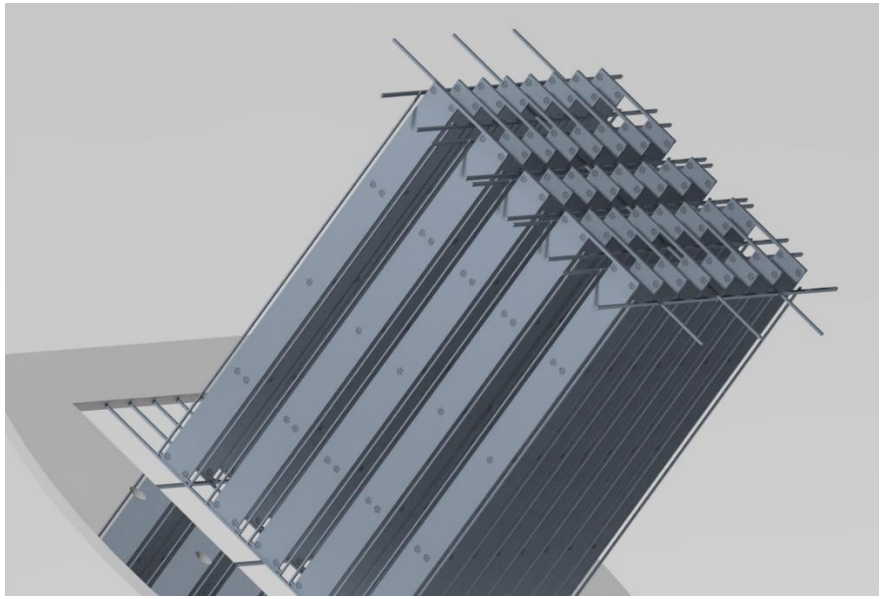
- plate length: 100 mm
- guide tube width: 13.4 mm
- guide tube thickness: 0.4 mm
- absorber cladding width: 11.2 m
- absorber cladding thickness: 0.
- absorber width: 10 mm

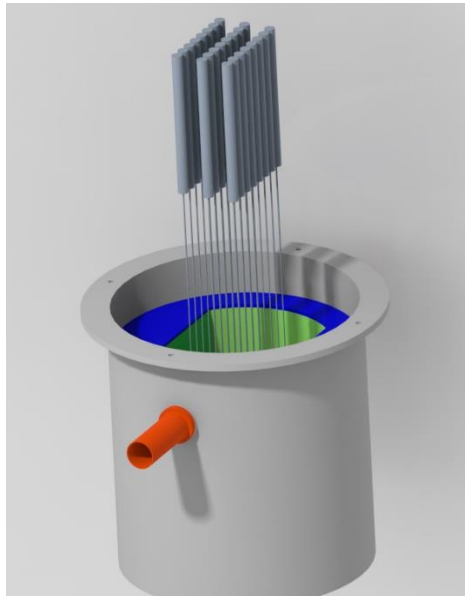
k_{eff} = 1.23228 ± 7 pcm
k_{eff_40CR} = 1.10138 ± 7 pcm

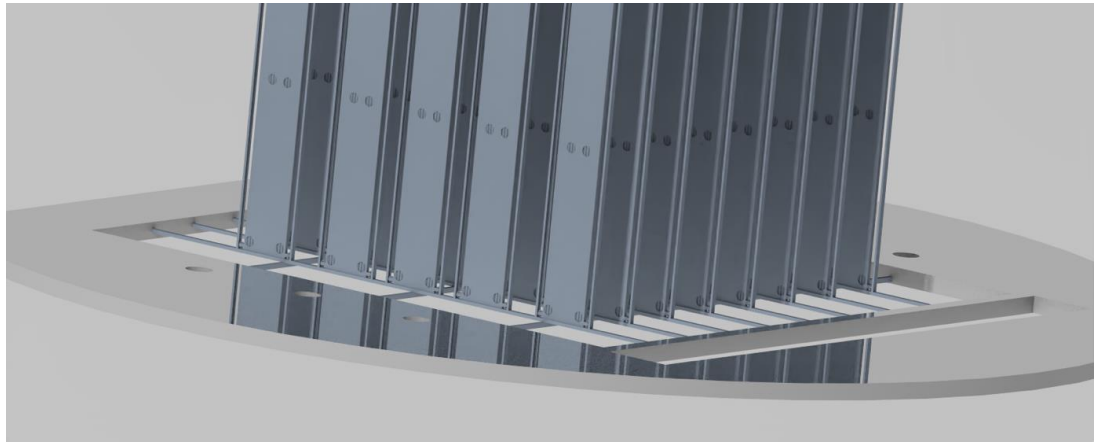


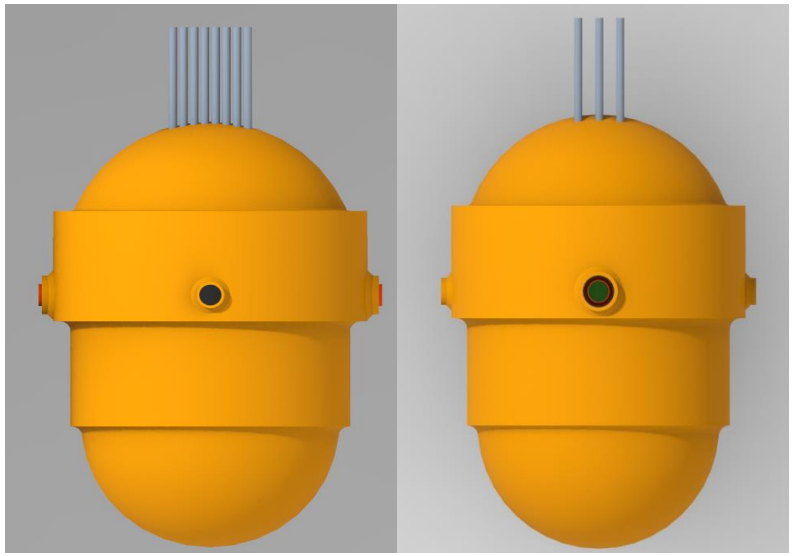


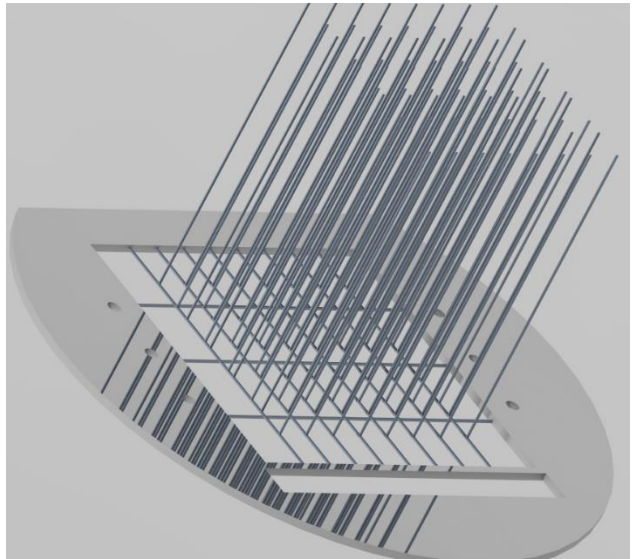
Reactivity control – first ideas

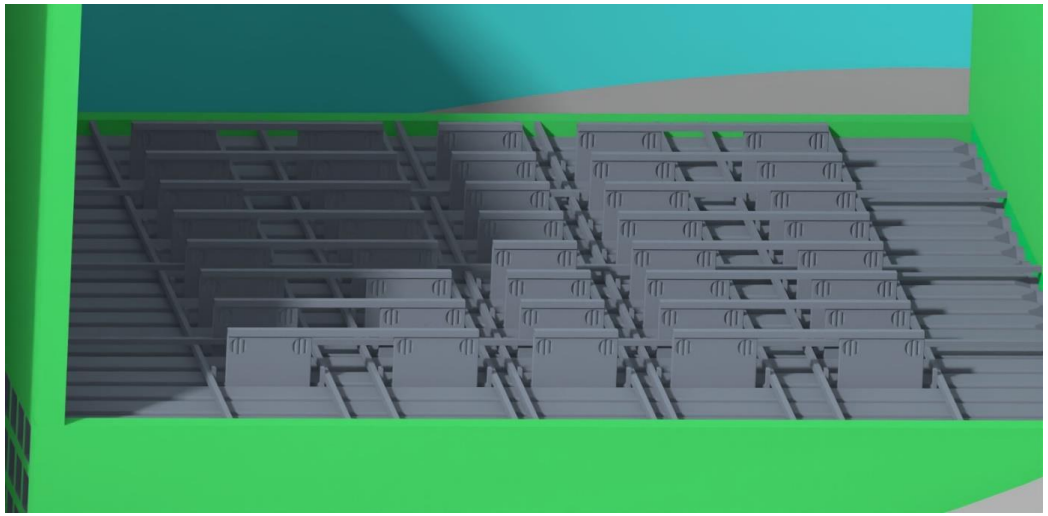








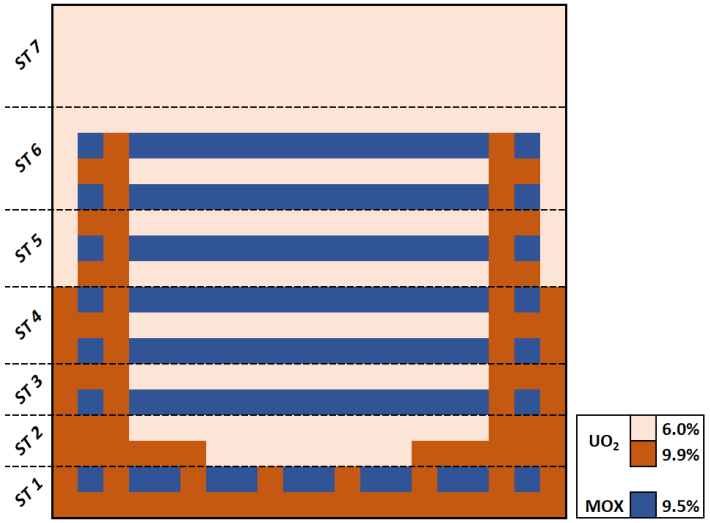




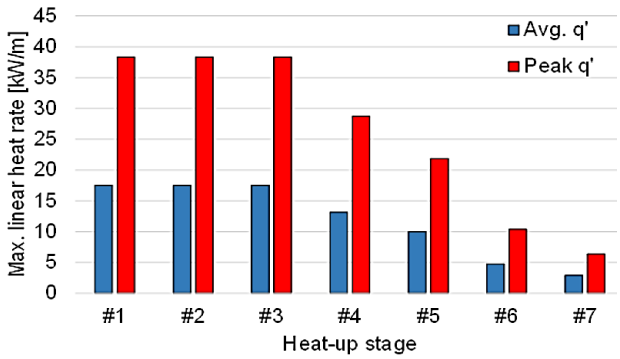
Characteristics of the latest core model

Characteristics of the latest core model:

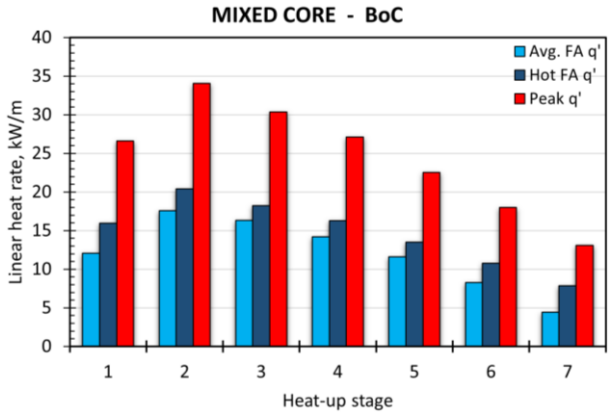
- fuel: UO2 (6.0% + 9.9%) + MOX (9.5%)
- coolant, moderator and fuel temperature and density profiles calculated with APROS
- hot, cold and average channels in every stage
- burnup cycle length (no shuffling): 2.5 years



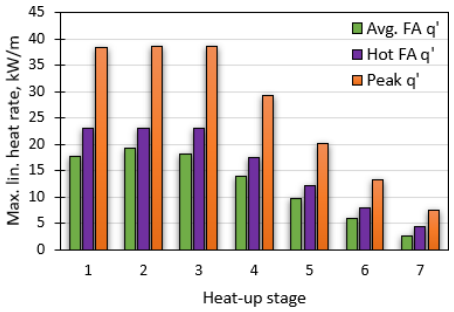
TARGET PROFILE

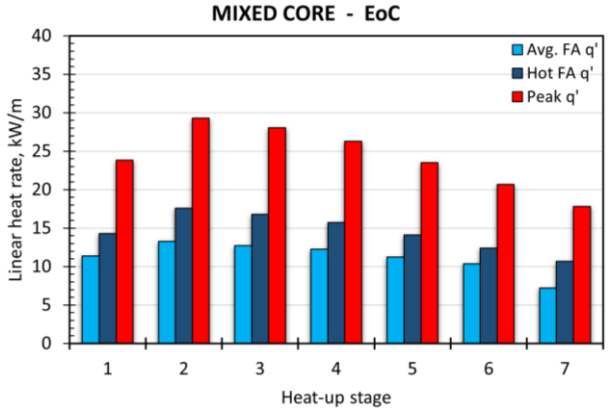


CURRENT LHR PROFILES



FORMER PROFILE





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Reactivity feedback coefficients

Important to understand and predict reactor behaviour in transient scenarios

→ power level changes affect several parameters
→ these parameters will induce a reactivity change
→ the reactivity affects the operational conditions

↓

Reactivity feedback

Positive reactivity feedback:

- results in reactivity increase
- changes in power level will be increasingly faster

Negative reactivity feedback:

- results in reactivity decrease
- changes in power level will be slowed down

- Doppler temperature coefficient (DTC)
- coolant temperature coefficient (CTC)
- moderator temperature coefficient (MTC)

Negative temperature reactivity coefficients serve the inherent safety of the reactor, as rising temperatures would mean a reactivity decrease and consequentially a negative reactivity feedback

BUT: in first few seconds of LOCA transient coolant density may increase!

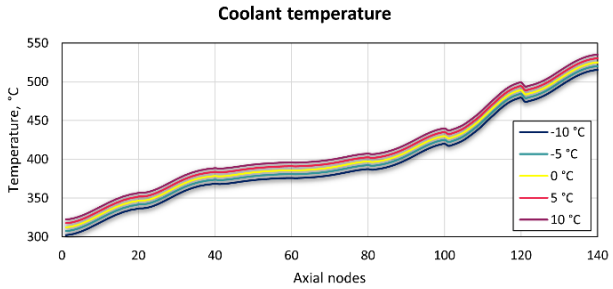
Reactivity feedback coefficients - results

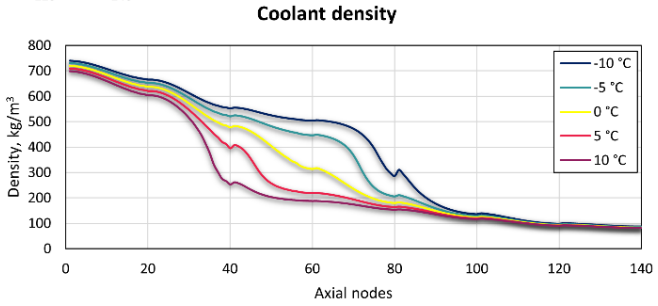
Calculation method:

- considering global and local temperature changes under nominal conditions
- temperature intervals:
  - → DTC: ± 20°C
  - → CTC: ± 10°C
  - → MTC: ± 10°C
- temperature modification in all axial sections uniformly
- density update based on the temperatures

Post processing:

- using linear regression on the obtained reactivities
- reactivity coefficients = gradient of ρ(T)





CASES	CTC, PCM/°C	2σ, PCM/°C
Global	-16.814	1.551
ST 1	-1.177	0.198
ST 2	-4.721	0.997
ST 3	-5.923	0.415
ST 4	-4.501	0.978
ST 5	-0.802	0.212
ST 6	-0.107	0.196
ST 7	-0.196	0.142

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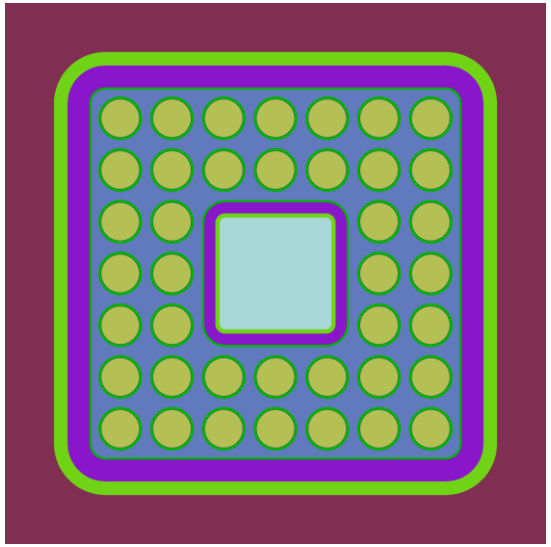
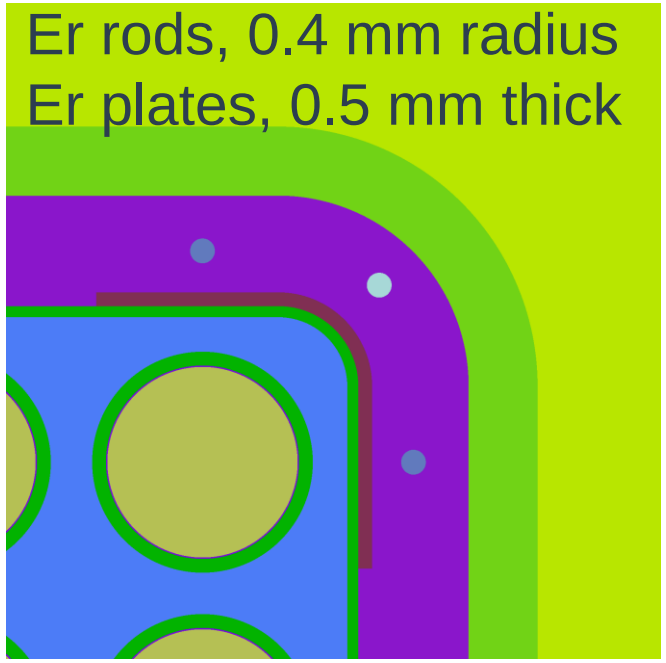
Burnable absorbers – Simulation settings

- The excess of reactivity at the beginning of the core life can be too high to be controlled only by mechanical control rods
- The concept is trying to match the decrease of k_{eff} due to fuel consumption with the increase due to absorbers burnout.

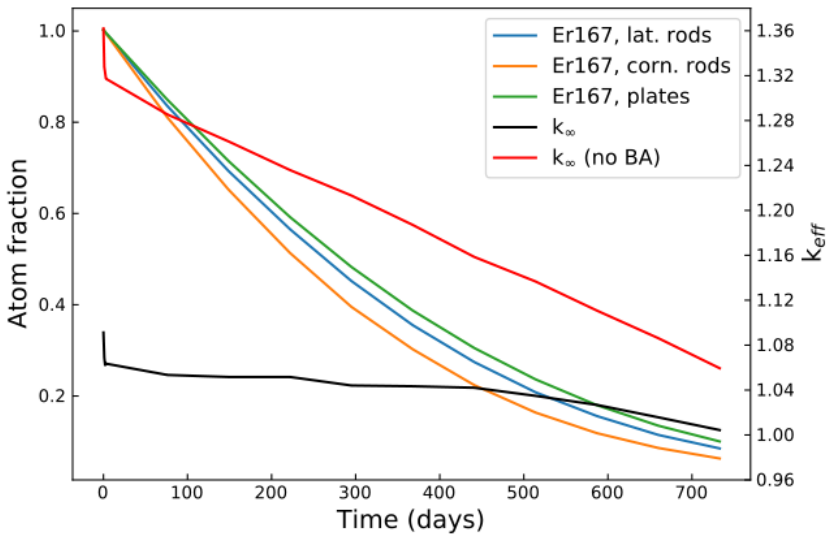
- The fuel assembly of reference for this study is based on UO_2 fuel only
- Different U^{235} enrichments will be considered
- Gd as burnable poison seems not promising since it burns out very rapidly, even if lumped
- Thus, attention has been mainly devoted to **Er and B**

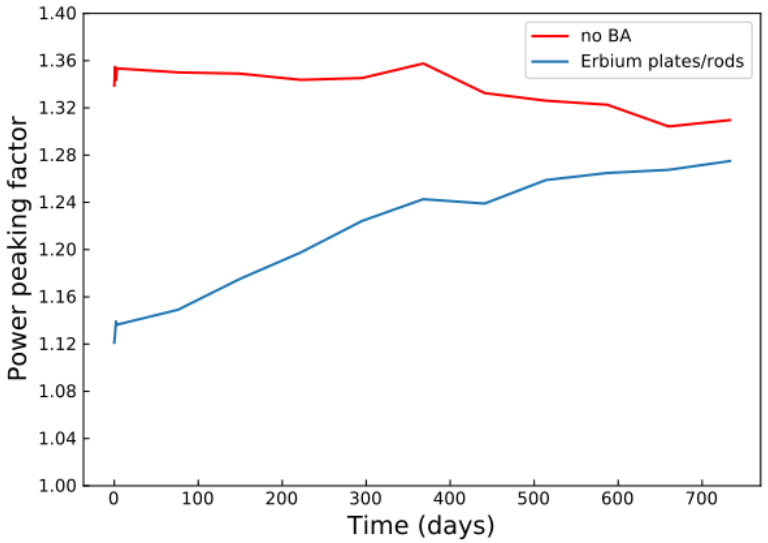


Burnable absorbers – Results



Fuel enrichment is uniform and equal to 7.5% by weight

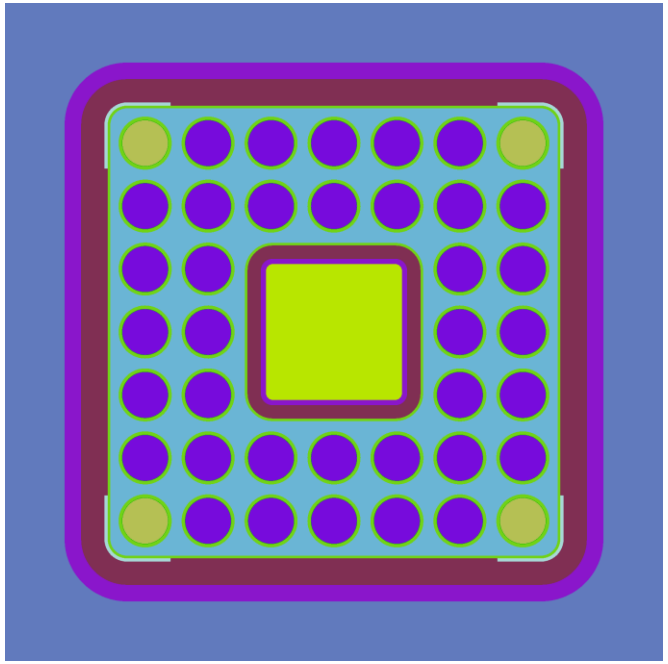




k_∞ shows a very flat trend, however Er is not burned completely

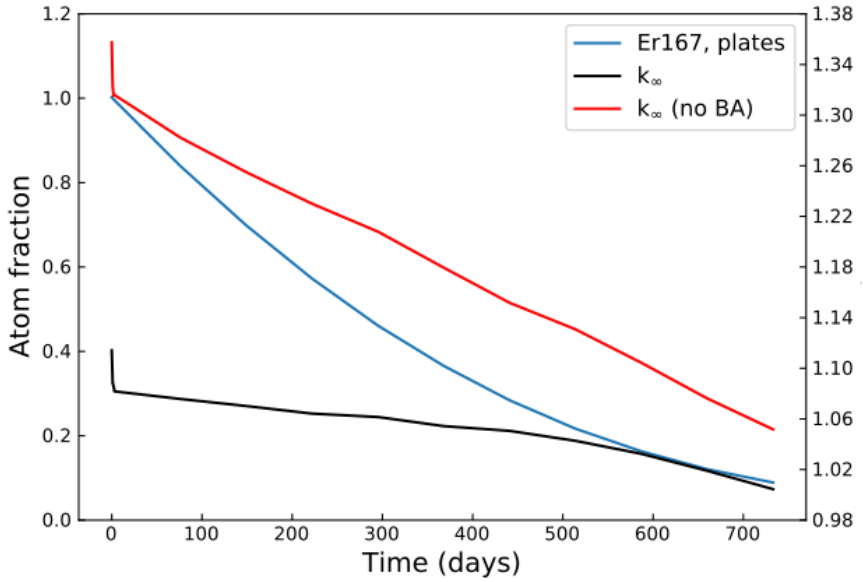
The power peaking factor constantly grows during operation from 1.13 to 1.28

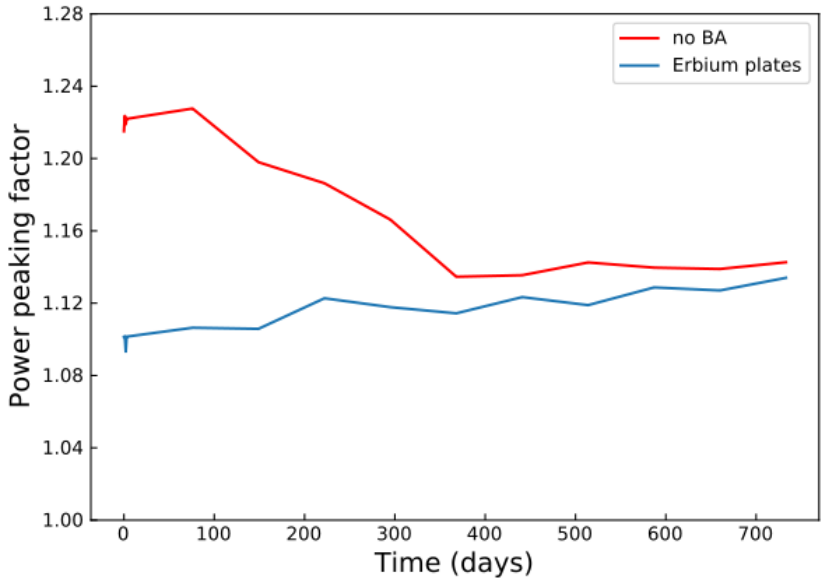
Burnable absorbers – Results



Er or B_4C plates wrapped on the corners of SS-310S

Fuel enrichment is 6.5%w in the corners, 7.5%w elsewhere

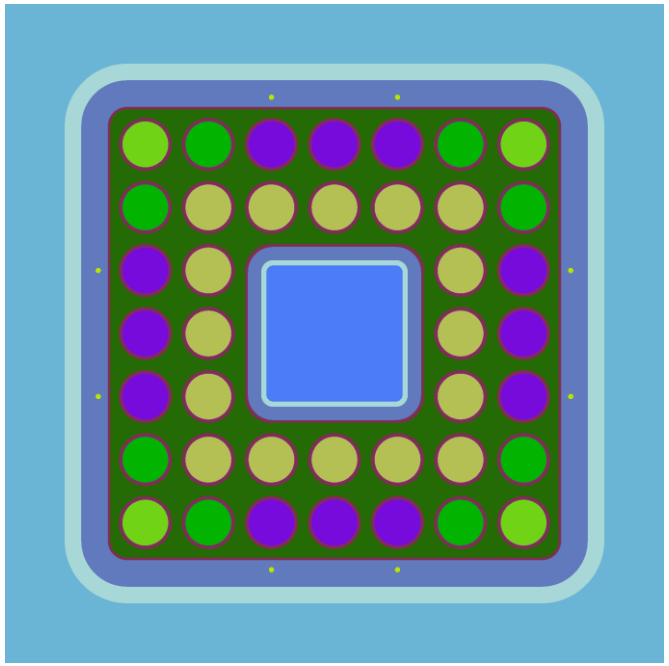




k_∞ slowly decreases, however, Er is still not burned completely

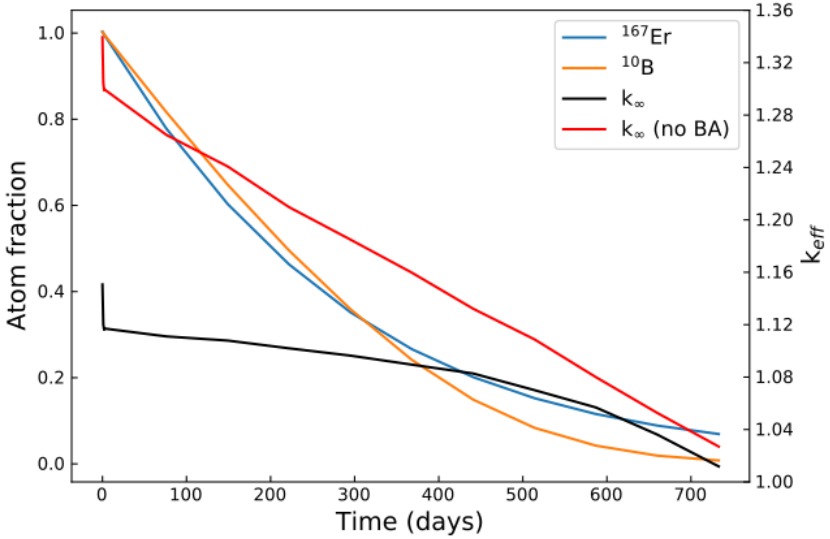
The power peaking factor growth is now much less pronounced

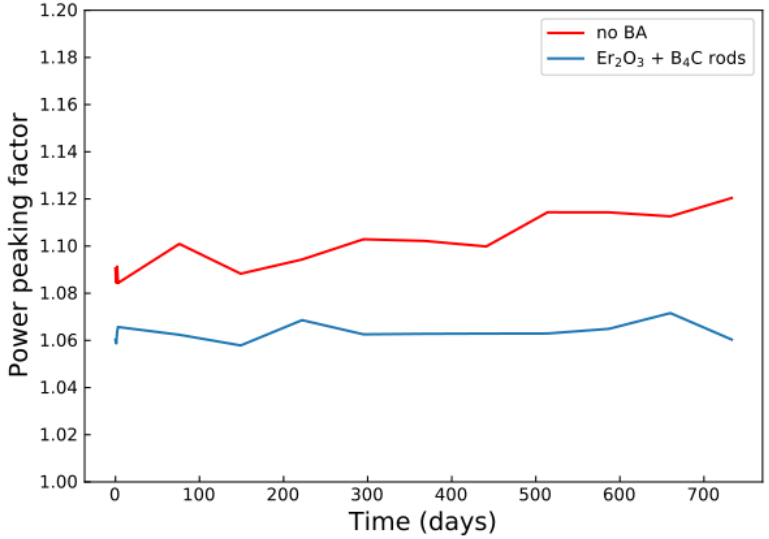
Burnable absorbers – Results



Enrichment: 5 … 7.5%
Er in fuel pins
B_4C rods in assembly wall insulator

Assembly with three different fuel enrichments and some rods loaded with Er_2O_3





k_∞ shows no swing, however some Er is still present at end

The power peaking factor is quite flat, with an average of 1.063

Connections – complexity of research

Fuel type, cladding material	→	Maximum temperature of cladding
Temperature distribution in core	→	Power distribution + thermal-hydraulics
Burnup-length	→	Neutronics
Neutronics	→	Radiation damage (dpa) of clading material
Temperatures, corrosive properties of coolant, radiation damage	→	Experimental investigations on cladding material

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Some important observations

- Use of fuel with above 5% enrichment
- Innovative materials for cladding
- Burnable absorbers in a new manner
- New control system
- Importance of coupling between neutronics and TH
- Reactivity feedback coefficients – local interpretation also
- Transient behaviour analysis

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Thank you for your attention!

JOINT **EUROPEAN CANADIAN CHINESE**
DEVELOPMENT OF SMALL MODULAR REACTOR TECHNOLOGY

This project has received funding from the Euratom Research and Training programme 2019-2020 under Grant Agreement No 945234.

2.16 Towards pre-licensing of ECC-SMART Andrej Prošek/Ildikó Boros, JSI/BME (In person)

JOINT EUROPEAN CANADIAN CHINESE
DEVELOPMENT OF SMALL MODULAR REACTOR TECHNOLOGY

Towards pre-licensing of ECC-SMART

Workshop on the Safety of Small Modular, Advanced and Fusion Reactors

Hotel Evropa, Celje, Slovenia
June 20-21, 2023

Andrej Prošek, Ildikó Boros

This project has received funding from the Euratom Research and Training programme 2019-2020 under Grant Agreement No 945234.

Outline

I. WP5.1 - Generic and specific safety criteria and requirements
II. WP5.2 - Safety related findings and conclusions
III. WP5.3 - Pre-licensing study

Introduction

- Public perception of the economy and safety of today's nuclear power plants will require future Small Modular Reactors (SMRs) to comply fully with the highest safety standards. At the same time, the economic viability of the future SMR will require the application of innovative ideas, involving among others combination of low power density fuels and accident resistant or resilient materials.
- The overall design of the reactor should practically eliminate the possibility of severe accidents with core meltdown and especially eliminate the possibility to release any substantial amount of radioactive materials to the environment.
- Generic and specific safety criteria and requirements for the SCW-SMR concept have been developed in WP5.1, by following and further developing the science-based recommendations by IAEA and GIF for SMRs.
- In the framework of WP5.2 the collection of a priori knowledge of the participating experts and the preliminary results has been started. For this qualitative analysis the Phenomena Identification and Ranking Table (PIRT) method has been selected.
- The pre-licensing study (WP5.3) will relate to the safety criteria and requirements for the SCW-SMR concept developed in the frame of WP5.1 with the safety-related behavior and features of the SCW-SMR as identified in WP5.2.

