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Identification of European experimental facilities for severe accident research within EU SEAKNOT-project: Analysis and mapping

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Abstract. Experimental facilities play a central role in reactor safety research for both design basis and severe accidents (SA). They are key to demonstrate the effectiveness and appropriateness of specific safety features of reactor designs and providing data for the validation of different models implemented in numerical tools used for safety demonstration. Hence, a well-designed and equipped experimental infrastructures in Europe is a fundamental pillar of European roadmap on reactor safety research. One objective of the EU SEAKNOT (Severe Accident research and KNOwledge management) project, is the analysis and mapping of European severe accident research facilities currently under operation. The responses to a questionnaire sent to European institutions were evaluated and the information collected about each facility was synthesized covering different issues such as age, design features, main phenomena addressed by latest research programs, including advanced technologies like Advanced Technology Fuels (ATFs) and Small Modular Reactors (SMRs). The extensive review of the collected information allowed the identification of critical conditions (human resources; preservation and enhancement of experimental competences, etc. that might jeopardize the current and forthcoming European experimental capabilities for severe accident research, according to the Severe Accident roadmap that is being built in SEAKNOT. This paper describes the methodology and major outcomes of this analysis.

1 Introduction

Experimental research is a key pillar to enhance knowledge and perform code validation. In addition, the construction and operation of experimental facilities equipped with state-of-the-art measurement devices to catch the physical phenomena of interest may be in some cases very costly. Nevertheless, key experimental investigations are mandatory in nuclear engineering which is highly regulated to assure robust safety features at high standards in the safe design and operation of nuclear reactors. The safety demonstration in the frame of a licensing process or during the regular supervision of the operation is based on numerical tools validated for the reactor design of interest and it is complemented by dedicated experiments. In view of the increased interest on the deployment of Generation 3 and 3+ Light Water Reactors (LWR) and of water cooled (WC) Small Modular Reactors (SMR) in the EU [1] and worldwide [2], it is of great interest to do a systematic screening of the experimental research programs across Europe, specifically dedicated to severe accident phenomena, nowadays running. Based on such studies, strategic recommendations to the stakeholders can be done to keep high level of knowledge needed to assess the safety features of any reactor design going to be built in the EU in the next years. In the EU, new initiatives were started e.g., in the European User Facility Network (OFFERR) with the goal to optimize the use of existing experimental facilities and open opportunities for research groups without experimental infrastructure to take profit of existing ones and to take part or even perform experiments according to their needs [3].

Hence, the Horizon Europe SEAKNOT project [4,5] that started in 2022 aims to contribute to the knowledge preservation and dissemination about severe accident research in Europe. To achieve these goals, the following objectives are defined: (1) perform a critical

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Table 1. Number of emails-requests, answers and facilities.

Category	Number of e-mails sent out	Number of answers/ number of facilities
Test facilities in SEAKNOT-Partners involved in WP3	20	20/52
Test facilities in SEAKNOT-Partners not involved in WP3	9	9/5
Test facilities in institutions of EU-Countries partners of SEAKNOT but not beneficiaries of SEAKNOT	12	2/1
Test facilities in institutions of EU-Countries not partners of SEAKNOT	12	4/1

analysis of the existing knowledge on severe accidents, (2) identify the needs for future experimental research required to understand the severe accident progression required for the optimization of mitigative measures aimed to minimize the radiological consequence of core meltdown accidents and (3) disseminate and improve the knowledge of young researchers on reactor safety regarding both analytical and experimental investigations on relevant severe accident domains. These goals can be translated in the following specific objectives:

- Elaborate a Phenomena Identification Ranking Table (PIRT) on severe accidents considering the available EU-capabilities on severe accident experimental research (Work Package 1),
- Elaborate a validation data base directory by developing a comprehensive mapping of the existing and future experimental European activity (2023–2030) (Work Package 2),
- Build a Severe Accident Infrastructure NETwork (SAINET) of the European research infrastructure on severe accident for the time horizon 2023–2030 and identify the severe accident phenomena addressed including ATFs, mitigation actions, and accident-resistant instrumentation including SMRs (Work Package 3), and
- Promote mutually beneficial collaborations between the experimental facilities and the various European partners such as universities, regulatory bodies, and industry (Work Package 4).

The Work Package 3 is focused on two tasks:

- **Mapping of Severe Accident Experimental Facilities (MAPEX)**: The goal here is to identify and list the experimental facilities devoted to severe accident research still in activity inside Europe (within SEAKNOT-partners, EU-institutions in countries partners of SEAKNOT, and in EU-institutions not participating in SEAKNOT).
- **Establishing a Severe Accident Infrastructure NETwork (SAINET)**: The goal here is to build SAINET infrastructure to gather main players in Europe on the field of severe accident research based on the outcome of the mapping activity and able to answer to future experimental needs defined in Work Package1 and 2.

