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EU Member States' Research and Development Activities in Reactor Safety

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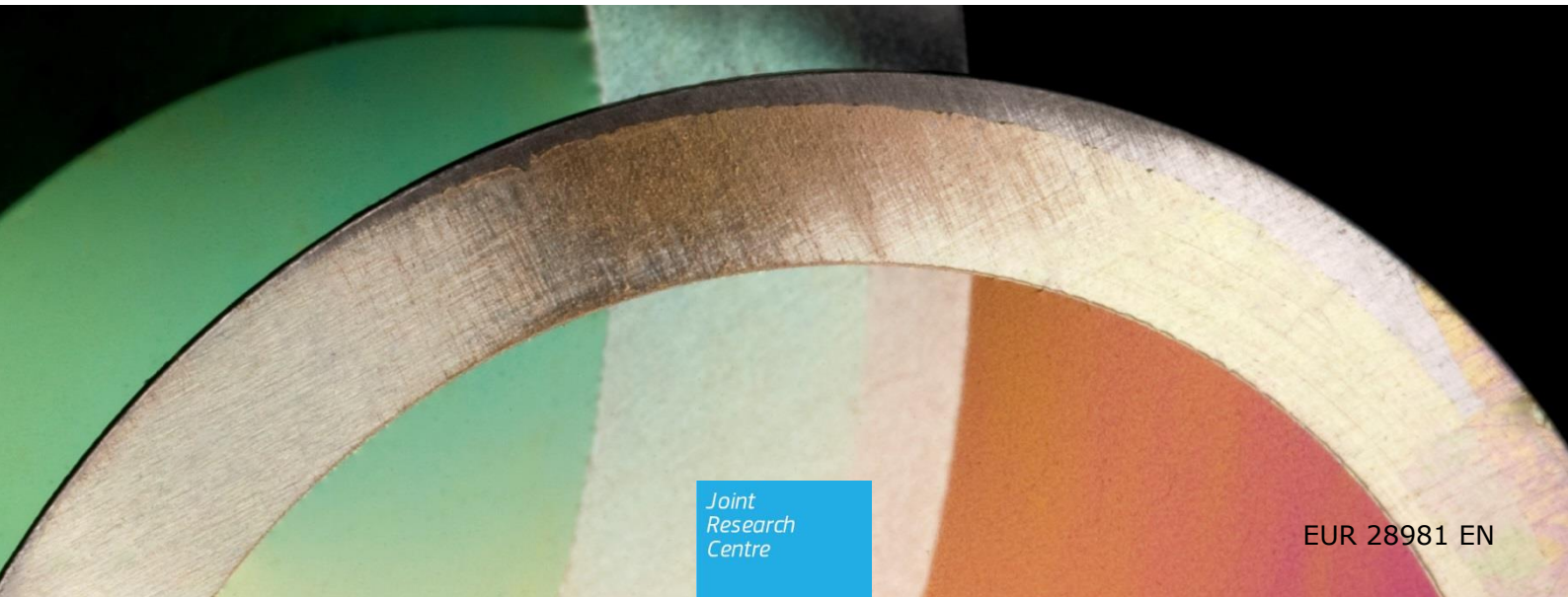

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Title EU Member States' Research and Development Activities in Reactor Safety

Abstract

The report summarises the present status of R&D activities in the area of nuclear power plant safety in EU member states. The report identifies the most relevant R&D organisations, their main research focus area, key research infrastructure, and possible national research programmes. The focus is mainly on Gen II and Gen III safety, but main activities related to Gen IV reactors are also mentioned. The report serves as a quick reference, providing links to the websites of main R&D organisations. The report aims at supporting the gap analysis of JRC activities in the field of reactor safety.

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Contents

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Abstract

The report summarises the present status of R&D activities in the area of nuclear power plant safety in EU member states. The report identifies the most relevant R&D organisations, their main research focus area, key research infrastructure, and possible national research programmes. The focus is mainly on Gen II and Gen III safety, but main activities related to Gen IV reactors are also mentioned. The report serves as a quick reference, providing links to the websites of main R&D organisations. The report aims at supporting the gap analysis of JRC activities in the field of reactor safety.

1 Introduction

This is a summary report on the member states' (MS) relevant work programmes and R&D activities in the area of nuclear power plant safety. Ideally the report would synthesise MSs' national R&D programmes in reactor safety. However, only few MS have a well-defined national R&D programme, and the activities can be very scattered and thus difficult to synthesise. As a consequence, this report is not restricted to MS-level R&D programmes, but identifies the most relevant R&D organisations and their main activities. The focus is mainly on national research institutions. The main universities having research activities in reactor safety are pointed out, but the industry R&D activities and facilities are not covered. The focus is mainly on Generation II and III safety, but the main activities related to Generation IV reactors are also mentioned.

The main sources of information are the MS presentation at the "NEA International Workshop on the Nuclear Innovation Roadmap (NI2050)" organised by the OECD Nuclear Energy Agency in July 2015 (NEA 2015), the IAEA country nuclear power profiles (IAEA 2017), the NUGENIA synthesis report on the implementation of national nuclear programmes (Reese et al. 2015), and websites of research organisations.

The report also summarises some main research infrastructure, but it should be noted that the lists are not exhaustive. For a more detailed summary on infrastructures, a *NUGENIA RD infrastructures database* (October 2016) is available for NUGENIA members on the NUGENIA Electronic Content Collaboration Platform (ECCP) http://app.lgi-consulting.org/ecm/nugenia.

2 Reactor safety research in the EU member states

The reactor safety research is organised in each member state in its own way. In MSs with a nationally coordinated research programme or a single strong research organisation, it is relatively straightforward to obtain a picture of the research activities and priorities. On the other hand, in some countries the research activities are widely scattered, which makes it more difficult to map the situation. This is the case e.g. in Germany, Sweden and the UK.

The Figure 1 shows the main reactor safety research organisations in European countries, where clearly one or two organisations can be identified. In the case of Germany and Sweden, the research activities are not as clearly focused, but split among more organisations.