WP5.1 Generic and specific safety criteria and requirements

Task 5.1: Generic and specific safety criteria and requirements (M1-M48)

Contributors: JSI (sub-task leader), CIEMAT, KIT, BME, CVR, ENEN, JRC

- The aim of WP5.1 was to develop generic and specific safety criteria and requirements for the SCW-SMR concept, by following and further developing the science-based recommendations by IAEA and GIF for SMRs, in particular the concept of defence-in-depth, physical protection and security, and nonproliferation principles (safety, security and safeguards).
- Deliverable: Safety criteria and requirements for the SCW-SMR concept (M12)

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Outline of WP5.1 presentation

1. Guiding Principles for the application of Generic Safety Elements in ECC-SMART
2. International legal frameworks for nuclear safety, security and safeguards
3. National legal frameworks for nuclear safety and security

I.1 Guiding Principles for the application of Generic Safety Elements in ECC-SMART

- The SCW-SMR designs comprised by ECC-SMART includes some specific design features, e.g. high-pressure tubes versus reactor pressure vessel (RPV). This is why specific safety elements identified for ECC-SMART should be further broken down into design-specific safety elements (would become necessary if a concrete SCW-SMR design becomes available).
- The determination of safety elements of ECC-SMART is made up of two steps:
  - 1) Identification of existing safety elements based on a structured literature review and applicability analysis.
  - 2) Development of safety elements from identified gaps related to specific fields of safety where accommodation of existing safety elements is not feasible.
- This two-step process is informed by four guiding principles as subsequently described.

SMR – Small Modular Reactor, SCW – Super Critical Water

I.1 Guiding Principles for the application of Generic Safety Elements in ECC-SMART (cont'd)

4 Guiding principles from review:

1. All **compatible** safety elements of new reactors (3rd Gen. NPPs) apply to ECC-SMART
2. Safety elements specific of SMR designs apply to ECC-SMART depending on the design, hence on a **case-by-case basis**. Safety demonstration dealing with passive safety systems performance and plant accident response need conservative safety margins.
3. All the top-level safety requirements identified by GIF apply to ECC-SMART, in particular, the **elimination of DEC-B scenarios [Large/Early Release]**.
4. **No new challenging safety requirement specific of ECC-SMART** in the accident domain is foreseen. Quantitatively more demanding phenomena affecting safety need robust safety demonstration and conservative safety margins.

DEC – Design Extension Conditions

I.2 International legal frameworks for nuclear safety, security and safeguards

Review of existing safety elements applicable to ECC-SMART and assigning the applicability scope of their elements upon the guiding principles:

- Safety elements belonging to new reactors **apply fully** to ECC-SMART, as derived from the first principle – abbreviated as 1P.
- Safety elements dealing with SMRs **apply on a case-by-case basis depending on the design**, as derived from the second principle – abbreviated as 2P.
- Generic safety elements dealing with 4th Gen. NPPs **apply fully** as derived from the third principle – abbreviated as 3P.
- Specific safety elements dealing with ECC-SMART come from the fourth principle – abbreviated as 4P.

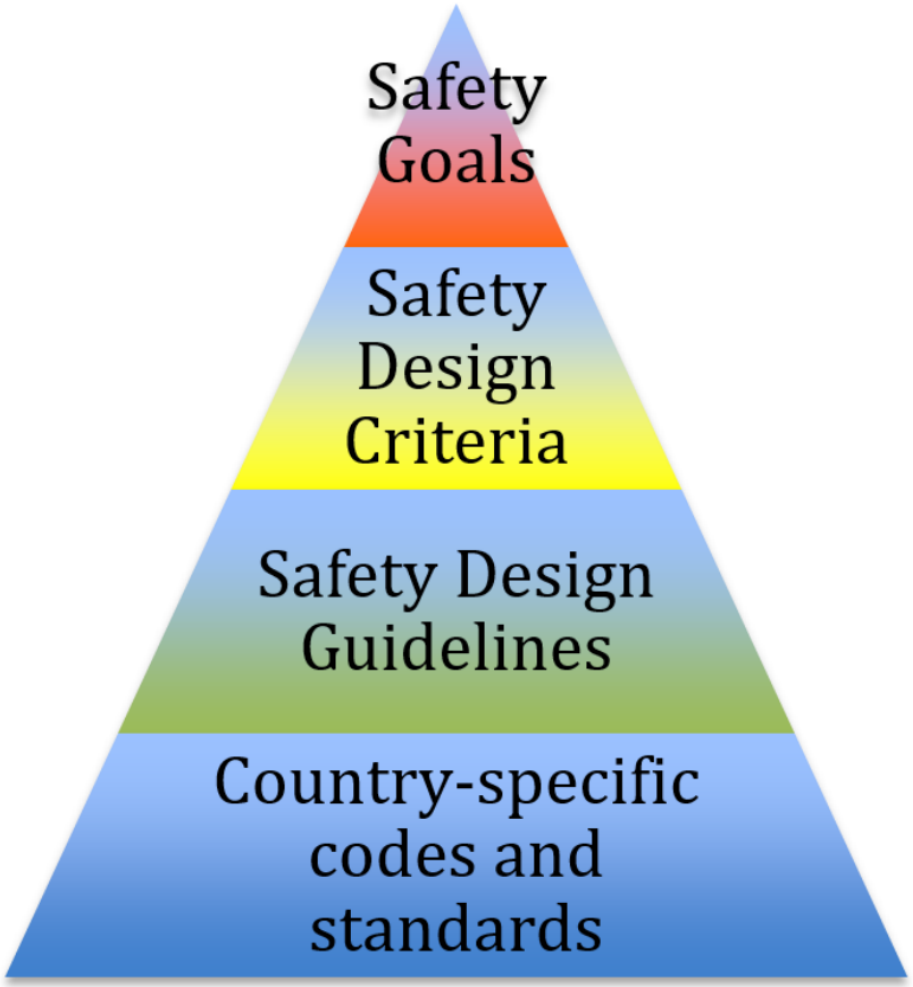
I.2.1 Main IAEA documents reviewed

IAEA document	Classification
Fundamental Safety Principles, Safety Fundamentals, SF-1	1P
Safety of Nuclear Power Plants: Design, Specific Safety Requirements, SSR-2/1	1P
Design of the Reactor Coolant System and Associated Systems for Nuclear Power Plants, Specific Safety Guide, SSG-56	1P
Design of the Reactor Containment and Associated Systems for Nuclear Power Plants, Specific Safety Guide, SSG-53	1P
Design of Auxiliary Systems and Supporting Systems for Nuclear Power Plants, Specific Safety Guide, SSG-62	1P
Applicability of Design Safety Requirements to Small Modular Reactor Technologies Intended for Near Term Deployment, TECDOC-1936	2P and 3P
Design and Safety Considerations for Water Cooled Small Modular Reactors Incorporating Lessons Learned from the Fukushima Daiichi Accident, TECDOC-1785	2P and 3P

I.2.2 Main GIF documents reviewed

- Gen IV Goals
- Safety Design Criteria for Generation IV Sodium-cooled Fast Reactor System (Rev. 1) (2017)
- Safety Design Guidelines on Safety Approach and Design Conditions for Generation IV Sodium-cooled Fast Reactor Systems (Rev. 1) (2019)
- An Integrated Safety Assessment Methodology (ISAM) for Generation IV Nuclear Systems (Version 1.1) (2011)
- Super-Critical Water-cooled Reactors (SCWR) Risk and Safety Assessment White Paper (Rev. 1) (2017)
- Supercritical-water-cooled reactor system (SCWR) System Safety Assessment (2018)

I.2.2 Main GIF documents reviewed (cont'd)



Safety Goals	Fundamental safety principles and common safety goals for all Gen-IV systems
Safety Design Criteria	A set of citeria reflecting GIF safety approach to achieve harmonized safety requirements of SFR system
Safety Design Guidelines	A set of guidelines on how to implement the design criteria and address SFR-specific safety topics
Country-specific codes and standards	Domestic regulations for design of reactor core, cooling system, and other structures, systems, and components

Figure: Hierarchy of Safety Standards [1]

Ref. 1: Safety Design Criteria for Generation IV Sodium-cooled Fast Reactor System (Rev. 1), SDC-TF/2017/02, Sept. 30, 2017.
Link to the public version

I.2.2.1 Gen IV Safety Goals

GIF Safety and Reliability 2 goal states:

"Generation IV nuclear energy systems will have a very low likelihood and degree of reactor core damage."

GIF Safety and Reliability 3 goal states:

"Generation IV nuclear energy systems will eliminate the need for offsite emergency response."

First goal looks at significantly reducing both the probabilistic and deterministic aspects of DEC-A scenarios whereas the second goal looks at preventing DEC-B scenarios. Reformulating these goals:

The frequency of DEC-A scenarios shall be very low and its damage extension limited.

I.2.2.1 Gen IV Safety Goals (cont'd)

Second goal is reformulated:

DEC-B scenarios shall be eliminated.

In conclusion:

- The first GIF safety goal does not impose any extra burden on ECC-SMART.
- The second GIF safety goal is transposed into challenging safety criteria dealing with the last static and dynamic safety barriers or physicochemical properties of the nuclear hazards. If relying on passive safety systems, compensation for the lack of reliability through redundancy, diversity or large grace periods should constitute an additional safety criterion.

I.2.2.2 Safety Design Criteria for Generation IV Sodium-cooled Fast Reactor System (Rev. 1) (2017)

Colour codes:

Accepted
Modified text not accepted
SCWR-related modification needed
Not relevant
Needs deeper evaluation

Table shows 10 out of 82 Criteria.

Criterion	10	Safety assessment										
			4.17	4.18	4.18.a							
Criterion	15	Design limits										
			5.4									
Criterion	17	Internal and external hazards										
			5.15A	5.15B	5.16	5.17	5.18	5.19	5.20	5.21	5.21A	5.22
Criterion	19	Design basis accidents										
			5.24	5.25	5.26							
Criterion	20	Design extension conditions										
			5.27	5.28	5.29	5.30	5.31	5.32				
Criterion	33	Safety systems, and safety features for design extension conditions, of units of a multiple unit nuclear power plant										
			5.63									
Criterion	35	Nuclear power plants used for cogeneration of heat and power, heat generation or desalination										
Criterion	46	Reactor shutdown										
			6.7	6.8	6.9	6.10	6.11	6.12				
Criterion	54	Containment system for the reactor										
			6.19C									
Criterion	77	Power conversion systems, including potential steam supply systems, feedwater systems and turbine generators										
			6.56	6.57	6.58	6.58A						

The criteria and requirements of the Safety Design Criteria (SDC) document have been evaluated and compared with the IAEA SSR-2/1. Results:

1. Most of the modifications made by the GIF Task Force for SMR cannot be accepted for SCWR regulation
2. Recommendation 1: IAEA SSR-2/1 (Rev. 1) should be used during the SCW-SMR development as a starting point for the design criteria development.
3. Recommendation 2: Besides SSR-2/1 (Rev. 1), the available SMR regulation standards and guidelines should be used as a basis in order to take into account the specific safety features of SMRs.

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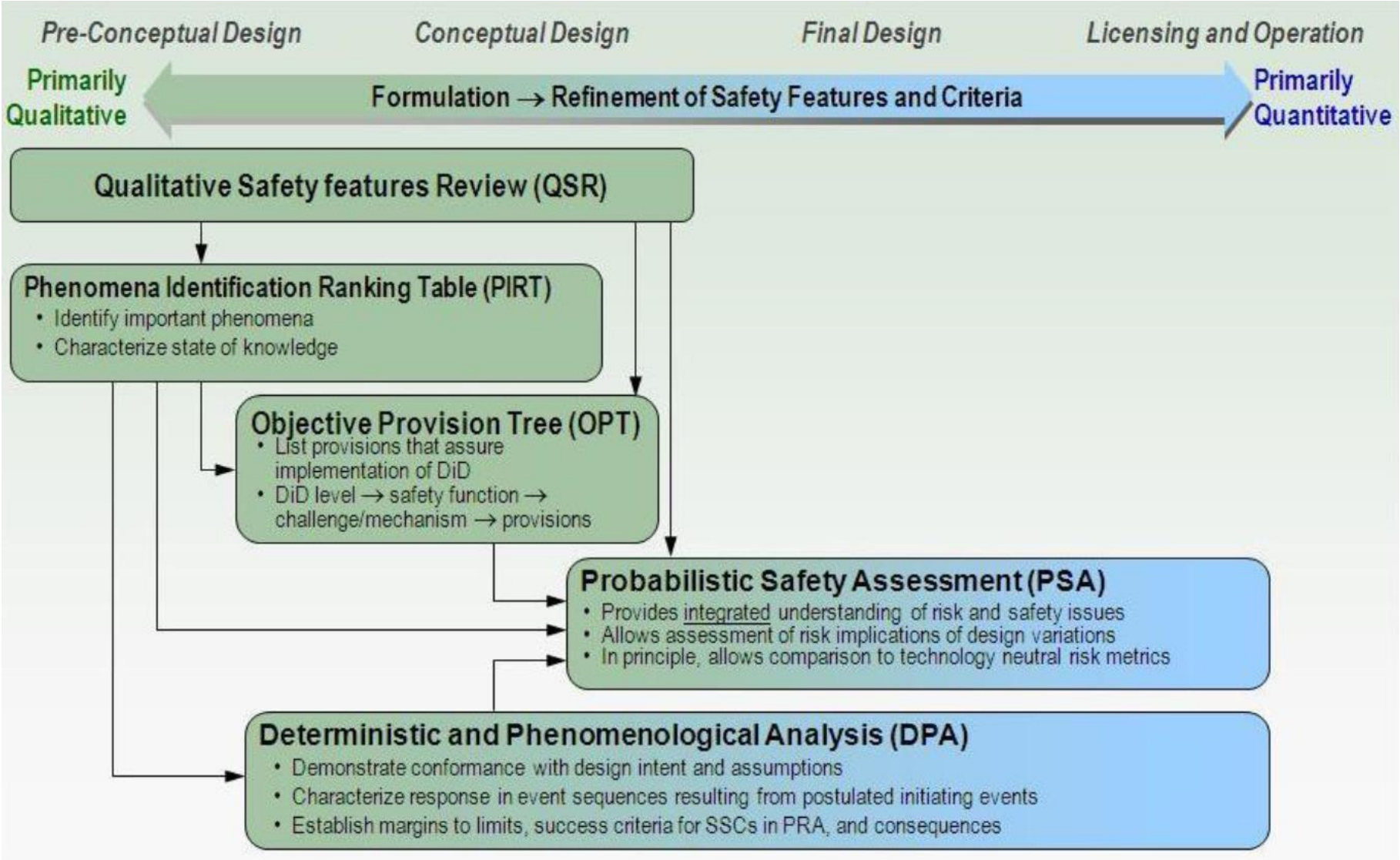
I.2.2.3 Safety Design Guidelines on Safety Approach and Design Conditions for Generation IV Sodium-cooled Fast Reactor Systems (Rev. 1) (2019)

- Section 1. Introduction
  - gives a short introduction about the regulation framework and the scope of the Guideline.
- Section 2. Main Characteristics of Gen-IV SFR Systems
  - presents the SFR technology systems and fundamental characteristics of four current Gen-IV SFR designs.
- Section 3. General Approach
  - describes the different plant states taken into consideration in the design basis. It introduces the concept of “practical elimination” and “residual risk”.
- Section 4. Guidelines for Application of Safety Design Criteria
  - contains the recommendations for meeting the requirements of Design Criteria.
- Section 5. Considerations for SFR reactivity characteristics
  - gives a detailed description of the reactivity characteristics (that is a very specific SFR issue because of the positive void factor of SFRs). It shows the considerations concerning reactivity accidents in Design Basis Accident (DBA) or DEC states.
- Appendix A
  - gives very useful insight into the use of Objective Provision Tree (OPT) method through the example of determination of the situations to be practically eliminated performed for the Japanese SFR (JSFR).
- Appendix B
  - gives a preliminary list of some Anticipated Operational Occurrences (AOO) and DBA initiating events.

I.2.2.3 Safety Design Guidelines on Safety Approach and Design Conditions for Generation IV Sodium-cooled Fast Reactor Systems (cont'd)

- The Safety Design Guidelines (SDG) document gives a good basis for the development of the set of regulation requirements. It can be used as a practical tool for the fulfilment of SDC requirements.
- However, as a rather technical document, the SDG is not really suitable to be used as a direct basis for the development of the similar documentation for SCWRs (for example to the SCW-SMR) because the technical differences are extremely large between the different Generation IV reactor concepts. After the development of the Design Criteria document for SCWRs/SCW-SMRs, a similar guideline should be issued.
- The review of the SDC document has been performed by the safety experts of BME NTI. The relevant pages from the document SDC document have been depicted on the left with the comments on the right.

I.2.2.4 An Integrated Safety Assessment Methodology (ISAM) for Generation IV Nuclear Systems (Version 1.1) (2011)



The ISAM consists of five distinct analytical tools.

It is intended that each tool be used to answer specific kinds of safety-related questions in differing degrees of detail, and at different stages of design maturity.

I.2.2.4 An Integrated Safety Assessment Methodology (ISAM) for Generation IV Nuclear Systems (Version 1.1) (2011)

- **QSR** provides a systematic means to identify and discuss the safety-related attributes and characteristics of the given Generation IV design and to evaluate the relevant references for it (IAEA, GIF, INPRO guidelines, etc.).
- **PIRT** is a well-known qualitative process to identify the importance of safety issues and to determine the knowledge of them.
- **OPT** is a relatively new analytical tool, developed mainly by the IAEA. It provides an exhaustive overview of the safety related architecture and allows the identification, for each level of the DiD, of all provisions that contribute to the achievement of safety functions as well as their mutual interrelations.
- **DPA** consists of the use of “conventional” deterministic and phenomenological analyses, as thermal-hydraulic, computational fluid dynamics (CFD), reactor physics analyses, structural models, etc.
- **PSA**: The basis of the ISAM methodology is the full-scope PSA. PSA can be applied rather in more matured design phases (from late pre-conceptual design), up to the licensing of the Generation IV system.

I.2.2.5 Overall recommendations from reviewed IAEA and GIF documents

Based on the review of the IAEA and GIF documents, the most important recommendations are the following:

- The IAEA SSR-2/1 (Rev. 1) should be used during the SCW-SMR development as a starting point for the design criteria development.
- The available SMR regulation standards and guidelines should be used as a basis in order to consider the specific safety features of SMRs.
- After the development of the Design Criteria document of the SCWRs/SCW-SMRs, a safety design guidelines (SDG) on safety approach and design conditions for Generation IV SCWR/SCW-SMR should be issued.
- An exercise to apply the ISAM should be performed on the SCW-SMR concept as soon as a sufficiently detailed SCW-SMR concept becomes available.
- In the meantime R&D on the SCWR and its different concepts to fill the knowledge gaps should be continued.

I.3 National legal frameworks for nuclear safety and security

- Safety requirements at national level in Canada, China, Czech Republic, Finland and United Kingdom have been reviewed.
- So far, no country that is seriously looking into SMRs has changed its national nuclear regulation to accommodate SMRs. But the regulators in some countries are in the process of changing their regulation accordingly or have announced that they will do so, e.g. STUK in Finland.
- In Canada and the U.S. some SMR designs (even non-water-cooled) are in the licensing or generic design assessment process. In the U.S. the licensing process for one LW-SMR, the PW-SMR of NuScale, is even completed.
- Although none of these SMR designs is a SCW-SMR design, some conclusions could be drawn from these processes for the SCW-SMR.

I.4 Conclusions

(Preliminary) Generic Safety Requirements:

- All high level (Gen2, Gen3) safety requirements apply
- Some similarities with BWR, PWR and PHWR
  - No major “surprises” expected.
- The high level GEN IV safety requirements apply (eliminate evacuation)
- The fast GEN IV reactor (Sodium, lead cooled) requirements in general not applicable (some might be considered)

To be further developed in WP5.3 using Integrated Safety Assessment Methodology (ISAM) for GEN IV, in particular:

- Qualitative Safety Features Review
- (parts of) Phenomena Identification Ranking Table

BWR – boiling Water Reactor, PWR – Pressurized Water Reactor, PHWR – Pressurized Heavy Water Reactor

WP5.2 – Safety related findings and conclusions

Task 5.2: Safety-related findings and conclusions of the WPs 2-4 (M1-M48)

Contributors: BME (subtask-leader), CIEMAT, KIT, ENEN, JRC, IPP (6 project partners)

- Aim of this task is to provide answers to the potentially outstanding issues and gaps in knowledge regarding the safety-related behavior of supercritical water reactor
- Outcome of this task will summarize the conclusions and lessons learned into a synthetic form to facilitate the future work of designers and nuclear safety analysts
- The work of WP5.2 relies on the results of WPs 2-4
  - WPs 2-4: contribution to the resolution of basic conceptual issues involving material challenges of SCW Technology (WP2), problems of flow and heat transfer in SCW (WP3), as well as neutronic aspects of an active core with SCW as coolant and moderator (WP4)
- Deliverable: Safety related features of the SCW-SMR concept (M40)

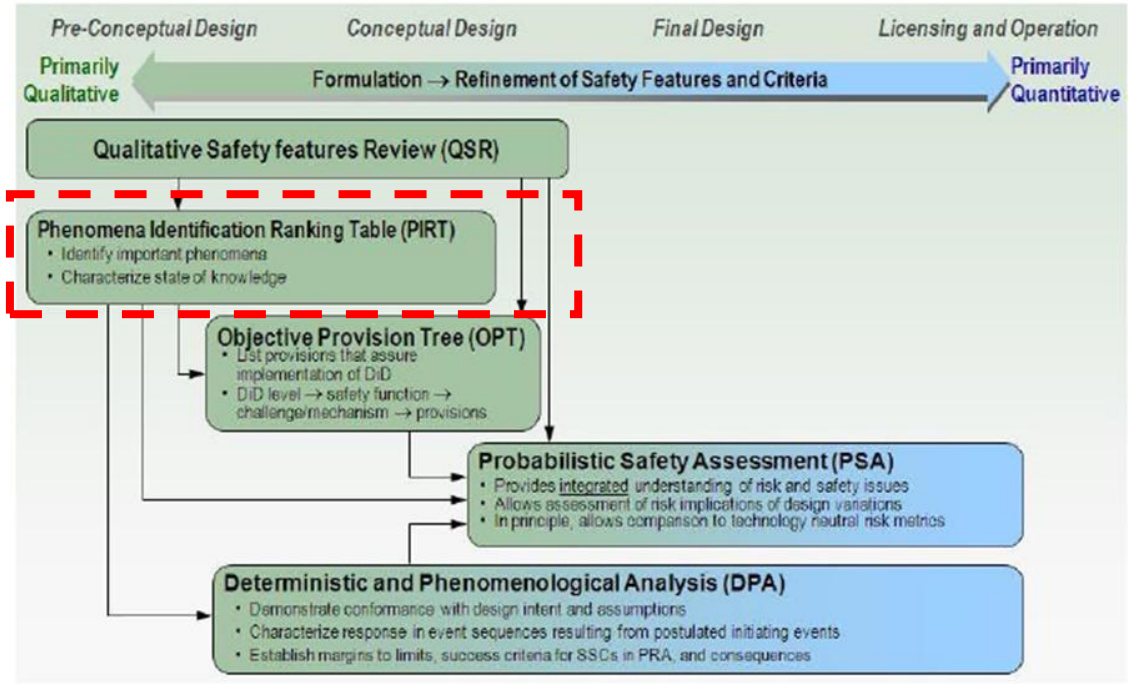
WP5.2 – Safety related findings and conclusions

- Challenges for WP5.2
  - In this very early design phase (Pre-PCD) mainly safety features originating from the basic physical features can be collected
  - Technology is subject to further changes
  - No final results from WP2-4 available yet
  - WPs focusing on rather special topics – more general issues should be identified
- ISAM (Integrated Safety Assessment Methodology) has been identified as an applicable approach for our task
  - At present phase only qualitative safety assessment can be performed;
  - Main goal is to identify knowledge gaps and main safety challenges for the selected technology.

WP5.2 - PIRT analysis

Phenomena Identification and Ranking Table (PIRT):

- Literature review:
  - PIRT is a well-known qualitative process to identify the importance of safety issues and to determine our knowledge level of them
  - Applied for Gen2 reactors (i.e. SFP events, SAM), Gen3 reactors (accident scenarios), Gen4 reactors (design aid tool)
- The method is based largely on expert elicitation
- The process involves:
  - selecting hardware (i.e., SCW-SMR concept),
  - selecting an operational states / accident scenario,
  - identification all plausible phenomena having important effect on safety.



Proposed GIF Integrated Safety Assessment Methodology (ISAM) Task Flow (source: D5.1)

WP5.2 - PIRT analysis

Phenomena identification → Expert panel ranking → Ranking matrix

- Process of analysis
- Important phenomena identified by WP2-4 members
  - Excel worksheet sent to participants in more rounds
- Each phenomenon is then ranked in order of relative importance (phenomena ranking, PR) and its state of knowledge (knowledge ranking, KR)
  - For ranking, table disseminated again
- Based on PR and KR data, a ranking matrix could be created
- Identification of high importance / low knowledge phenomena
  - Ranges defined previously
- The results can be used for the determination of further analytical and / or experimental investigations, determining a priority R&D effort

Phenomena Ranking Scales	Knowledge Based Ranking Scales
High (H)	4 - Fully known, small uncertainty
Medium (M)	3 - Known, moderate uncertainty
Low (L)	2 - Partially known, large uncertainty
Insignificant (I)	1 - Very limited knowledge, uncertainty can not be characterized

Figure 1. Typical phenomena ranking scales, applied for our analysis

Figure 2. PIRT matrix

Knowledge level / Importance	4	3	2	1
Insignificant				
Low				
Medium				
High				

Colour codes: low significance, medium significance, high significance

Preliminary results – WP2

Phenomena identification → Expert panel ranking → Ranking matrix

- Very thorough work performed by members
- 7 answers from 6 institutions received in 3 rounds
- 23 phenomena have been identified for normal operation / all operational states
- Lessons to learn: it is worth to separate the phenomena collection and the expert ranking

WP2 – part of the phenomena identification and ranking table

#	Descriptive name of material phenomena:	Short description of the item or notes:	Phenomena Ranking (PR):	Rational of PR by the proposer of the item:	Comments/Reasons for Selected Ranking	Knowledge Ranking (KR):	Rational of KR by the proposer of the item:	Reasons for Selected Ranking	Operating status:
1	Through wall penetrations produced by general corrosion	The resistance of cladding matererial is a key parameter for reactor safety. The cladding must contain the fuel and retain the fission gases	Phenomena Ranking Scales	Takes place more or less frequently in present LWRs. Results in increased radiation exposure of personnel in the vicinity of the reactor coolant circuit.Should be observed easily from the first cracks.	Please specify!	Knowledge Based Ranking Scales	Only knowledge is based on lab tests on small samples.	Please specify!	All operations
2	Oxide build-up that impedes heat transfer	The oxide thickness could affect the heat transfer and the efficience of the reactor	Phenomena Ranking Scales	May result in overheating of the fuel and cladding. Probably most pronounced where the temperature is close to Tc.	Please specify!	Knowledge Based Ranking Scales	Limited knowledge on the effect on heat transfer and cladding integrity. Possibility of accumulation depends on many unknown factors, e.g., nominal flow condition and properties of formed deposits/depositing oxide particles.	Please specify!	Normal operation
3	Oxide release from the cladding surface by dissolution/evaporation	The release of irradiated oxides can contaminate other reactor areas	Phenomena Ranking Scales	Results in increased radiation exposure of personnel in the vicinity of the reactor coolant circuit.	Please specify!	Knowledge Based Ranking Scales	Only knowledge is based on lab tests on small samples.	Please specify!	Normal operation

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Preliminary results – WP2

Phenomena identification → Expert panel ranking → Ranking matrix

- Very thorough work performed by members
- 7 answers from 6 institutions received in 3 rounds
- 23 phenomena have been identified
- Lessons to learn: it is worth to separate the phenomena collection and the expert ranking

	Contributor / Phenomenon	CIEMAT		VTT		DG		CNL		RATEN		CVR		JRC		Ranking	
		Importance	Kowledge level	Importance	Kowledge level	Importance	Kowledge level	Importance	Kowledge level	Importance	Kowledge level	Importance	Kowledge level	Importance	Kowledge level	Importance	Kowledge level
1	Through wall penetrations produced by general or localized corrosion	M (Medium)	3	L (Low)	2	M (Medium)	3	M (Medium)	3	H (High)	2	L (Low)	3	H (High)	3 - Known, moderate uncertainty	2,17	2,66667
2	Oxide build-up that impedes heat transfer	M (Medium)	2	M (Medium)	2	M (Medium)	2	M (Medium)	2	H (High)	3	H (High)	2	H (High)	3 - Known, moderate uncertainty	1,67	2,16667

WP2 – Result of expert panel's ranking

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Preliminary results – WP2

Phenomena identification → Expert panel ranking → Ranking matrix

- Result of the work is the ranking matrix
- Experiences:
  - Usually good agreement among the experts' answers
  - Finer resolution is needed in analysis of the answers

Colour codes:

- low significance,
- medium significance,
- high significance

Importance \ Knowledge level	4	3	2	1
Insignificant				
Low				
Medium		1; 3; 9	2; 3a; 4; 5; 6; 7; 11; 12; 15; 16; 18; 19; 20; 21; 22	12
High		13	5; 10; 14; 17	8

WP2 – Ranking matrix

1	Through wall penetrations produced by general or localized corrosion
2	Oxide build-up that impedes heat transfer
3	Oxide release from the cladding surface
3a	by dissolution / evaporation
4	Pellet cladding interaction
5	Environmental Assisted cracking (EAC)
6	Changes in the mechanical properties of the materials produced by ageing and/or irradiation
7	Changes in the geometry of tubes produced by irradiation, creep
8	Radiolysis processes
9	Physicochemical properties of water within the SC region
10	Resistance of cladding materials under LOCA conditions SCWR
11	Impurity enrichment
12	Oxide release from the cladding surface by spalling
13	Irradiation embrittlement due to He
14	IASCC
15	Hydriding
16	Cladding collapse
17	Overheating of the Cladding
18	Overheating of Fuel Pellets
19	Cladding rupture
20	Fuel Rod Mechanical Fracturing
21	Strain Fatigue
22	Fretting Wear

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Preliminary results – WP3

Phenomena identification → Expert panel ranking → Ranking matrix

- 22 phenomena have been identified
  - Improvement based on WP2 experiences: online worksheet on SharePoint
- List of phenomena to be sent to WP3 members

WP3 – phenomena identified by WP members

- Steep non-linear change of SCW fluid material properties
- Heat transfer in water under supercritical pressure conditions (trusted prediction of heat transfer coefficient)
- Pressure drop (Δp) in water under supercritical pressure conditions in SCW-SMR (SCWR) relevant geometries
- Turbulent heat and mass transfer in water under supercritical pressure conditions in SCW-SMR relevant (in horizontally installed tube but mainly rod bundle) geometries
- Heat and mass transfer of coolant/moderator SCW along corroded and rough surfaces of the core structural element
- Deterioration of heat transfer (DHT) or heat transfer deterioration (HTD)
- Transition from supercritical to subcritical pressure water state
- Steam and liquid water two phase flow in SCW-SMR primary loop
- Natural circulation of water under super- or sub-critical pressure conditions in SCW-SMR primary loop
- Strong coupling between the thermal hydraulics (e.g. SCW density field) and the reactor physics (e.g. heat production by nuclear fission in the core)
- Depressurisation of the primary loop and the travelling depressurisation wave and its path in case of a LOCA
- The effect of the presence of large and hot structural components (large amount of structural material) in the reactor pressure vessel (RPV) during accidents
- Flow instability under supercritical pressure conditions in SCW-SMR relevant (in horizontally installed tube but mainly rod bundle) geometries
- Allowable maximum cladding temperature during normal operation (WP2-WP3) in the SCW-SMR
- Flow stratification in horizontal channels. the lighter fluid will tend to move upwards in the fuel assembly
- flooding.
- Thermalhydraulics and Neutronic coupled instabilities.
- CHF near the critical point.
- Fluid induced vibration
- Decay heat
- Mechanical deformation (coupled with th)
- Pellet/cladding interaction (conductance)

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Preliminary results – WP4

Phenomena identification → Expert panel ranking → Ranking matrix

- 22 phenomena have been identified by for normal / all operational states
- 8 further phenomena for REA (rod ejection accident)
- Input only from the BME NTI
  - Identified issues covered mainly simulation questions

WP4 – phenomena identified by WP members

RP PIRT: normal and all operations				
#	Descriptive name of reactor physical phenomena:	Short description of the item or notes:	Reference for the item:	Operating status:
Computation methodology 1: Deterministic calculations (e.g. for TH coupling) FoMs: ability to determine the effective multiplication factor (FoM1) or neutron flux distribution (FoM2)				
1	Required transport approximation	Diffusion or higher-order transport approximations (e.g. SP3) are necessary to accurately model the reactor power distribution.	n.a.	All operations
2	Number of necessary energy groups and energy group structure	Due to higher temperatures, and harder spectrum, it is relevant to investigate the number of necessary energy groups and specific energy group structure for the deterministic simulations (especially the thermal energy range).	W. Shen: Assessment of the traditional neutron-diffusion core-analysis method for the analysis of the Super Critical Water Reactor, Annals of Nuclear Energy 45 1–7, 2012. & A. Moghrabi, D.R. Novog: Determination of the optimal few-energy group structure for the Canadian Super Critical Water-cooled Reactor, Annals of Nuclear Energy 115 27–38, 2018.	All operations
3	Spatial discretization	It is necessary to determine the appropriate spatial discretisation, e.g. FA node level or pinlevel calculations are necessary, what is the required number of axial nodes. Besides, in the light of the applied numerical method, the numerical spatial discretization level can also have an influence.	n.a.	All operations
4	Time discretisation	It is necessary to determine the appropriate temporal discretization applied in time-dependent calculations.	n.a.	All operations
5	Reflector boundary and group contants	For deterministic codes the modeling of reflector region is not as straightforward as for neutron transport codes.	n.a.	All operations
Computation methodology 2: Monte Carlo calculations				
6	Geometric parameters	Appropriate modeling of geometric parameters is necessary	n.a.	Normal operation

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Roadmap

WP2 PIRT

- Phenomena identification ✔
- Ranking by expert panel ✔
- PIRT matrix created ✔

WP3 PIRT

- Phenomena identification ✔
- Ranking by expert panel (in progress)
- PIRT matrix created

WP4 PIRT

- Phenomena identification ✔
- Ranking by expert panel (in progress)
- PIRT matrix created

Safety features of SCWR-SMR

- Synthesis of WPs results
- Documentation in D5.2

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WP5.3 Pre-licensing study

Task 5.3: Pre-licensing study (M1-M48)

Contributors: JSI (sub-task leader), BME, KIT, CIEMAT, CVR, ENEN, JRC, IPP

- The aim of WP5.3 is the development of pre-licensing study, which will summarize both the already achieved safety criteria and the potential gaps to be further investigated in future research projects.
- Deliverable: Pre-licensing study (M46)

WP5.3 Pre-licensing study

- Regulations present requirements binding on all persons and organizations who receive a license.
- The guides provide guidance to licensees and applicants on implementing specific parts of the regulations.
- The ECC-SMART pre-licensing study relates to the safety criteria and requirements for the SCW-SMR concept developed in the frame of WP5.1 (dealing with generic and specific safety criteria and requirements) with the safety-related behavior and features of the SCW-SMR as identified in WP5.2.
- The ECC-SMART pre-licensing study is aiming to demonstrate the feasibility of the conceptual design to be licensed.
- No specific experimental verifications are planned for the pre-licensing study.