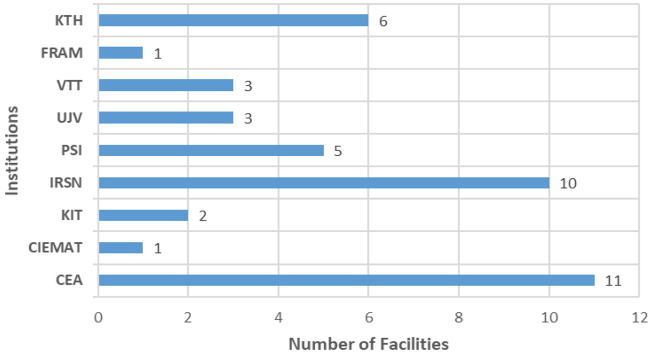

Fig. 1. Number of facilities per institution- SEAKNOT-WP3.

This paper describes the main outcomes of the critical review performed for MAPEX considering facilities of different stake-holders (universities, research centers, industry, TSOs) in the European Union focused on severe accident research by means of a questionnaire. Valuable information was collected such as type of facilities, their main characteristics in term of operation conditions, severe accident domain, instrumentation, use of data, and appropriateness of data for code validation, operational team, critical issues as funding, retirement of operational/scientific team, future work program, and current funding frameworks. Based on it, a European research platform for experimental investigations can be proposed.

2 Methodology

For the purpose of gathering information for the MAPEX, European experimental facilities under operation on severe accident topics and still operational until 2022/2023 were identified within the SEAKNOT-consortium and outside it. Future experimental activity between 2023 and 2030 has been assessed, too. In this approach, attention has been paid to the topics of the experimental programs devoted to single or coupled phenomena that may take place in all phases of a severe accident progression in LWR and SMRs.

To achieve these goals, the following methodology has been applied:

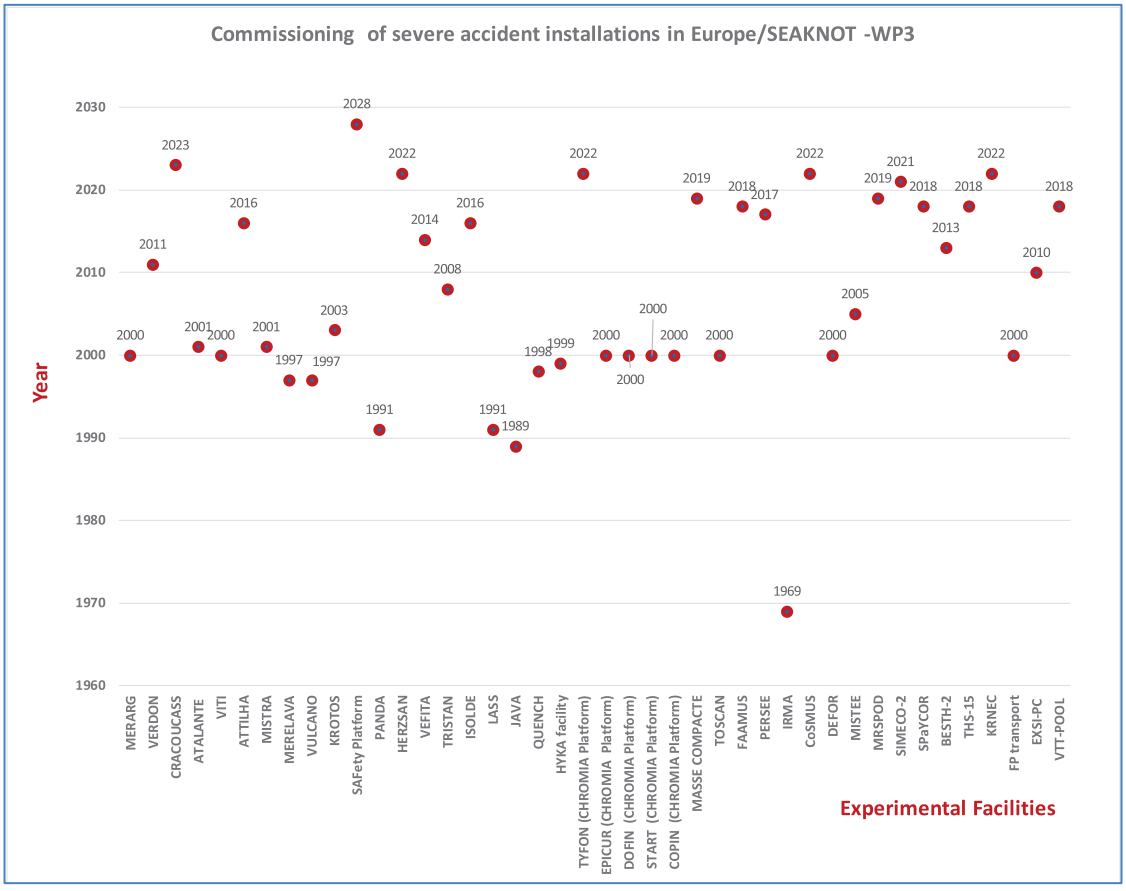

Fig. 2. List of facilities with the year of commissioning of the SEAKNOT-WP3.