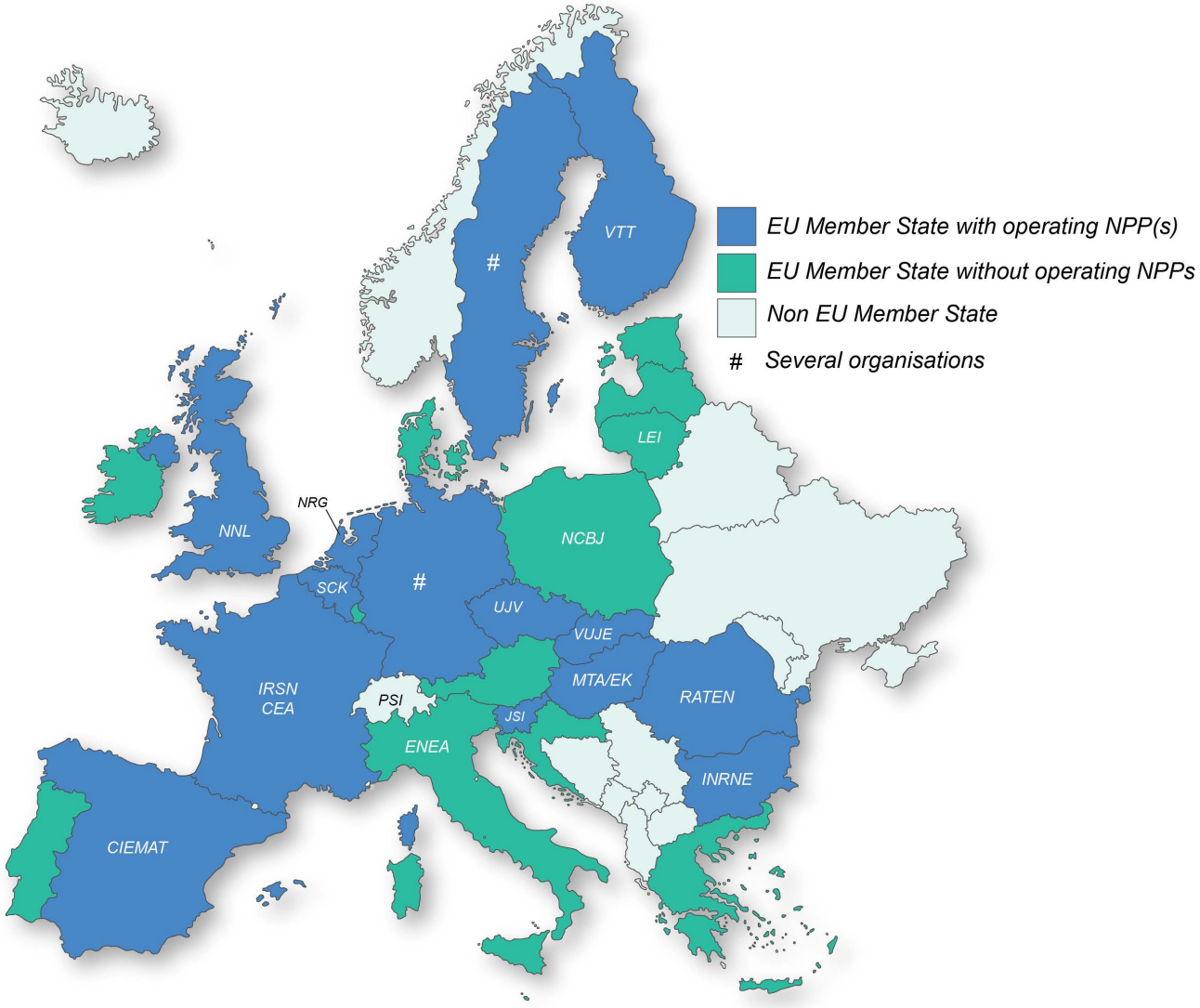

Table 1 lists the main research organisations that are members in NUGENIA[1] and/or ETSON[2]. Also the possible Collaboration Agreement (CA) or Memorandum of Understanding (MoU) with JRC is indicated. Switzerland is included in the table, as they are one of the most active Associated Country participating in the European reactor safety research co-operation.

[1] NUGENIA = Nuclear GENeration II & III Association http://www.nugenia.org/
[2] ETSON = European Technical Safety Organisations Network http://www.etson.eu/

Table 1. Main European research organisations that are members of NUGENIA or ETSON.

COUNTRY	Organisation*	NUGENIA member	ETSON member	Relation with the JRC**
Belgium	Bel V	X	X	
	SCK-CEN	X		CA
Bulgaria	INRNE	X (academia)	X	
Czech Republic	NRI-REZ	X		CA
	CVR	X	X	
Finland	VTT	X	X	MoU
France	IRSN	X	X	CA
	CEA	X		CA
Germany	GRS	X	X	
	HZDR, KIT, FZJ, IZFP	X		
Hungary	MTA/EK	X	X	CA
	NUBIKI, BZN	X		
Netherlands	NRG	X		CA
Romania	RATEN (ICN Pitesti)	X		
Slovakia	VUJE	X	X	
Slovenia	JSI – Josef Stefan Institute	X	X	
Spain	CIEMAT	X		CA
Sweden	ES-KONSULT, STUDSVIK, Inspecta	X		
Switzerland	PSI	X	X	
United Kingdom	Amec Foster Wheeler	X (industry)	X	
	NNL, BO-NRC	X		
Lithuania	LEI	X	X	
Italy	ENEA	X		MoU
Poland	NCBJ	X		CA
	INCT	X		

* For the abbreviations see the country-specific subsection in the document
** MoU = Memorandum of Understanding, CA = Collaboration Agreement

Figure 2 summarises the participation of the main European research organisations in FP7 and H2020 projects related to reactor safety issues (Gen IV included). The figure shows those 31 organisations that have been members of consortia in at least six of the selected 49 projects.

NUGENIA has produced a synthesis report on the implementation of national nuclear programmes and proposals for integration in NUGENIA of all programmes for technical and financial aspects (Reese et al. 2015). However, the report focuses more on describing the organisational structure of R&D funding rather than on R&D activities.

A number of national presentations on nuclear fission research and innovation activities were given at the "NEA International Workshop on the Nuclear Innovation Roadmap (NI2050)" organised by the OECD/NEA in July 2015. The presentations are available on the internet (NEA 2015).

In the following sub-sections the main reactor safety research activities and infrastructure are summarised by country. This summary is divided in two parts: 1) countries with current nuclear energy production, and 2) countries without nuclear power generation. In the latter case, the focus is on the few countries having relevance in nuclear safety R&D.

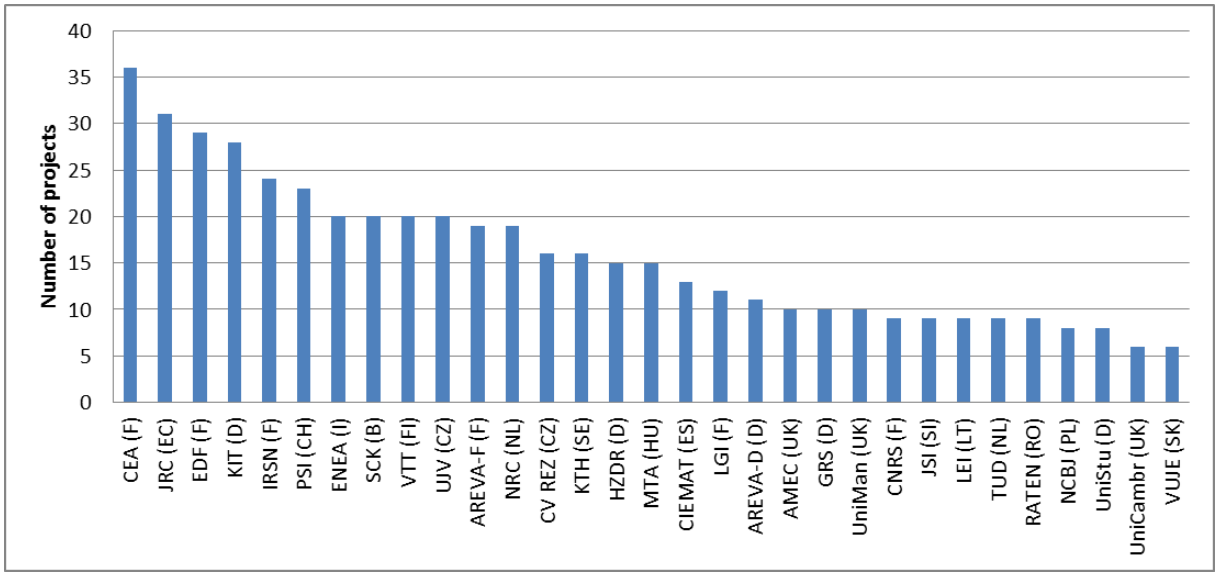

Figure 2. European research organisations with most participation in FP7 and H2020 projects related to reactor safety issues. (Source: Cordis)

Note that this summary focuses mainly on national research institutions, and points out the main universities having research activities in reactor safety. Instead, the industry R&D activities and facilities are not covered. However, it is not always straightforward, and not even practical to distinguish between public research organisations and private for-profit entities. During past years, many originally public research organisations have been privatised, but still contribute to publicly funded research activities. Thus several private consultancies have also been referred to in this report. The main criterion for their inclusion is the participation in several Euratom research projects.