WP5.3 Pre-licensing study (cont'd)

(Preliminary) Specific Safety Requirements:

- Yet to be developed (very limited formal rules available)
- Very low frequency of DEC-A (core damage) events
- Eliminate DEC-B (off site response due to radioactive release) events
- Many design specific "details" might need specific (quantitative) attention, e.g.:
  - Coupling of TH & neutronics
  - Passive? removal of residual heat
  - Materials at given environments (temperature, pressure, steam, irradiation)
  - ➔ depending very strongly on the preliminary design to be used

It is expected that the pre-licensing study will identify three sets of the safety criteria and requirements:

(1) fulfilled with reasonable certainty within the limits of already available knowledge,

(2) fulfilment is probable, further research needed, and

(3) fulfilment is improbable, design changes are needed.

WP5.3 Pre-licensing study (cont'd)

Assessment will start when WP5.2 results will be available on resolving the basic conceptual issues involving material challenges, problems of flow and heat transfer, as well as neutronic aspects of an active core with SCW as coolant and moderator.

The RSWG strongly believes that using all of the elements of the ISAM in an integrated way will improve and optimize all aspects in which safety is implemented, will reduce technology development cycle time, will reduce development costs, and will facilitate the licensing of Gen IV systems.

Therefore, Integrated Safety Assessment Methodology (ISAM) for GEN IV will be used in pre-licensing study, in particular:

- Qualitative Safety features Review (QSR)
- (parts of) Phenomena Identification Ranking Table (PIRT)

RSWG – Risk and Safety Working Group

2.17 HARMONISE Project and Stakeholders Involvement, Mirela Nitoi, RATEN (In person)

Harmonising Fission & Fusion Reactor Licensing

HARMONISE project and stakeholders involvement

Dr. Mirela NITOI
RATEN ICN, mirela.nitoi@nuclear.ro

Overview

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- Steps in developing the stakeholder network
- Relevant stakeholders for the project
- Stakeholders categories
- Strategy to engage
- Strategy to maintain connections
- Topics for discussion

Background

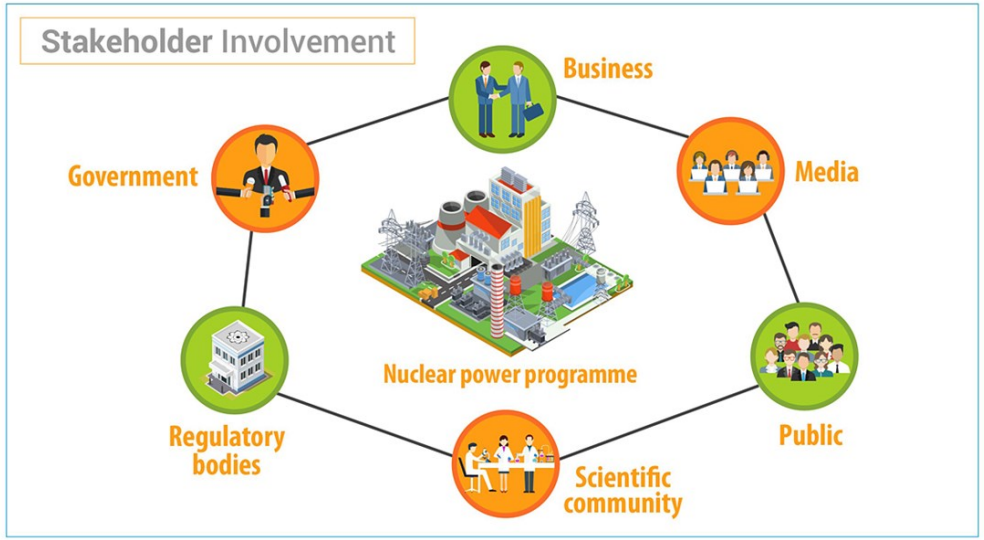
Stakeholder

someone or a party with an interest or useful information or experience in a particular matter (licensing of innovative fissions and fusion power plants)

- Implementing a new technology process is affected by several different organizations, e.g. licensees, safety authorities, vendors, non-governmental organizations, public and media
- Project and stakeholders - close relation

Steps

- Creating the stakeholder list (identification of relevant stakeholders)
- Developing the stakeholder network (making contact, engaging, informing)
- Maintaining the stakeholder network (communicating, obtaining feedback)



Creating the stakeholders list

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- The project stakeholders group - representatives of: different international organizations; National safety authorities; Industry; Research; Education & training communities; Relevant non-nuclear communities
- The list of the relevant stakeholders, along with a short description, objectives, activities and motivation for inclusion in the stakeholder group, as well as the information regarding the person considered contact point for a specific stakeholder was developed.
- **Challenges**: elaborate a comprehensive list; find the right person for contact

Stakeholders responsiveness, pro-active and collaborative attitude during the implementation of the project will be needed to achieve a high-level quality for the project outcomes.

International organizations

HARMONISE aims at an extensive consultation process with:

- **European Nuclear Safety Regulators Group** (ENSREG)
- **Western European Nuclear Regulators Association** (WENRA)
- **European Technical Safety Organisations Network** (ETSON)
- **Sustainable Nuclear Energy Technology Platform** (SNETP)
- **The Generation IV International Forum** (GIF)
- **IAEA** (Division of Nuclear Installation Safety – Nuclear Harmonization and Standardization Initiative (NHSI) ; SMR Regulators Forum
- **Organisation for Economic Cooperation and Development / Nuclear Energy Agency** (NEA OECD)
- EUROfusion, NuclearEurope
- **Standards development organisations** (SDO)
- **Association for design and construction rules for nuclear island components** (AFCEN)
- **European Nuclear Installation Safety Standards** (ENISS)
- **World Nuclear Association - Cooperation in Reactor Design Evaluation and Licensing** (WNA- CORDEL)

Goal: to benefit from the accomplishments achieved and the progress made in collaborative initiatives (in standardisation and nuclear safety)

Nuclear Regulators

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- CNSC Canada - Canadian Nuclear Safety Commission
- ONR UK - Office for Nuclear Regulation
- US NRC - Nuclear Regulatory Commission
- National regulators
- The national safety authorities will be informed on the project evolution primarily through their membership in the corresponding international associations such as ENSREG, WENRA and ETSON.
- Those interested in direct contact with the HARMONISE project will be provided with all necessary information.

Industry

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- Several industrial companies are developing designs of advanced nuclear systems – they are direct users and main benefiters of harmonized frameworks ruling how their designs will be licensed.
- Surveying the European framework, the most noticeable industrial companies with active initiatives on the development of advanced nuclear (fission and fusion) systems were included in the list.

ANSALDO NUCLEARE
EDF
FINNUCLEAR
FORTUM
LEADCOLD
NEWCLEO
ROLLS ROYCE
SEABORG TECHNOLOGIES
WESTINGHOUSE

Relevant EURATOM projects

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- A number of research actions are ongoing in Europe, dealing with advanced nuclear technologies. A screening has been made to reveal those dealing with a subject that can directly or indirectly impact on the activities of HARMONISE. Two criteria were considered for this selection:
    - projects addressing licensing aspects of advanced systems, from a normative standpoint (thus directly impacting on HARMONISE);
    - projects addressing non-normative aspects of advanced systems, such as research, development, design or safety, but with a potential connection to the technical requirement that substantiate the licensing framework (thus indirectly impacting on HARMONISE).
- A non-exhaustive list of Euratom-funded projects was elaborated, with a short description of each where elements of synergy are identified.

- On the same time, it was noticed that relevant Euratom projects have been completed and 'Capitalization on progress made' has added on the list projects as: ELSMOR, PASCAL, ARCADIA, ESNII PLUS, SARGEN_IV, etc.

Research and Education & Training communities

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- With the aim to raise awareness of wider nuclear energy community on the objectives, approaches, activities and outcomes of HARMONISE by extending the group of project potential stakeholders, a communication with the European networks such as ENEN, NEA and European User Facility Network was established, and respective projects/ initiatives in the area of education, training and experimental research, such as ENEN2plus, NEA NEST and OFFERR.
- The information provided by HARMONISE to the stakeholders may be used in their education and training activities, disseminated in course of various international events, as well as it may initiate further research to be carried out as part of the NEA-NEST projects.
- HARMONISE will welcome any feedback from the above-mentioned stakeholders on the project related topics.

Relevant non-nuclear communities

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Efforts were made to enrich the stakeholder network with key players from other than the nuclear community fields that are subjected to regulated safety practices (e.g., aviation, medical).

Aviation Regulation

- Both nuclear and aviation industries operate within regulated regimes, and share an overall goal of excellence in safety and reliability. The international regulatory framework in aviation is influenced by the fact that aircraft frequently cross the national borders. Nuclear power plants may also have a cross-border impact, as radiological consequences of an accident might spread to other countries.

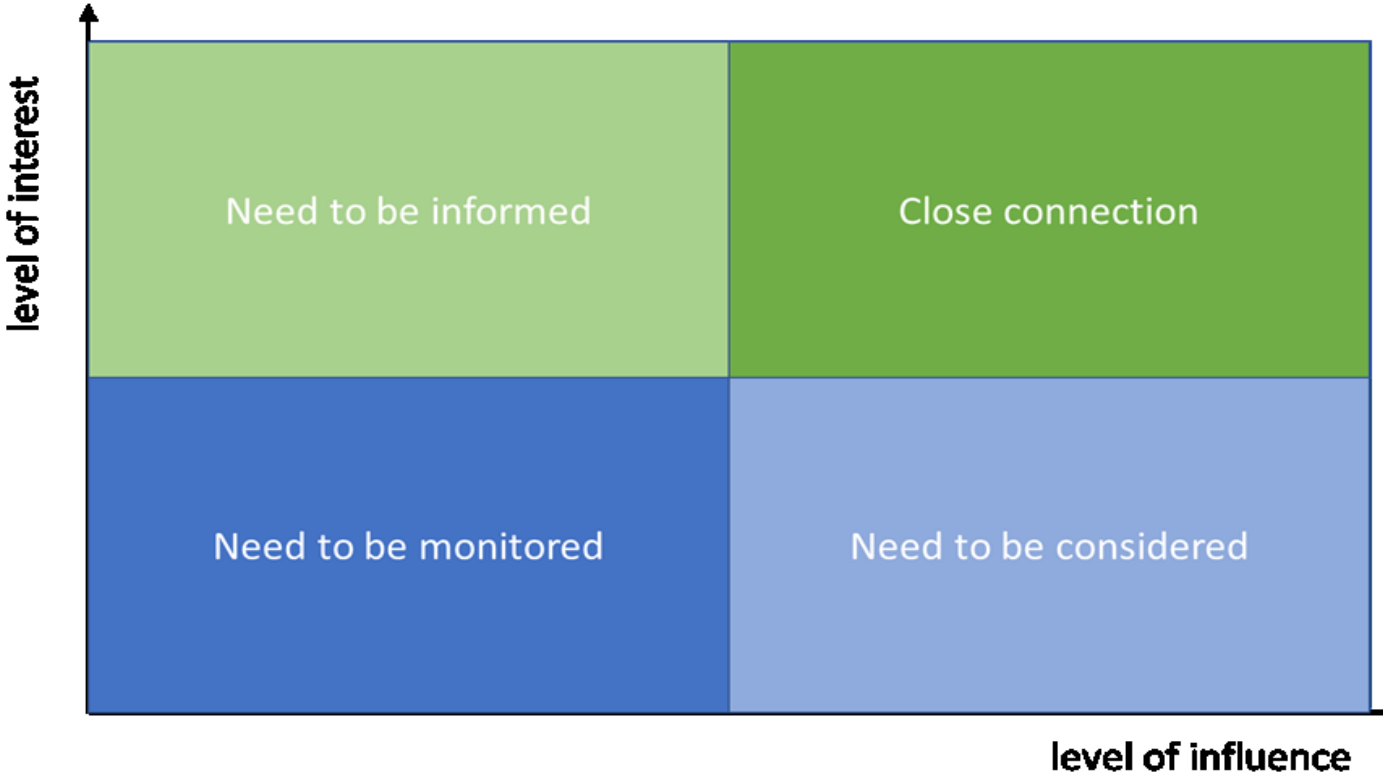
Medical Physics Community

- The basic regulations with respect to the radiation protection of workers are very much aligned to the regulation of the radiation protection of the nuclear workers. The radiation protection of the patients, on the other hand, appears to be much more aligned with the comparative assessment of the risks and benefits of individual patients than the radiation protection of general public potentially affected by the radioactive materials from nuclear power facilities.
- The insights into the comparative assessment of the risks and benefits of individual patients (e.g., performance-based regulations) and related experience may be very useful also for the nuclear community.

Stakeholders map

- The y-axis shows the level of interest, from highest on the top to lowest on the bottom, corresponding to how much the stakeholders are interested on the outcomes of the project.
- The x-axis measures the stakeholder's level of influence, or how much can the stakeholder influence the project.
- A scale from 1 to 5 may be used to rank both level of influence as the interest in the project.
- Four stakeholders groups –defined, regarding the recommended relations and communication strategy

A four-quadrant influence-interest matrix - used to categorize stakeholders in terms of their influence and interest in the project.



Stakeholders categories

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Need to be monitored	Need to be informed	Need to be considered	Close connection
• low on both influence and interest • **Will to be informed only about the big steps/ events in the project**	• low influence • high interest • **Will receive updates on the progress**	• high level of influence in the project • not as much interest • Their feedback is important • **Will receive regular updates**	• High level of influence • High level of interest • Their feedback is crucial • **Organize dedicated meetings with them**

Engaging stakeholders

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- Information is a prerequisite for any stakeholder involvement. It should be accessible, clear and as comprehensible as possible.
- Informing someone is giving him the opportunity to act.
- Stakeholders have different priorities that may evolve over time - useful to develop and agree on the customized plans for engagement.
- The right engagement strategy can help the project members make their results and opinions known, and also make a top priority for stakeholders to give feedback.
- Managing the stakeholder network means keeping open lines of communication, and finding the best solution to engage them to reach the common goal.

Attributes for an effective communication

- Clear content of the communications
- Maintain credibility by respecting the engagements
- Keep stakeholders up to date with the progress
- Remain open to stakeholders' feedback

Stakeholder Involvement Process

1. **Categorize the stakeholders**
2. **Identify the best Communication Channels/ Tools**
3. **Establish and agree on Frequency**
4. **Elaborate Messages**
5. **Maintain connection and ask for feedback**

AN EFFECTIVE COMMUNICATION STRATEGY FOR STAKEHOLDER ENGAGEMENT

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STEP1 - Present information about the project in a clear, concise way, using an easy to comprehend format	• The more is shared in this way, the more likely is that stakeholders will take the time to comprehend the intentions, what their role is and how to act.
STEP2 - Communicate in the manner that works best for the stakeholder	• Recognize that each person or community is different and select the most suitable communication channel (email, website, social media, meetings…). Stakeholders should be offered a variety of options to communicate and to provide their feedback.
STEP2 - Understand the stakeholder motivation	• Keeping an open attitude will help both sides to understand each-other and to receive a proper feedback.
STEP4 - Provide an adequate frame for receiving feedback	• Ensure the opportunities for project team members to participate to meetings with stakeholders, to share information and define follow-up actions.
STEP5 - Keep a record of stakeholder communications over time	• Misunderstandings can be prevented if both parties shared an agreed document and a recorded consensus regarding the follow-up actions.

Strategy to maintain connection

An active communication with stakeholders aims to help communicating the position and findings of the project members towards the stakeholders' group, and to get clear and direct feedback from different stakeholders groups (regulators, industry, policy makers, etc.).
The HARMONISE participants will meet – on a semester basis – with the network of stakeholders during dedicated workshops hosted on video platforms or at the partner premises. The workshops format will promote a constructive dialogue among all participants.

- HARMONISE partners will disseminate the project findings at European and international associations and organizations they interact with, such as: ENSREG, WENRA, ETSON, EUROfusion, SNETP, GIF, IAEA and OECD/NEA.
- The project results will be reported to Member States' nuclear safety regulators to facilitate their involvement regarding safety verifications and licensing of future fission and fusion installations thus, assisting in shaping a new policy.

Tools /Goal

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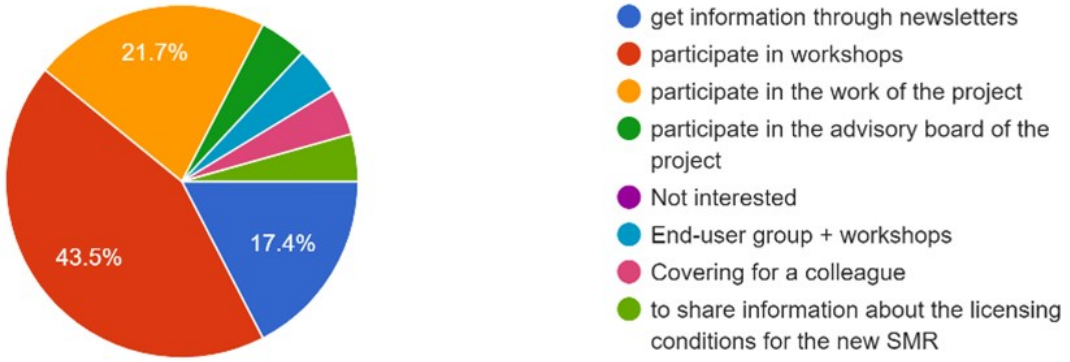
Project website	• Visual identity, information hub, communication of project related activities (results, events etc)
Newsletters	• Raising awareness – project promotion - increasing visibility
Social media	• Raising awareness – project promotion - increasing visibility
Videos	• Raising awareness – project promotion - increasing visibility
Press releases	• Improved communication of results and information provision
Informative material distributed at events	• Awareness raising, increasing visibility, promoting the results
Stakeholders workshop	• Feedback from International organizations, Regulators, TSO, Industry, research, getting validation
Scientific publications, presentations at international scientific events	• Scientific community, getting validation

Previous…

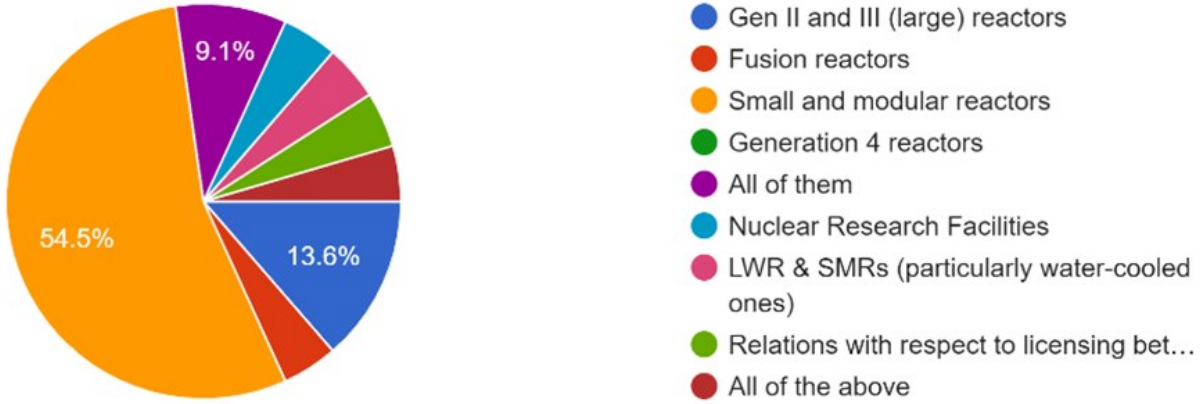
Which is your preferred level of interaction with HARMONISE?

23 responses



Which nuclear technology are you mainly interested in?

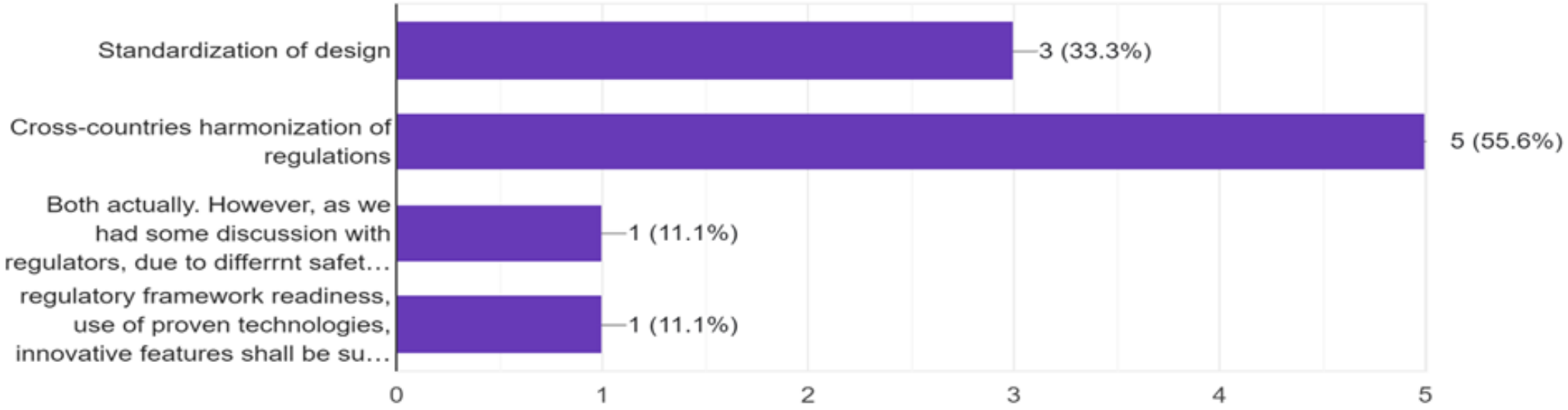
22 responses



- Nuclear power safety –main interest.
- More than 50 % of the stakeholders are interested in small and modular reactors.

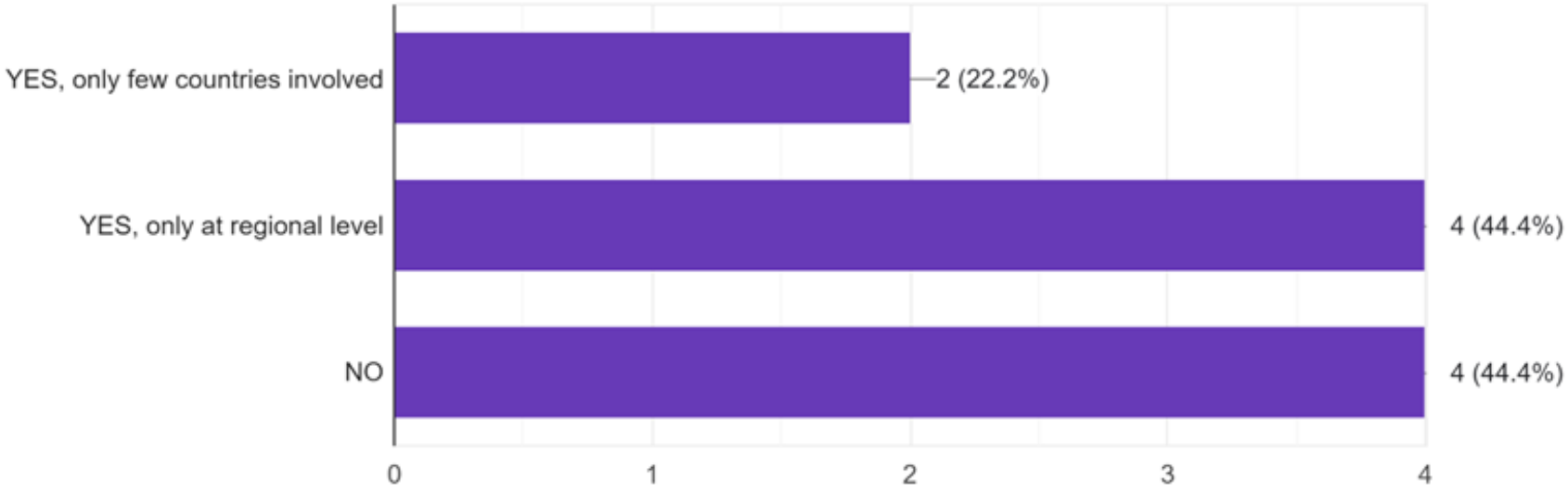
Question 1

Which one of the following are you consider as being the determinant factor in deployment of advanced reactors?



Question 2

Do you believe that harmonization has better chances to be achieved only at small level (only few countries or at regional level)?



Question 3

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What do you see as the main challenge in harmonization of regulatory framework?

- Lack of regulator involvement beforehand
- Resistance of regulatory authorities to change their modus operandi to align to other states
- Since regulatory framework has differences by each country. This has to be standardized and centric over international body.
- The willingness of individual authorities to step back from current practice and accept the approach from other countries, extending the scope from PWR/LWR only to advanced (GenIV) reactors.
- Shared understanding of some key fundamental principles and requirements.
- Differing nuclear regulatory approaches of each technology and local legal requirements.
- The effort required to revise the regulations starting from the top-level requirements down to specific guidelines especially for the countries with developed regulatory framework; need to rethink some approaches that have demonstrated reasonable acceptability in the past, difficulties to adapt new requirements to existing facilities (or to maintain separate sets of regulations for an old fleet and advanced facilities)

Question 4

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What could be the main drivers to achieve an effective harmonization?

- Intention of several countries to build advanced reactors.
- Political support pushing for harmonization
- Consistent Regulations and Standards: Developing consistent regulations and standards is essential for harmonization. This involves aligning legal frameworks, technical standards, and regulatory requirements across different jurisdictions or industries. Harmonized regulations and standards simplify compliance and facilitate the free flow of goods, services, and information.
- Faster and cheaper commissioning of new NPPs
- To achieve harmonization, first strong base should be constructed for regulatory basis.
- Economic pressure from industry to implement new nuclear power sources as part of decarbonization
- We must be able to correctly interpret the notion of "Paradigm shift“
- International cooperation at the regulators level / vendors driven effort
- Common interest of participating countries in harmonization (licensing or pre-licensing of the same type of technology)

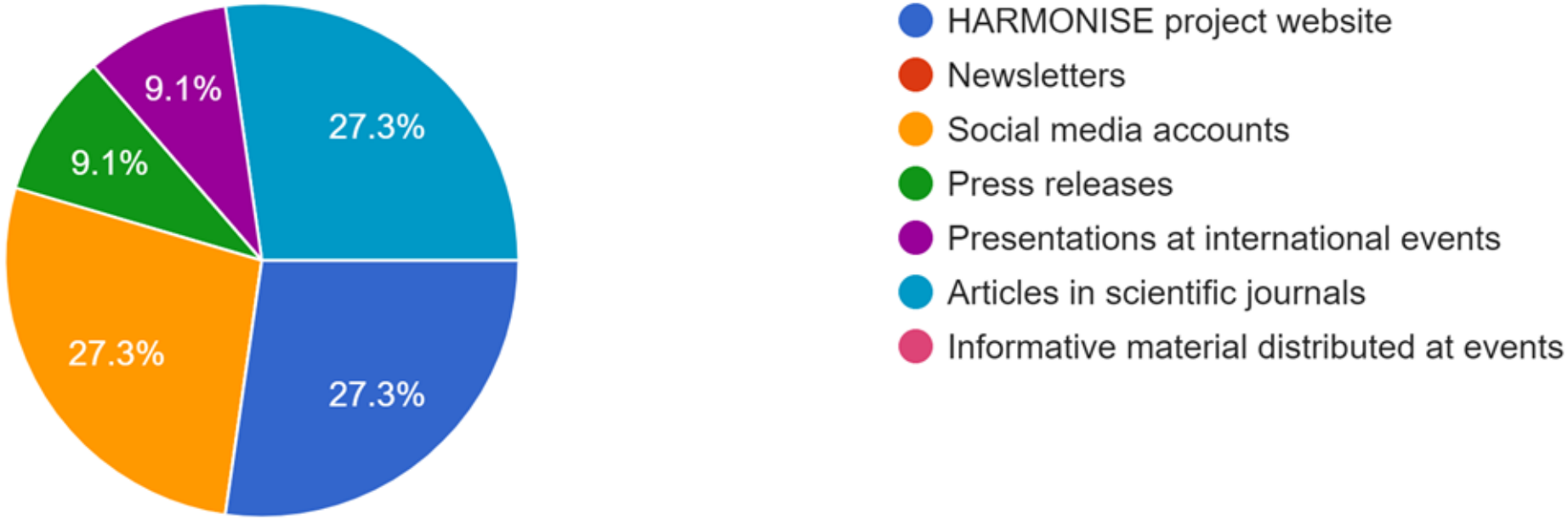
Question 5

In your opinion, what could be the motivating factor for a stakeholder to provide feedback?

- Direct benefits from the results of such projects.
- To include their view on how the future framework should be shaped and to enhance possibilities that their peculiarities are taken into account
- Stakeholders who possess specialized knowledge or expertise in a particular field or industry may be motivated to provide feedback to contribute their insights and help improve the decision-making process. They understand that their unique perspective can add value and lead to better outcomes.
- They are motivated enough. They need to see that the regulators are serious about this and are already prepared to unify. If they don't see any progress from the side of the regulators, why should they bother with it?
- To achieve fast and simplified processes would be a key for stakeholder feedbacks.
- Any benefit for this stakeholder
- The chance to see the enlarged deployment of nuclear energy
- Willingness to series production, reducing unit investment.

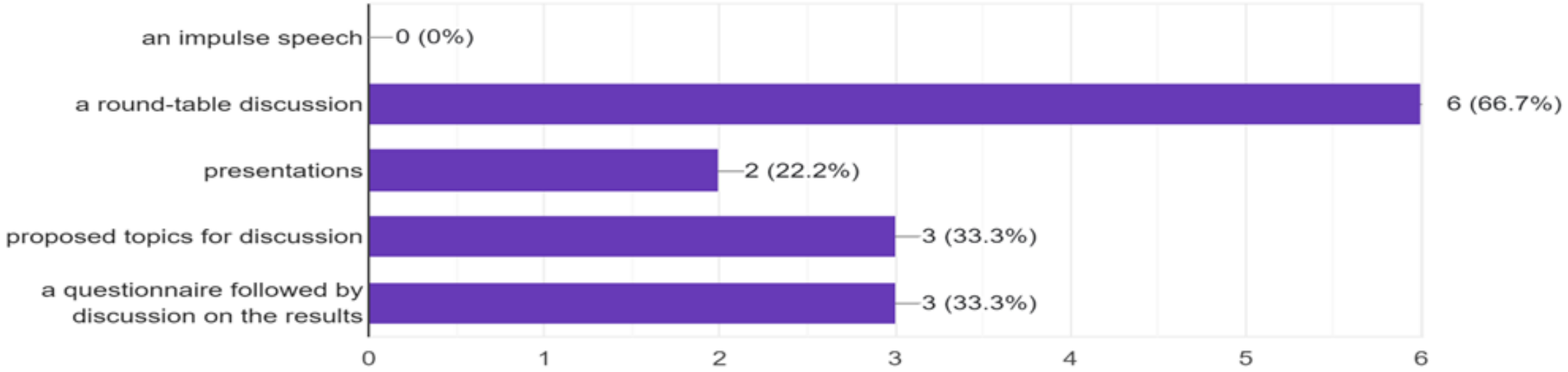
Question 6

Let us know from the following means which one will be your choice, considering the impact/frequency in use? If you wish to choose more, please rank them in order of your preferences.



Question 7

Which format seems in your opinion the most appropriate to organize the discussions during WS?



Question 8

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We intend to use the workshops format as an efficient tool to promote a constructive dialogue among all participants (project members and stakeholders). What topics are you recommending for discussions?

- Expectations and needs of the industry, expectations and needs of the regulators.
- How to engage decision makers into the harmonisation process
- Standardization of design and relations concerning SMR's
- Who should make the first step to unify the regulations and what will be the first steps that actually have some meaning and can convince others to join and work towards unification.
- Regardless in sense of topic, people working in different areas should come together. This is very important to create new ideas/solutions
- The notion / content of the "Paradigm shift"
- Exchange of experience on technology licensing procedures
- Challenges in licensing and deployment of SMRs
- Existing efforts for harmonization and the experience gained with them. E.g. did they result in actual harmonization licensing requirements in different countries.