- Building of a questionnaire for the experimental mapping activity (see appendix 1)
- Identification of test facilities in SEAKNOT-Partners involved in Work Package 3,
- Identification of test facilities in SEAKNOT-Partners not involved in Work Package 3,
- Identification of test facilities in institutions of EU-Countries partners of SEAKNOT but not belonging to the SEAKNOT-consortium,
- Identification of test facilities in institutions of EU-Countries not partners of SEAKNOT.

According to this methodology, the following steps [6] were carried out to draw conclusions about the assessment of the capabilities of the European severe accident experimental facilities: Identify institutions and contact persons to answer the questionnaire. For it, four target groups of institutions were considered: Group-1: SEAKNOT-Partners involved in the Work Package 3, Group-2: SEAKNOT-Partners not involved in Work Package 3, Group-3: Institutions in EU-Countries partners of SEAKNOT but not beneficiaries, and Group-4: Institutions in EU-Countries not partners of SEAKNOT.

Identify key-persons in all the four-target groups to answer the questionnaire: Evaluate the questionnaire regarding e.g., Total number of test facilities, mapping of experimental facilities with SA research domain, and identify experimental facilities under risky situation regarding funding, research team, and perspective. More details of the methodologies can be found in [6].

Table 1 shows the number of requests sent out and the number of responses/facilities identified by evaluating the questionnaire.

One first challenge was concerning the number of answers. As it can be seen in Table 1, SEAKNOT partners have answered but less than one third of organizations outside of SEAKNOT have answered to the questionnaire. Nevertheless, it can be considered that the mapping of European Severe Accident activities is relatively complete because the main severe accident facilities in activity were belonging to SEAKNOT consortium.

3 Quantitative evaluation of the questionnaire

The synthesis hereafter is structured around the following topics of relevance for SEAKNOT: main phenomena addressed by research programs of experimental facilities, main severe accident phases covered by programs of experimental facilities, reactor types targeted by experimental programs, experimental programs addressing ATF, experimental programs addressing SMR-issues, experimental facilities without a defined research topic for

Table 2. Overview of the severe accidents current and future research programs SEAKNOT-WP3.

Institution	Name	Current SA program-2023	Future SA program (2025–2030)
CEA	MERARG	Nuclear Fuel Industry Research (NFIR) V, VI, VII	NFIR VI, ISAC
CEA	VERDON	ISTP, JAEA	yes until 2028
CEA	CRACOUCASS	OECD/ESTER	yes until 2028
CEA	ATALANTE	TCOFF-2, CORIU, TERPF	LESSAC under preparation
CEA	VTI	National SA program for LWR Gen II, 3 and 4 (SFR)	National SA program, EU SAINET, OECD/NEA COPS
CEA	ATTILHA	Laser heating to investigate high-T behavior of U-containing system	OECD/NEA COPS
CEA	MISTRA	Study of SA in PWR focused on H2-risk	Sprying in super-heated atmosphere
CEA	MERELAVA	MIT3BAR national project	Corium Properties, uncertainties OECD/NEA COPS
CEA	VULCANO	International Cooperation with Japan	OECD/NEA COPS
CEA	KROTOS	ICE national program (post-Fukushima), Gen 4 SFR	Mitigation OFFERR, SAINET EU
CEA	SAFeTy Platform	not yet	Dry/wet MCCI, IVR, Na FCI, open for ATF and SMR, int. Cooperation
	PANDA	QECD/NEA PANDA	no
PSI	HERZSAN	International Project. Industry project, national	no
PSI	VEFITA	International Project. Industry project, national	no
PSI	TRISTAN	National program	no
PSI	ISOLDE	no	no
CIEMAT	LASS	OFFER, (H-Europe), APIAS (CSN)	APIAS (CSN)
FRAM	JAVA	Until 2017	no
KIT	QUENCH	QUENCH-ATF, ATF-TS	OECD/NEA projects
KIT	HYKA	None, one in fusion	no
IRSN	TYFON	Ongoing PhD	Until 2025, then redirection
IRSN	EPICUR Gamma & LEAR hot cell	ESTER OECD	Focus on ATF
IRSN	DOFIN	IRSN material qualification	no
IRSN	START	until 2024	no
IRSN	COPIN	PhD until 2025	no
IRSN	MASSE COMPACTE	National program	no
IRSN	TOSCAN	Study of H2 and aerosol behavior in containment	FUK decomtamination (2025), Aerosol mitigation in CONT. naval propulsion
IRSN	FAAMUS	Study of Flash Atomisation Aerosols Mobilization under vacUum System	no
IRSN	PERSEE	IRSN internal Polymer ageing project	no
IRSN	IRMA	IODINE R&D program of IRSN	ODINE R&D program of IRSN
KTH	CoSMUS	ROSAU int. Program	National APRI program
KTH	DEFOR	National APRI program	APRI: focus on melt fragmentation and debris bed formation
KTH	MISTEE	National APRI program	National APRI program
KTH	MRSPOD	National APRI program	National APRI program
KTH	SIMECO-2	National APRI program	National APRI program
KTH	SPaYCOR	National APRI program	National APRI program
UJV	BESTH-2	no	Project on LWR and SMR
UJV	THS-15	no	Plans for international projects
UJV	KRNEC	Commercial PTS tests program for Czech utility	not yet
VTT	VTT-FP transport	NKS-R TRIO Nordic program	EURATOM EXCESS IM, SAFER2028
VTT	EXSI-PC	no	NKS nordic program, SAFER2028
VTT	VTT-POOL	SAFER2028/ALISA project	SAFER2028/ALISA project, NUGENIA TA2.4, IPRESCA Project