The report also lists the main research infrastructures, but these lists are not exhaustive. A detailed summary of the research facilities in its member organisations has been collected by NUGENIA. This summary is available for NUGENIA members.

2.1 Member States with nuclear energy production

In this sub-section we summarise the reactor safety research activities and main research infrastructure in the 14 member states having nuclear energy production. Switzerland, although not an EU member state, is also included due to their significant contribution to the European reactor safety research activities.

2.1.1 Belgium

Although Belgium has decided to phase out nuclear electricity production, the country will continue investing in nuclear research. Bel V is the technical support organisation for the Belgian safety authority, and acts as expert for the safety assessments of nuclear projects. Bel V also actively participates in meetings and working groups that are organized in the framework of international organizations.

Most of the nuclear R&D is carried out at the Belgian Nuclear Research Centre SCK•CEN. Their expertise focuses on the ageing processes of nuclear reactors. Some of the main activities of SCK•CEN in reactor research are the following (NEA 2015):

- Material testing and qualification for Generation II, III and IV reactors
- Fuel development, testing, validation and qualification (Gen. II & III, Gen. IV, advanced Fuels for transmutation)
- Safe long term operation: structural materials, cables ageing, concrete ageing

The SCK•CEN has the following research infrastructures:

- BR2 100 MWth Materials Testing Reactor: Material and fuel testing for all type of reactor technologies
- BR1 research reactor & GUINEVERE lead-ZPR & ADS mock-up: Benchmark experiments for reactor and core physics, codes verification & validation
- LHMA Highly instrumented Hot Labs: Material & fuel R&D, Minor Actinides radiochemistry, Heavy Liquid Metal environment
- HADES Underground Research Lab: HLW research in Clay, Semi-industrial technology & technics demonstration for geological disposal
- HLM Complex for Pb and Pb-Bi technology: HLM Chemistry & conditioning, Corrosion & Thermal-hydraulics testing, Thermal-Physics properties determination, Instrumentation development and demonstration, Components qualification

The SCK•CEN is managing the MYRRHA project (Multi-purpose hYbrid Research Reactor for High-tech Applications) to construct the very first prototype of a nuclear reactor driven by a particle accelerator in the world. The SCK•CEN leads (together with EdF) the European Sustainable Nuclear Industrial Initiative (ESNII) Task Force comprising research organisations and industrial partners to address the need for demonstration of Gen-IV Fast Neutron Reactor technologies, together with the supporting research infrastructures, fuel facilities and R&D work.

Other Research Infrastructures for nuclear fission available in Belgium are (NEA 2015):

- Von Karman Institute: CFD and Thermal-hydraulics highly instrumented facilities, Turbo-machinery qualification test benches, 3-D seismic test facility for HLM Sloshing study
- LABORELEC: Mechanical Testing laboratories for RPV and reactor internals, LTO : Cable aging
- IRE: Radiochemistry facilities, Radioisotopes production procedures V&V facilities
- Ondraf-Niras/Belgoprocess: Waste conditioning & management, Decontamination & site restoration

References: www.belv.be, https://www.sckcen.be/

2.1.2 Bulgaria

The Institute for Nuclear Research and Nuclear Energy (INRNE) of the Bulgarian Academy of Sciences is the leading research centre for reactor safety in Bulgaria. The NUGENIA report (Reese et al. 2015) did not identify any MS programme or project relevant to NUGENIA Technical Areas. Participation in Euratom fission projects has also been low (lowest of all nuclear countries). The INRNE was a member of the severe accident research network SARNET, and participated/participates in thermal-hydraulics and severe-accident related projects (NURESAFE, CESAM, IVMR, ASAMPSA).

Nuclear safety related knowledge management and transition is maintained with the support of the EC through the FP7 Project CORONA "Establishment of a Regional Center of Competence for VVER Technology and Nuclear Applications" and the H2020 Project CORONA II "Enhancement of training capabilities in VVER technology through establishment of VVER training academy ".

Other Bulgarian nuclear R&D organisations are: the Department of Nuclear Physics, the Department of Nuclear Technology and Nuclear Power Engineering and the Radiochemical laboratory of the Sofia University "St Kl. Ohridski" ; the Department of Power and Nuclear Engineering of the Technical University of Sofia; the Department of Nuclear Physics of the Plovdiv University "Paisii Hilendarski". (IAEA 2017)

References: www.inrne.bas.bg

2.1.3 The Czech Republic

According to the presentation in the NEI workshop (NEI 2015), the Czech Republic has the following R&D Targets in the subarea "Nuclear resources of the energy":

1. Efficient long-term use of nowadays nuclear power plants

- Ensuring reliability and long-term efficient operation of existing nuclear installations (Gen II)
- Advanced materials and technologies for nuclear power sector (Gen III, Gen IV)
- Decommissioning of nuclear facilities (Gen II)

2. Support of the safety of the nuclear facilities

- Promoting safety of the nuclear facilities for regulator needs (Gen II and Gen III)
- Promoting safety of operating and planned nuclear facilities (Gen II and Gen III)

3. Research ensuring support of the construction and running of the new economically efficient and safe units

- Ensuring quality of documentation for licensing processes in the field of nuclear safety and ensuring the high quality necessary experts. (Gen II, Gen III)
- Ensuring increased reliability, durability and effectiveness of new nuclear facilities (Gen III)
- Developing procedures and evaluation methods to ensure a comprehensive view of the technical feasibility and economic efficiency of long-term operation for a minimum period of 60 years. (Gen III, Gen IV)

The Czech Republic is one of the most active participants in Euratom funded projects. Most R&D activities are carried out by ÚJV Řež (NRI) and its daughter company Centrum výzkumu Řež (Research Centre Řež, CVR) who owns the research infrastructure.

The ÚJV Řež has a wide expertise in reactor safety domains. They provide services in deterministic and probabilistic safety assessments, fuel safety, ageing and plant life management, analyses of structural and mechanical properties, etc.

Some of the main infrastructures in the UJV Řež are the following:

- LR-0 pool-type research reactor serves as an experimental reactor for measuring neutron-physical characteristics of VVER reactors.
- The research reactor LVR-15 with an operational power level of 10 MWth is used (among other things) for material research.
- Testing laboratories for mechanical and material properties (autoclaves, hot cells, etc.)

The Sustainable Energy Project, SUSEN, is implemented as a regional R&D centre with following activities: 1) Technological Experimental Loops (S-ALLEGRO Loop for supporting ALLEGRO Project, HTHL 2 Loop for supporting experimental V/HTR R&D, SCWR Loop for supporting experimental SCWR R&D), 2) Structural and System Diagnostics, 3). Nuclear Fuel Cycle, 4) Material Research. The existing infrastructure of CVR will be significantly enhanced through the SUSEN project.