Concluding remarks

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- ✓ The main objective of communication with the stakeholders is to inform them about the objectives and progress of the HARMONISE project in order to receive input and feedbacks regarding their views on the expected results.
- ✓ The development of stakeholder list was the starting point for further interactions between the project partners and the stakeholders.
- ✓ Having an effective stakeholder network for the project means more than creating the network, maintaining the network active is as important as the development
- ✓ The right engagement strategy can help the project members make their results and opinions known, and may also help in making a priority for stakeholders to give feedback.
- ✓ The Stakeholder Involvement Process include the following steps: Categorize the stakeholders; Identify the best communication channels/ tools ; Establish and agree on frequency; Elaborate messages ; Maintain connection and ask for feedback
- ✓ Besides the traditional channel of communication, the stakeholders will be informed about the progress of the HARMONISE during the workshops planned every six months.
- ✓ Stakeholders responsiveness, pro-active and collaborative attitude during the implementation of the project will be needed to achieve a high-level quality for the project outcomes.
- ✓ The feedback received from the stakeholders will be documented in related project deliverables.

Thank You

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2.18 The Vision for a Bidimensional Harmonisation in the Licensing Framework, Giacomo Grasso, ENEA (Remote)

Harmonising Fission & Fusion Reactor Licensing

The vision for a bidimensional harmonisation in the licensing framework

Giacomo Grasso
WP2 leader

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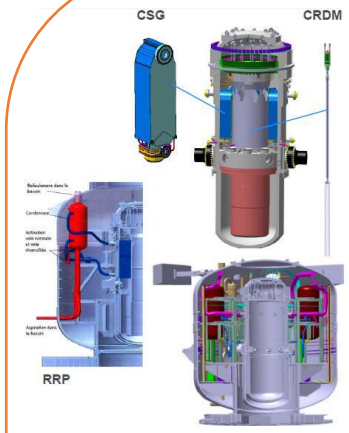
International context

Harmonising Fission & Fusion Reactor Licensing



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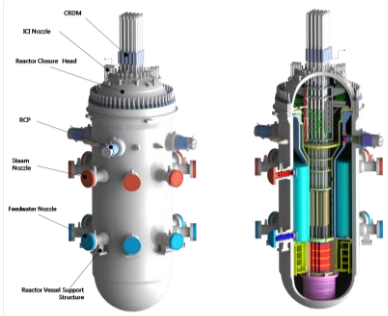

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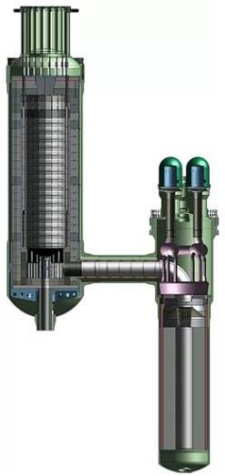
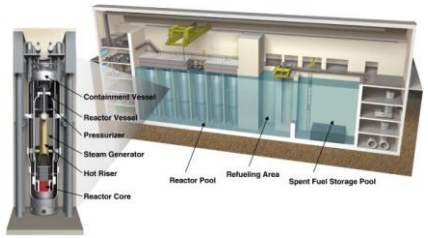


Xe-100

SMRs

AP300



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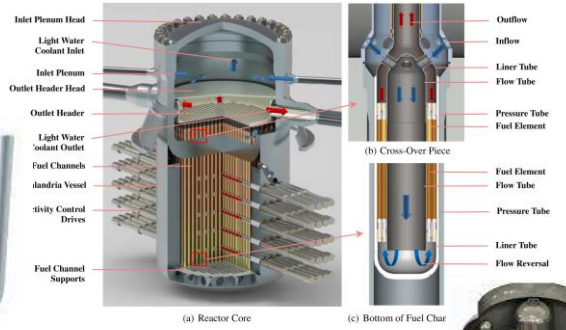
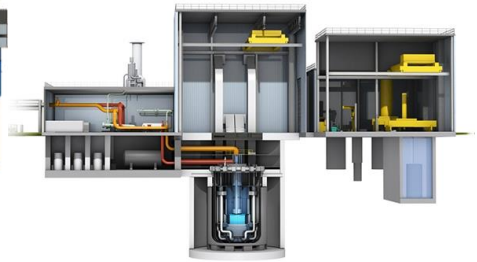


SCWR

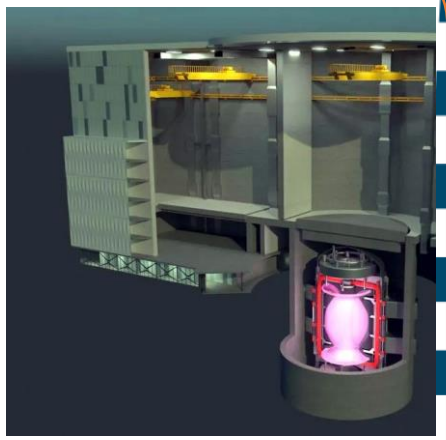
Gen-IV

GFR

LFR



SFR



Fusion

International context

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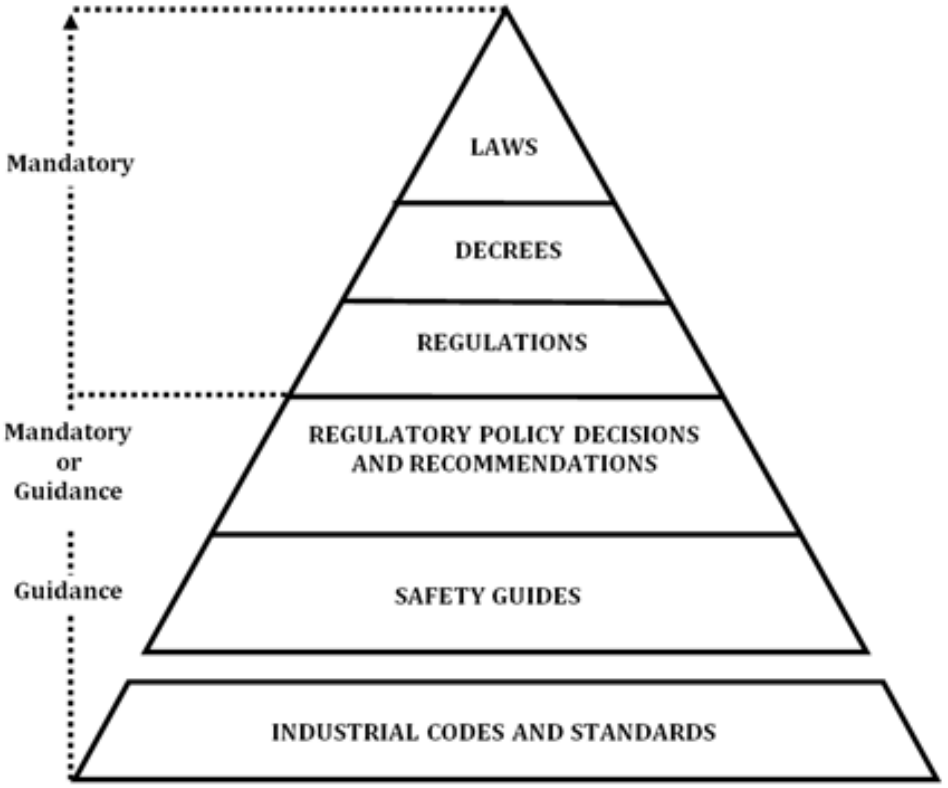
- There are manyfold projects out there, covering manyfold advanced technologies including LW-SMRs, HTRs, Generation IV NES, and fusion
- The projects are characterized by extremely different features:
  - different coolants: water, supercritical water, sodium, lead, gas, salts, …
  - different fuels: HALEU or high-Pu; oxide, nitrides, carbides, liquid salts, …
  - different spectra: thermal, epithermal, fast, …
  - different layouts: loops, pools, integral loops, …
  - different sizes: micro, small, medium, large…
- Each feature introduces peculiarities to be dealt with in building the safety architecture, and in drafting the safety approach

The licensing framework

- The pursued safety architecture and approach must meet the expectations of the regulator, the independent authority entitled to issue the construction and operation permits

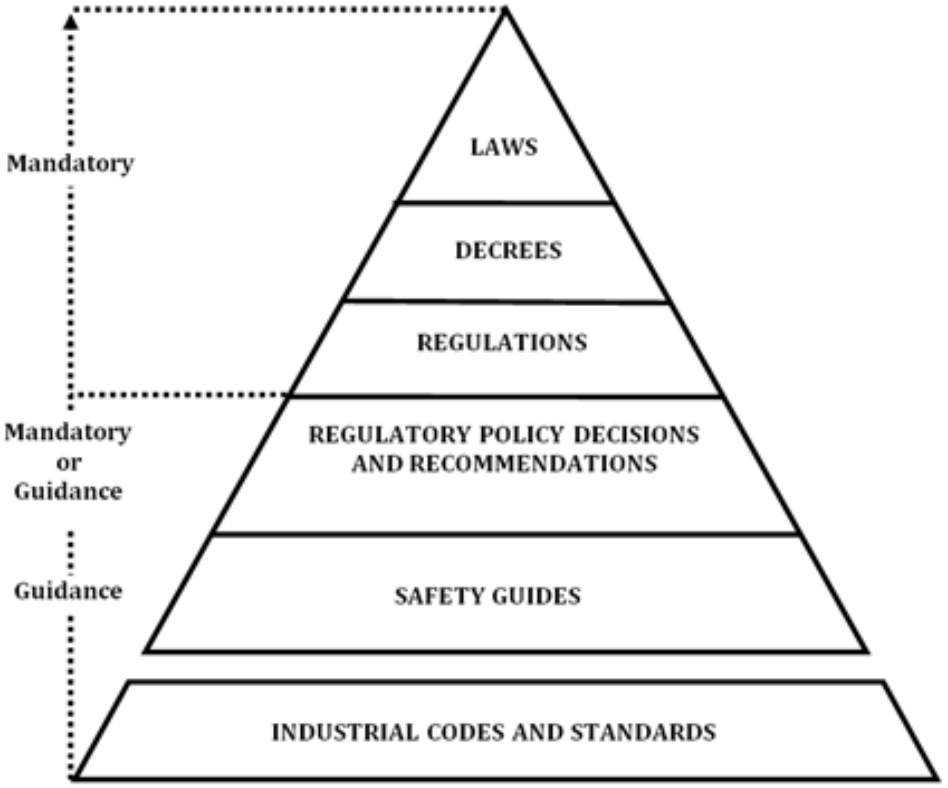
The licensing framework

- The regulator's expectations are formalized in the national laws, decrees, regulations, norms, associated guidelines, and codes and standards – altogether, the licensing framework



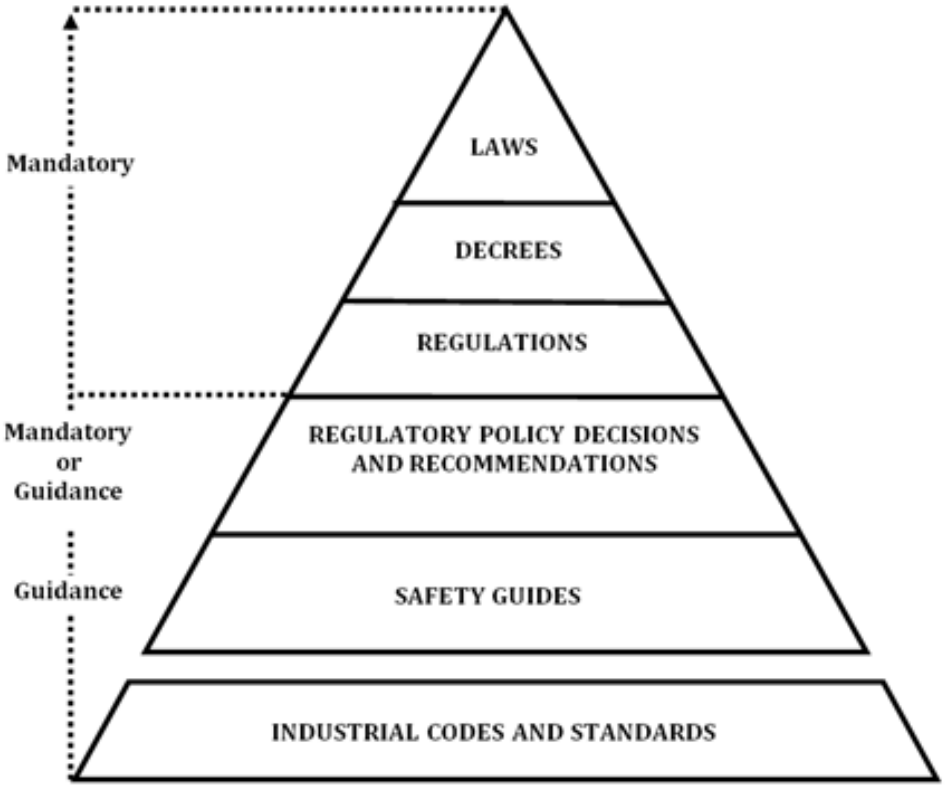
The licensing framework

- Descending from the top to bottom levels, the general principles are translated into requirements, progressively declined from general to particular, which are then implemented into design rules, procedures and limits



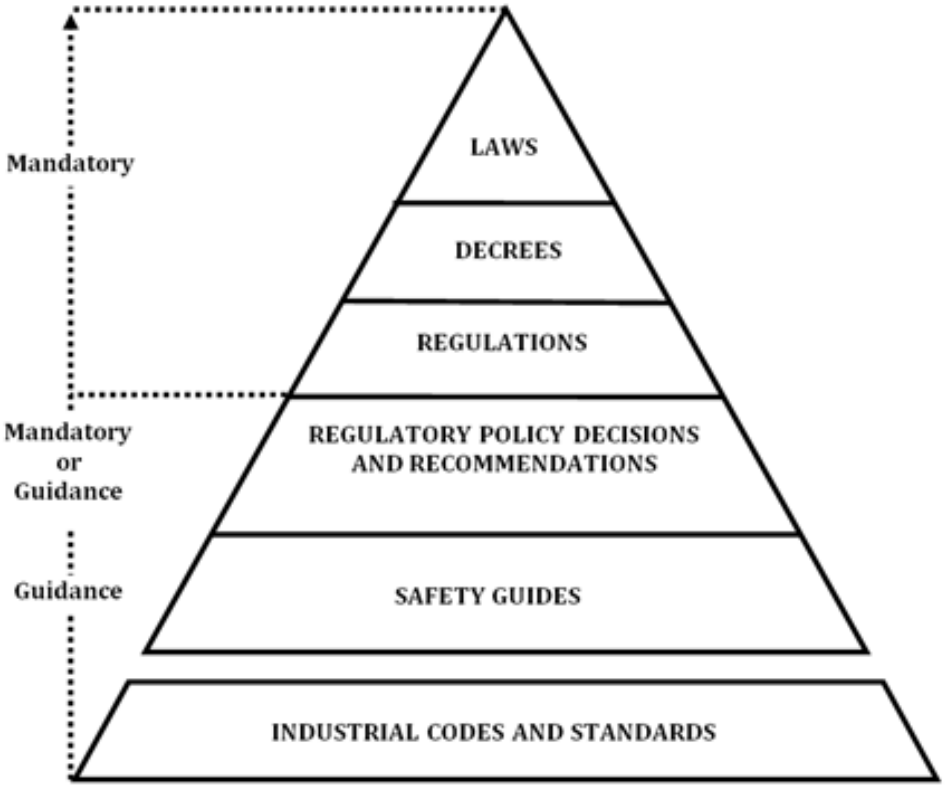
The licensing framework

- In general, already at the level of principles (in laws and decrees), the expectations may vary from country to country – even though the ultimate objective (to protect people and the environment) and the main philosophies (defence in depth, ALARA, etc.) are the same



The licensing framework

- Entering then in the particular details, the reference reactor technology also typically assumes a more and more important role in defining the specific regulations that apply



Bidimensional harmonisation

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1st axis: Technology

- Different technologies might lead to different regulations
- A harmonisation towards technology neutrality would permit aligning regulations on common bases and uniform principles, enhancing safety and streamlining licensing

Bidimensional harmonisation

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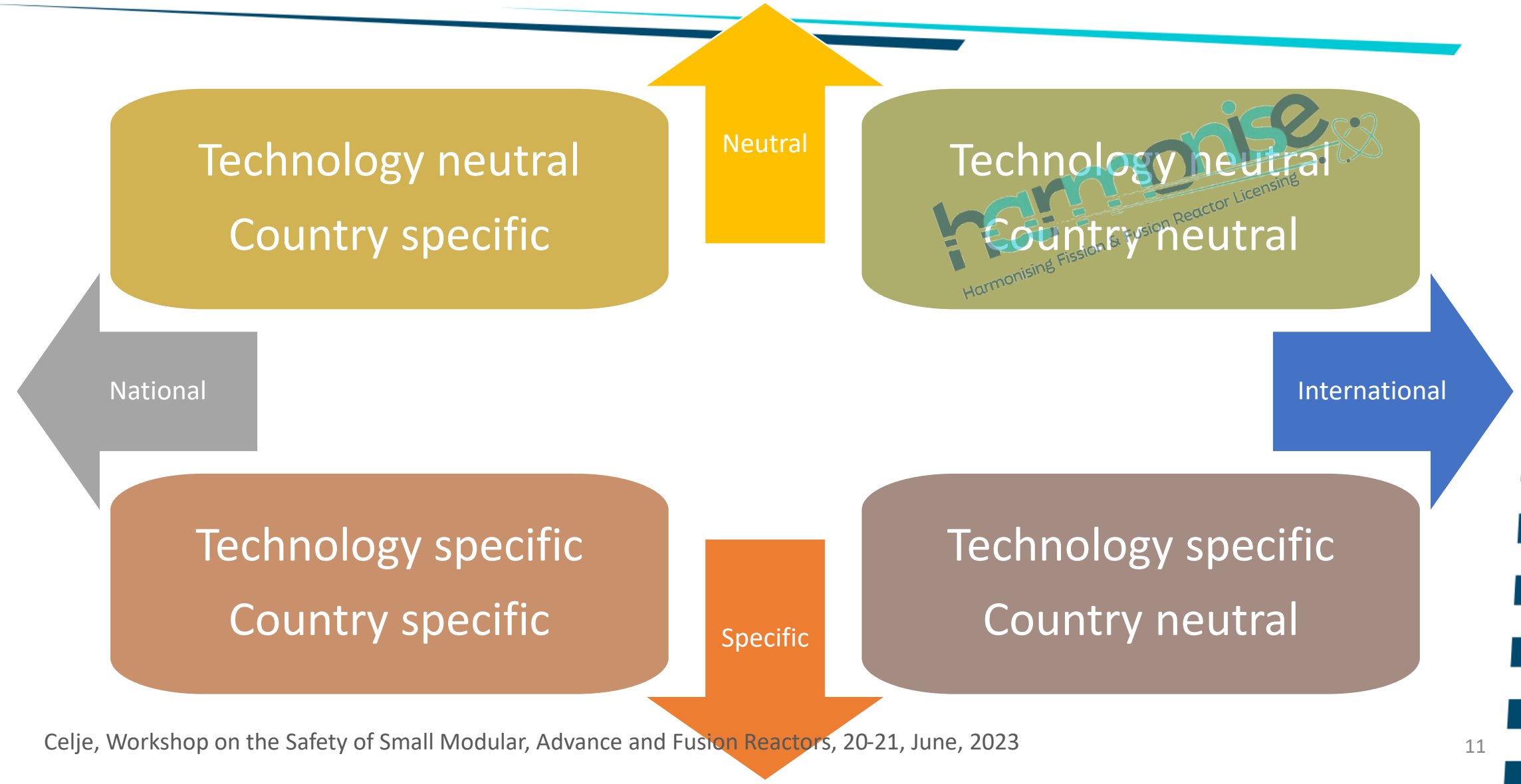
2nd axis: Regulation

- Different countries might aim at different standards
- A harmonisation towards country neutrality would permit aligning regulations on common targets, and uniform metrics, again enhancing safety and streamlining licensing

Bidimensional harmonisation



HARMONISE and harmonisation

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Work Package 2

«Licensing needs of innovative NPPs»

- Task 2.1
  - «Review of future innovative nuclear power technologies»
- Task 2.2
  - «Issues with existing licensing process for innovative nuclear power technologies»
- Task 2.3
  - «Recommendations on overcoming the issues identified»

✓ 1st axis: Technology

✓ 2nd axis: Regulation

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Task 2.1 - Review of future innovative nuclear power technologies

- Initial review of the specificities associated with innovative reactor technologies, so as to point out not only the safety-related needs associated with those, but also their relevance in terms of a perspective licensability of power plants harnessing such reactor technologies
  - survey of as many European designs as practical by means of a questionnaire
  - review of the surveyed specific needs in terms of licensing
  - focus on elements that can be anticipated to pose novel challenges

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Task 2.1 - Review of future innovative nuclear power technologies

- In-depth study on specific considerations addressing the lowest levels of the hierarchical licensing framework, progressively focusing on ALFRED (case study for fission technologies) and DEMO (case study for fusion technologies), leveraging the participation in the HARMONISE consortium of industrial designers and technology developers directly involved in the advancement of such innovative reactor concepts
  - establish whether and where a limit should be envisaged in a technology-neutral approach
  - establish whether and where complementary technology-specific elements should be foreseen to make future licensing frameworks effectively enforceable
  - extension of the general principles, approach and conclusions of the in-depth study to all other technologies initially surveyed by the questionnaire

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Task 2.2 - Issues with existing licensing process for innovative technologies

- Review of the anticipated compliance of the current licensing processes with the specific needs identified in Task 2.1, to understand how these needs can be addressed while meeting the requirements established in the national regulations, with a holistic approach that harmonizes the different specificities of the national regulations investigated
  - compilation of a compliance matrix, by matching the needs resulting from innovative reactor technologies, with the requirements imposed by the national regulations
  - identification of the gaps, whose filling will permit the current licensing processes to be transposed to innovative technologies
  - analysis of possibly identified differences in the national regulatory processes, and their summary by “item” and “country” indexes

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Task 2.2 - Issues with existing licensing process for innovative technologies

- Initial work on all technologies, at the highest levels of the hierarchical licensing framework
- Subsequent focus on ALFRED and DEMO, as selected case study, for the specific work on the lowest levels of the licensing framework
- Transposition of the work to all surveyed technologies

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Task 2.3 - Recommendations on overcoming the issues identified

- Building on the gaps identified in Tasks 2.1 and 2.2, development of recommendations that would permit to address the needs of all investigated technologies, as a basis for establishing future licensing processes in a harmonized way
  - examination of each item listed in the matrix of the differences between national regulations, addressed in a dedicated discussion to highlight the commonalities that might represent the bases for the harmonized new process
  - specific discussions to analyze the emerged gaps, and collection possible solutions that might secure the transposition of the general licensing principles to future plants
  - formulation of the possible solutions in the form of recommendations

Thank You

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2.19 Towards Technology-Inclusive Risk-Informed Performance-Based (T-I RIPB) Regulatory Framework for Advanced Nuclear Facilities, Alex Matev, BelV (In person)

HARMONISE PROJECT

TOWARDS
TECHNOLOGY-INCLUSIVE
RISK-INFORMED PERFORMANCE-BASED
(T-I RIPB)
REGULATORY FRAMEWORK
FOR ADVANCED NUCLEAR FACILITIES

Presenter: Alex MATEV

BEL V

21 June 2023
Celje, Slovenia

CONTENTS

1.) Requirements for establishing a Regulatory Framework and Reactor Oversight Processes

2.) DETERMINISTIC Approach to Establishing a Regulatory Framework

3.) Defense-in-Depth Implementation Problems

4.) RISK-INFORMED Approach to Establishing of a Regulatory Framework

5.) NEI 18-04 Technology-Independent Risk-Informed Performance-Based Approach to Establishing a Regulatory Framework

6.) NEI 18-04 T-I RIPB Process Steps

7.) NEI 18-04 T-I RIPB Process Overview

8.) Conclusions

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Requirement #1

1. The plant meets the established ***limits for the adequate protection*** of the public health and safety.

- The plant must be capable of responding to credible challenges in a safe manner.
- There must be **confidence** that the plant will comply with the chosen Safety Goals

Requirement #2

2. The ***safety functions, design features and functional design criteria*** relied upon to meet the safety criteria are defined.

Requirement #3

3. The selected **Licensing Basis Events** (**LBEs=DBEs+Beyond-DBEs)** adequately ***cover the range of hazards*** that a specific design is exposed to.

- A comprehensive list of design-specific plant challenges has been developed.
- The relative credibility of each challenge is understood.
- The plant response to credible challenges has been adequately characterized.

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Requirement #4

4. The **SSCs are categorized** according to their safety significance.

Requirement #5

5. The design reflects the application of an appropriate philosophy of Defense-in-Depth, including accounting for important uncertainties associated with the design and the response of SSCs to plant challenges.

Requirement #6

6. The **special treatment** for SSCs, and associated **programmatic controls** and human actions, provide reasonable assurance that the SSCs will perform the safety functions for which they are relied upon.

Requirement #7

7. The ***scope and level of detail*** for the design and analysis of the plant in the licensing-basis information adequately describes the safety case.

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Reactor Oversight Process (ROP)

- Initiating events occurrence monitoring and diagnosis
- Maintain adequate state of prevention, protection and mitigation systems
- DiD barrier integrity
- Emergency preparedness
- Occupational radiation safety
- Public radiation safety
- Security

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DETERMINISTIC Approach

Currently, the basis for evaluation of NPP safety and decision-making

Precautionary Principle - "*Better be safe than sorry*"

- Policy-makers demand action to ***preclude exposure to hazards*** when scientific ***evidence*** to confirm existence and characterize the extent of intolerable threats, is ***ambiguous, unconvincing or lacking***.
- ***Act NOW ! to preclude or reduce*** potential harm when having (reasonable) concerns, thus avoid "***paralysis by analysis***"

When does one apply the Precautionary Principle ?

- ***Large uncertainties*** in defining hazards and characterization of threats they pose;
- ***Extreme severity*** of threats – (magnitude of adverse impacts on humans and environment, long disruption of normal social life, large immediate and staggered financial costs and the size of irrecoverable losses;
- ***Complexity*** of the impact - difficult to characterize, prioritizing effects of multiple adverse impacts;
- ***Political tensions*** - different stake-holders may have rather conflicting views on how hazards should be characterized, how the threats' severity should be ascertained, and how adverse impacts on humans, society, and the environment should be controlled and mitigated.

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SAFETY GOALS – *primary criteria when decision-making*

Qualitative description of both ***Individual*** and ***Societal*** **Risks**

- ***Individual members of the public*** *shall be provided a level of protection from the consequences of operating a given nuclear facility such that there is* ***no significant additional risk*** *to the life and health of these individuals*
- ***Societal risks to life, health, and well-being*** *from operating a given nuclear facility are less than other broadly-accepted risks and* ***should not add significantly*** *to* ***overall societal risk***

Hazard Analysis - **Serves to:**

- Examine the complete spectrum of accidents;
- Qualitatively determine event's occurrence frequency;
- Determine the resultant consequences;
- Identify preventive and mitigation features suitable for each accident scenario;
- Identify representative accident scenarios for further, detailed analysis.

"Hazard" - **Danger or Threat** (i.e., material, energy source, or operation) with the potential to cause illness, injury, or death to a person, or damage to a facility, or to the environment ***without regard given to the likelihood, or credibility of accident scenarios,*** or consequences mitigation.

Difference between *"Hazard"* and *"Risk"*.

"Hazard" is an important part of **"R*isk*",** but ***does not include an important dimension*** in characterizing the risk - the *likelihood* of the exposure to danger or threat

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Hazard Analysis

1) *Hazards Characterization*
2) *Hazards Exposure Analyses*
3) *Hazards Controls Selection*

1) Hazard Characterization: **Use HAZOP, FMEA, PIRT, MLD, etc.**

- *Hazard identification;*
- *Hazards classification, i.e. radiological, chemical, fire, etc.*
- *Hazards evaluation and ranking.*

2) Hazards Exposure Analyses

- *Construct hazard-specific, **unmitigated** scenarios of Design Basis Accidents*
- *Clarify the values and the use of **initial** and **boundary** conditions for a given accident scenario and conservative bounding parameters in accident's consequences calculations*
- *Determine the hazard-specific **source terms**, i.e. both **radiological** and **non-radiological** ones, such as release of harmful chemicals, etc.*
- *Source Term dispersion analysis – establish the rules how to evaluate the **impact from exposure to unmitigated** hazards both on-site (i.e. harm to personnel) and off-site (i.e. harm to general public).*
- *Evaluate the consequences from exposure to **unmitigated** hazards*

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3) Hazards Controls Selection

- *Determine design and performance requirements, and criteria to evaluate the adequacy of the Safety Class Structures, Systems, Components (SC SSCs) for use in hazard mitigation*
- *Determine the design and performance requirements, and criteria to evaluate the adequacy of the Safety-Significant SSC (SS SSCs) for use in hazard mitigation;*
- *Determine what other controls are needed for hazard mitigation*

Hazard Analysis Outcomes:

- **Design Basis Accidents** - several categories of postulated accident scenarios
- **SSCs** classification and requirements
- **Define necessary** Defense-in-Depth provisions

Question-1 (red-hot one!): ***If not using HAZARD*** *analysis (HAZOP, FMEA),* ***what*** *should one use to* ***identify all fault and event sequences*** *that have* ***significance for the hazards characterization*** *and ensure there is a* ***comprehensive evaluation of the exposure*** *to them?*

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DETERMINISTIC Safety Analysis *Objectives*

- *Confirm facility meats the requirements to implement Defense-in-Depth provisions*
- *Confirm Limits and Conditions for Operation (**LCO**) and Operating Tech. Specs. (**OTS**) are consistent with facility's design, operation, and safety requirements;*
- *Prevent "**unknown unknowns**": Confirm ITAAC (Inspection, Tests, Analyses, Acceptance Criteria) requirements:*

***Example**: For PSA **afficiandos**: Use PSA output as **Fussell / Vesely importance measures**, to grade and schedule ITAAC activities*

- ***Support development** and **validation** of operating, emergency, and accident management procedures and guidelines*
- *Support demonstration that Safety Goals that serve to limit both **individual** and **societal** risks, **are fully met**.*

IAEA Definition of Defense-in-Depth

Level-1: Prevent deviations from normal operation

Level-2: Detect and control deviations

Level-3: Incorporate safety systems and use procedures to prevent core damage

Level-4: Mitigate the consequences of accidents

Level-5: Mitigate radiological consequences

Defense-in-Depth Implementation Problems

1) Single Failure Criterion *(SFC):* Primary means to define redundancy and diversity in D-i-D implementation

Using SFC in all five D-i-D Levels, as defined by IAEA?

Too cumbersome, unyielding, and even dangerous ! Renders system opaque

*But, what if … **ATWS**, **SBO** occur?*

*USNRC solution to SFC limitation: Apply … **Patches***

(Bill Gates does it all the time ! Cure-all option!)

ATWS: 10CFR50.62 Requirements for reduction of risk from anticipated transients without scram events for light-water-cooled nuclear power plants.

SBO: 10CFR50.63 Loss of all alternating current power.

2) Lack of means to quantify how adequate is D-i-D implementation

- How to relate margins to safety limits and consequences from loss of particular D-i-D provisions?
- How to relate results from inspections, test, analyses to consequences from loss of particular D-i-D provision? … ***Davis Basse Reactor Vessel Head degradation***

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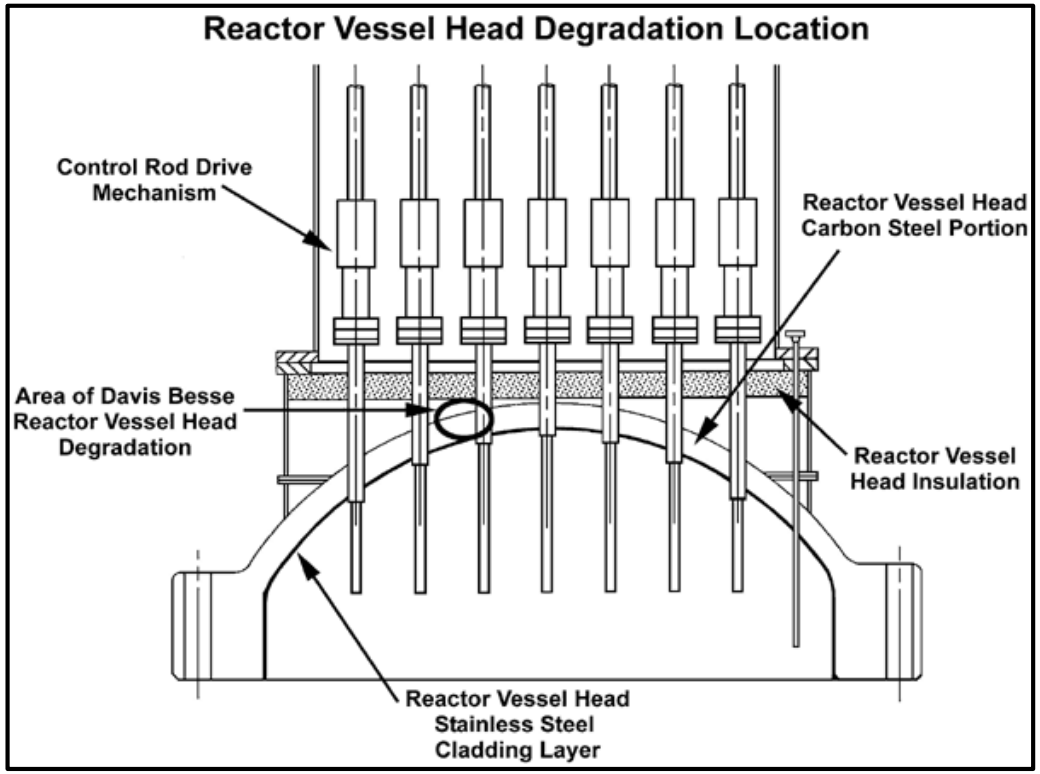
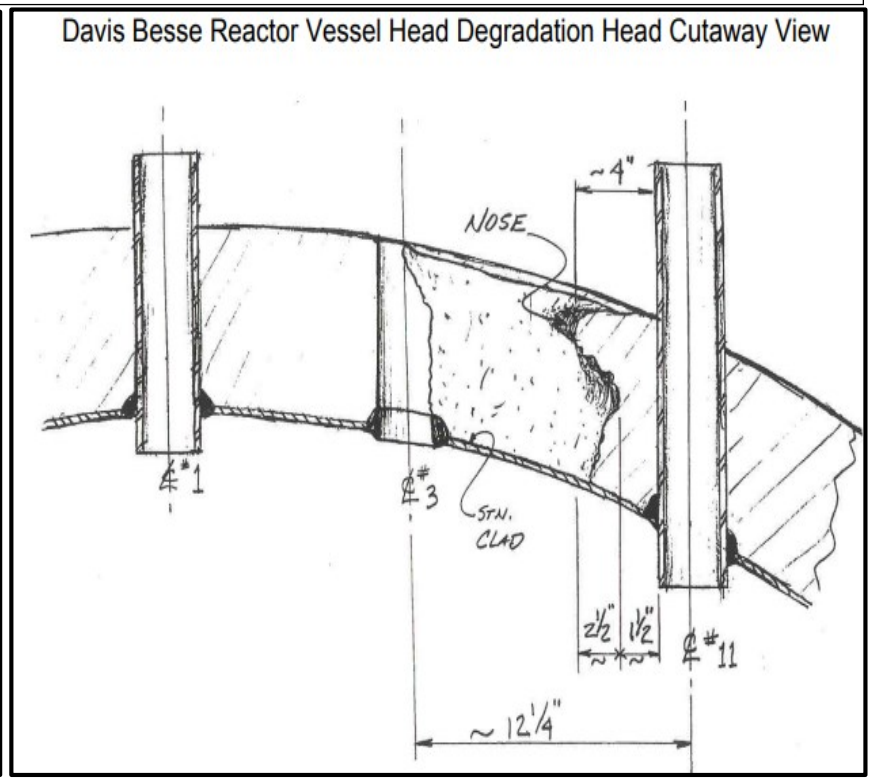
Defense-in-Depth Implementation Problems





Question-2: … Davis Besse got lucky: 18cm thick wall devoured by corrosion … it went unnoticed for…N days, no one's bothered, no one's seemed to care !