Table 3. Overview of the severe accidents current and future research fields and topics- SEAKNOT-WP3.

Institution	Name	Commisioning	SA research fields	Topics
CEA	MERARG	2000	FP source term, fuel relocation	LWR, SMR
CEA	VERDON	2011	Source term, fuel behavior	LWR, SMR, ATF
CEA	CRACOUCASS	2023	Delayed source term	LWR
CEA	ATALANTE	2001	Liquid source term after SA	Other: Waste management
CEA	VITI	2000	In-vessel, Ex-vessel, ST, Containment	Gen ll, 3 and 4, ATF, SMR, instrumentation
CEA	ATTILHA	2016	Chemical systems	LWR, SMR, ATF
CEA	MISTRA	2001	Containment issues e.g., hydrogen risk, steam condensation, turblent gas mixing	LWR, SMR, ATF
CEA	MERELAVA	1397	In-vessel, Ex-vessel, and containment	LWR, mitigation, instrumentation
CEA	VULCANO	1997	Ex-vessel	Mitigation, instrumentation
CEA	KROTOS	2003	FCl, debris bed formation, cooling, mitigation	LWR, SMR, ATF, SFR, instrumentation, mitigation
CEA	SAFeTY Platform	2028	MCCI, FCI, corium properties, IVR	LWR, open for SMR and ATF
PSI	PANDA	1991	Containment, Hydrogen	LWR, SMR, mitigation, instrumentation
PSI	HERZSAN	2022	Source term mitigation	Source term mitigation
PSI	VEFITA	2014	Source term mitigation by FCVS	Mitigation of ST for LWRs by wet scrubber FCVS
PSI	TRISTAN	2008	Pool scrubbing, two-phase flow hydrodynamics	Mitigation of ST for LWR's, pool scrubbing, instrument development
PSI	ISOLDE	2016	Gas-water two-phase flow mass transfer phenomena	Mitigation of ST, pool scrubbing hydrodynamics, instrumentation
CIEMAT	LASS	1991	Aerosol scrubbing in pools	LWR, Mitigatin, instrumentation
FRAMATOME	JAVA	1989	FP, qualification, performance, mitigation	LWR, CANDU, WER
KIT	QUENCH	1998	In-vessel SA, DBA	LWR, ATF
KIT	HYKA	1999	Containment, hydrogen	LWR, SMR, ATF, mitigation
IRSN	TYFON	2022	Source term, pool scrubbing	LWR
IRSN	EPICUR Gamma & LEAR hot cell	2000	Radiochemistry of FP in SA	LWR, ATF, source term
IRSN	DOFIN	2000	Source term, filterdevices	LWR, source term
IRSN	START	2000	Chemistry-transport	LWR, source term
IRSN	CO PIN	2000	Sump filter dogging	LWR
IRSN	MASSE COMPACTE	2019	In-vessel, ex-vessel	LWR
IRSN	TOSCAN	2000	Containment, Mitigation, decomissioning	LWR, H2/aerosol in containment, decommisioning
IRSN	FAAMUS	2020	ITER fusion	Flash atomisation aerosols mobilization under vacuum system, fusion
IRSN	PERSEE	2017	Radioactive gaseous effluents purification	Mitigation
IRSN	IRMA	1969	Co-60 irradiation, ageing of NPP components	Material behavior under irradiation
KTH	CoSMUS	2022	Ex-vessel	LWR
KTH	DEFOR	2000	FCl including melt fragmentation, debris formation, debris coolability	LWR
KTH	MISTEE	2005	FCl, ex-vessel	LWR
KTH	MRSPOD	2019	In-/Ex-vessel debris bed behavior	LWR, in-/ex-vessel
KTH	SIMECO-2	2021	In-vessel debris behavior, debris bed coolability, dryout, and remelting	LWR
KTH	SPaYCOR	2018	In-vessel retention	LWR
UJV	BESTH-2	2013	IVR, RPV-coolant interactions	LWR, SMR
UJV	THS-15	2018	IVR, CHF	VVER-1000
UJV	KRNEC	2022	In-vessel, PTS, RPV external cooling	LWR, instrumentation
VTT	VTT-FP transport	2000	In-vessel, source term	LWR, SMR, HTGR
VTT	EXSI-PC	2010	Source term, FP chemistry	LWR, SMR
VTT	VTT-POOL	2018	Source term, containment	LWR, SMR, mitigation