Research projects in the area of nuclear safety are also implemented at the Faculty of Nuclear Science and Physical Engineering of the Czech Technical University in Prague. The faculty operates the VR-1 zero-power school reactor that is used for research as well educational and training purposes. The nuclear safety research areas include development of neutron detectors, optimizing reactor fuel loads, spent fuel treatment, long term operation of irradiated reactor internals, new types of reactor fuel cladding, etc.

An institution currently managing research programmes on the national level is the governmental Technologic Agency of the Czech Republic (TACR). It has been developing, among others, a Theta Research Programme including nuclear safety topics like: New technologies and approaches for long-term operation of nuclear power plants, Development and applications of nuclear safety assessment methods, Study and modelling of mechanical behaviour of nuclear fuel or Development of software applications for prediction of distribution of radioactivity in atmosphere and hydrosphere.

References:

https://www.ujv.cz/en/products-and-services-1, http://cvrez.cz/en/infrastructure/

http://www.reaktor-vr1.cz/en/activities/research

https://www.tacr.cz/index.php/en/programmes/theta-programme.html

https://www.tacr.cz/dokums_raw/theta/1VS/Temata_Theta_PREFIN.compressed.pdf

2.1.4 Finland

Finland has a long tradition in national research programmes on nuclear power plant safety. The national programme is led by the government, and is based on the Finnish Nuclear Energy Act. The programme is funded by the Finnish State Nuclear Waste Management Fund, as well as other key organisations operating in the area of nuclear energy. The current programme, SAFIR2018, runs from 2015 until the end of 2018.

The planning period for the SAFIR2018 up to 2018 involves several licence procedures for new and existing power plants: modernisation of the automation for two units, one operating licence application, and one construction licence application. These processes are reflected in many ways in national safety research.

The research programme involves all Finnish stakeholders in the area, with the Radiation and Nuclear Safety Authority (STUK) in a central role. The Technical Research Centre of Finland (VTT) is the largest research partner and coordinator of the on-going programme, SAFIR2018. Another relevant organisation is the Lappeenranta University for Technology (LUT) especially for experimental thermal-hydraulics studies.

The research activities in SAFIR2018 are grouped under four main research areas: 1) Plant safety and systems engineering, 2) Reactor safety, 3) Structural safety and materials and 4) Research infrastructure.

The research work in the projects is guided by six reference groups:

- Automation, organisation and human factors
- Severe accidents and risk analysis
- Reactor and fuel
- Thermal hydraulics
- Structural integrity
- Research infrastructure

Research on Gen IV is excluded from the SAFIR2018 programme, but is performed separately by VTT, universities and industry.

Finland has recently renewed its main research infrastructure for nuclear safety research hosted by VTT, housing the hot-cells and including mechanical and microstructural

characterisation of materials, radiochemistry, iodine filter testing, etc. VTT has also materials technology research facility for broad coverage of different areas of material testing. The LUT hosts thermal hydraulics experimental facilities.

Finland's only research reactor of type Triga Mark II, has been permanently shut down.

NUGENIA and SAFIR2018 have signed a Memorandum of Understanding on scientific and technical co-operation in the area of nuclear safety research.

References: http://safir2018.vtt.fi/index.htm, www.vtt.fi, www.lut.fi

2.1.5 France

In France, the two main organisations in nuclear safety research are the Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA) and the Institut de Radioprotection et de Sûreté Nucléaire (IRSN). In addition, EdF, AREVA and many universities contribute to the nuclear safety R&D, as well as the National Centre for Scientific Research (Centre National de la Recherche Scientifique, CNRS). The CNRS is mainly focused on fundamental research, but participates in many Euratom funded projects in the area of fuel and materials research. As France is a leading nuclear research country in Europe, it is impossible to make any brief summary of the main activities. Practically everything is covered, but regarding the operating reactor types, the focus is on PWRs, as the currently operating reactors are all PWRs. In Gen IV R&D the focus is on sodium-cooled fast reactors following the Phénix and Superphénix prototype reactors based on this technology.

The CEA is a French government-funded institution playing a major role in nuclear R&D, with unique platforms of facilities (research reactors, large experimental and simulation tools such as hot laboratories, facilities for physics). The CEA provides scientific and technical support to the French government as well as to the definition of the short, medium and long term French energy policies.

The CEA research areas relevant to the safety of operating and future fission reactors are:

- Optimisation of the current nuclear industry
- Materials for the nuclear industry
- Safety of nuclear facilities
- Jules Horowitz research reactor (JHR)
- Future reactors (Generation IV)

The construction of the new Jules Horowitz experimental fission reactor (100 MWth) was started in 2007. It will be used for experiments on nuclear materials and fuels and production of medical radio-isotopes. The operation is foreseen around 2021. The European Commission is a member of the JHR consortium.

The Gen IV activities are focused on ASTRID project for a sodium-cooled fast reactor led by CEA. The CEA is also involved in the ALLEGRO initiative on demonstration of gas-cooled fast reactor technology.

The IRSN is France’s public service expert in nuclear and radiation risks, and the TSO for the French nuclear safety authority ASN. IRSN's activities cover all the related scientific and technical issues, and the research activities are most often carried out within the framework of international programmes. The IRSN Nuclear Safety Unit carries out research in the following fields (IRSN website):

- Nuclear fuel mechanics and thermohydraulics
- Nuclear reactor core meltdown accidents
- Fires in confined environments
- Metrology and confinement
- Neutronics and criticality

The IRSN has the following nuclear safety research laboratories:

- Corium Physics Study Laboratory (LEPC)
- Corium and Radioelement Transfer Research Laboratory (LETR)
- Reactor Physics Research and Safety Assessment Laboratory (LNR)
- Criticality Research and Neutronics Development Laboratory (LNC)
- Loss of Coolant Accident and Uncertainties Modelling Laboratory (LIMAR)
- Material Physics and Thermal-Mechanics Laboratory (LPTM)
- Civil Engineering Assessment Section (BEGC, ex-BAGCS)
- Mechanics and Materials Experimental Research Laboratory (LE2M)
- Environment and Chemistry Experimental Research Laboratory (L2EC)
- In pile experimental research laboratory (L2EP)
- Explosion and Fire Laboratory (LIE)
- Fire Experimentation Laboratory (LEF)
- Aerosol Physics and Metrology Laboratory (LPMA)
- Research and Modelling Laboratory for Airborne Dispersion and Containment (LEMAC)
- Containment, Purification and Ventilation Experimental Research Laboratory (LECEV)
- Human and Social Sciences Laboratory (LSHS)

Both the CEA and the IRSN have a vast research infrastructure in Saclay and in Cadarache. The CEA facilities in Cadarache support studies of fuel, irradiated materials, severe accident and thermal hydraulics. Saclay hosts e.g. CEA's ISIS and OSIRIS reactors and mechanical/structural testing. The IRSN hosts in Cadarache e.g. thermal hydraulics and severe accident research facilities, where OECD/NEA projects have been conducted (CABRI, STEM). Other important facilities are available e.g. for material characterisation and cable fire testing. The IRSN also has thermohydraulics facilities in Orléans and Saclay. The NUGENIA infrastructure summary lists 14 major facilities for the CEA and 9 for the IRSN.

References: http://www.cea.fr/, http://www.irsn.fr/EN/Pages/home.aspx, http://www.cnrs.fr/

2.1.6 Germany

In Germany, The Helmholtz Association (HGF) distributes core funding from the German Federal Ministry of Education and Research (BMBF) to its 18 autonomous research centres. After the Fukushima accident the German parliament decided to phase out the nuclear energy production with the last NPP to be shut down in 2022. The HGF programme Nuclear Waste Management, Safety and Radiation Research (NUSAFE) aims at making the German phase-out as safe as possible. About one third of the funding is allocated to reactor safety, while two thirds are allocated to the waste management. The research activities of the Reactor Safety programme topic comprise not only the operational safety of nuclear power plants but also in-depth examinations of design-basis and beyond-design-basis accidents in nuclear power plants and systems.