*Are **HAZARD Analysis** and **DSA** (Deterministic Safety Analysis) the best means to establish all pertinent requirements for the Safety Class SSCs?*

Question-3: (How to fill in *gaping holes* - *pun intended* !)

Is **Patching-up** the best way to improve the Regulatory Framework?

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3) Can D-i-D help prevent and/or mitigate Organizational Failures?

Chernobyl, … Fukushima, … ?

In order to control properly complex and hazardous technologies, one needs to take into account ***not only the engineering aspects of their use***, but also assure that ***operating*** *organizations* and ***oversight*** *institutions* execute ***properly*** their own responsibilities.

Traditional approach to Disaster/Catastrophe Analysis

- The cause for failure has been either a human error, or equipment malfunction;
- The failure has occurred suddenly, with little or no prior warning.

Organizational failures always have multiple causes

- Focusing only on human errors ***misses the systemic*** contexts in which the accident occurred and can happen again.
- In many cases ***human errors are consequence*** rather than the principal cause of the accident.
- They occur because organizations choose or have to put up with ***"conditions with latent deviations"*** that become **inevitably an inalienable** part of their functioning

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3) Can D-i-D help prevent and/or mitigate Organizational Failures?

Organizational failures due to "*conditions with latent deviations*"

"*conditions with latent deviations*": *translated into English means:* ***someone didn't bother, or care, to do his job properly***.

- *Poor system's design;*
- *Gaps in supervision;*
- *Undetected manufacturing defects or failures;*
- *Unworkable procedures with ambiguous instructions, incorrect set-points, typing errors;*
- *User-unfriendly, clumsy automation;*
- *Shortfalls in training;*
- *Less than adequate tools or equipment used during inspections and tests, etc.*

3) Can D-i-D help prevent and/or mitigate Organizational Failures?

"Normal Accident Theory":

(*Ref. Perrow, **Charles**. (1999), Normal Accidents: Living With High Risk Technologies, Princeton University Press, Princeton, NJ.*)

Main message distilled from his studies:

Major accidents – ***INEVITABLE*** ergo ***NORMAL*** in ***interactively complex, tightly coupled*** technological systems, e.g. chemical plants, NPP.

Complex system:

a) Opaque **-** a multitude of deviations occur, brood, interact, and fester to become failures

The more defenses – the murkier the system becomes, opaqueness rises… overloads the man-machine interface, breakdown occurs

b) ***Lots of feedback loops within complex systems*** **-** some poorly, or are **even suspected to exist**!

Positive feedback loops cause **unexpected, non-linear**, system behavior that is **incomprehensible** to operators – results in breaching **multiple levels** of defense

Tightly-coupled:

Initial failures propagate quickly and uncontrollably, resulting in cascades of failures that lead to a major system breakdown.

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3) Can D-i-D help prevent and/or mitigate Organizational Failures?

Information Processing Impairments – these render organizations helpless in the face of major crises:

a) Epistemic blind spots

Warnings are not heeded, because the information drawn from their assessment, does not fit existing beliefs, or there is no frame of reference that lets the warnings be recognized.

b) Risk denial

Warning signals and alarming events are discarded

c) Structural impediment

Warning signals are recognized, but organizational response is hobbled by structural rules, multiple control roles, and vaguely-defined

Question-4:

Can one use D-i-D philosophy to fix up …an **impaired** … operating organization and **out-of-depth, superficial, aloof** regulatory?

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Information Processing Impairments – these render organizations helpless in the face of major crises:

a) Epistemic blind spots*:*

Warnings are not heeded, because the information drawn from their assessment, does not fit existing beliefs, or there is no frame of reference that lets the warnings be recognized.

Some organizations brand their mission, vision, and values as being unquestionable and incontestable. They tend to accept only evidence that upholds such beliefs and act biased towards ignoring information that contradicts the premises it uses for decision-making. Such organization will rarely abandon its beliefs or paradigm in favor of another.

Epistemic Blind Spots *arise because humans tend to prefer information that confirms and concurs with their beliefs. When information contradicts their beliefs, rather than questioning if their beliefs may need to change, people often choose to ignore the information, discredit its reliability, re-interpret its message to remove the alarm, and diminish its significance;*

b) Risk denial:

Warning signals and alarming events are discarded and thus no action is taken, because the organization's values, norms, and performance priorities overrule any conflicting interpretation one may draw from the warnings' evaluation;

c)Structural impediment:

Warning signals are recognized as such, but the organizational response is hobbled by structural rules, multiple control roles, and vaguely-defined responsibilities. As a result, the information drawn from the warnings evaluation is incomplete and patchy, so it renders the response being lame, late, and sometimes entirely inadequate.

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Probabilistic Safety Analysis (Probabilistic Risk Assessment)

PSA objectives are:

- *Evaluate the **frequencies (occurrence probability**) of severe accidents that result in core melt and / or large release into the environment of radioactivity and compare them to the Safety Goals;*
- *Evaluate the **effect of hardware modifications** or changes in **operational procedures** on the on the frequency of accidents*
- *Evaluate the **effectiveness of Defense-in-Depth** (DiD) provisions;*
- *Evaluate of the **effectiveness of the Accident Management Program' actions** to control the accident evolution and to **meet the safety goals objectives**, defined in terms of radiation release frequency and radiation release.*
- *Etc.*

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Probabilistic Safety Analysis (Probabilistic Risk Assessment)

Comparison of DSA and PSA Approaches

DSA:

- **Small** number of accident scenarios in an explicit manner
- Uncertainties – ***bounded by using conservative initial and boundary*** conditions to envelope other possible accident's scenarios and to compensate for uncertainties.

PSA:

- **Very large** number of accident scenarios – valuable tool when simulating complex systems and multiple human actions
- Realistic perspective of **entire spectrum** of accidents by determining their likelihood (i.e. Event sequences occurrence frequencies)
- Uncertainties - characterized by modifying the respective model parameters(s); thus, the **uncertainty is propagated thru the model**, so that its impact on results is clearly visible.

PSA Use in Licensing and Regulatory Oversight

Acknowledged Benefits from PSA:

PSA studies' results and insights based on them - improved NPP safety and operational flexibility

Move towards Risk-Informed Regulations in Licensing and Oversight

Move from right side ("Bounding Approaches") towards left side ("Quantitative Risk Information")

Leaning towards extensive use of PSA quantitative results

Development of new risk-related approaches, performed by:

- Regulatory agencies,
- Nuclear industry,
- International consulting bodies (e.g. IAEA, OECD),

All of the above actors and doers have shown a **strong leaning** towards placing **heavier emphasis** in the use of **quantitative PSA results**, or **"risk measures".**

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PSA Use in Licensing and Regulatory Oversight

Quantitative Safety Goals: CDF, L(E)RF…

Core Damage Frequency**: **PSA Level-1

The sum of frequencies of all event sequences that can lead to significant degradation;

Early Release Frequency**: **PSA Level-2

*The sum of frequencies of all event sequences that can lead to a release of such radioactive nuclides (e.g. radioactive iodine, polonium, etc.) that may require **temporary** evacuation of the population residing in locations affected by the release. The ERF provides a measure of the immediate **individual risk** to the most vulnerable persons, i.e. children.*

Large Release Frequency**: **PSA Level-2

*The sum of frequencies of all event sequences that can lead to of such radioactive nuclides (e.g. radioactive cesium, plutonium, etc.) that may require **long-term** evacuation of the population residing in locations affected by the release. The LRF provides a measure of the **total societal risk**.*

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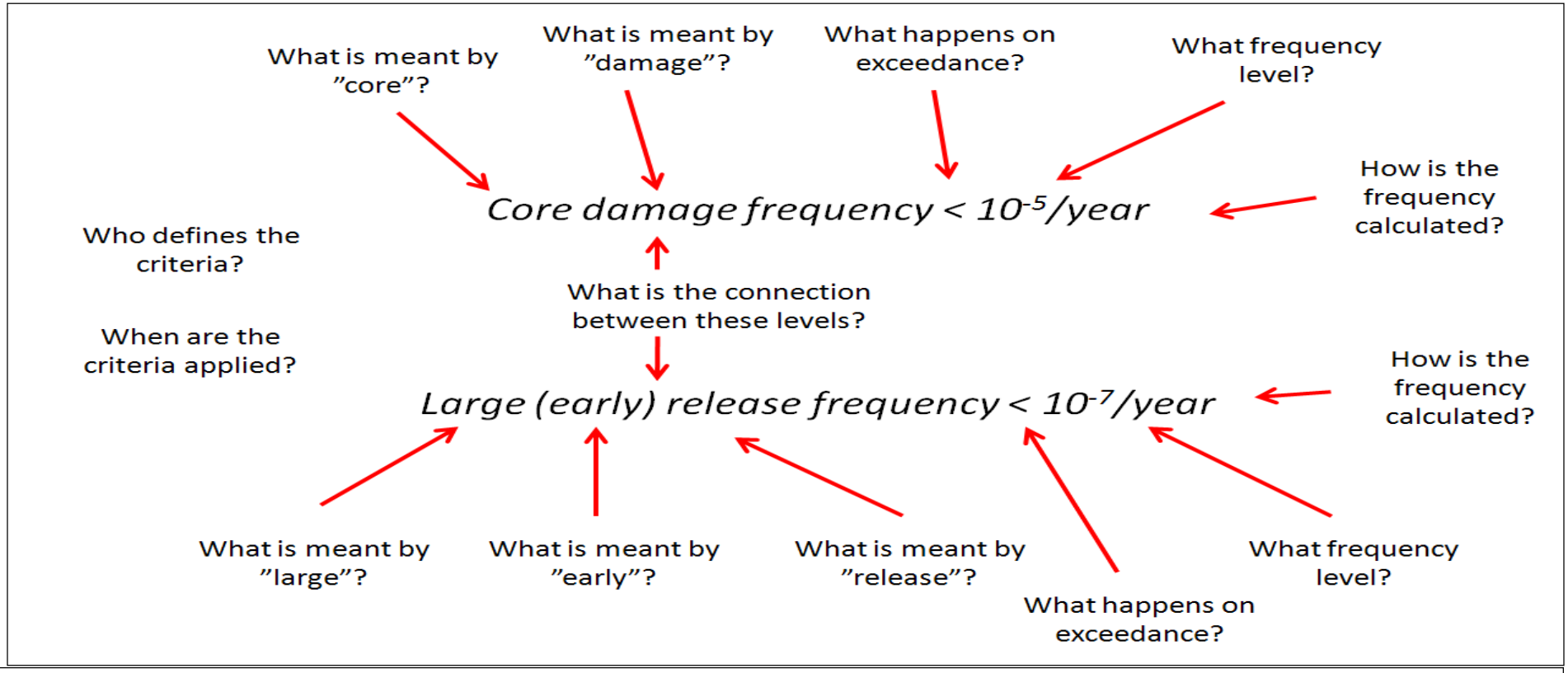
PSA Results for Use in Licensing and Regulatory Oversight



CDF and **LERF**

- Surrogates for Quantitative Safety Goals
- Measures of integral risk – you can't regulate risk if you can't meter it?

Example: Your reactor in the US is OK if it complies with Quantitative Health Objectives: **Prompt Fatality < 0.1%, Latent Cancer Fatality < 0.1%),** or **CDF < 10^{-4}** per reactor-year; **LERF < 10^{-5}** per reactor-year

PSA Results for Use in Licensing and Regulatory Oversight

Can one use CDF and LERF for Advanced Nuclear Reactors?

- **HTGR, (PBMR): TRISO fuel -** doesn't melt, doesn't make Hydrogen, doesn't burn like LWR fuel cladding
- **LWR with advanced fuel (TRISO) – see above**
- **Pb- or Pb–Bi cooled fast reactors – u can't boil Pb or Pb-Bi ! T_{BOIL}= 1700 C**
- **Molten Salts fuel** – it's **already molten**, so **CDF** is **not 10^{-4},** but is **= 1.0**

Last, but **not least…**

While ***all LWR*** that are currently in use are … ***the same***: Lots of **volatile RANs**, lots of internal energy sources to provide the push that can scatter them beyond site's EAB !

1) Advanced Nuclear Reactors are ***very different***, at least as far as the Radiological Source Term is concerned!
2) What about release of ***hazards, other*** than radiation?

Question-5: If **CDF** and **LERF** *are* **not relevant** for **advanced nuclear reactors: How shall one concoct replacements for the Quantitative Safety Goals?**

- **Design-specific** surrogates**?**
- **Measure of the accident's cost to society, ($, £, €, yuan) ?**

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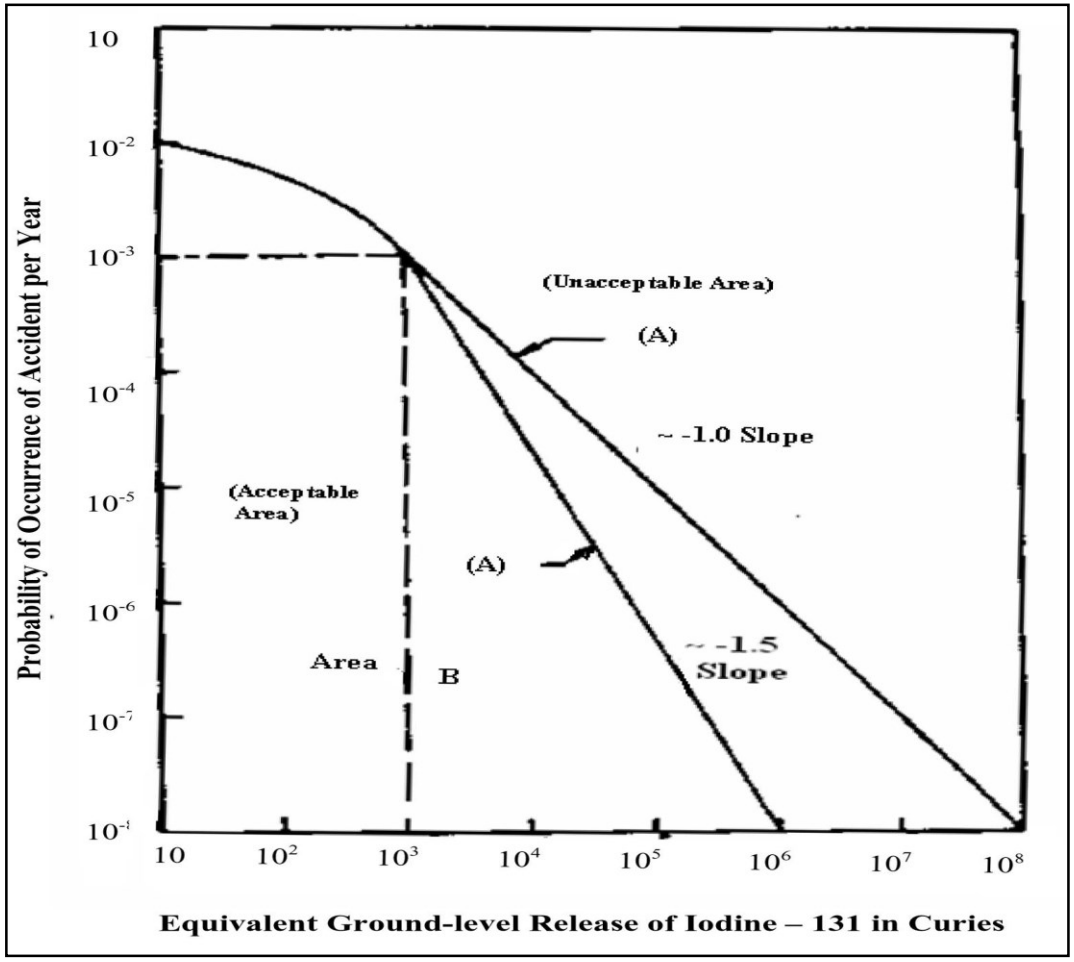
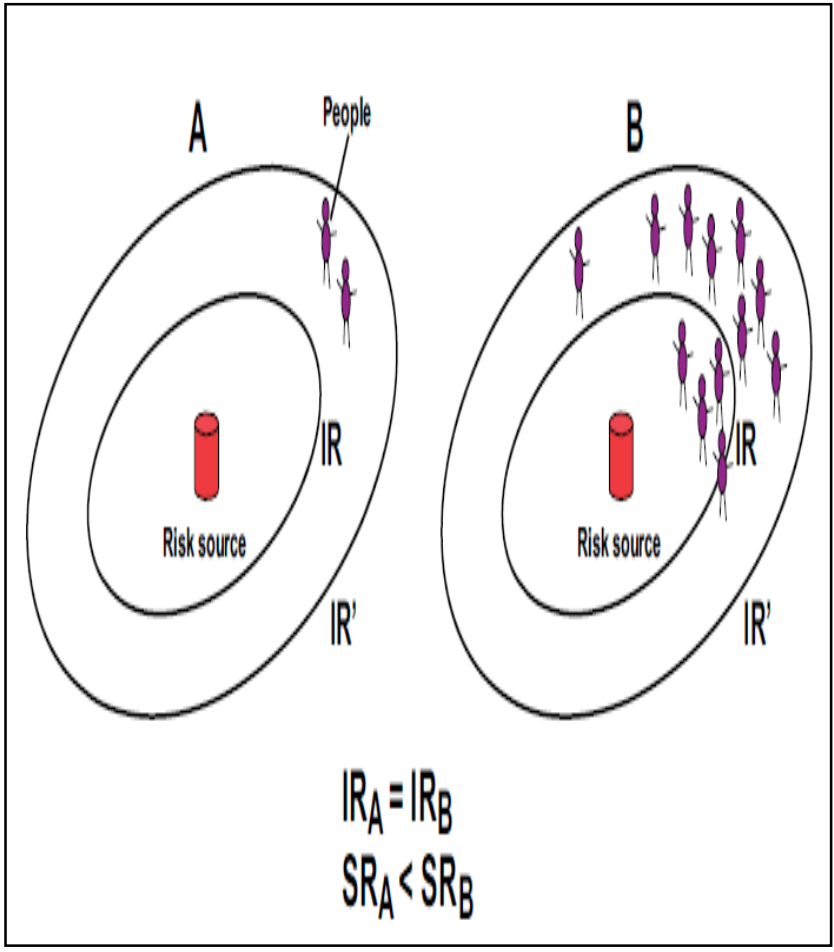
PSA Results for Use in Licensing and Regulatory Oversight





*Frank R Farmer Curve (**1967**)*

*Measure of Acceptable RISK: release of **10^3** (Ci Iodine-131) **f= 10^{-3} r-y***

Comparison of Individual Risk (IR) and Societal Risk (SR) from two identical facilities, A and B

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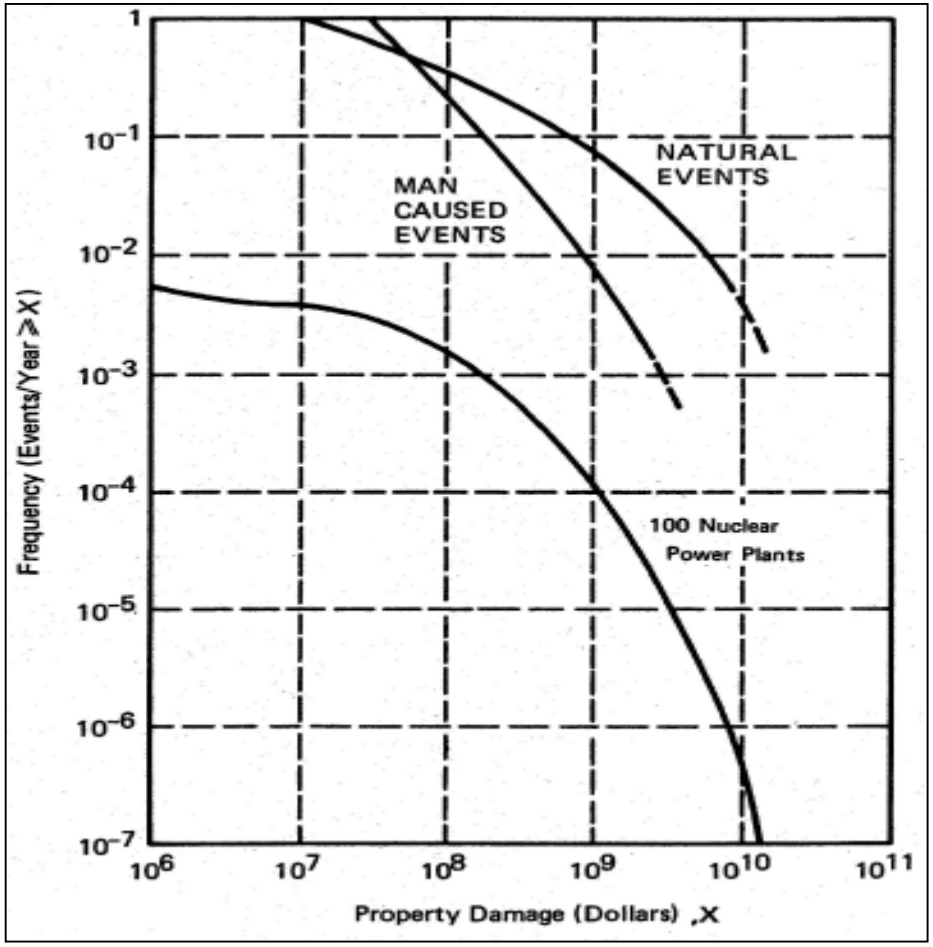
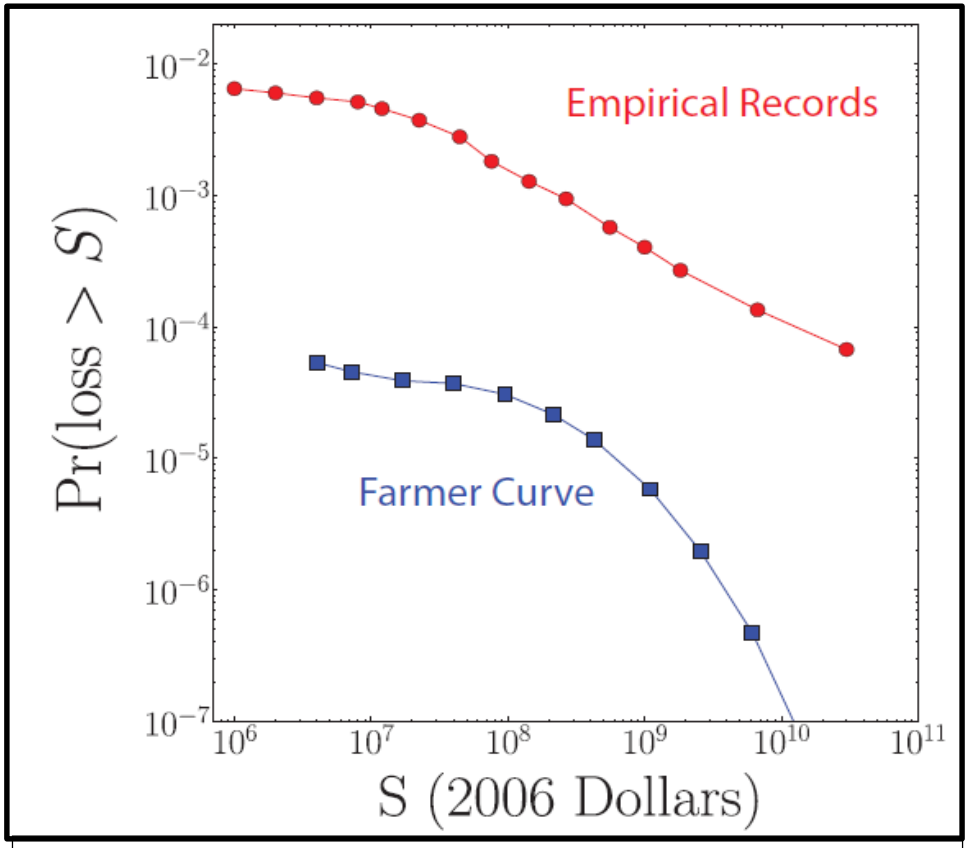
PSA Results for Use in Licensing and Regulatory Oversight



Frequency vs Property Damage Due to Natural and Man-Caused Events (ref. WASH-1400 study, 1975)



Empirical records (major nuclear accidents)

***Didier SORNETTE** et al.: **"Exploring the limits of safety analysis in complex technological systems"**, (2012)*

*The "**Farmer Curve**" here represents the data from WASH-1400 for property damage from 100 reactors in USA.*

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RISK Limitations

RISK definition: ***Risk, R*** *- a function of a* "Set of triplets" **R={<s_i, p_i, x_i>}** *scenarios, s_i, occurring with probabilities p_i, and resulting in consequences, x_i.*
(Ref. ***Kaplan*** *and* ***Garrick****, "****On the Quantitative Definition of Risk****", Packard, Lowe, and Garrick, Inc., 1980*)

RISK: Set of Triplets R={<s_i, p_i, x_i>}

1. **Scenarios (s_I): What can go wrong?**
2. **Probability of occurrence (p_I): How likely is it that that will happen?**
3. **Consequences (x_I): If it does happen, what are the consequences?**

RISK is more than a Set of Triplets R={< s_i, p_i, x_i, K_i, U_i>}

1. **s_i (scenarios)**: What bad can happen, or go wrong?
2. **x_i (consequences)**: If it does happen, what are the consequences?
3. **p_i (likelihood)**: How likely is that it will happen and give these consequences?
4. **K_i (knowledge)**: What is the knowledge supporting the s_I, x_I, p_I judgments?
5. **U_i (Uncertainties**, i.e. aleatory, epistemic): How strong is the knowledge?

4. RISK-INFORMED Approach to Establishing Regulatory Framework: Limitations

Don Rumsfeld's (Sec. US DoD, 2001) contribution to Risk Management:

My free translation into English of his rendition: Why do we discard certain events?

KK: Known Knowns (Surprises): Event is known, but believed it won't occur because (someone,… an expert?) judged low its probability

UK: Un-Known Knowns (Unforeseen, unanticipated):

Event is known by someone out there, but not by the people, who have to make a decision here and now! That's why Nassim N. Taleb's **Black Swans** hit us ***out of the blue every so often***!

UU: Un-Known Un-Knowns (Unthinkable, unimaginable):

Epistemic events – no one expects them, nor understands them, or has a clue how to respond.

Question-6: How does the **K_I dimension in the RISK definition** affect the **quality of the PSA results?**

If **RISK insights** are to play a **much greater role** in the **future Regulatory Framework (**e.g. Licensing and ROP**), what criteria** shall one establish to:

- **Regulate** the **methodology development** (example: RG 1.203, EMDAP, i.e. BEPU for LWR),
- **Do uncertainties control**,
- Ensure adequate **extent** and proper **quality** of the **knowledge database** used for **RISK assessment?**

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PSA Limitations due to Uncertainties in:

- Probabilistic quantification of the rates of single- and common-cause hardware, or software failure,
- Occurrence and evolution of certain physical phenomena that dominate the plant response to severe accidents;
- Modeling human errors of omission and commission,
- Modeling radiological source terms: e.g. nuclides composition, interaction between nuclides or with reactor materials;
- Modeling radionuclide release and transport mechanisms.
- Modeling digital I&C systems – potential for CCF scenarios !
- Modeling passive systems – difficult to carry out their reliability evaluation, stronger effect from human errors

PSA Limitations due to Uncertainties:

- DSA uncertainties **can be reduced** (aleatory) or **eliminated** (epistemic) by using test, research, feedback from prototypes
- PSA uncertainties: **far more difficult** to characterize, quantify, not readily reducible

HENCE: This is the **primary** reason for having a ***LOWER degree of confidence in PSA*** results then in conclusions, drawn from DSA studies.

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5. NEI T-I RIPB Approach to Establishing Regulatory Framework

PRA Policy Statement (1995): USNRC ushered in RISK-INFORMED approaches in regulation

Primary role: DETERMINISTIC (D-i-D philosophy+ Safety Margins+ ROP)

Secondary role: RISK-INFORMED (State-of-the-art PRA) **complements** DETERMINISTIC approach

Lots of frothy paper flow went under the bridge since then ...

NEI 18-04 (Aug.2019) and **USNRC RG-1.233** (Jun.2020):

Launch of **T-I RIPB**

Primary role: **RISK-INFORMED**

Secondary role: DETERMINISTIC (D-i-D plus safety margins) **complements** RISK-INFORMED approach

5. NEI T-I RIPB Approach to Establishing Regulatory Framework

Red Question-1: *If **not using HAZARD** analysis (HAZOP, FMEA), **what** should one use to identify all fault and event sequences that have **significance for the hazards characterization** and ensure there is a **comprehensive evaluation of the exposure** to them?*

Red-hot Question-2:

Are HAZARD Analysis and DSA (Deterministic Safety Analysis) the best means to establish all pertinent requirements for the Safety Class SSCs?

Red-hot Question-3:

Is ***Patching-up*** the best way to improve the Regulatory Framework?

Red-hot Question-4:

Can one use D-i-D philosophy to sort out institutional problems?

Red-hot Question-5:

If CDF and LERF are not relevant for advanced nuclear reactors: How shall one concoct replacements for the Quantitative Safety Goals?

- Design-specific surrogates?
- Measure of the accident's cost to society?

Red Question-6: How does the **K_I dimension in the RISK definition** affect the **quality of the PSA results?**

If **RISK insights** are to play a **much greater role** in the **future Regulatory Framework (**e.g. Licensing and ROP**), what criteria** shall one establish to:

- **Regulate** the **methodology development** (example: RG 1.203, EMDAP, i.e. BEPU for LWR),
- **Do uncertainties control**,
- Ensure adequate **extent** and proper **quality** of the **knowledge database** used for **RISK assessment?**

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NEI 18-04 T-I RIPB Process Steps Description

NEI 18-04 Methodology Step #1 *Selecting relevant Licensing Basis Events (LBEs):*

- *What are the plant initiating events and event sequences that are associated with the design and site?*

NEI 18-04 Methodology Step #2

Establish the safety classification of SSCs and associated special treatments for them

- *Use RIPB to better focus on establishing of special treatment requirements for SSC safety classification*
- *How do the proposed design and its SSCs respond to initiating events, and what roles do the SSCs play in the event sequences?*
- *What are the margins provided by the facility's response to accidents, in terms of keeping radiological releases within prescribed limits?*

NEI 18-04 Methodology Step #3

Evaluate adequacy of D-i-D provisions – is there enough safety

- Is the philosophy of D-i-D adequately reflected in the ***design*** and ***operation*** of the facility?
- What are the performance-based requirements that one can use to assess D-i-D adequacy?