Table 4. List of institutions and test facilities including the severe accident research field and scaling SEAKNOT-WP3.

Institution	Name	SA research fields	Scaling		
			small	mid	large
CEA	MERARG	FP source term, fuel relocation	×		
CEA	VERDON	Source term, fuel behavior		×	
CEA	CRACOUCASS	Delayed source term	×		
CEA	ATALANTE	Liquid source term after SA		×	
CEA	VITI	In-vessel, Ex-vessel, ST, Containment		×	
CEA	ATTILHA	Chemical systems			×
CEA	MISTRA	Containment issues e.g., hydrogen risk, steam condensation, turblent gas mixing			×
CEA	MERELAVA	In-vessel, Ex-vessel, and containment			×
CEA	VULCANO	Ex-vessel			×
CEA	KROTOS	FCI, debris bed formation, cooling, mitigation		×	
CEA	SAFeTY Platform	MCCI, FCI, corium properties, IVR			×
PSI	PANDA	Containment, Hydrogen			×
PSI	HERZSAN	Source term mitigation			×
PSI	VEFITA	Source term mitigation by FCVS			×
PSI	TRISTAN	Pool scrubbing, two-phase flow hydrodynamics			×
PSI	ISOLDE	Gas-water two-phase flow mass transfer phenomena			×
CIEMAT	LASS	Aerosol scrubbing in pools			×
FRAMATOME	JAVA	FP, qualification, performance, mitigation			×
KIT	QUENCH	In-vessel SA, DBA		×	
KIT	HYKA	Containment, hydrogen			×
IRSN	TYFON	Source term, pool-scrubbing		×	
IRSN	EPICUR Gamma & LEAR hot cell	Radiochemistry of FP in SA		×	
IRSN	DOFIN	Source term, filter devices			×
IRSN	START	Chemistry-transport		×	
IRSN	COPIN	Sump filter clogging		×	
IRSN	MASSE COMPACTE	In-vessel, ex-vessel			×
IRSN	TOSCAN	Containment, Mitigation, decomissioning			×
IRSN	FAAMUS	ITER fusion		×	
IRSN	PERSEE	Radioactive gaseous effluents purification			×
IRSN	IRMA	Co-60 irradiation, ageing of NPP components			×
KTH	CoSMUS	Ex-vessel		×	
KTH	DEFOR	FCI including melt fragmentation, debris formation, debris coolability		×	
KTH	MISTEE	FCI, ex-vessel	×		
KTH	MRSPOD	In-/Ex-vessel debris bed behavior		×	
KTH	SIMECO-2	In-vessel debris behavior, debris bed coolability, dry-out, and remelting		×	
KTH	SPaYCOR	In-vessel retention		×	
UJV	BESTH-2	IVR, RPV-coolant interactions			×
UJV	THS-15	IVR, CHF			×
UJV	KRNEC	In-vessel, PTS, RPV external cooling			×
VTT	VTT-FP transport	In-vessel, source term		×	
VTT	EXSI-PC	Source term, FP chemistry		×	
VTT	VTT-POOL	Source term, containment		×	

2024–2030, and experimental programs under critical conditions (man-power shortage, knowledge loss, etc.).