In 2015-2019 the reactor safety research topics in NUSAFE are:

- Reactor Operation and DBA (multi-physics modelling, multi-scale modelling; validation of TH models; cladding materials behaviour during reflooding)
- Safety research for innovative reactors (advanced codes for safety analysis of innovative reactors; measurement techniques for liquid metal flows)
- Beyond Design Basis Accidents (core coolability and debris cooling, fuel coolant interaction, molten corium concrete interaction, hydrogen mixing and combustion; containment behaviour)

The organisations participating in the reactor safety research in NUSAFE are the Karlsruhe Institute of Technology (KIT),the Helmholtz-Zentrum Dresden-Rossendorf (HZDR) and the Forschungszentrum Jülich GmbH (FZJ). In addition to these

organisations, reactor safety R&D is carried out in several other research institutes and the universities in Germany, the most relevant being the Fraunhofer Institut for non-destructive testing (IZFP) and University of Stuttgart. The main reactor safety related research areas of these organisations are summarised below:

- KIT Institute for Nuclear and Energy Technologies: severe accident analyses, hydrogen studies, thermal hydraulics, Monte-Carlo core simulations, Gen IV technologies, liquid metal technologies KIT has also fuel and materials research, participating in Gen IV -related projects.
- HZDR: RPV ageing, TH simulation.
- FZJ: reactor theory, accident phenomenology and CFD simulation, experimental facilities for e.g. aerosol studies and recombiners.
- IZFP: Structural integrity, NDE.
- Uni Stuttgart: Structural integrity, NDE, Severe accidents.

GRS (Gesellschaft für Anlagen- und Reaktorsicherheit) is the technical support organisation, and is largely involved in European and international projects. One of the key issues of research and development at GRS has been to develop and validate computer codes for the analytical simulation of incidents and accidents concerning the reactor core, the reactor coolant system and the containment as well as for probabilistic safety analyses.

KIT and FZJ host several large-scale experimental facilities for severe accident investigations. FZJ operates also hotcell laboratories, but they are mainly used for radioactive waste studies. The University of Stuttgart has facilities for mechanical testing, for studying fluid-structure interactions and for investigations of environmental effects on materials.

References: http://www.iket.kit.edu/english/, https://www.hzdr.de/db/!Topics?pId=16&pNid=269, http://www.fz-juelich.de/iek/iek-6/DE/forschung/reaktorsicherheit/_node.html, https://www.izfp.fraunhofer.de/en.html, http://www.ike.uni-stuttgart.de/forschung/index.en.html

2.1.7 Hungary

The long term use of nuclear energy is part of Hungary's National Energy Strategy published in 2011 (NEA 2015).

The three pillars of the Technology Platform (and the nuclear research) in Hungary are:

- Ageing of structural materials
- Spent fuels and radioactive waste management
- Advanced modelling and simulation (multiphysics)

The most important R&D areas in Hungary are:

- Development of the regulatory framework
- Support and modernization of the regulatory work
- New nuclear facilities
- Decommissioning and radioactive waste management
- Development of operational safety
- Development of on-line process monitoring systems and full-scope simulators
- Development of risk informed supervisory instruments
- Analysis of beyond design basis and severe accidents
- Nuclear emergency response
- Nuclear material accountancy and control
- Supervision of radioactive material
- Physical protection
- Regulatory control of radioactive waste storage facilities.

The main research organisation in Hungary is the Hungarian Academy of Science Centre for Energy Research (MTA EK). Other strategic partner TSOs for the safety authority are the Nuclear Safety Institute (NUBIKI) and the Institute of Nuclear Techniques of the Budapest University of Technology and Economy (BME NTI). NUBIKI has activities in the fields of PSA and severe accident research. BME NTI's expertise is in reactor physics and thermal hydraulics, including Gen IV R&D. It hosts a small training reactor and a TH test loop.

MTA EK participates in the ALLEGRO project since 2010, aiming at constructing a gas cooled fast spectrum demonstrator reactor in the Central European region. A Centre of Excellence for Gen IV studies was formed among HU, SK, CZ and PL in 2013. MTA EK hosts the research on advanced fuel.

MTA EK operates a 10 MW research reactor in Budapest. The BNC (Budapest Neutron Centre) uses the research infrastructure of this reactor to conduct neutron experiments. Other facilities of the research infrastructure are the Severe accident facility CODEX (Core degradation experiment), the Pressure vessel external cooling facility CERES, the PMK-2 thermal-hydraulic test loop and the Radiation ageing of structural materials facility BAGIRA.

References: http://www.energia.mta.hu/en, http://www.nubiki.hu, http://reak.bme.hu/en/

2.1.8 The Netherlands

The nuclear R&D activities in the Netherlands are carried out largely by NRG (NEA 2015).

Research in the area of Reactor Operation & Safety is focused on:

1. Reactor safety: Hydrogen Management, Core cooling (thermal & mechanical behaviour), System behaviour, Fires, Spent fuel pool
2. Long term operation: RPV material and internals, Pressurized Thermal Shock, Fatigue, Stress Corrosion Cracking
3. Fuel behaviour & efficiency: Fuel creep

Advanced Nuclear Technology (SMR, LMFR, HTR, MSR) activities are related to:

1. Safety & design: Core cooling (thermal & mechanical behaviour), System behaviour
2. Advanced fuels & materials: Accident Tolerant Fuel & Cladding
3. Resource optimization: Fast reactor fuels, Molten salt behaviour under irradiation

As infrastructure, NRG operates the 45MW high flux reactor (HFR) in Petten. R&D examples at the HFR are: RPV steel for light water reactors, HTR graphite, thorium fuel cycle, transmutation, and fuels for fast reactors. NRG also operates several hot cells. There are plans to replace the HFR with a new research reactor PALLAS. PALLAS should be operational around 2025.

The Delft Technical University (TU Delft) is also participating in nuclear safety research, and is a partner in several Euratom projects. The TU Delft operates one 2MW research reactor (HOR) and a subcritical assembly. At TU Delft, the research is focused on Gen IV (MSR and HTGR) and SMRs, especially in relation to fuel and thermal hydraulic studies.

References: https://www.nrg.eu/, https://www.tudelft.nl/en/energy/research/nuclear-energy/

2.1.9 Romania

The Technologies for Nuclear Energy State Owned Company (RATEN) is a strategic Romanian legal Entity coordinating the R&D activity in the nuclear energy field, which maintains and develops the scientific and technological support for the National Nuclear Energy Program. RATEN has two subsidiaries: the Institute for Nuclear Research Pitesti (RATEN ICN) and the Center of Technology and Engineering for Nuclear Projects, Bucureşti Magurele (RATEN CITON).