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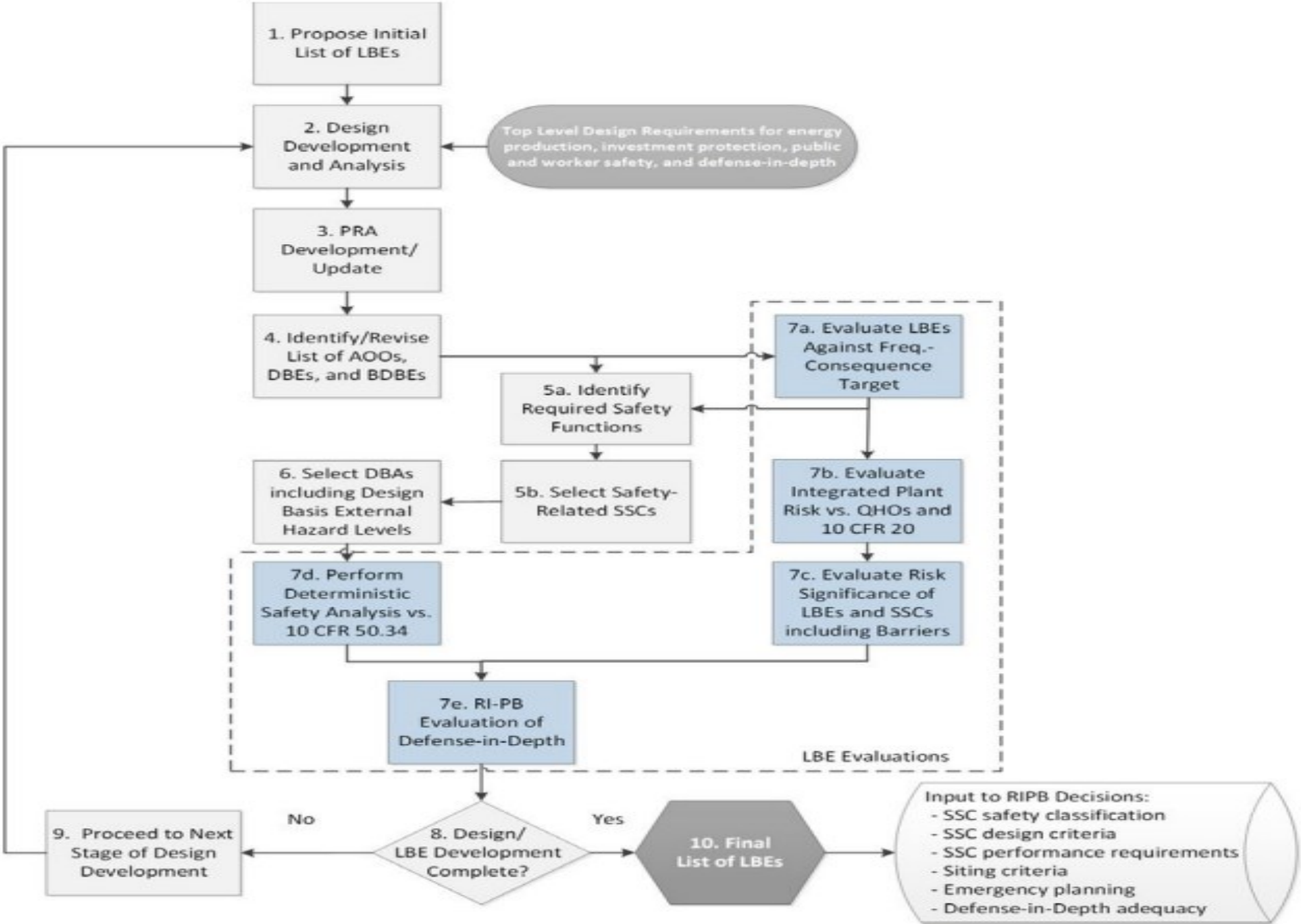
6. NEI 18-04 T-I RIPB Process Step #1: Select and Evaluate LBEs



6. NEI 18-04 T-I RIPB Process Step #1: LBEs Categories

AOOs *(Abnormal Operating Occurrences)*:

Anticipated event sequences occur ***one or more times during the life*** of a NPP, which may include one or more reactor modules. AOOs take into account the ***expected response of all SSCs*** within the plant, regardless of safety classification.

DBEs *(Design Basis Events):*

Infrequent event sequences - ***not expected to occur in the life*** of a nuclear power plant, which may include one or more reactor modules; they are less likely than AOOs.

DBEs take into account the ***response of all SSCs*** regardless of safety classification.

BDBEs *(Beyond Design Basis Events):*

Rare event sequences - not expected to occur in the life of a nuclear power plant, which may have one or more reactor modules; they are less likely than a DBE.

BDBEs take into account the ***response of all SSCs*** regardless of safety classification.

DBAs *(Design basis accidents)*:

Postulated event sequences - used to set design criteria and performance objectives for the design of safety-related SSCs.

DBAs are derived from DBEs based on the capabilities and reliabilities of safety-related SSCs needed to mitigate and prevent event sequences, respectively.

DBAs are derived from the DBEs by prescriptively ***assuming that only safety-related SSCs are available*** to mitigate postulated event sequence consequences to within the dose limits set by 10 CFR 50.34.

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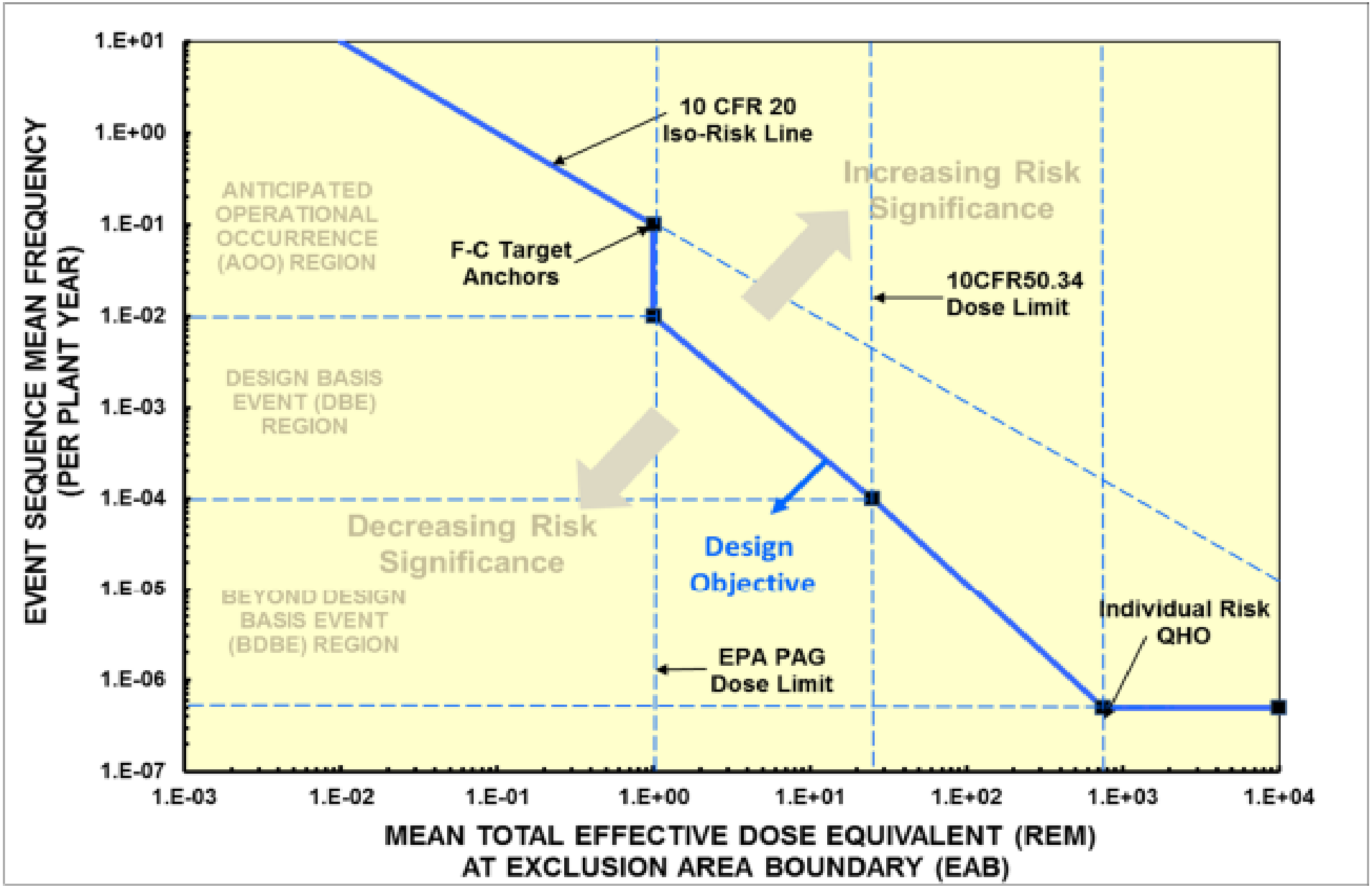
6. NEI 18-04 T-I RIPB Process Step #1: F-C Curve



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NEI 18-04 Dose Targets for all LBEs categories –

Given as **frequency-consequence (F-C) curve.**

- Assess each LBE by using this **mean annual frequency** of occurrence and realistic (mechanistic, not postulated source term) consequences, i.e. dose calculations.
- Full **quantitative assessment of uncertainties** in both the frequencies and consequences.
- The **list of LBEs** and their assessments is to be **refined in an iterative fashion** as the design and PRA evolve and mature.

- **DBEs** and **high-consequence BDBEs**: Used to ***identify required safety functions***.
- Use these safety functions to decide **which SSCs should be classified as safety-related**.
- This assessment includes consideration of **DBEs due to external hazards** (e.g., earthquakes, flooding, high winds, etc.) as well.

- Comparison of US NRC's **QHOs with mean estimates of PSA results** – serve to indicate the overall level of safety of the design.
- This comparison is performed for all radionuclide sources within a plant. They take into account interactions among **multiple units** that might exist and address sources beyond the reactor core (eg spent-fuel pool), for all modes of operation of the plant and for all relevant hazards.

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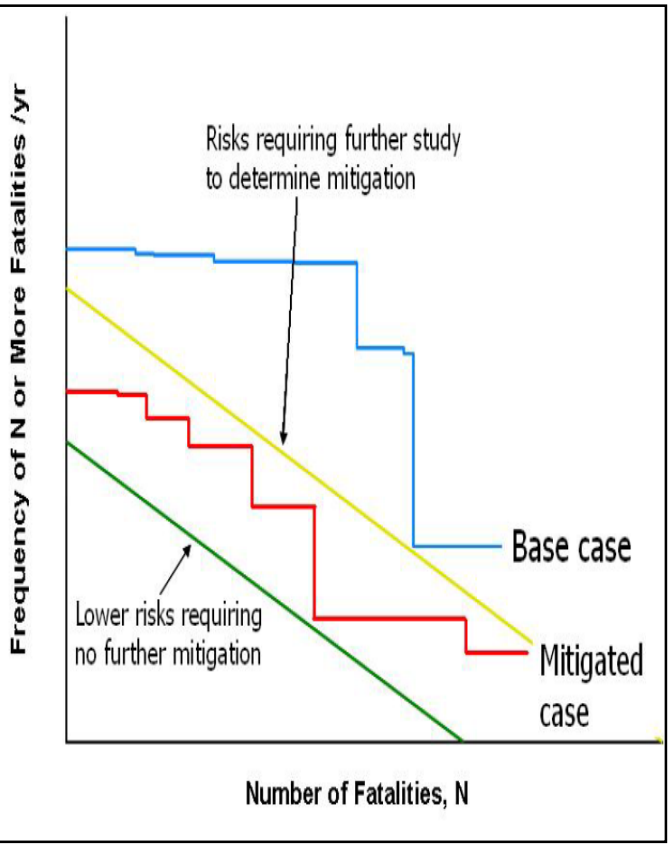
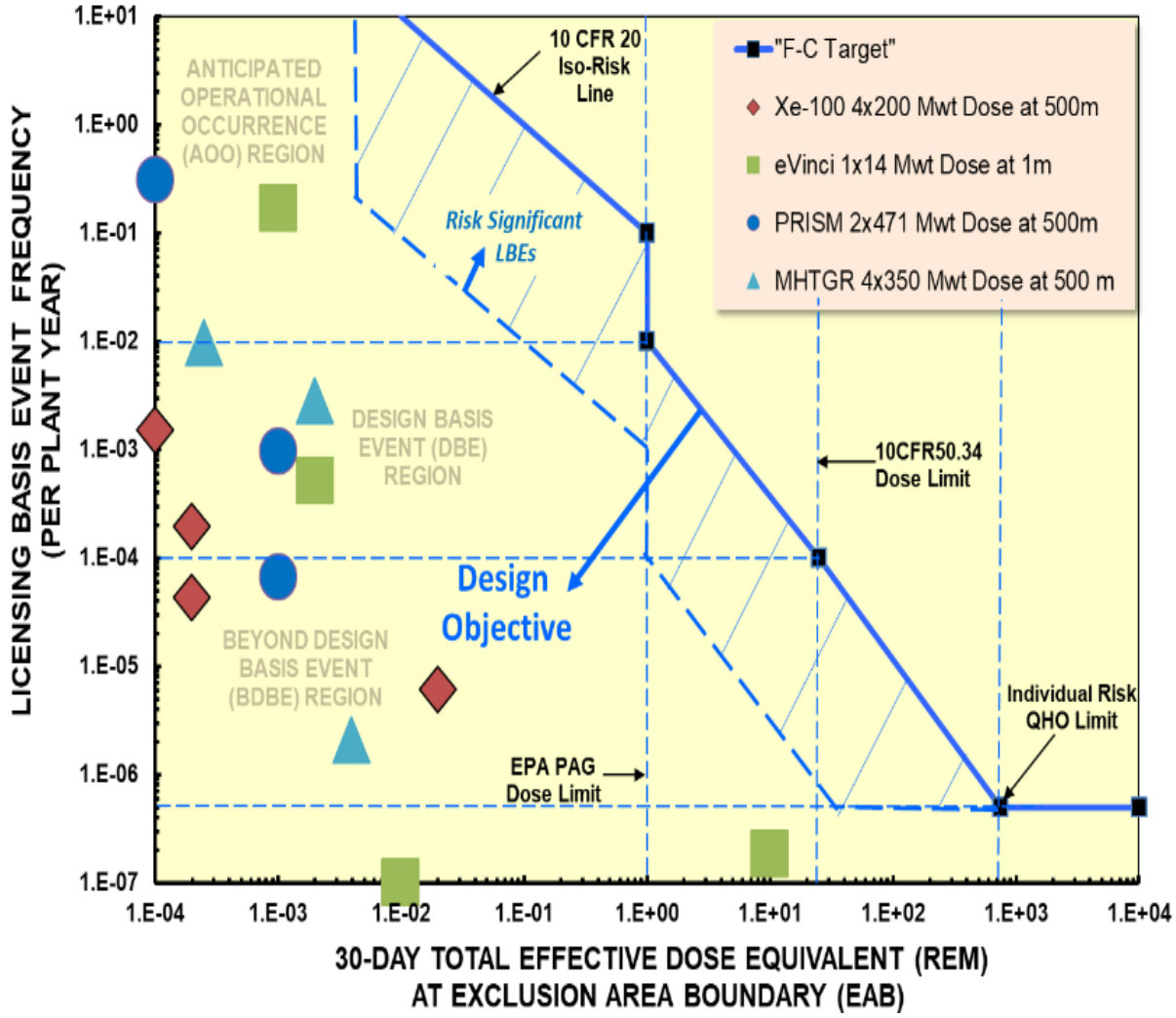
6. NEI 18-04 T-I RIPB Process Step #1: F-C Curve

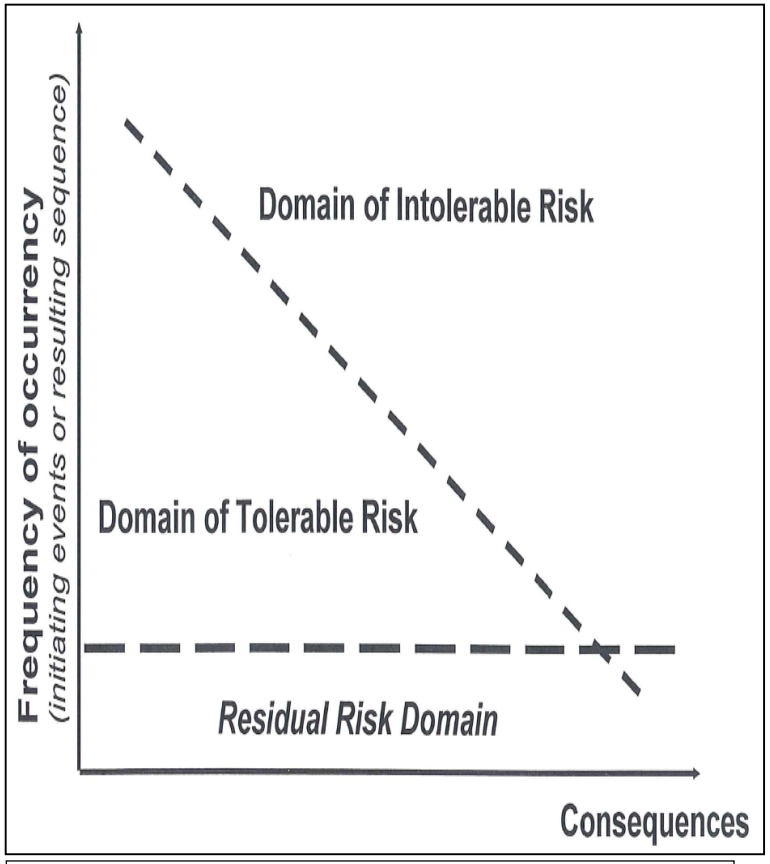


The Middle Zone (between yellow and green lines): a means to accommodate uncertainties



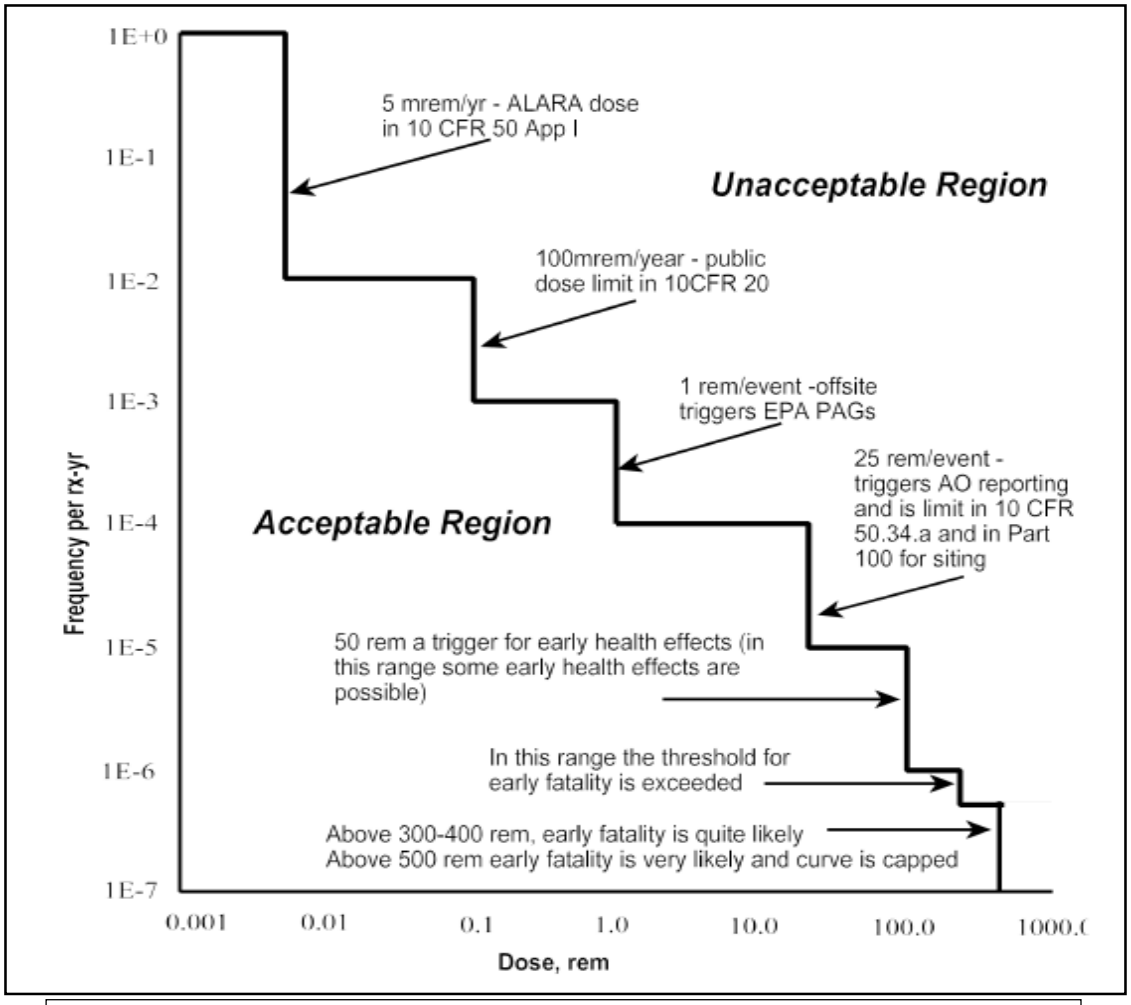
Recall FR Farmer Curve (1967)
Are the points along the line "same-risk" points?
Is "RISK aversion" incorporated in NEI 18-04 F-C curve

6. NEI 18-04 T-I RIPB Process Step #1: F-C Curve



US NRC NUREG-1860 "Feasibility Study for Risk-Informed Performance-Based Regulatory Structure", **2007**

EPA PAGs Environ. Prot. Agency Protect. Action Guide



Use F-C risk curve to illustrate the concepts of **Tolerable**, Intolerable, and **Residual Risks** – important when holding discussions with multiple stake-holders, who may have rather different views on RISK and its management

US NRC ACRS (Advisory Committee on Reactor Safeguards): strong criticism of NUREG-1860 and its F-C curve

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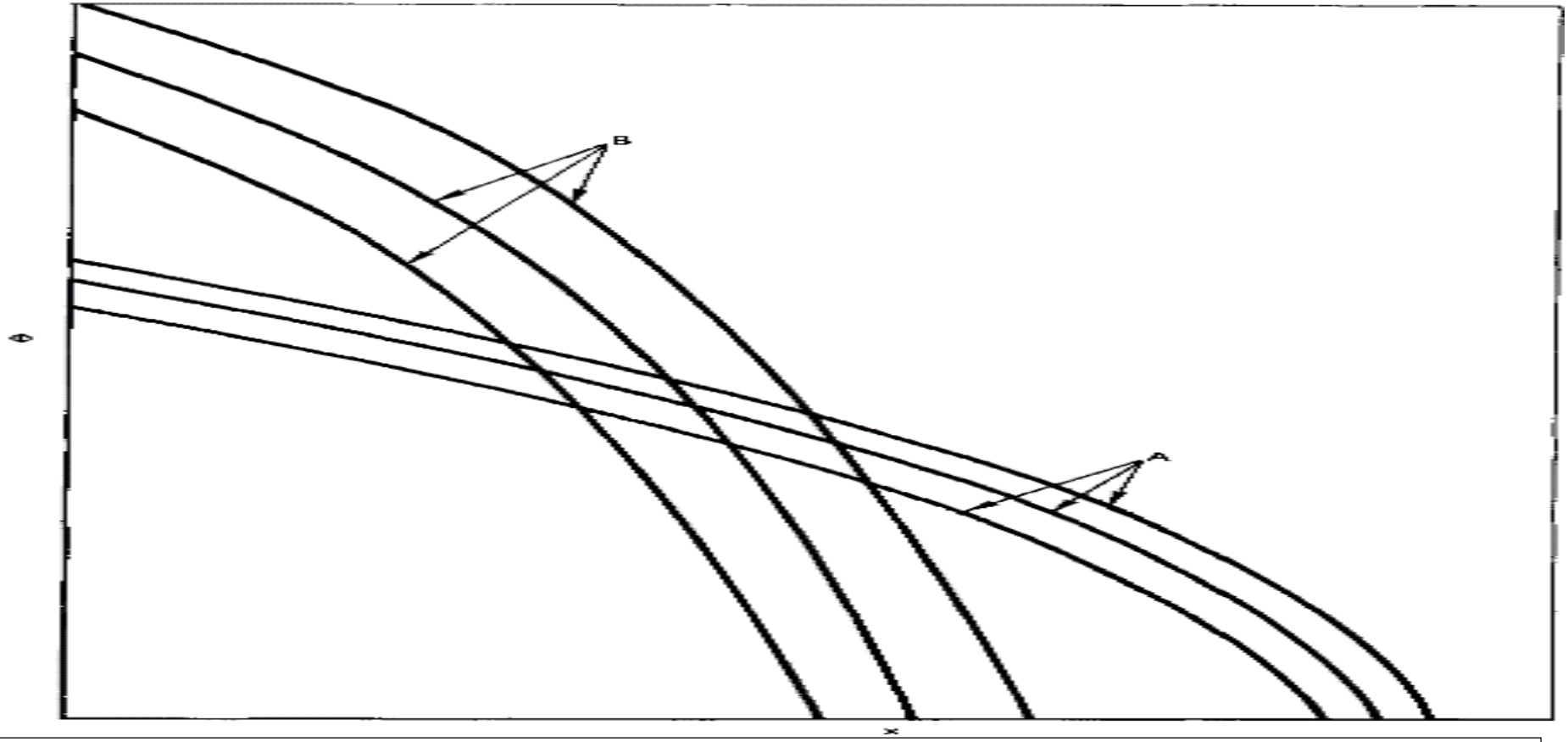
One needs guidance how to compare different designs: by using not the INTEGRAL risk, but inputs as uncertainties and risk from individual event sequences (ie AOO, DBE, DBA, BDBE…)

Example: Consider RISK profiles of Reactors A and B:

If the TOTAL (integral) risks are equal, which one is better (or acceptable)?



If RISK-insights start to play a **lead** role in regulatory decision-making, one may have to introduce not only a metric for the **integral risk**, but a **metric** for the **individual one,** ie the risk from **individual** event sequences)

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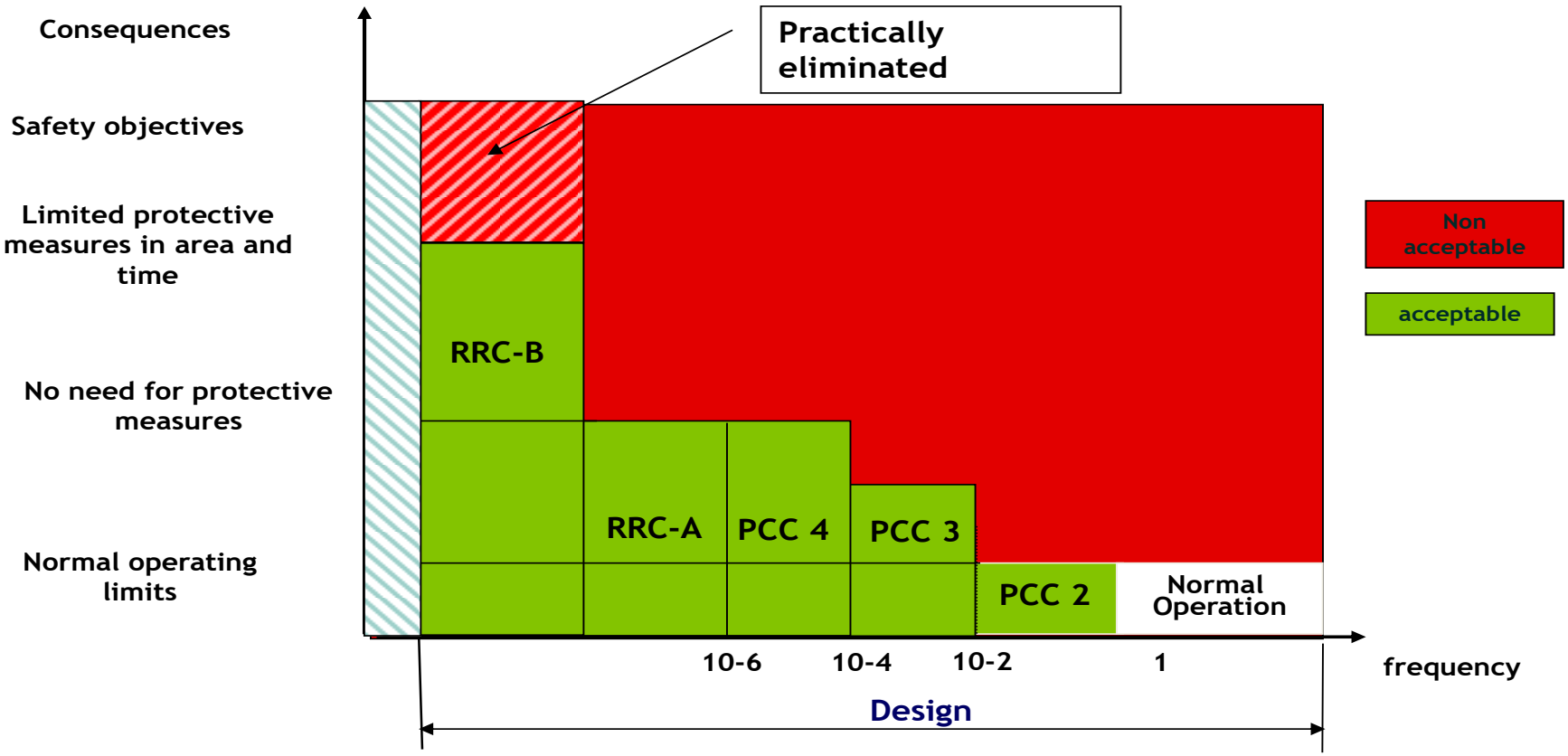
Events considered in the design



PCC: Plant Condition Category
RRC: Risk Reduction Category

RRC-A: multiple failures situations, without core melt
RRC-B: core melt situations

1

AREVA use of Risk Matrix to define Plant Conditions and Risk Reduction Categories for EPR 1600.

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CONSEQUENCEs are multi-dimensional !

If RISK-insights start to play a **leading** role in regulatory decision-making, one may have to assess **different types of CONSEQUENCEs -** Note: Refer to **"Public Image"** column in table below:

"Perceived RISK" plays an important role, since different stake-holder have rather different views on RISK, its assessment and management

Qualitative Risk Assessment by using a **Risk Matrix with Multiple Criteria** for **Impact Assessment** and **Quantified Occurrence Probability**

CONSEQUENCES DESCRIPTION					LOW PROBABILITY HIGH				
Severity	Humans	Assets	Nature	Public Image	Improbable 1 in 100 000 years	Remote 1 in 10 000 years	Occasional 1 in 1000 years	Probable 1 in 100 years	Frequent 1 in 10 years
Catastrophe	Multiple fatalities	Extensive loss	Massive impact	International response					
Severe	Few fatalities	Major Damage	Major Effects	National Event			HIGH RISK		
Critical	Few injuries	Localized Damage	Localized Effects	Local Impact					
Marginal	Minor injuries	Minor damage	Minor Effects	Minor impact		MEDIUM RISK (ALARP)			
Negligible	Slight health effect	Slight damage	Slight effect	Slight impact	LOW RISK				

T-I RIPB Process Step #2 Objective:

Establish a systematic approach to assess and determine appropriate relationships between the needed capabilities and reliabilities for SSCs and the role of those SSCs in mitigating and preventing LBEs.

- **Assessing the SSCs risk significance**

The safety classification process and the corresponding special treatments check the frequencies and consequences of the LBEs in relation to the F-C target and ensure that the cumulative risk metrics are not exceeded.

- **Need for SSC Special Treatment:**

Determine if special treatments beyond normal industrial practices are needed to ensure SSC performance of safety functions in the prevention and mitigation of LBEs.

- **Iterative Process:**

Safety classification of SSCs and determination of performance criteria are directly related to and performed in an iterative process, along with the identification and assessment of LBEs and D-i-D

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NEI 18-04 Methodology Second Step (Cont'D)

- **Assessing the SSCs risk significance**

Safety related SSCs:

– SSCs selected by designer from the SSCs that are available to perform the required safety functions to mitigate the consequences of DBEs to within the LBE F-C target, and to mitigate DBAs that only rely on the safety related SSCs to meet the dose limits of 10 CFR 50.34 using conservative assumptions.

– SSCs selected by designer and relied on to perform required safety functions to prevent the frequency of BDBE with consequences greater than the 10 CFR 50.34 dose limits from increasing into the DBE region and beyond the F-C target.

Non-Safety related SSCs with special treatment:

– Non-safety related SSCs are relied on to perform risk-significant functions that prevent or mitigate any LBE from exceeding the F-C target, or make significant contributions to the cumulative risk metrics selected for evaluating the total risk from all analyzed LBEs.

– Nonsafety-related SSCs relied on to perform functions requiring special treatment for DID adequacy.

Non-Safety related SSCs with no special treatment:

– All other SSCs (with no special treatments beyond normal industrial practices).

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NEI 18-04 Methodology Third Step: D-i-D Adequacy Assessment

- NEI 18-04 uses ***probabilistic*** and ***deterministic*** assessment techniques to establish D-i-D, together with a combination of plant capabilities and programmatic controls.
- Evaluations should determine whether ***additional measures*** are appropriate to address an ***overreliance on specific SSCs***, or to address ***uncertainties***.
- NEI 18-04 assessment of D-i-D uses a similar process, as the one defined in *IAEA Specific Safety Requirement No*. ***SSR-2/1***, *"Safety of Nuclear Power Plants: Design."*

NEI 18-04 Methodology for D-i-D Adequacy Assessment

(1) Prevention of abnormal operations, initiating events and AOOs;

(2) Return to normal operation, following a possible AOO, and prevention of DBEs;

(3) Perform required safety functions in response to possible DBE, and prevent BDBEs;

(4) Maintain required safety functions for retention of radioactive material; and

(5) Prevent adverse impacts to both public health, well-being, and society safety.

This approach includes evaluating each LBE to ***identify the D-i-D attributes***, incorporated into the design to ***prevent*** and ***mitigate accident sequences*** and to ensure that they reflect ***adequate SSC reliability*** and ***capability.***

Evaluate each LBE to confirm that ***risk targets*** *are met* ***without exclusive reliance*** on a ***single element of design***, a single ***program***, or a single ***D-i-D attribute***.