3.1 Experimental facilities operated by SEAKNOT-Partners and their age

In Figure 1, the number of severe accident experimental facilities operated by European institutions partners of SEAKNOT is shown. Geographic repartition in Europe is not uniform: more than 50% of these experimental facilities are still operating in 3 main European countries: France (CEA, IRSN), Sweden (KTH) and Switzerland (PSI). The other countries are less involved in experimen-

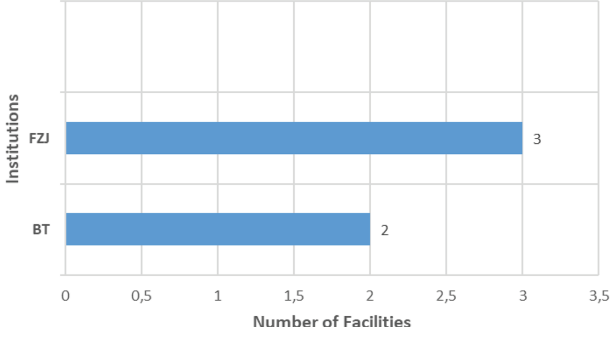

Fig. 3. List of facilities with the year of commissioning of the SEAKNOT-WP3.

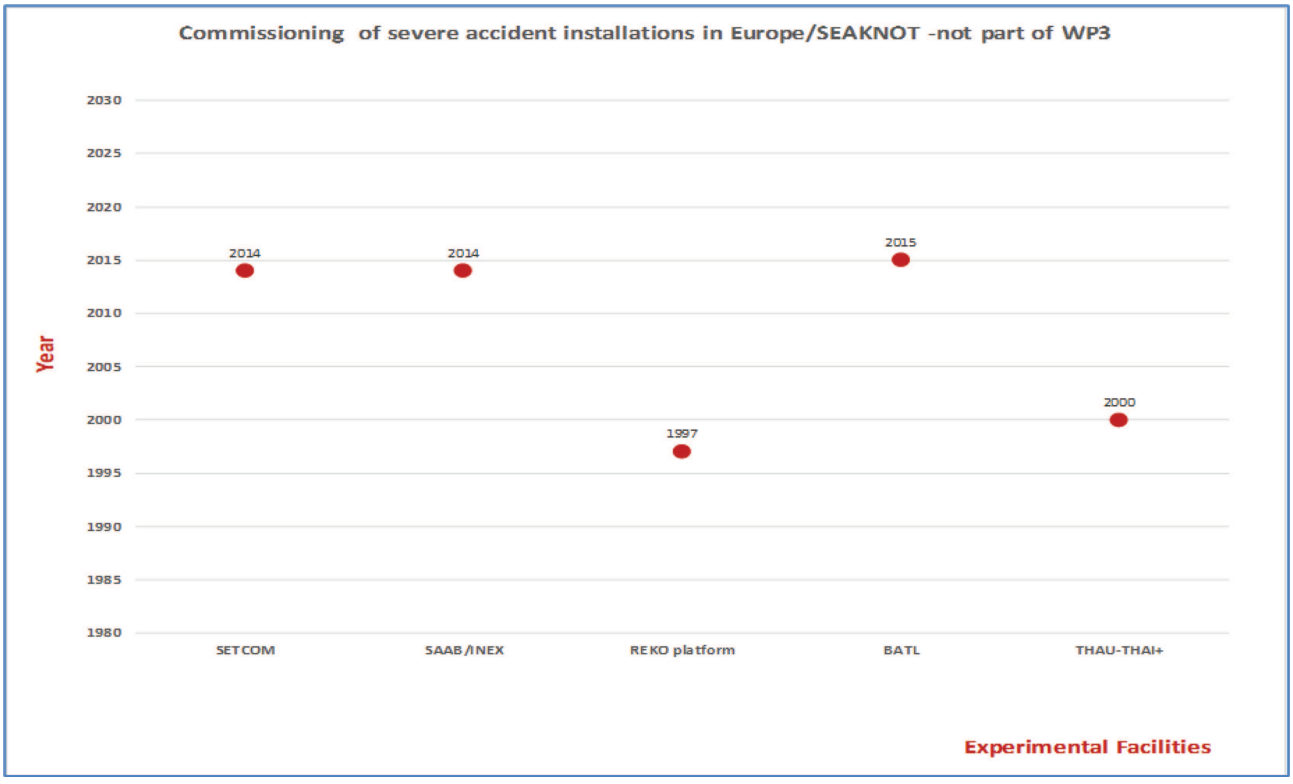

Fig. 4. List of facilities with the year of commissioning of the SEAKNOT-partners not involved in SEAKNOT WP3.

tal activities whereas a lack of experimental data has been identified by the SEAKNOT partners [4].