The RATEN ICN is consistently involved in the work associated with the national nuclear safety programs: nuclear fuel, reactor physics, radiation protection, generic CANDU technologies, and management of radioactive waste. Almost all of the Institute's activities were oriented towards providing scientific and technical support for the Nuclear Power Program in Romania. The R&D programs are focused among others on:

- Nuclear safety, to ensure the technical and scientific support needed for the safety assessment of Cernavoda NPP during its lifetime
- Nuclear fuel, to elaborate technology and new methods to optimize fuel utilization in Cernavoda NPP
- Radiation protection, to integrate all aspects regarding ecological impact of nuclear power and to develop techniques for operating nuclear installations based on ALARA principles
- CANDU technologies intended to ensure an optimized maintenance of NPP systems and components

RATEN CITON services cover e.g.:

- detailed design for process and support systems associated with a CANDU-600 NPP, as well as civil design for the reactor building, the turbine hall, the service building, spent fuel and waste management and detailed design for adjacent installations and support systems for nuclear research reactors and labs
- reliability and probabilistic assessment studies
- nuclear safety analyses, including environmental impact analyses in case of accidents, fires, earthquakes, flooding etc.
- thermohydraulic calculations and stress analyses for various working regimes

RATEN ICN hosts the R&D infrastructure. A few examples of the facilities are:

- TRIGA SSR 14 MW research reactor
- TRIGA ACPR that can work up to 20 000 MW pulse
- a post-irradiation examination laboratory
- Nuclear materials and corrosion department is composed of several laboratories to study both CANDU and Gen IV materials

Romania is going to host ALFRED, the European Lead Fast Reactor Demonstrator.

References: https://www.raten.ro/?lang=en

2.1.10 Slovakia

The leading organization in the nuclear safety research and development in Slovakia is the Research Institute of Nuclear Power Plants (VUJE). It was established in 1977 as a state research institute, but privatised in 1994, meaning also a change from an originally research organisation into an engineering company that presently implements large projects mainly in the field of nuclear power generation.

VUJE performs thermal-hydraulic transient and accident analyses, probabilistic safety assessments, core neutronic calculations, and analyses of beyond design-basis accidents and accidents with severe core damage. The results of analyses are used for designing and reviewing safety enhancement, for safety evaluation, and for the development of operating procedures and emergency operating procedures. VUJE develops concept

issues of nuclear safety, carries out analyses of safety related events in plant operation. It develops drafts of safety rules and guidelines for the national nuclear regulatory authority (UJD).

VUJE has an accredited laboratory for equipment qualification with e.g. environmental test chambers for accident simulation, thermal ageing, and seismic tests.

Slovakia participates in the Gas Cooled Fast Reactor project ALLEGRO.

The IAEA (2017) mentions several other organizations which conduct research and development in Slovakia. The most relevant for reactor safety are:

- VUEZ, a.s., Levice: mechanical strength calculations
- Relko, Ltd., Bratislava: PSA and deterministic analyses
- Slovak Technical University, Bratislava: materials research

Further, the IVS (Inzinierska vypoctova spolocnost Trnava, s.r.o. /Company for Engineering Calculations Trnava, Ltd) provides services in the field of computational modelling of design basis and beyond design basis accidents.

References: www.vuje.sk, http://www.relko.sk/, www.stuba.sk, www.ivstt.sk

2.1.11 Slovenia

In Slovenia, there is no public R&D funding exclusively earmarked for nuclear fission. The Slovenian Research Agency (ARRS) as an independent public funding organisation performing tasks relating to the National Research and Development Programme and the creation of the European Research Area. Research proposals in the nuclear field need to compete for funding within the ARRS calls which include national, bi-lateral and international tenders. ARRS calls are published for a pre-defined set of fields, according to priorities set by the ARRS. The nuclear field is not mentioned specifically. Proposals related to nuclear fission/fusion are mostly submitted within the energy or material field. Calls for research and investment proposals are published. However, the ARRS budget has been decreasing in the period 2010-2015 so the financing is quite limited.

Several organizations are involved within the research in the nuclear field, mainly the Jožef Stefan Institute (JSI), the University of Ljubljana and the Slovene National Building and Civil Engineering Institute (ZAG). The JSI is the leading Slovenian research organization. Research in the Reactor engineering division of the JSI focuses on the following topics:

- Thermal-hydrodynamics
  - Modeling of basic thermal-hydrodynamical phenomena
  - Modeling of severe accidents
  - Thermal-hydrodynamical safety analyses
- Structural mechanics
  - Simulations of intergranular cracking
  - Deterministic and probabilistic structural safety analyses
- Reliability, industrial hazard and risk
  - Risk and uncertainty analyses
  - Probabilistic safety analyses

The Reactor Infrastructure Centre (RIC) is a part of JIS. The main purpose of the centre is the operation of a TRIGA Mark II research reactor for the needs of JIS and other research groups.

References: https://www.ijs.si/ijsw/Reactor%20Engineering%20R4

2.1.12 Spain

The CEIDEN is a Spanish organization for the coordination of the efforts and needs of Nuclear Fission Technology R&D. It defines and develops joint projects, and presents a common position for national and international commitments and proposals in the Nuclear Fission R&D field. The strategic agenda of CEIDEN consists of three major fields: 1) Long term operation, 2) Spent fuel and waste management and 3) New projects and technologies. One of the relevant projects is the ZIRP project, which is related to materials degradation studies based on material samples extracted from the reactor pressure vessel internals of Jose Cabrera (Zorita) reactor, currently being dismantled. Another outstanding project, the Concrete project, investigates the evolution of the material characteristics in samples removed from several concrete structures of Zorita NPP.

The CIEMAT (Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas) is an institution attached to the Ministry of Economy and Competitiveness. One of its duties is nuclear research.

In reactor safety research, the CIEMAT concentrates on developing and validating methods of analysis and risk assessment and on lowering the uncertainties in hypothetical situations that could arise in a nuclear accident. The CIEMAT is working in the following areas:

- Severe accidents
- Thermal mechanics of nuclear fuel
- Safety of innovative nuclear systems
- Materials research

The CIEMAT has a large research infrastructure. Some of the main facilities are:

- Facilities for corrosion studies (stress corrosion cracking in various environments)
- Hot laboratories (radioactive facility IR-09 with mechanical testing machines)
- Multi-purpose facility for TH and source term testing, aerosol experiments

TECNATOM is an engineering company that provides services to the nuclear industry. The main activities are related to inspection and component structural integrity services, the training of operations personnel, engineering in support of plant operation, and operating experience and corrective action management. Another engineering company participating in several Euratom research consortia is Empresarios Agrupados Internacional SA (EA). EA participates in several international projects for developing Gen III advanced nuclear reactors, and provides support services to operating plants.

The Technical University of Madrid (UPM) has a Reactor Physics group with research experience in reactor simulation. The Universitat Politècnica de Catalunya (UPC) has an Engineering Research Group with activities in the topics related to safety (PSA) and instrumentation.

References: www.ciemat.es, https://ceiden.com/wp-content/uploads/2012/07/2016-PRESENTACION-CEIDEN_INGLES_v6.pdf, www.tecnatom.es, www.empresariosagrupados.es, www.upm.es, https://nerg.upc.edu/en

2.1.13 Sweden

Sweden does not have any major single research organisation for the nuclear safety. Most of the research and development in the field of nuclear safety is performed at universities, Westinghouse Electric Sweden, Studsvik, at the Vattenfall central laboratory and by consultancies. Research to support nuclear safety supervision is focused on a number of strategic areas, such as safety assessment, safety analysis, reactor technology, material and fuel questions, human factors, emergency preparedness and non-proliferation. (IAEA 2017)

The Swedish Radiation Safety Authority (SSM) finances research assignments within basic research. External undertakings and institutions such as consulting firms, universities and colleges are the main organisations conducting research assignments on behalf of the Authority. Some of the assignments are given to foreign research institutes and consulting firms. Only a small number of research assignments are conducted by the SSM itself.