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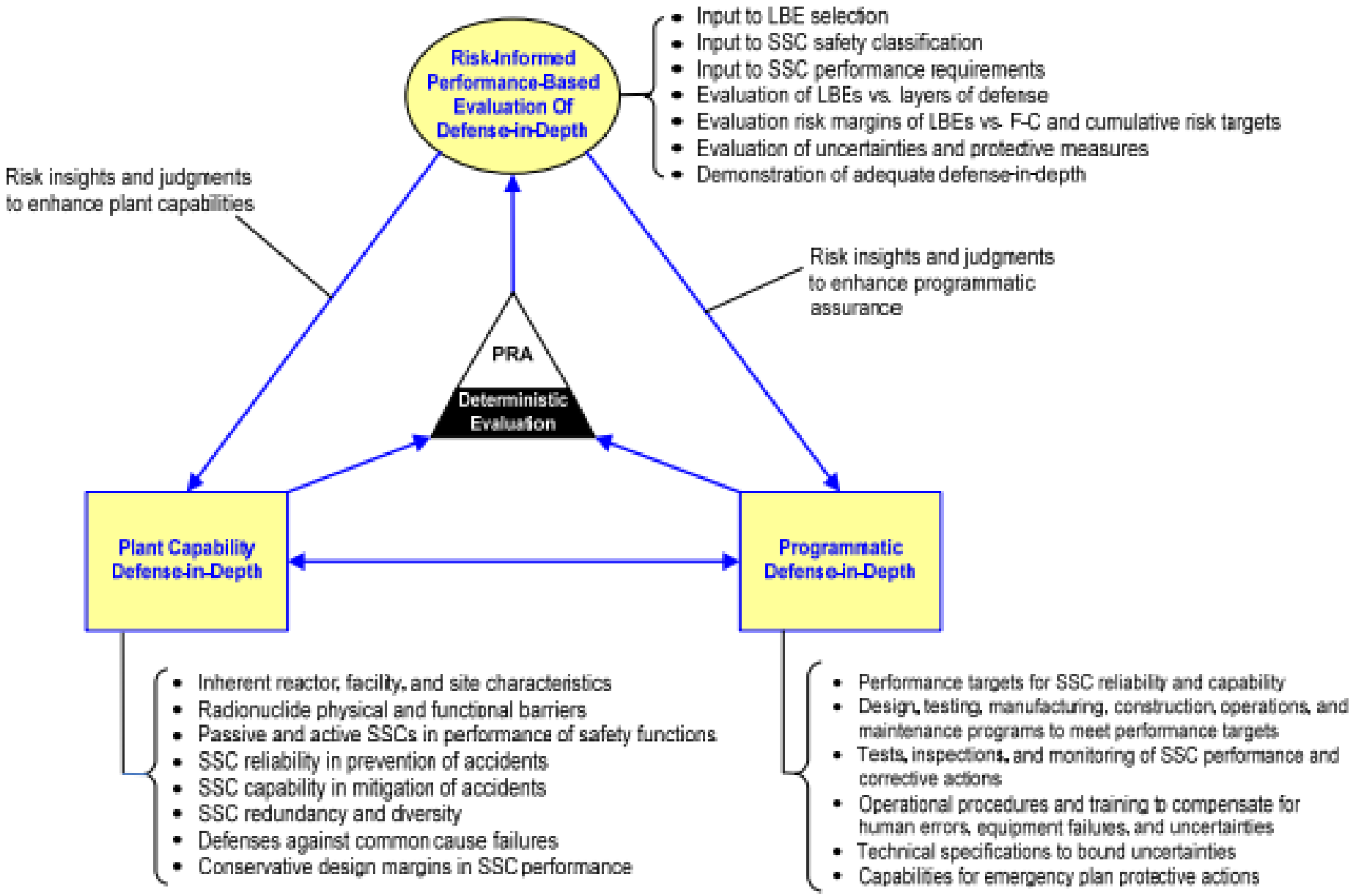
6. NEI 18-04 T-I RIPB Process Step #3: Evaluation of Defense-in-Depth Adequacy



NEI 18-04 TI-RIPB Principle

Requirement #1

1. The plant meets the established limits for the adequate protection of the public health and safety.

- The plant must be capable of responding to credible challenges in a safe manner.
- There must be confidence that the plant will not present a challenge to the NRC's Safety Goal Policy.

NEI 18-04 TI-RIPB Principle

Implementation

- The PRA is used to establish the set of challenges to be addressed and, together with the deterministic analyses, determine whether the plant is capable of responding in a safe manner.
- The PRA characterizes the frequencies and consequences associated with the LBEs, and these are compared to targets presented in the form of a F-C curve to help ensure that the plant is capable of responding to challenges safely and with margin.
- Mean results from the PRA demonstrate that the QHOs limits are not challenged.

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NEI 18-04 TI-RIPB Principle Requirement #2

2. The safety functions, design features and functional design criteria relied upon to meet the safety criteria are defined.

NEI 18-04 TI-RIPB Principle Implementation

The PRA delineates the relevant safety functions for each type of LBE.

These safety functions, in turn, are used to define the design features to select the appropriate functional design criteria.

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NEI 18-04 TI-RIPB Principle Requirement #3

3. The selected LBEs adequately cover the range of hazards that a specific design is exposed to.

- A comprehensive list of design-specific plant challenges has been developed.
- The relative credibility of each challenge is understood.
- The plant response to credible challenges has been adequately characterized.

NEI 18-04 TI-RIPB Principle Implementation

- After the preliminary identification of potential initiating events, the systematic searches for initiating events and the delineation of event sequences integral to the PRA lead to **identifying the LBEs in a comprehensive** manner.
- The **frequencies of the LBEs, complemented by engineering reviews**, determine the extent to which each LBE is credible.
- Plant response is characterized through **deterministic analyses** (realistic analyses supporting the PRA and conservative analyses for DBAs) that provide information regarding the outcomes for each LBE.

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NEI 18-04 TI-RIPB Principle Requirement #4

4. The SSCs are categorized according to their safety significance.

NEI 18-04 TI-RIPB Principle Implementation

SSCs are categorized according to the roles they play in satisfying the safety functions defined in the PSA.

NEI 18-04 TI-RIPB Principle Requirement #5

5. The design reflects the application of an appropriate philosophy of Defense-in-Depth, including accounting for important uncertainties associated with the design and the response of SSCs to plant challenges.

NEI 18-04 TI-RIPB Principle Implementation

- Provisions for Defense-in-Depth are evaluated by examining the LBEs identified and analyzed via the PSA. Systematic determinations are made regarding the adequacy of these provisions.
- Consideration of DID adequacy includes the need to account for uncertainties in the plant response and the characterization of the LBEs.

NEI 18-04 TI-RIPB Principle Requirement #6

6. The special treatment for SSCs, and associated programmatic controls and human actions, provide reasonable assurance that the SSCs will perform the safety functions for which they are relied upon.

NEI 18-04 TI-RIPB Principle Implementation

- The need for special treatments is determined based on the categorization of the SSCs.

The PSA provides input to the integrated decision-making panel to identify special treatments needed beyond those required for safety-related SSCs.

- Quantitative reliability targets are defined for SSCs that play a significant role in the LBEs.

NEI 18-04 TI-RIPB Principle Requirement #7

7. The scope and level of detail for the design and analysis of the plant in the licensing-basis information adequately describes the safety case.

NEI 18-04 TI-RIPB Principle Implementation

Not addressed at this time.

Alex.Matev@BelV.be

8. CONCLUSIONS

The NEI 18-04 approach to establishing a T-I RIPB framework entails a ***large reliance on PSA*** results.

It may be best suited for a reactor design for which the ***possibility of different system interactions*** may need to be addressed. This may be the case, if the design employs a ***mix of both passive safety systems and active (non-safety***) systems that limit the challenges to the passive systems, or could serve as a backup in the event that one of the passive systems failed to perform its intended function.

This approach might be of great use for ***plants that have multiple units***, i.e. modules, on the same site, ***with many important interactions among these modules***.

This approach also requires ***detailed assessment*** of the ***reliability of safety and relevant non-safety*** systems, including ***extensive uncertainty analyses.***

This approach would also yield the ***most extensive set of risk insights*** with respect to ***categorizing SSCs*** and determining ***special-treatment requirements***.

And without further ado: In order to declare **T-I RIPB is Acceptable** one still needs to:

Get a "Passed" Mark from a Successful Application Test on Advance Nuclear Reactor

Alex.Matev@BelV.be

I am done - Over and out, … finally !

Thanks a lot for the patience !

Questions ?

Alex.Matev@BelV.be

2.20 Towards New Technologies, Lucien Allais, CEA (In person)

Harmonising Fission & Fusion Reactor Licensing

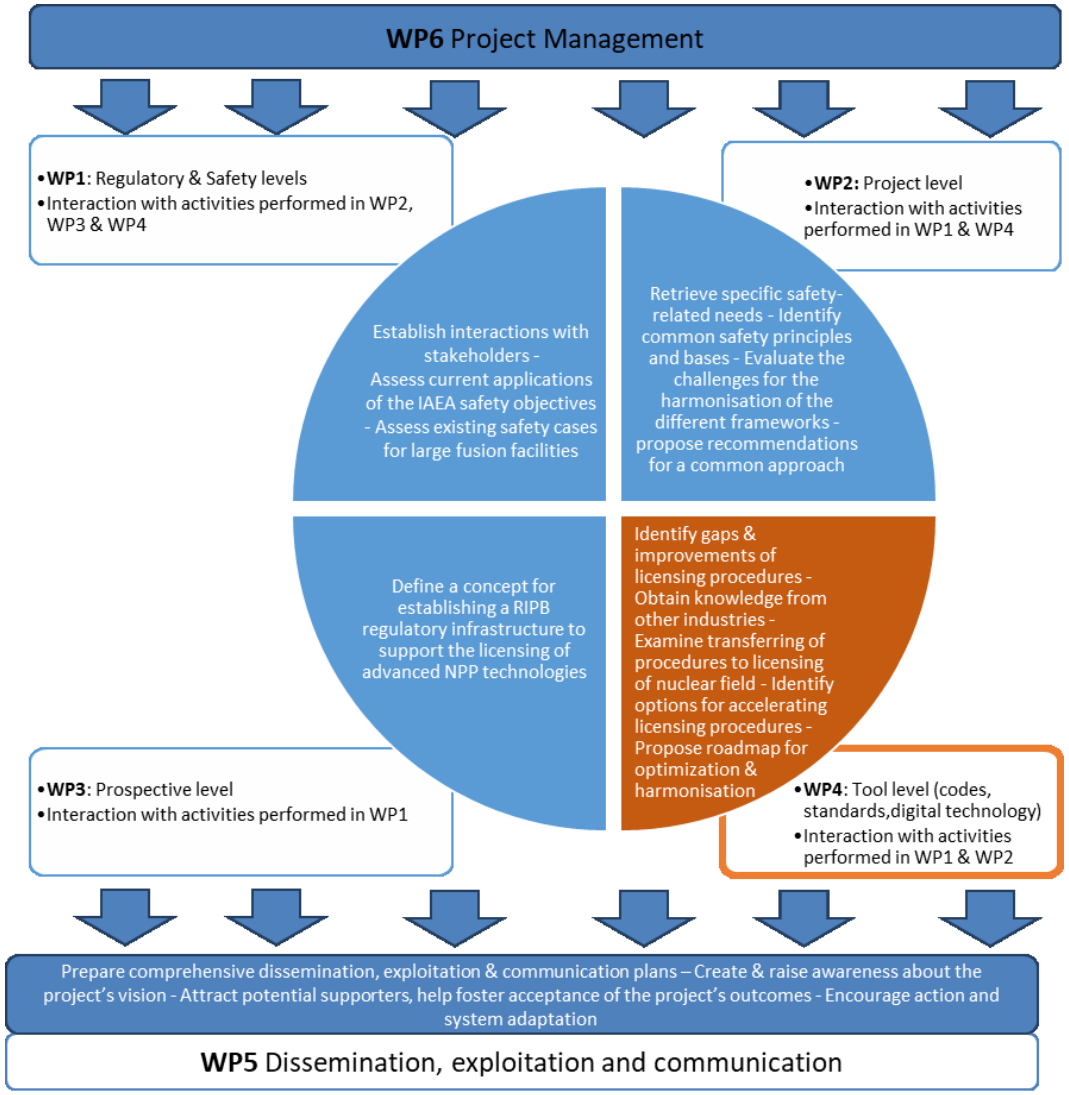
HARMONISE WP4

ALLAIS Lucien

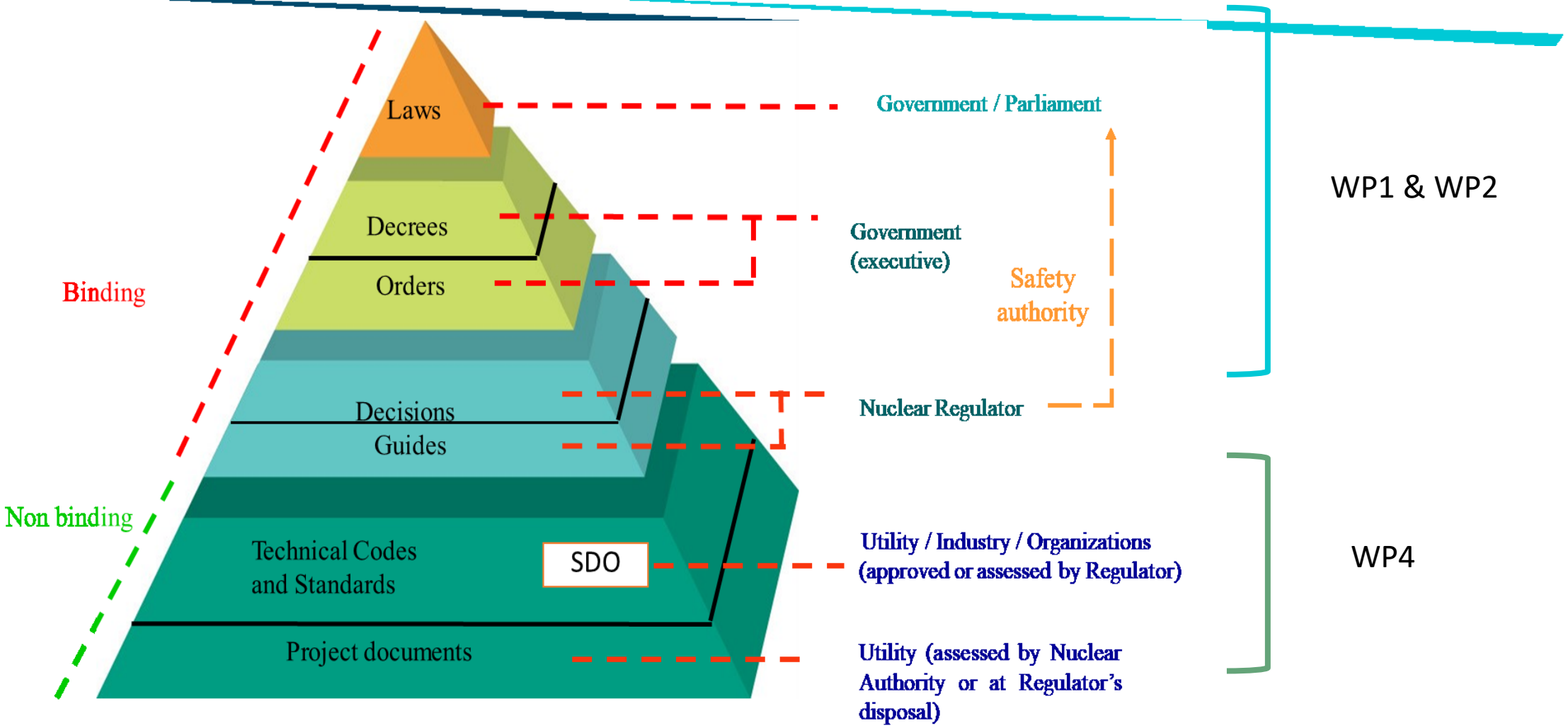
WP4 leader, CEA, Lucien.allais@cea.fr

WP4 location in HARMONISE project

Harmonising Fission & Fusion Reactor Licensing



WP4 issues: codes & standard location



WP4 issues: importance of codes and standards

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- determine costs and lead times throughout the life of the reactor, from design to operation,
- integrate the latest technological improvements,
- Answer to new regulation requirements,

➔central role in a context of strong nuclear development:

  - For electricity production decarbonization,
  - answer to electricity consumption increase (mobility, …)
  - new non-electric uses (hydrogen production, heat supply, …)

WP4 objectives

- To identify the needs to support innovative reactor projects in terms of codes & standards and digital technology,
- To draw a map of the scope already covered by codes and the needs for additional scope (in such cases, WP4 will propose recommendations)

WP4 challenges

- To integrate innovations not already standardized as innovative manufacturing process, to switch to new digital technologies that could be done by learning from other industrial sectors,
- To be able to respond to the varied and harsh conditions specific to different types of reactor,
- To be able to cover longer operation times specially for materials behaviour

WP4 methodology

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Needs collect → **Questionnaire sent** → **Map & recommendations**

HARMONISE partners:
- DEMO,
- ALFRED,
- …

Innovative reactor projects
- Nuward,
- NewCleo,
- Thorizon,
- NAAREA,
- …

Survey

STANDARD DEVELOPMENT ORGANIZATIONS
- AFCEN,
- ASME,
- …

Other industrial sectors
- Aeronautics,
- Rail,
- …

Analyse of SDO & other industrial sectors answers

↓

Covered needs map
&
Recommendations for uncovered needs

Task 4.1 | Task 4.2 | Task 4.3

Organization of WP4

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- Task 4.1 : **Innovative technology needs**
  - Task 4.1.1 : *Codes and standards needs* : Leader: ANN, Participants: LEI, GRS, CEA, SCK·CEN, RATEN, AFCEN, ENEA, NUCL21, JRC

  ➔ Develirable D42
  - Task 4.1.2 : *Digital technologies* : Leader: GRS, Participants: RATEN, LEI, NCSRD

  ➔ Develirable D43
- Task 4.2 **: Identification of solution options** : Leader: SCK·CEN, Participants: LEI, GRS, NCSRD, CEA, SCK·CEN, RATEN, ENEA, ANN, JRC

➔ Develirable D41 : Questionnaire for the Standards Development Organisations

- Task 4.3 : **Recommendations on codes and standards, new digital technologies and harmonisation** : Leader: CEA, Participants: GRS, CEA, SCK·CEN, RATEN, ENEA, ANN, JRC, AFCEN

➔ Develirable D44 : map of covered needs D45 : recommandations for uncovered needs

WP4 targets : kind of reactors

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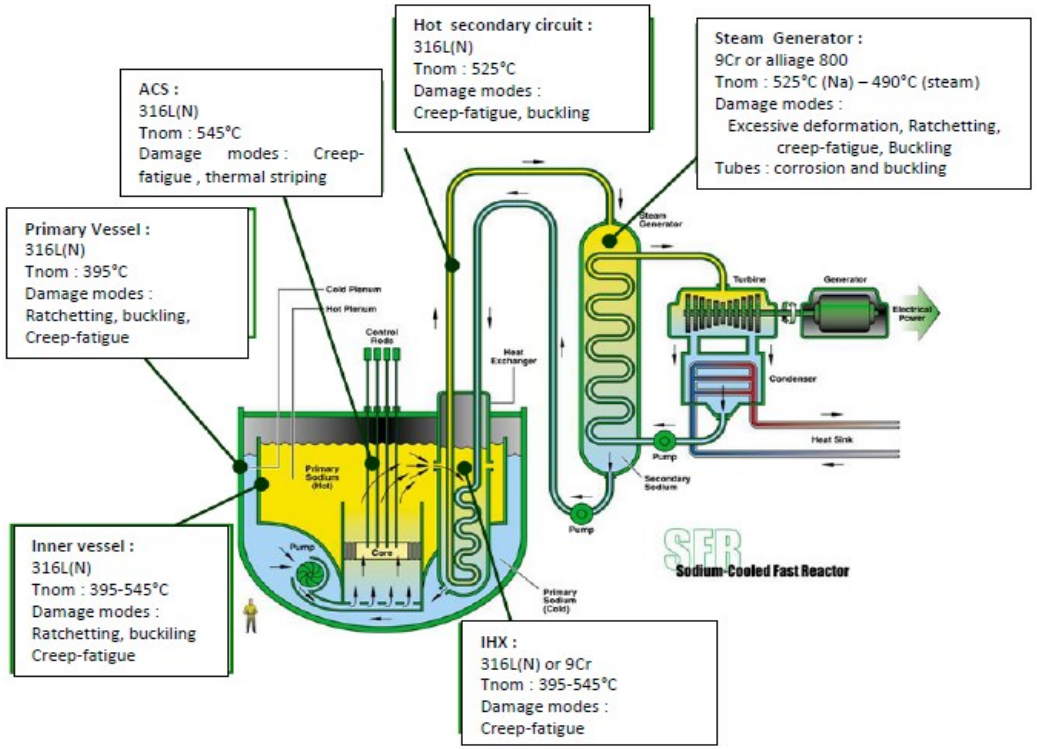
- Lead Fast Reactor (LFR): ALFRED, NEWCLEO, LeadCold,
- Gaz Fast Reactor (GFR): ALLEGRO,
- Molten Salt Reactor (MSR): INNUMAT, NAAREA, FlexReactor, SEABORG, Thorizon,
- Sodium Fast Reactor (SFR): HEXANA,
- Small Modular Reactor (SMR-LWR): NUWARD™, Rolls Royce SMR Ltd
- High Temperature Reactor (HTR): JIMMY,
- Fusion Reactor: DEMO, ITER, Marvel Fusion, FirstLight Fusion,
- Accelerator Driven System (ADS): MYRRHA,

Example of codification needs : SFR



- ***<u>Materials and Technical challenges specific to Astrid project</u>***

- Material characteristics at high temperatures
  - 316LN, 9%Cr, 800 Alloys, …
- Lifetime and irradiation issues
  - 60 Years Lifetime
  - Irradiation issues (He consideration)

- Structural analysis and design issues
  - Adaptation of the ratcheting rules for 9%Cr
  - Adaptation of the creep-fatigue rules for 9%Cr
  - Complete the pumps design rules for sodium application
  - Complete the bellows rules for sodium application
- Joining processes
  - Welding qualification and caracterisation in sodium
  - Hard rolling
  - Hard facing materials
  - Hot Isostatic Pressing for sodium-gaz compact heat exchangers

Available data : components

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Some standardization needs regarding innovative reactors components are already on the table:

- innovative (compact and microchannel) Heat exchangers,
- FA Cladding,
- Fuel assembly,
- Vessel & Inner Vessel,
- Internal structure,
- TBM & Breeding Blanket,
- Primary circuit,
- …

Data available : materials

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And also regarding materials:

- Austenic stainless steels : 316L(N), 310 N stainless steels, AIM1 (1515Ti), 316Ti, …
- Coating : Al_2O_3, AFA steel weld overlay on 316L(N) & weld, aluminizing on 316L(N) & 316Ti,
- Nickel alloys: 800 alloy
- Ti alloys,
- Eurofer,
- CrCuZr….

Available data : topics

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And more generally regarding topics:

- Innovative manufacturing process qualification,
- Innovative materials codification,
- in-service behavior justification / codification,
- long term operation,
- Long term environment effect,
- Non Destructive Testing qualification for innovative environment,
- coating manufacturing process,
- Design integration ,
- …

Available data: digital technology

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In the same way, some topics regarding digital technologies are known:

- AI supported/enhanced simulation tools for material properties,
- HMI improvements,
- Wireless applications,
- machine learning based material models,
- Digital twin of plant structures,
- Virtual Reality for Operation & Repair,
- …

State of progress

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Results analysis in progress

Needs collect

HARMON[illegible]:

- DEM[illegible]
- ALEF[illegible]
- [illegible]

DONE

- [illegible]vey
- Thr[illegible]on,
- NAAREA,
- …

Questionnaire sent

STANDARD DEVELOPMENT ORGANIZATION

- AFCEN,
- ASME,
- …

Other industrial sectors

- Aeronautics,
- Rail,
- …

Map & recommendations

Analyse of SDO & other industrial sectors answers

Covered needs map
&
Recommendations for uncovered needs

Task 4.1

Task 4.2

Task 4.3

Conclusion

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- It is still time to send us your needs
- A next step is going to start on the collection of solutions to answer to the needs of innovatives projects
- This step needs also to get the feedback of standardisation organisations
- All contributions are welcome
- General overview of the new challenges of all type of nuclear power plants, fission and fusion (news techniques, new materials , digitaliation....) and their impact on codes and standards.
- Main goal : detailed map of the topics already covered and the needs of the topics must be developed

➔ Very useful imput data to be treated in the framework such as CEN/workshop 64 « Design and Construction Codes for Gen II to IV nuclear facilities »

Thank You

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LITHUANIAN ENERGY INSTITUTE

GRS

VTT

DEMOKRITOS

cea

SÚRO

FANC
FEDERAAL AGENTSCHAP VOOR NUCLEAIRE CONTROLE

Jožef Stefan Institute

sck cen

SSTC NRS

RATEN

BEL V

afcen

ENEA

ANSALDO NUCLEARE
Ansaldo Energia Group

NUCLEAR 21
PERSPECTIVE FOR YOUR DECISIONS

European Commission
Joint Research Centre

This project has received funding from the European Commission-Euratom under Grant Agreement No 101061643

Annex 3: Materials of the lecture in Section 2.16

Towards pre-licensing of ECC-SMART

Dr. Andrej Prošek, Expert-research Councillor
Jožef Stefan Institute (JSI)
role: JSI is lead beneficiary of WP5

M.Sc. Ildikó Boros
BME
role: BME is leader of WP5.2

ABSTRACT

The pre-licensing study of Joint European Canadian Chinese development of Small Modular Reactor Technology (ECC-SMART) relates to the safety criteria and requirements for the Supercritical Water-cooled Small Modular Reactor (SCW-SMR) concept developed in the frame of WP5.1 with the safety-related behaviour and features of the SCW-SMR as identified in WP5.2. The results of WP5.1 and partially WP5.2 are presented, and the process to be used for pre-licensing study, which will identify three sets of the safety criteria and requirements: (1) fulfilled with reasonable certainty within the limits of already available knowledge, (2) fulfilment is probable, further research needed, and (3) fulfilment is improbable, design changes are needed.

5 INTRODUCTION

Public perception of the economy and safety of today's nuclear power plants will require future Small Modular Reactors (SMRs) to comply fully with the highest safety standards. At the same time, the economic viability of the future SMR will require the application of innovative ideas, involving among others combination of low power density fuels and accident resistant or resilient materials. The overall design of the reactor should practically eliminate the possibility of severe accidents with core meltdown and especially eliminate the possibility to release any substantial amount of radioactive materials to the environment. Generic and specific safety criteria and requirements for the SCW-SMR concept have been developed in WP5.1, by following and further developing the science-based recommendations by International Atomic Energy Agency (IAEA) and Gen IV International Forum (GIF) for SMRs. In the framework of WP5.2 the collection of a priori knowledge of the participating experts and the preliminary results has been started. For this qualitative analysis the Phenomena Identification and Ranking Table (PIRT) method has been selected. Finally, the pre-licensing study (WP5.3) will relate to the safety criteria and requirements for the SCW-SMR concept developed in the frame of WP5.1 with the safety-related behaviour and features of the SCW-SMR as identified in WP5.2.

6 WP5.1 - GENERIC AND SPECIFIC SAFETY CRITERIA AND REQUIREMENTS

The aim of WP5.1 was to develop generic and specific safety criteria and requirements for the SCW-SMR concept, by following and further developing the science-based recommendations by IAEA and GIF for SMRs, in particular the concept of defence-in-depth, physical protection and security, and non-proliferation principles (safety, security and safeguards). In the following, guiding principles for the application of generic safety elements in ECC-SMART, international legal frameworks for nuclear safety, security and safeguards, and national legal frameworks for nuclear safety and security are presented.

6.1 Guiding Principles for the application of Generic Safety Elements in ECC-SMART

The SCW-SMR designs comprised by ECC-SMART includes some specific design features, e.g. high-pressure tubes versus reactor pressure vessel. This is why specific safety elements identified for ECC-SMART should be further broken down into design-specific safety elements (would become necessary if a concrete SCW-SMR design becomes available). The determination of safety elements of ECC-SMART is made up of two steps:

- Identification of existing safety elements based on a structured literature review and applicability analysis.
- Development of safety elements from identified gaps related to specific fields of safety where accommodation of existing safety elements is not feasible.

This two-step process is informed by four guiding principles as subsequently described:

- All compatible safety elements of new reactors (3rd Gen. nuclear power plants) apply to ECC-SMART.
- Safety elements specific of SMR designs apply to ECC-SMART depending on the design, hence on a case-by-case basis. Safety demonstration dealing with passive safety systems performance and plant accident response need conservative safety margins.
- All the top-level safety requirements identified by GIF apply to ECC-SMART, in particular, the elimination of DEC-B scenarios [Large/Early Release], where DEC means Design Extension Conditions.
- No new challenging safety requirement specific of ECC-SMART in the accident domain is foreseen. Quantitatively more demanding phenomena affecting safety need robust safety demonstration and conservative safety margins.

6.2 International legal frameworks for nuclear safety, security and safeguards

Review of existing safety elements applicable to ECC-SMART has been done and the applicability scope of their elements upon the guiding principles has been assigned following:

- Safety elements belonging to new reactors apply fully to ECC-SMART, as derived from the first guiding principle – abbreviated as 1P.
- Safety elements dealing with SMRs apply on a case-by-case basis depending on the design, as derived from the second guiding principle – abbreviated as 2P.
- Generic safety elements dealing with 4th Gen. nuclear power plants apply fully as derived from the third guiding principle – abbreviated as 3P.
- Specific safety elements dealing with ECC-SMART come from the fourth guiding principle – abbreviated as 4P.

There are four key sources of information concerning international legislation or guidance applicable to nuclear reactors: IAEA, GIF, European Union legal acts and international fora at European level. IAEA and GIF are further discussed below.

Table 1: Main applicable IAEA safety standards and reports with their scope of application to ECC-SMART

IAEA REPORT	CLASSIFICATION	APPLICATION
Fundamental Safety Principles, Safety Fundamentals, SF-1	1P	Full application
Safety of Nuclear Power Plants: Design, Specific Safety Requirements, SSR-2/1	1P	Full application
Applicability of Design Safety Requirements to Small Modular Reactor Technologies Intended for Near Term Deployment, TECDOC-1936	2P and 3P	Full application

Design and Safety Considerations for Water Cooled Small Modular Reactors Incorporating Lessons Learned from the Fukushima Daiichi Accident, TECDOC-1785	2P and 3P	Partial application
Design of the Reactor Coolant System and Associated Systems for Nuclear Power Plants, Specific Safety Guide, SSG-56	1P	Full application
Design of the Reactor Containment and Associated Systems for Nuclear Power Plants, Specific Safety Guide, SSG-53	1P	Full application
Design of Auxiliary Systems and Supporting Systems for Nuclear Power Plants, Specific Safety Guide, SSG-62	1P	Full application
Protection against Internal Hazards in the Design of Nuclear Power Plants, Specific Safety Guide, SSG-64	1P	Full application

The main GIF documents reviewed have been the following:

- Gen IV Goals
- Safety Design Criteria for Generation IV Sodium-cooled Fast Reactor System (Rev. 1) (2017)
- Safety Design Guidelines on Safety Approach and Design Conditions for Generation IV Sodium-cooled Fast Reactor Systems (Rev. 1) (2019)
- An Integrated Safety Assessment Methodology (ISAM) for Generation IV Nuclear Systems (Version 1.1) (2011)
- Super-Critical Water-cooled Reactors (SCWR) Risk and Safety Assessment White Paper (Rev. 1) (2017)
- Supercritical-water-cooled reactor system (SCWR) System Safety Assessment (2018)

GIF safety and reliability 2 goal states that generation IV nuclear energy systems will have a very low likelihood and degree of reactor core damage. It was reformulated that the frequency of DEC-A scenarios shall be very low and its damage extension limited. GIF safety and reliability 3 goal states that Generation IV nuclear energy systems will eliminate the need for offsite emergency response. This goal has been reformulated that DEC-B scenarios shall be eliminated. The first GIF safety goal does not impose any extra burden on ECC-SMART. The second GIF safety goal is transposed into challenging safety criteria dealing with the last static and dynamic safety barriers or physicochemical properties of the nuclear hazards. If relying on passive safety systems, compensation for the lack of reliability through redundancy, diversity or large grace periods should constitute an additional safety criterion.

Based on the review of the IAEA and GIF documents, the most important recommendations are the following:

- The IAEA SSR-2/1 (Rev. 1) should be used during the SCW-SMR development as a starting point for the design criteria development.
- The available SMR regulation standards and guidelines should be used as a basis in order to consider the specific safety features of SMRs.
- After the development of the Design Criteria document of the SCWRs/SCW-SMRs, a safety design guidelines (SDG) on safety approach and design conditions for Generation IV SCWR/SCW-SMR should be issued.
- An exercise to apply the ISAM should be performed on the SCW-SMR concept as soon as a sufficiently detailed SCW-SMR concept becomes available.
- In the meantime, R&D on the SCWR and its different concepts to fill the knowledge gaps should be continued.

Council Directive 2014/87/Euratom amending Council Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations, applies to all nuclear stations. Therefore, it is classified as 1P. Council Directive 2013/59/Euratom of 5 December 2013 only contains important information related to Annex I concerning reference levels for public

exposure, which are important in order to establish arrangements for emergency preparedness. Since all the content applies to all nuclear stations, it is classified as 1P. Western European Nuclear Regulators Association (WENRA) objectives and key positions apply to all existing and new plants, and hence are classified as 1P.

6.3 National legal frameworks for nuclear safety and security

Safety requirements at national level in Canada, China, Czech Republic, Finland and United Kingdom have been reviewed. So far, no country that is seriously looking into SMRs has changed its national nuclear regulation to accommodate SMRs. But the regulators in some countries are in the process of changing their regulation accordingly or have announced that they will do so, e.g. regulator STUK in Finland. In Canada and the U.S. some SMR designs (even non-water-cooled) are in the licensing or generic design assessment process. In the U.S. the licensing process for one LW-SMR, the integral pressurized water SMR of NuScale, is even completed. Although none of these SMR designs is a SCW-SMR design, some conclusions could be drawn from these processes for the SCW-SMR.

7 WP5.2 – Safety related findings and conclusions

Aim of this task is to provide answers to the potentially outstanding issues and gaps in knowledge regarding the safety-related behaviour of SCW. Outcome of this task will summarize the conclusions and lessons learned into a synthetic form to facilitate the future work of designers and nuclear safety analysts. The work of WP5.2 relies on the results of WP2 to WP4: contribution to the resolution of basic conceptual issues involving material challenges of SCW Technology (WP2), problems of flow and heat transfer in SCW (WP3), as well as neutronic aspects of an active core with SCW as coolant and moderator (WP4).