The time life of experimental facilities is also an important parameter. In the frame of SEAKNOT assessment activity of severe accident facilities still in operation, it has been asked to SEAKNOT partners to provide insights into the average age of the experimental facilities (Fig. 2). Furthermore, an overview of the facilities expected to remain operational until 2030 for future R&D activities has been also assessed.

European severe accident facilities are relatively old: the majority of the test facilities were constructed between the eighties and end of the nineties, meaning that their average age is around 30 years. The maintenance of old facilities are crucial but very expensive, meaning possible closure by 2030.

3.1.1 Severe accident current and future research programs

Based on the information collected, an important aspect was to identify in which current and future research programs the facilities are involved or not. This information is essential for assessing the capability of European experimental facilities to meet both current and future (2030) research needs, derived from SEAKNOT PIRT activities (WP1) and to propose future European programs in order to answer to nuclear safety challenge for SMRs and new mitigation tool for nuclear energy in Europe.

Table 2 lists the facilities with the current and future severe accident programs in which the facilities are involved. The majority of European severe experimental facilities have some domestic and international programs, but almost no European program activities. But, some experimental facilities at IRSN (France), PSI (Switzerland) and KIT (Germany) have no program planned for the period 2025–2030, meaning in most unfavorable situation the mothballing of the facilities, leaving them vacant while continuing to cover maintenance costs. European experimental expertise in the field of severe accident has taken several years and has been very costly for European community whereas it can be lost rapidly if any European program in the 2025–2030 is proposed.

3.1.2 Severe accident fields and topics addressed by the experimental facilities

Based on the information collected, an important aspect was to identify the actual research topics of test facilities. This information will be useful for identifying relevant topics for which only a limited number of experimental facilities are available. In Table 3, the experimental facilities are listed with their respective severe accident research fields and topics provided in the questionnaire. Almost all severe accident topics, identified in the frame of SEAKNOT project, are covered as it can be seen in Table 3. But it will be only at the end of the PIRT activity of SEAKNOT that it will be possible to assess if European facilities can answer to all experimental needs in the field of severe accident for the period 2025–2030.

Experiment facilities are focused on quite diverse research fields and mainly related to LWRs including CANDU reactors and water-cooled SMRs. It is impor-

Table 5. Overview of the severe accident research fields and topics addressed by the facilities of the SEAKNOT-partners not involved in WP3.

Institution	Facility name	Start operation	Short description	Severe accident Research fields	Topics
BT	THAU/THAI+	2000	Study of behaviour of hydrogen, iodine and aerosols in the containment of light water reactors during severe accidents	TH, H2, PAR, FP, Pool scrubbing	LWR, SMR, Mitigation, Instrumentation, passive systems
BT	BATL	2015	Study of aerosol behaviour in light water reactors durinq severe accidents	FP, Aerosols, FCVS, passive systems	
FZJ	REKO Platform	1997	Study of PARS behavior	Containment, Severe Accidents, Hydrogen Mitigation	LWR, SMR, Mitigation
FZJ	SAAB/IN EX	2014	Study of pool scrubbing phenomena and particle depletion/interaction	Containment, Aerosol Behaviour, Pool Scrubbinq	LWR, SMR
FZJ	SETCOM	2014	Separate Effect Tests on Condensation Modeling	Containment TH	LWR, instrumentation, SMR

Table 6. Overview of the current and future research programs of the different facilities run by the SEAKNOT-partners not involved in WP3.

Institution	Facility name	Start operation	Short descrption	Current severe accident program 2023	Future severe accident program 2024–2030
BT	THAU/THAI+	2000	Study of behaviour of hydrogen, Iodine and aerosols in the containment of light water reactors during severe accidents	THEMIS, THAI PVII, IPRESCA	THEMIS, nat. THAI
BT	BATL	2015	Study of aerosol behaviour in light water reactors durinq severe accidents	Coop, with FRAM	
FZJ	REKO Platform	1997	Study of PARS behavior	EU AMHYCO, nat. NUSAFE	EU SASPAM, NUSAFE SMR
FZJ	SAAB/INEX	2014	Study of pool scrubbing phenomena and particle depletion/interaction	NUSAFE POF IV	EU SASPAM, NUSAFE SMR
FZJ	SETCOM	2014	Separate Effect Tests on Condensation Modeling	BMWi KEK, SETCOM	CFD-development, containment

tant to note that no specific tests for SMR are devoted to severe accident conditions, except the ones dedicated to passive heat removal systems. The tests devoted to mitigation are related to source term and containment issues.

3.1.3 Experimental facilities and scaling

Table 4 lists the different facilities along with their operator, facility name, associated severe accident research fields, and the scaling information.