The SSM is formulating an overall research strategy in order to more closely define the type of research to be conducted, the extent of research in the short and long term as well as the extent to which the research financed by the Authority is to contribute to competence nationally.

The most important Swedish organisations supporting the safety authority in reactor safety research are the following:

- KTH Royal Institute of Technology, division of Nuclear Power Safety: severe accident research
- Chalmers University of Technology: core simulation (Chalmers is coordinating a H2020 project on core monitoring techniques), nuclear chemistry
- Studsvik Nuclear: fuel and materials testing, fuel and reactor management software
- Quantum Technologies AB (Uppsala Science Park): reactor physics, fuel, severe accidents
- Inspecta Technology: structural integrity, inspections

Other relevant consultancies are e.g. ÅF-consulting, Lloyd's Register Consulting.

The Nordic co-operation, especially between Sweden and Finland, is also worth mentioning, e.g. Nordic Nuclear Safety Research (NKS), NORTHNET for thermal hydraulics, and Nordic PSA-group (NPSAG).

As an important research infrastructure, the KTH hosts the Swedish Corium Research experimental platform to study different phenomena of corium-water interaction, jet fragmentation and debris formation and coolability. Studsvik Nuclear hosts a large infrastructure for fuel and material testing.

References: www.ssm.se, www.kth.se, www.studsvik.com, www.chalmers.se

2.1.14 The United Kingdom

The UK Nuclear Industrial Strategy, published in 2013, identified priorities that government and industry will work on together in a long-term partnership. The strategy included a better coordination of R&D and innovation through new bodies. In order to have a co-ordinated approach to nuclear R&D, the government established the Nuclear Innovation and Research Advisory Board (NIRAB), which is charged with ensuring that the publicly-funded programmes of R&D are aligned to underpin the UK Government's strategic energy and industrial policies and maximise synergies across the portfolio. NIRAB's remit includes the whole fuel cycle including existing generation, decommissioning, waste management and disposal, nuclear new build, small modular reactors, Generation IV reactors and their fuel cycles.

The NIRAB has developed recommendations for research which can be grouped into five key programmes:

1. The UK's Strategic Toolkit: Underpinning decisions on which emerging nuclear technologies are brought to market to give the best economic return for the UK.
2. Future Fuels: Making more efficient, safer nuclear fuels of the future.
3. 21st Century Nuclear Manufacture: Advanced materials, manufacturing and modular build in nuclear factories of the future.

4. Reactor Design: Delivering the people, processes and tools to make the UK the partner of choice as the world designs SMRs and 4th generation nuclear power plants.
5. Recycling Fuel for Future Reactors: Developing cost effective technologies to deliver a secure and sustainable low carbon fuel supply.

The UKs nuclear R&D capability is distributed across a wide range of public and private sector organisations, including universities, national laboratories and industrial partners. The principal R&D organisation to underpin UK's national nuclear programmes is the National Nuclear Laboratory (NNL). It supports the UK's entire civil nuclear fission programme, including continued operation of existing reactors, new nuclear build and Gen IV development.

The NNL hosts some major UK nuclear research infrastructure at several sites: The flagship facility is the Central Laboratory in Sellafield, including activities in nuclear science and plant process support. The Windscale laboratory has facilities e.g. for post-irradiation examination of nuclear fuel and irradiated materials, material analysis and mechanical testing.

The wide variety of organisations involved in nuclear R&D in the UK and their complex inter-relationships is presented in the UK R&D map (http://www.nnl.co.uk/science-technology/uk-rd-map/). It includes e.g. 31 universities and 14 private companies. Amec Foster Wheeler is a member of both ETSON and NUGENIA. The Nuclear Research Centre (NRC), which is a joint venture between the University of Bristol and the University of Oxford, is also a NUGENIA member.

References: http://www.nirab.org.uk/media/6233/uk-nuclear-innovation-and-research-programme-recommendations.pdf, www.nnl.co.uk

2.1.15 Switzerland

In Switzerland, nuclear research will continue despite the decision to not build new reactors.

The Paul Scherrer Institute (PSI) is the largest research centre for natural and engineering sciences within Switzerland, and the national competence centre for nuclear research is the Nuclear Energy and Safety Division (NES) at PSI.

The PSI's Nuclear Energy and Safety Division encompasses the following laboratories (PSI-website):

- Laboratory for Reactor Physics and Systems Behaviour (LRS)
- Laboratory for Thermal-Hydraulics (LTH)
- Hot Laboratory Division (AHL)
- Laboratory for Waste Management (LES)
- Laboratory for Energy Systems Analysis (LEA)
- Laboratory for Nuclear Materials (LNM)
- Laboratory for Radiochemistry (LRC)

The activities of the most relevant laboratories are listed below:

- LRS: Improved understanding of the complex phenomenology of nuclear safety; physics of complete fuel cycle closure in the context of plutonium management and waste reduction.
- LTH: Engaged in both analytical and experimental R&D related to the normal operation, design basis accident, beyond design basis accident and severe accident conditions of current and future nuclear power plants.
- AHL: Examination and understanding of high burn-up LWR fuel behaviour (UO2 and MOX), and damage analyses of core structural components. The laboratory also ensures an immediate support of Swiss nuclear power stations in case of urgent need of material investigation.

- LNM: Materials behaviour and ageing in nuclear installations. A special emphasis is placed to the safety and safe long-term operation of the existing Swiss nuclear power plants.
- LEA: Safety analysis based on Probabilistic Safety Assessment (PSA) and focused on Human Reliability Assessment (HRA)

The PSI participates in Gen IV research in GIF with contributions to Fast reactors (mainly SFR) neutronics and thermohydraulics analyses, high temperature materials and (in future) to MSR, and via bilateral cooperation (NEA 2015).

The main infrastructures are the hot laboratory and the large-scale, thermal-hydraulics test facility PANDA. The PSI has also several other thermal hydraulics facilities and materials testing laboratories.

References: https://www.psi.ch/nes/nuclear-energy-and-safety-nes

2.2 Member states without present nuclear energy production

The main countries without present nuclear energy production but having significant reactor safety research activities are Italy and Lithuania. Both of these states have had operating nuclear power plants in the past. A third country of interest is Poland, which is planning to build a nuclear power plant in the near future. The other non-nuclear countries do not have research organisations or activities worth mentioning in this report. These countries are Austria, Estonia, Croatia, Cyprus, Greece, Ireland, Latvia, Luxembourg, Malta and Portugal. Amongst the EU Associated Countries, it is worth mentioning Norway due to its international reactor safety research activities in Halden.

2.2.1 Italy

Despite having closed its last reactors in 1990, Italy has remained an important contributor to the reactor safety research in Europe. The leading agency for applied nuclear research is the ENEA (Agenzia nazionale per le nuove tecnologie, l'energia e lo sviluppo economico sostenibile). Although most R&D is focused on decommissioning and wastes, basic research has continued in order to maintain the nuclear option.

Since the Fukushima accident, the ENEA's nuclear fission activities have been limited to:

- Safety studies related to NPP located in other European countries close to Italy's borders,
- Waste management activities
- Decommissioning of old reactors
- Research and Development in support to nuclear of the future, namely Gen IV lead-cooled fast reactors.