The main challenges for WP5.2 are that in this very early design phase mainly safety features originating from the basic physical features can be collected, the technology is subject to further changes, no final results from WP2 to WP4 are available yet and that WPs are focusing on rather special topics – more general issues should be identified.

Integrated Safety Assessment Methodology (ISAM) has been identified as an applicable approach for this task. The ISAM consists of five distinct analytical tools. At present phase only qualitative safety assessment can be performed. The main goal is to identify knowledge gaps and main safety challenges for the selected technology. An analytical tool called Phenomena Identification and Ranking Table (PIRT) has been used.

7.1 PIRT analysis

PIRT is a well-known qualitative process to identify the importance of safety issues and to determine our knowledge level of them applied for Gen2 reactors (i.e. spent fuel pool events, severe accident management), Gen3 reactors (accident scenarios), Gen4 reactors (design aid tool). The method is based largely on expert elicitation. The process involves selecting hardware (i.e., SCW-SMR concept), selecting an operational states / accident scenario, and identification all plausible phenomena having important effect on safety.

Important phenomena have been identified by WP2 to WP4 members. The Excel worksheet has been sent to participants in more rounds. Each phenomenon is then ranked in order of relative importance (phenomena ranking, PR) and its state of knowledge (knowledge ranking, KR). The typical ranking schemes are shown in Figure 1.

Phenomena Ranking Scales	Knowledge Based Ranking Scales
High (H)	4 - Fully known, small uncertainty
Medium (M)	3 - Known, moderate uncertainty
Low (L)	2 - Partially known, large uncertainty
Insignificant (I)	1 - Very limited knowledge, uncertainty can not be characterized

Figure 1: Typical phenomena ranking scales, applied for analysis

Preliminary results for phenomena identification for WP2 to WP4 have been obtained. For WP2 in total 7 answers from 6 institutions have been received in 3 rounds. In total 23 phenomena have been identified for normal operation / all operational states. The lessons learned was that it is worth to separate the phenomena collection and the expert ranking. For phenomena identification ranking, Excel worksheet has been disseminated again. Based on PR and KR data, a ranking matrix could be created as shown in Figure 2(left). In Figure 2(right), the phenomena taken from PIRT table are shown.

Colour codes: low significance, medium significance, high significance

Knowledge level / Importance	4	3	2	1
Insignificant				
Low				
Medium		1; 3; 9	2; 3a; 4; 5; 6; 7; 11; 12; 15; 16; 18; 19; 20; 21; 22	12
High		13	5; 10; 14; 17	8

1	Through wall penetrations produced by general or localized corrosion
2	Oxide build-up that impedes heat transfer
3	Oxide release from the cladding surface
3a	by dissolution / evaporation
4	Pellet cladding interaction
5	Environmental Assisted cracking (EAC)
6	Changes in the mechanical properties of the materials produced by ageing and/or irradiation
7	Changes in the geometry of tubes produced by irradiation, creep
8	Radiolysis processes
9	Physicochemical properties of water within the SC region
10	Resistance of cladding materials under LOCA conditions SCWR
11	Impurity enrichment
12	Oxide release from the cladding surface by spalling
13	Irradiation embrittlement due to He
14	IASCC
15	Hydriding
16	Cladding collapse
17	Overheating of the Cladding
18	Overheating of Fuel Pellets
19	Cladding rupture
20	Fuel Rod Mechanical Fracturing
21	Strain Fatigue
22	Fretting Wear

Figure 2: PIRT matrix for WP2

For WP3 in total 22 phenomena have been identified. The improvement based on WP2 experiences was establishment of online worksheet on SharePoint. The list of phenomena is to be sent to WP3 members. For WP4 in total 22 phenomena have been identified for normal / all operational states. There are 8 further phenomena for REA (rod ejection accident). Both in WP3 and WP4 ranking by expert panel is in progress, which will be followed by PIRT matrix creation.

8 WP5.3 - PRE-LICENSING STUDY

The aim of WP5.3 is the development of pre-licensing study, which will summarize both the already achieved safety criteria and the potential gaps to be further investigated in future research projects.

The ECC-SMART pre-licensing study relates to the safety criteria and requirements for the SCW-SMR concept developed in the frame of WP5.1 (dealing with generic and specific safety criteria and requirements) with the safety-related behaviour and features of the SCW-SMR as identified in WP5.2. The ECC-SMART pre-licensing study is aiming to demonstrate the feasibility of the

conceptual design to be licensed. Namely, regulations provide requirements binding on all persons and organizations who receive a license. The guides provide guidance to licensees and applicants on implementing specific parts of the regulations. To obtain license, all requirements set by regulated must be fulfilled. Finally, no specific experimental verifications are planned for the pre-licensing study.

(Preliminary) Specific Safety Requirements are yet to be developed (very limited formal rules available). Regarding DEC, very low frequency of DEC-A (core damage) events should be prevented and DEC-B with off-site response due to radioactive release should be eliminated. Many design specific "details" might need specific (quantitative) attention, e.g.: coupling of thermalhydraulics & neutronics, passive removal of residual heat, materials at given environments (temperature, pressure, steam, irradiation). The design specific details very strongly depend on the preliminary design to be used.

It is expected that the pre-licensing study will identify three sets of the safety criteria and requirements:

(1) fulfilled with reasonable certainty within the limits of already available knowledge,

(2) fulfilment is probable, further research needed, and

(3) fulfilment is improbable, design changes are needed.

Assessment will start when WP5.2 results will be available on resolving the basic conceptual issues involving material challenges, problems of flow and heat transfer, as well as neutronic aspects of an active core with SCW as coolant and moderator.

The RSWG strongly believes that using all of the elements of the ISAM in an integrated way will improve and optimize all aspects in which safety is implemented, will reduce technology development cycle time, will reduce development costs, and will facilitate the licensing of Gen IV systems. Therefore, ISAM for GEN IV will be used in pre-licensing study, in particular Qualitative Safety features Review (QSR) and (parts of) PIRT. QSR provides a systematic means to identify and discuss the safety-related attributes and characteristics of the given Generation IV design and to evaluate the relevant references for it (IAEA, GIF, International Project on Innovative Nuclear Reactors and Fuel Cycles (INPRO) guidelines, etc.).

Annex 4: Feedback from the students

Report on the selection process and lessons learned in the process of a group application for ENEN2plus mobility support for a group event

Dear ENEN2plus Mobility Committee,

I am writing on behalf of the ECC-SMART project consortium that co-organized the Workshop and thanks to the approved financial support from the ENEN2plus project, we could support a group of students to participate in this networking event.

Summary of the application

Within the ECC-SMART project implementation, alongside the main organizers from the HARMONISE project and co-organizing the ELSMOR project, we helped to co-organize the Workshop on the Safety of Small Modular, Advanced and Fusion Reactors. The workshop was held in Celje, Slovenia on June 20-21, 2023 and its main focus was on the safety and licensing aspects of advanced nuclear reactors and facilities. Many experienced researchers gathered and together with students and young researchers fostered collaboration and shared knowledge across different generations and levels of expertise. In order to support students and young researchers, we requested financial support from the ENEN2plus project to help them to cover travel and lodging expenses.

Description of the selection criteria

There were 12 selected participants (M.Sc students, PhD students, or early career professionals pursuing nuclear careers). We expected each participant a reimbursement of 500 EUR for travel expenses and a lump sum of 300 EUR to cover 3 days' expenses (according to the event agenda). The total budget requested from the ENEN2plus project is 9 600 EUR (12 selected participants x 800 EUR per participant).

From our Project Management Board, we appointed 5 members for the **Selection and Steering Committee**:

- Eliška Krychová (CVŘ, Czech Republic), Project Administrator/Co-Coordinator,
- Monika Šípová (CVŘ, Czech Republic), Project Coordinator,
- Alberto Sáez Maderuelo (CIEMAT, Spain), WP2 Materials Testing leader,
- Ivan Otic (KIT, Germany), WP3 Thermal Hydraulics & Safety leader,
- Szabolcs Czifrus (BME, Hungary), WP4 Neutronics and physics leader.

To choose the right applicants and comply with the ENEN2plus Mobility criteria, we defined the following qualifications for application.

- Applicant should be either an M.Sc student, PhD student or early career professional with less than 10 years of professional experience.
- The applicant must apply with a form (see Annex 2), curriculum vitae and a motivation letter describing their motivation for participation in the Workshop.

The ECC-SMART project has received funding from
the Euratom research and training programme 2019-2020
under grant agreement No 945234.

- The criteria for selection of the participants were based on the quality of submitted documents. We confirm that all applicants were handled equally regardless of nationality, ethnicity, gender, language, religion etc.

The application procedure consisted of submitting the three required documents to ENEN Platform and sending copies to the e-mail address eliska.krychova@cvrez.cz before the deadline, which was defined for 21st April 2023.

Report on the selection process

In total, we received 14 applications from students coming from 5 different universities and 4 different countries. However, we had to exclude 2 applications that were sent after the deadline because we have only asked in our application for the support of 12 applicants. All the required documents from candidates were received on time and required the necessary information, complying with the established criteria. All selected participants were eligible for financial support under the conditions of the ENEN2plus project, they are citizens of an EU member country willing to travel abroad and none of them is from the hosting country.

The application documents were shared with the Selection and Steering Committee members before an internal meeting (held on 28th April 2023). During the meeting, the applicants were approved by all members. By May 5th, applicants received information about the decision and an email describing the next steps. Once the applicants were approved also via the ENEN Platform where they submit their application, they could fill in their bank accounts to receive the mobility grant and arrange the travel (after successful registration to the workshop via the event website).

Unfortunately, after concluding this process, we were informed by 2 applicants that they have to draw away their applications due to other work duties that interfere with the same date as the workshop. As it was already late for other candidates, we didn't manage to find substitute candidates and had to continue with 10 applicants only.

Following up on the participation of the applicants in the workshop, we asked them to submit not only the report to the ENEN Platform but also to fill in our questionnaire (including their pictures). Based on that, together with our ENEN colleagues responsible for communication activities, we prepared an external newsletter summarizing the main outcomes and mobility assessment.

Lessons learned in the process, especially any suggestions or recommendations to the Mobility Committee top improve the process in the future

This group application was our first experience within the ECC-SMART project. Although we support many students in project activities, we were glad to benefit from this mobility opportunity and provide support to even more young researchers. We have to highlight smooth and effective cooperation with applicants as well as with the mobility providers. All raised questions were quickly clarified and it helped us to submit the application successfully.

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under grant agreement No 945234.

From the applicant's reports required after the mobility, we can mention a few details demonstrating their satisfaction.

Applicant n1

Nothing negative to mention. Thank you for funding for this great opportunity. The workship helped me to understand discussion on challenges with licensing of nuclear powerplants. This knowledge will help me in the future to have a more holistic view on the research I am participating in.

Applicant n2

I would like to thank all the organizers, presenters and the ENEN2plus for allowing me facilitatin attending this workshp. I really enjoyed it.

Applicant n4

As a participant of the ECC-smart project focused on SMR attending this kind of workshop is very valuable for my career and general development. My expectation was to meet and listen to professionals from nuclear field and broaden my knowledge. This expectation was fulfilled. I will try to implement obtained knowledge in future teaching.

Applicant n5

Thanks to the workshop in Celje, Slovenia, I met new people who are dealing with similar issues as me. By discussing the materials I found out why some of them are used and made new contacts. Thanks to the knowledge gained on the course, I will be able to look at the issue of small modular reactors more comprehensively than before. Regarding the improvement, I don't have any, everything was well organized and beneficial.

Applicant n9

The only thing that comes to mind is that there wasn't a specified date at which the mobility funding was supposed to come. I don't consider it a negative experience though. It is just not that convenient and may rise some uncertainty. However, I am delighted that I got the opportunity to participate in the workshop. It wouldn't be easy for me without the mobility grant.

We didn't identify any major risks during the process. The only issue that can be mentioned is the time shortage as we started the whole process at the last minute and needed to manage in time. (What wouldn't have been a problem having a previous experience with the process.) Moreover, when applicants submit an individual application, they know what steps need to be done and what are approximate deadlines in the process. Although we sought to inform all our applicants regularly and on time, sometimes, when we were waiting for others to complete some information or some documents, it makes it slightly harder for us to know when all applicants do so.

For our future workshops and events that we plan to organize within the project, we will consider the mobility support opportunity again in order to support more students and increase their interest in the related field of nuclear engineering. Nevertheless, we will better plan the group application process and award all of us with more time.

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Overall, we can evaluate the group mobility application as successful. As co-organizer of the event, we positively evaluated the participation of young generation researchers and networking with experienced senior researchers to discuss the current focus topics. We believe that thanks to the ENEN2plus support of educational and networking opportunities for M.Sc students, PhD students, and early career professionals in the nuclear disciplines, it served as a valuable contribution to their career progress.

On behalf of the ECC-SMART project consortium

Sincerely,

Eliška Krychová
Řež, 21st July 2023

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Joint European Canadian Chinese development of Small Modular Reactor Technology

Building European Nuclear Competence through continuous Advanced and Structured Education and Training Actions

Group application – Mobility Report

About participant	Name of the participant:	Fabian Wiltschko
	Current position/study programme:	PhD Student
	Sending institution:	Karlsruhe Institute of Technology (KIT), Germany
	Your background:	*I am M. Sc. In Mechanical engineering and PhD Student at KIT, doing experimental investigation of heat transfer to fluids at supercritical pressure. (As member of ECC-SMART)*
	Would you take part if you hadn't get funded by ENEN2plus Mobility Programme?	*I think I would have had the chance to finance it from ECC-SMART travel budget. If this would not have been possible I would have participated remotely.*

About mobility action	Action:	*Workshop on the Safety of Small Modular, Advanced and Fusion Reactors*
	Start and end dates of the mobility action:	*19th – 21st June 2023*
	Website of the event:	*https://r4.ijs.si/harmonise-workshop#elf_l1_Lw*
	Receiving institution:	*Jozef Štefan Institute, Slovenia (JSI)*

Your motivation (before/after)	Why did you decide to enrol to this course?	*I am interested in the future if nuclear reactors in europe. Furher, it was a chance to meet some of the project partners from ECC-SMART, what in the past always have been very beneficial.*
	What were your expectations out of the course? And were they satisfied?	*I expected to get a general view on what is happening in the research commumity with Small Modular Reactors worldwide. Further, I was very interested in getting to now more researchers from this community. Both was satisfied.*
	What area of knowledge covered by the course is more interesting for you?	*For me, the SMR-dashboard was one of the most interesting presentations, since it covered a wide range of different reactor concepts and futrher there current state of the art. Further, presentations covering the neutronics in the reactor are always very interesing for me, since I am not an expert in this field.*

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	How are you going to use knowledge obtained during the workshop?	*The workship helped me to understand discussion on challenges with licensing of nuclear powerplants. This knowledge will help me in the future to have a more holistic view on the research I am participating in.*

Feedback on your participation	Summary of the work performed (including the level of the fulfilment of the work plan):	*As planned, I attended the workshop.* *Further, I had an important discussion about ECC-SMART experiment with a project partner. This face to face discussion was planned previous to the workshop.*
	List publications that are at least in part result of the mobility action: (if any)	*There are no publications related to the workshop where I contributed to.*
	Do you expect any positive impact of the course to your career?	*A discussion with an ECC-SMART project partner which I had there, will help me to enhance current experimental campaign. Further, I was able to expand my network in the nuclear science community.*
	Description of the positive outcomes of the completed mobility action:	*I gained valuable insights in challenges with licensing of small modular reactors. Further, I got to know new colleagues from the community. A very important outcome is, that future cooperation and communication between ECC-SMART project partners was enhanced.*
	Note of any negative experiences of the completed mobility action as well as potential suggestions of how these could be minimized or avoided in the future:	*Nothing negative to mention.*
	Statement on how the mobility action improved your knowledge, skills and competitiveness for nuclear careers:	*In my current daily research work, I am focusing on thermal-hydraulics in the reactor core. The workshop helped me to improve my knowledge on the whole system, especially on regulations of it. Further, connecting with experts from different fields among the community was a great benefit.*

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	Additional comments:	*Thank you for funding for this great opportunity.*

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Group application – Mobility Report

About participant	Name of the participant:	Jakub ŠPAČEK
	Current position/study programme:	PhD student of Energy and process engineering
	Sending institution:	CTU in Prague, Faculty of Mechanical Engineering
	Your background:	*Student in the nuclear field and researcher in nuclear safety at SÚRO TSO.*
	Would you take part if you hadn't get funded by ENEN2plus Mobility Programme?	*No, as a student I don't have the money to travel multiple times a year.*

About mobility action	Action:	*Workshop on the Safety of Small Modular, Advanced and Fusion Reactors*
	Start and end dates of the mobility action:	*19th – 21st June 2023*
	Website of the event:	https://r4.ijs.si/harmonise-workshop#elf_l1_Lw
	Receiving institution:	*Jozef Štefan Institute, Slovenia (JSI)*

Your motivation (before/after)	Why did you decide to enrol to this course?	*Because the topic of harmonisation of regulations has interested me for a long time and I would like to help with it.*
	What were your expectations out of the course? And were they satisfied?	*I was expecting a presentation of different problems and discussion about how to solve them. This was indeed what happened and therefore I'm satisfied.*
	What area of knowledge covered by the course is more interesting for you?	*I'm more interested in the harmonisation than the ECC-SMART project but because of my PhD research this project is something I can be more involved in.*
	How are you going to use knowledge obtained during the workshop?	*The information gained from HARMONISE part of the workshop is useful for any further discussion and work on SMRs. Getting to know about ECC-SMART is very useful in my study and in my work.*

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Feedback on your participation	Summary of the work performed (including the level of the fulfilment of the work plan):	*The workshop consisted of a series of presentations about different topics and ECC-SMART and HARMONISE progress meetings. These presentations were in fact presented so one could say that the work plan was fulfilled.*
	List publications that are at least in part result of the mobility action: (if any)	
	Do you expect any positive impact of the course to your career?	*Yes. The knowledge gained is important to know and after a conversation with my colegue I may become a part of the HARMONISE team.*
	Description of the positive outcomes of the completed mobility action:	*As mentioned before, the information from the presentation is useful and I have gained a lot of contacts from different spheres of the nuclear field.*
	Note of any negative experiences of the completed mobility action as well as potential suggestions of how these could be minimized or avoided in the future:	*I can't think of any.*
	Statement on how the mobility action improved your knowledge, skills and competitiveness for nuclear careers:	*Before the workshop I didn't know much about both projects. It is knowledge that is not really taught at school, which is a shame because these topics are important in the current state of nuclear field.*
	Additional comments:	

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Joint European Canadian Chinese development of Small Modular Reactor Technology

Building European Nuclear Competence through continuous Advanced and Structured Education and Training Actions

Group application – Mobility Report

About participant	Name of the participant:	Gürel Özesme
	Current position/study programme:	Ph.D. Student
	Sending institution:	Karlsruhe Institute of Technology
	Your background:	*I'm a M.Sc. Nuclear Engineer and Ph.D. Student in KIT which is focused on the analysis of turbulent conjugate heat transfer calculation with CFD.*
	Would you take part if you hadn't get funded by ENEN2plus Mobility Programme?	*I'd take part remotely if it would be possible.*

About mobility action	Action:	*Workshop on the Safety of Small Modular, Advanced, and Fusion Reactors*
	Start and end dates of the mobility action:	*19th – 21st June 2023*
	Website of the event:	https://r4.ijs.si/harmonise-workshop#elf_l1_Lw
	Receiving institution:	*Jozef Štefan Institute, Slovenia (JSI)*

Your motivation (before/after)	Why did you decide to enroll in this course?	*The topic of licensing is completely different issue for people working on design side. I wanted to hear from professionals and construct new connections.*
	What were your expectations out of the course? And were they satisfied?	*Licensing of nuclear reactors or in specific SMR's still has a way to discover and progress. I wanted to hear recent changes regarding this issue. Which is completely covered.*
	What area of knowledge covered by the course is more interesting for you?	*Not specific to course but discussion about understanding needs of regulatory and design professionals and their expectations from each other is very interesting.*
	How are you going to use knowledge obtained during the workshop?	*According to my observations there is a way to go for complete harmonisation for licensing SMRs. Workshop provided me an insight what professionals on the licensing side are require.*

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Feedback on your participation	Summary of the work performed (including the level of the fulfilment of the work plan):	*My aim for this workshop it to attend and connect with other professionals which I had a chance to make valuable discussions.*
	List publications that are at least in part result of the mobility action: (if any)	*There are no publications made that I take a part.*
	Do you expect any positive impact of the course to your career?	*I expect positive outcomes in very long term which I have a chance to get decision making position related reactor design and its licensing.*
	Description of the positive outcomes of the completed mobility action:	*My positive outcomes mainly focused on increased knowledge of licensing processes regarding SMR's and contribution to professional network.*
	Note of any negative experiences of the completed mobility action as well as potential suggestions of how these could be minimized or avoided in the future:	*I have no suggestions regarding mobility.*
	Statement on how the mobility action improved your knowledge, skills and competitiveness for nuclear careers:	*As a professional in nuclear area, I understand importance of networking and connecting with professionals dealing with different aspects of nuclear industry. As a part of this understanding, the mobility action helped me to progress on this path.*
	Additional comments:	*I thank you for people take a part in organizing this workshop and mobility action.*

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Building European Nuclear Competence through continuous Advanced and Structured Education and Training Actions

Group application – Mobility Report

About participant	Name of the participant:	Tiberiu Dragnea
	Current position/study programme:	Bachelor's student in Nuclear Engineering
	Sending institution:	University "Politehnica" of Bucharest
	Your background:	Bachelor's student in Nuclear Engineering
	Would you take part if you hadn't get funded by ENEN2plus Mobility Programme?	*Probably not, because the travel expenses would rise to a higher than I can afford sum of money*

About mobility action	Action:	*Workshop on the Safety of Small Modular, Advanced and Fusion Reactors*
	Start and end dates of the mobility action:	*19th – 21st June 2023*
	Website of the event:	*https://r4.ijs.si/harmonise-workshop#elf_l1_Lw*
	Receiving institution:	*Jozef Štefan Institute, Slovenia (JSI)*

Your motivation (before/after)	Why did you decide to enrol to this course?	*I consider the participation of this course to be a grate possibility to increase my knowledge in the field.*
	What were your expectations out of the course? And were they satisfied?	*I expected that the course will be a mix between nuclear technologies topics and so to gather information's in the whole field and yes, my expectations were satisfied*
	What area of knowledge covered by the course is more interesting for you?	*The technical part of the course was the most interesting for me given my background*
	How are you going to use knowledge obtained during the workshop?	*In will use the information for my bachelors theses, which is done on SMR's, and furthermore the information will constitute an advantage in my career*

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Feedback on your participation	Summary of the work performed (including the level of the fulfilment of the work plan):	*Attended all the courses and presentations that were included into the course program. The courses were full of new information of the related topic of SMR's and more.*
	List publications that are at least in part result of the mobility action: (if any)	•
	Do you expect any positive impact of the course to your career?	*Yes*
	Description of the positive outcomes of the completed mobility action:	*An advantage that will be applied in the future in the field of Nuclear Engineering, the field that I want to work in.*
	Note of any negative experiences of the completed mobility action as well as potential suggestions of how these could be minimized or avoided in the future:	*None*
	Statement on how the mobility action improved your knowledge, skills and competitiveness for nuclear careers:	*The mobility grant made possible the exchange of information between me and experts from this field. So it made possible the sharing of ideas and concepts to furthermore evolve in the field*
	Additional comments:	

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Building European Nuclear Competence through continuous Advanced and Structured Education and Training Actions

Group application – Mobility Report

About participant	Name of the participant:	Jan Loskot
	Current position/study programme:	Finished 1st year of 2-year M.Sc. degree study programme 'Nuclear energetic devices' on Faculty of Mechanical Engineering, CTU in Prague.
	Sending institution:	CVR
	Your background:	*Graduated in 2019 at Secondary technical school of mechanical and electrical engineering. Bachelor's degree finished in 2022 at Faculty of Mechanical Engineering, CTU in Prague, study programme 'Theoretical basis of mechanical engineering'.*
	Would you take part if you hadn't get funded by ENEN2plus Mobility Programme?	*Definitely not, I wouldn't be able to afford it comfortably as a student.*

About mobility action	Action:	*Workshop on the Safety of Small Modular, Advanced and Fusion Reactors*
	Start and end dates of the mobility action:	*19th – 21st June 2023*
	Website of the event:	*https://r4.ijs.si/harmonise-workshop#elf_l1_Lw*
	Receiving institution:	*Jozef Štefan Institute, Slovenia (JSI)*

Your motivation (before/after)	Why did you decide to enrol to this course?	*I considered this course a great opportunity to have an insight into what's currently going on in the industry. As safety is super important in the nuclear field, I find getting fresh information about harmonisation progress (and future ambitions) very valuable.*
	What were your expectations out of the course? And were they satisfied?	*I expected to meet people from various parts of the industry and gain up-to-date knowledge regarding nuclear safety, harmonisation of regulation and thermohydraulic research of the latest nuclear technologies. My expectations were completely fulfilled.*
	What area of knowledge covered by the course is more interesting for you?	*Namely the latest ideas and progress in the R&D of innovative nuclear technologies (like the SCWR) and thermohydraulic analysis of such projects.*
	How are you going to use knowledge obtained during the workshop?	*As there is not that much space for fresh and up-to-date information presentation during the courses in school semester, I can get better understanding of concepts that I am about to learn. I feel like it will help me studying some topics quicker and more effectively.*

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Feedback on your participation	Summary of the work performed (including the level of the fulfilment of the work plan):	*I attended the 2-day long sessions filled with presentations about various topics. I took notes about specific information to better understand the presentations from the workshop that'll be officialy posted on the website. I discussed some concrete topics/questions with other participants.*
	List publications that are at least in part result of the mobility action: (if any)	• *As a member of the audience, I don't think there'll be any publications directly impacted by my presence.*
	Do you expect any positive impact of the course to your career?	*Definitely. Quite the contrary – I don't expect any negative impact on my career. All the knowledge gained can only improve my spectrum of view.*
	Description of the positive outcomes of the completed mobility action:	*I gained a lot of new, very concrete, knowledge from the field. Considering the access to speaker's presentations, I also gained new information sources for my future career. I also need to mention that I got the chance to visit the beautiful city of Celje and it's Old Castle.*
	Note of any negative experiences of the completed mobility action as well as potential suggestions of how these could be minimized or avoided in the future:	*The only thing that comes to mind is that there wasn't a specified date at which the mobility funding was supposed to come. I don't consider it a negative experience though. It is just not that convenient and may rise some uncertainty.*
	Statement on how the mobility action improved your knowledge, skills and competitiveness for nuclear careers:	*It improved my knowledge in the fields of new technologies, progress of harmonisation of safety and regulation in the field. All the information presented was also up-to-date. I improved my communication skills a little bit, especially regarding nuclear-related, technical English words. I can certainly benefit from the whole experience in the future.*
	Additional comments:	*I am delighted that I got the opportunity to participate in the workshop. It wouldn't be easy for me without the mobility grant.*

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Group application – Mobility Report

About participant	Name of the participant:	Grosu Florentina
	Current position/study programme:	Master Degree Programme
	Sending institution:	University Politehnica of Bucharest
	Your background:	*I'm a student in nuclear field and I will work here.*
	Would you take part if you hadn't get funded by ENEN2plus Mobility Programme?	*Depends of the cost of mobility programme.*

About mobility action	Action:	*Workshop on the Safety of Small Modular, Advanced and Fusion Reactors*
	Start and end dates of the mobility action:	*19th – 21st June 2023*
	Website of the event:	*https://r4.ijs.si/harmonise-workshop#elf_l1_Lw*
	Receiving institution:	*Jozef Štefan Institute, Slovenia (JSI)*

Your motivation (before/after)	Why did you decide to enrol to this course?	*Because I wanted to lern more about safety and to meet people with a nuclear background.*
	What were your expectations out of the course? And were they satisfied?	*yes, it were satisfied.* *My expectations about this workshop were to find out new information except what I learnt to school, witch will help me in the future.*
	What area of knowledge covered by the course is more interesting for you?	*About nuclear reactors.*
	How are you going to use knowledge obtained during the workshop?	*I hope in the future in my job.*

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Feedback on your participation	Summary of the work performed (including the level of the fulfilment of the work plan):	
	List publications that are at least in part result of the mobility action: (if any)	•
	Do you expect any positive impact of the course to your career?	
	Description of the positive outcomes of the completed mobility action:	
	Note of any negative experiences of the completed mobility action as well as potential suggestions of how these could be minimized or avoided in the future:	
	Statement on how the mobility action improved your knowledge, skills and competitiveness for nuclear careers:	
	Additional comments:	

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Building European Nuclear Competence through continuous Advanced and Structured Education and Training Actions

Group application – Mobility Report

About participant	Name of the participant:	David Dasek
	Current position/study programme:	Ph.D. student
	Sending institution:	UCT Prague
	Your background:	*Ph.D. student of corrosion science in nuclear engineering*
	Would you take part if you hadn't get funded by ENEN2plus Mobility Programme?	*I would try to find funding somewhere else (university funding or other). Thanks to the Mobility Programme it was much easier to attend.*

About mobility action	Action:	*Workshop on the Safety of Small Modular, Advanced and Fusion Reactors*
	Start and end dates of the mobility action:	*19th – 21st June 2023*
	Website of the event:	https://r4.ijs.si/harmonise-workshop#elf_l1_Lw
	Receiving institution:	*Jozef Štefan Institute, Slovenia (JSI)*

Your motivation (before/after)	Why did you decide to enrol to this course?	*As a participant of the ECC-smart project focused on SMR attending this kind of workshop is very valuable for my career and general development.*
	What were your expectations out of the course? And were they satisfied?	*My expectation was to meet and listen to professionals from nuclear field and broaden my knowledge. This expectation was fulfilled.*
	What area of knowledge covered by the course is more interesting for you?	*As a material engineer focused on nuclear the technical area was more interesting to me.*
	How are you going to use knowledge obtained during the workshop?	*I will try to implement obtained knowledge in future teaching.*

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Feedback on your participation	Summary of the work performed (including the level of the fulfilment of the work plan):	*The workshop was very well organised and the programme and lectures were immersive.*
	List publications that are at least in part result of the mobility action: (if any)	*None.*
	Do you expect any positive impact of the course to your career?	*Any gained knowledge regarding SMR has a positive impact on my career, this workshop is no exception.*
	Description of the positive outcomes of the completed mobility action:	*Contact with other participants, knowledge gained.*
	Note of any negative experiences of the completed mobility action as well as potential suggestions of how these could be minimized or avoided in the future:	*None.*
	Statement on how the mobility action improved your knowledge, skills and competitiveness for nuclear careers:	*Thanks to well prepared lectures and enough space for discussion the whole workshop gave me better insight on discussed topics and positive view for the future of SMRs.*
	Additional comments:	*None.*

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Building European Nuclear Competence through continuous Advanced and Structured Education and Training Actions

Group application – Mobility Report

About participant	Name of the participant:	*Petr Roztočil*
	Current position/study programme:	*PhD student*
	Sending institution:	*University of Chemistry and Technology Prague*
	Your background:	*I graduated with a Master's degree in Chemical Technologies in Power Engineering at the faculty of Environmental Technology, University of Chemistry and Technology, Prague.*
	Would you take part if you hadn't get funded by ENEN2plus Mobility Programme?	*I see participation in courses and conferences as one of the most important parts of my PhD studies. The ENEN2plus funding was of course a great motivation to participate. Otherwise, I would probably try to find a source of funding directly in the ECC SMART project or at the UCT Prague Power Engineering Department.*

About mobility action	Action:	*Workshop on the Safety of Small Modular, Advanced and Fusion Reactors*
	Start and end dates of the mobility action:	*19th – 21st June 2023*
	Website of the event:	*https://r4.ijs.si/harmonise-workshop#elf_l1_Lw*
	Receiving institution:	*Jozef Štefan Institute, Slovenia (JSI)*

Your motivation (before/after)	Why did you decide to enrol to this course?	*Our research group on UCT Prague has been involved in the ECC SMART project since its inception. My master thesis is focused on corrosion of materials in supercritical water environments. In my participation in the course in Celje.*
	What were your expectations out of the course? And were they satisfied?	*I saw the opportunity to gain new knowledge and different perspectives on this topic.*
	What area of knowledge covered by the course is more interesting for you?	*Sections of course dealing with small modular reactor technologies, in particular supercritical water-cooled ones.*

The ECC-SMART project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945234.

The ENEN2plus project (HORIZON-EURATOM-2021-NRT-01-13 101061677) is funded by the European Union.

https://ecc-smart.eu/

https://enen.eu/index.php/portfolio/enen2plus-project/

	How are you going to use knowledge obtained during the workshop?	*In my future work at the Institute of Power Engineering, UCT Prague, writing an article and dissertation focused on candidate materials for supercritical water-cooled reactors.*

Feedback on your participation	Summary of the work performed (including the level of the fulfilment of the work plan):	-
	List publications that are at least in part result of the mobility action: (if any)	-
	Do you expect any positive impact of the course to your career?	*Thanks to the knowledge gained on the course, I will be able to look at the issue of small modular reactors more comprehensively than before.*
	Description of the positive outcomes of the completed mobility action:	*Thanks to the workshop in Celje, Slovenia, I met new people who are dealing with similar issues as me. By discussing the materials I found out why some of them are used and made new contacts.*
	Note of any negative experiences of the completed mobility action as well as potential suggestions of how these could be minimized or avoided in the future:	*No, everything was well organised and beneficial.*
	Statement on how the mobility action improved your knowledge, skills and competitiveness for nuclear careers:	*I learned to look at the issue of small modular reactors from different angles. I learned what thermohydraulic calculations in reactor environments entail and, thanks to one of the presentations, rehearsed the advantages and disadvantages of supercritical water-cooled reactors from the ground up.*
	Additional comments:	-

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