For severe accident studies and nuclear safety, scaling effect is crucial to be able to have reliable data for extrapolation to reactor case. The majority of the test facilities are devoted to PWRs, and BWRs, some to VVER, and CANDU (current generation 2 European fleet). SMRs activity is also concerned, but no specific facility is strictly devoted to severe accident studies for SMRs. The majority of the facilities are categorized as of medium and large-scale. Only few of them are of small scale mainly to perform analytical studies. Based on this classification, 21 facilities are categorized as “large-scale”, 18 as “mid-scale” and 3 as small-scale facilities. However, this declared categorization by the facility technical staff, should be technically supported in case of future application for SMR SA investigation, whatever the design.

3.2 Experimental facilities operated by SEAKNOT-Partners not involved in WP3

The SEAKNOT-partners not involved in the WP3- have also answered to the SEAKNOT questionnaire (Fig. 3). Five facilities are operated by two German institutions, namely Becker Technologies (BT) and Research Center Jülich (FZJ). Figure 4 shows the starting dates of the operation of the facilities operated by two German institutions. These facilities are recently operated (after 2000) except for REKO.

Table 5 summarizes the current research fields and topics addressed by the five facilities. The main topics of severe accident research are devoted to containment phenomena during severe accidents relevant for LWRs and SMRs. Some activities are planned till 2030 mainly focused on CFD approach and SMRs application (Tab. 6).

4 Summary and conclusions

In the frame of the European project SEAKNOT (Severe Accident research and KNOwledge management) project, an analysis and mapping of European severe accident research facilities currently under operation has been performed. Through a general questionnaire, SEAKNOT partners have been able to answer about their current and future (2025–2030) experimental activities in the field of severe accidents including LWRs and SMRs. The questionnaires evaluated comprise data of 59 facilities.

A systematic evaluation of the provided information was performed, which included the description of the facilities, current and future research focus, main severe accident phenomena addressed, reactor types considered. In this context, particular attention was given to identify research programs addressing new topics such as ATF and SMRs. The information collected and the evaluation performed pave the way for the mapping of European severe accident facilities under operation and it allows to identify experimental needs in the severe accident research for LWRs and SMRs until 2030.

In 2025, the main topics interesting severe accident studies LWRs and SMRs are covered by several experimental facilities belonging to SEAKNOT consortium. 22 experimental facilities do not have concrete "research plan" established yet for the period 2024–2030 which is a bad indicator for research in nuclear safety.

European experimental expertise in the field of severe accident has taken several years and has been very costly for European community. This level of excellence, recognized worldwide, can be lost rapidly if any European program in the 2025–2030 takes into account the field of severe accident for the current and future nuclear fleet.

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Conflicts of interest

Authors VHSE, PP, and LEH certify that they have no financial conflicts of interest (e.g., consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) in connection with this article.

Data availability statement

Data associated with this article cannot be disclosed due to legal reason of the different owner of the data.

Author contribution statement

VHSE: Writing, Editing, Conceptualization, Formal Analysis, Methodology, Data Curation, Investigation, PP: Reviewing, Conceptualization, Investigation, Reviewing, LEH: Funding acquisition, Reviewing, Methodology.

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Appendix A: SEAKNOT questionnaire for the mapping of severe accident facilities in Europe

Organization-Country	
Business	☐ Industry; ☐ Authority; ☐ University; ☐ Research; ☐
Contact Person	
Email	

1. Is your Institution operating an experimental facility in 2023 on the following severe accident areas?

a) In-vessel ☐
b) Ex-vessel ☐
c) Source term ☐
d) Containment ☐
e) Other ☐

2. Test facility description in 2023

(In case of several facilities, please provide below information separately for each facility)

Name of the facility	
Starting year of operation	
Brief description	
Main Severe Accident research fields	
Scale of the test facility ■ Volume ■ Height ■ Power ■ Other	
Figure of the test facility (if possible)	
Design parameters ■ Pressure ■ Temperature ■ Other	
Materials: ■ Simulant ■ Prototypic ■ Irradiated fuel	
Current SA Program (2023) ■ International (research topics) ■ National (research topics)	
Future SA Program (2024–2030) ■ International (research topics) ■ National (research topics)	
Topics ■ LWR ■ SMR ■ Mitigation ■ ATF ■ Instrumentation ■ Other	
Experimental team ■ Number of permanent persons ■ Number of non-permanent persons ■ Number of Ph-D students, Post-Graduated ■ Critical competences[1]	
Use of experimental data bases ■ Code validation ■ Analytical work ■ Scaling	
References ■ Technical reports ■ Open literature ■ Journal ■ Others	

3. Other topics

[1] Critical competences for the next 5 years: The experimental activity will be stopped, person with critical experimental competences will be retired and not replaced, the experimental activity will be reoriented, others.