The main lines of the R&D activities in safety assessment of LWRs are the following:

- Acquisition, development and validation of codes and methods for safety assessment
- Development of advanced methods, models and use of mechanistic and integral computer codes for accident analyses
- Experimental studies in support of qualification of systems, instrumentation and innovative components, and of model validation

The ENEA has several research centres around the country involved in nuclear fission and fusion research. Several research reactors are still operating, including two Triga Mark II units – the University of Pavia's 250 kWt LENA reactor (operating since 1965) and the 1 MWt Triga RC-1 (operating since 1960) at ENEA's Casaccia Research Centre near Rome. Research facilities and related activites on lead and lead-bismuth technology are located

at ENEA's Brasimone Research Centre. Thermal hydraulic test facilities are located in Piacenza.

Several universities are also contributing to the reactor safety research. The CIRTEN Consortium was established in 1994 by Politecnico di Milano, Politecnico di Torino and Università di Padova, Palermo, Pisa and Roma "La Sapienza". CIRTEN promotes the scientific and technological research, and coordinates the universities participation in collaboration with national and international research institutes.

Ansaldo Nucleare is also involved with international R&D on Gen IV new reactor systems (mainly LFR).

References: www.enea.it, www.cirten.it

2.2.2 Lithuania

Lithuania permanently shut down the Ignalina RBMK type NPP units in 2004 and 2009. The main research organisation, Lithuanian Energy Institute (LEI), is still actively involved in reactor safety research both with national funding and participating in international co-operation.

The Lithuanian government is funding long-term R&D projects. In 2016, a five-year long-term institutional R&D programme "Scientific research of safety important processes in nuclear and nuclear fusion facilities", was completed. The objective of the programme was to prepare a complex safety assessment methodology for deterministic and probabilistic analysis of nuclear fission and fusion installations with regard to uncertainties and severe accident scenarios. In 2016, a new three-year work "Expansion of best-estimate method for research of heat and neutron transfer processes" was launched.

As can be noticed from the list below, the activities of the Laboratory of Nuclear Installations Safety at LEI cover nearly all aspects of reactor safety:

- safety assessment of nuclear power plants
- analysis of new generation nuclear power plants
- analysis of thermal-hydraulic accident and transient processes
- assessment of change of thermal-hydraulic parameters in NPP containments and other premises
- simulation of transport of radionuclides and aerosols in premises
- analysis of reactivity initiated accident processes of nuclear reactor and justification of modifications in reactor core
- safety assessment of decommissioning and dismantling of nuclear installations
- reliability estimation and control of energy systems
- level 1 and level 2 probabilistic safety assessment of NPPs
- strength analysis of structures, piping and components in complex technical systems
- failure analysis and engineering assessment for complex technical systems
- risk and hazard assessment of industrial objects
- assessment of security of energy supply
- modelling and reliability assessment of processes in energy supply networks
- probabilistic modelling and analysis of unusual events
- analysis of sensitivity and uncertainty of modelling results
- fundamental research in thermal physics

The LEI also has a Nuclear Engineering Laboratory, with activities e.g. in the following areas: spent fuel safety, safety of radioactive waste management, decommissioning, assessment of fire hazard at NPPs, and research related to construction of new nuclear power plant in Lithuania.

References: www.lei.lt

2.2.3 Poland

Poland is planning to build nuclear capacity in the near future. The main nuclear research organisation is the Poland's National Centre for Nuclear Research (NCBJ). The NCBJ is participating in several FP7 and H2020 projects related to reactor safety. Poland is also financing a national project "Development of high temperature reactors for industrial applications (HTRPL)" paving the way for the demonstration of HTR cogeneration.

The Laboratory of Nuclear Energy and Environmental Studies of the NCBJ has e.g. the following activities:

- Neutron-physics analysis of research and power reactors
- Development of Gas Cooled Reactor Technology and nuclear cogeneration (ALLEGRO participation)
- Activities in the field of safety assessment, code development and validation
- Development of computing tools for the safety analysis and optimization of the exploitation of light water reactors

As a research infrastructure, the NCBJ has a 25 MW research reactor MARIA, and a nuclear materials research laboratory.

Institute of Nuclear Chemistry and Technology (INCT) does basic research, development and applications as well as various services related to the profile of its activities. The INCT has participated e.g. in cable ageing related Euratom projects (ADVANCE, TeaM Cables).

The NCBJ has signed an agreement to collaborate with the JRC, in particular in fields such as the development of nuclear technologies for power generation, cyber security and the medical applications of ionising radiation.

References: www.ncbj.gov.pl, www.ichtj.waw.pl

2.2.4 Norway

The Halden Reactor Project (HRP) is a NEA joint project operating since 1958, bringing together an important international technical network in the areas of nuclear fuel reliability, integrity of reactor internals, plant control/monitoring and human factors. The project is led by the Institute for Energy Technology (IFE) in Halden, Norway.

The HPR programme of work is in general split into two areas. The first one – the Fuel and Materials programme - includes:

- Fuels Safety and Operational Margins, including loss-of-coolant accidents
- Plant Ageing and Degradation
- International Gen IV Research.

The second one – the Man, Technology and Organisation programme - contains:

- Human Factors Research for Existing and New Reactors
- Digital Systems Research for Existing and New Reactors

The Halden Boiling Water Reactor (HBWR) is a natural circulation boiling heavy water reactor. The maximum power is 25 MWth.

https://www.oecd-nea.org/jointproj/halden.html, www.ife.no

3 Conclusions

The aim of this report is to provide a brief summary of the main research organisations and research activities in reactor safety in the EU member states. The research infrastructure is also considered, but not in detail. The report serves as a quick reference guide providing links to relevant websites.

In most EU member states, the public reactor safety research is often largely conducted in one major research organisation, with smaller activities at universities. In states with very significant nuclear industry, such as France, the UK and Germany, the research community is more scattered. It should be born in mind that in these countries there is also remarkable research done by the nuclear industry, which is mostly excluded from this report.

The co-ordination of research at national level varies a lot between the countries. One extreme covers countries that do not seem to have any national research strategy, e.g. Slovenia. The other extreme is Finland, with a long tradition of national NPP safety research programme. Many countries have defined a national research strategy, e.g. Nuclear Industrial Strategy in the UK, CEIDEN Technology Platform in Spain, or Sustainable Atomic Energy Technology Platform in Hungary.

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NEA 2015. NEA International Workshop on the Nuclear Innovation Roadmap (NI2050), Paris 7-8 July 2015. https://www.oecd-nea.org/ndd/workshops/ni2050/

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List of acronyms

ADS	Accelerator driven system
ALARA	As low as reasonably achievable
CFD	Computational fluid dynamics
DBA	Design basis accident
EU	European Union
FP7	Framework Programme 7
H2020	Horizon 2020
HLM	Heavy liquid metal
HLW	High level waste
HRA	Human reliability assessment
HTGR	High temperature gas cooled reactor
HTR	High temperature reactor
IAEA	International Atomic Energy Agency
JRC	Joint Research Centre
LFR	Lead-cooled fast reactor
LMFR	Liquid-metal-cooled fast reactor
LTO	Long term operation
MS	Member state
MSR	Molten salt reactor
NDE	Non-destructive examination
NEA	Nuclear Energy Agency
NPP	Nuclear power plant
OECD	Organisation for Economic Co-operation and Development
PSA	Probabilistic safety assessment
R&D	Research and development
RPV	Reactor pressure vessel
SCWR	Supercritical water reactor
SFR	Sodium-cooled fast reactor
SMR	Small modular reactor
TH	Thermal hydraulic
TSO	Technical safety organisation
ZPR	Zero power reactor

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