SNETP FORUM 2023 PROCEEDINGS

July, 2023

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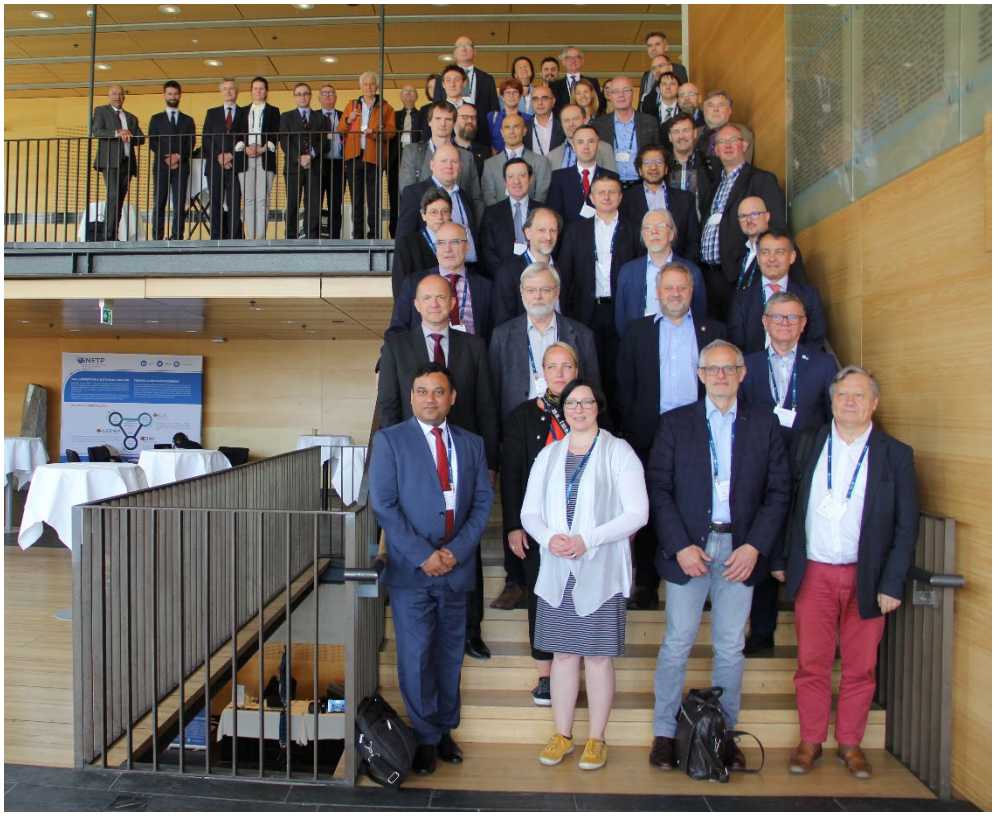
1. Executive Summary



SNETP General Assembly

SNETP is an international association (AISBL) composed of around 110 members from 25 countries, gathering nuclear power plant operators, research centres, nuclear industry and technical support organizations. The association has been supporting the creation and the implementation of R&D programmes since 2007.

European Technology Platforms (ETPs), such as SNETP, are industry-led stakeholder fora recognised by the European Commission as key players in driving innovation, knowledge transfer and European competitiveness. Among their numerous activities, they develop research and innovation agendas supported by private and public funding for an implementation at EU but also at member state levels.

SNETP believes that continuous technological innovation is fundamental to maintaining a high-level of safety and competitiveness in the EU nuclear sector and requires the establishment of a coordinated R&D&I programme at European level in close collaboration with international partners. In a context of climate change and global competition, SNETP is convinced that nuclear energy can play a significant role in meeting climate objectives as a zero-greenhouse gas emissions energy source, especially in areas there are not easy to decarbonise like industry and transportation.

The SNETP FORUM 2023 was held from 15th May to 17th May 2023 in Gothenburg, Sweden hosted by the Chalmers University of Technology. Over 200 participants from all European countries were actively involved in this edition.

The main aim was to discuss and analyse recent technological innovations in the field of SMRs, AMR and advanced nuclear, safety, waste management & recycling, non-electricity applications, LTO and improved NPP operation, fuel elements and hybridisation, to enable the nuclear sector to play its role in the mitigation of climate change and to contribute to climate neutrality. The aim is to underpin the topics of interest to the European community and those that would eventually lead to R&D and innovation priorities and the harmonization of best practices within EU countries and beyond. Methodologies should be shared between LWR, Gen IV and ADS development for reinforcing innovation in nuclear technologies.

In addition, plenary sessions were dedicated to:

- The host policy and planning: Sweden that had the opportunity to present its energy mix and its national strategy towards nuclear, in a context where Sweden recently changed its government and is assuming the EU presidency for 6 months. The new government views nuclear as an essential component of shift towards a sustainable and reliable energy production.
- The Challenges of the nuclear sector to play its role in tackling Climate Change discussed by representatives from the IAEA, the European commission DG-RTD, DG-ENER and DG-JRC and some representatives of EU member states and Ukraine
- How nuclear sector can collaborate with other sectors discussed by invitees from EERA, PIANOFORTE.

Presentation of the Swedish energy mix and strategy toward nuclear

1.1. Organisation

The programme was designed with the help of the Scientific and Industrial Innovation Committee (SIIC) including moderators of the SNETP FORUM:

- ✓ Abderrahim Al Mazouzi (EDF)
- ✓ Marco Cherubini (NINE),
- ✓ Fulvio Mascari (ENEA),
- ✓ Stéphane Sarrade (CEA),
- ✓ Pavel Kral (UJV),
- ✓ Sanjeev Gupta (BT),
- ✓ Anthony Banford (NNL),
- ✓ Gerald Senentz (Orano),
- ✓ Jozef Sobolewski
- ✓ Dominique Hittner (USNC),
- ✓ Michael Futterer (JRC),
- ✓ Ferry Roelofs (NRG),
- ✓ Marc Schyns (SCK CEN),
- ✓ Marco Frigani (ANN),
- ✓ Jean Dhers (Framatome),
- ✓ Sasha Szabolcs (Bay Zoltan),
- ✓ Luis Enrique Herranz (Ciemat),
- ✓ Marjorie Bertolus (CEA),

And the organisation committee:

- ✓ Abderrahim Al Mazouzi (EDF)
- ✓ Gilles Quénéhervé (LGI)
- ✓ Clara Demange (LGI)
- ✓ Candice Boudet (LGI)
- ✓ Alina Giesler (LGI)
- ✓ Zahra Kharbouch (LGI)

2. Plenary Session 1

The SNETP Forum 2023 was introduced by the host, C. Ekberg Professor Nuclear Chemistry in the Chalmers University of Technology, by the city, H. Eriksson, Deputy Lord Mayor of Gothenburg Town, and by the country, M. Lundbäck, political adviser on Energy to Deputy prime minister of Sweden.

Following this warm introduction from Sweden, the SNETP president opened the 2023 SNETP forum.

2.1. Presentation of the Swedish energy mix and strategy towards nuclear

The first session of the forum was dedicated to the Swedish energy mix and the national strategy towards nuclear, in a context where Sweden recently changed its government and is assuming the EU presidency for 6 months. The new government views nuclear as an essential component of shift towards a sustainable and reliable energy production.

This round table was moderated by Maja Lundbäck, political adviser on Energy to Deputy prime minister of Sweden.

As an introduction to the session, she shared her views explaining that a battle of power sources was taking place in the recent decades in Sweden, which posed problems for the security and reliability of energy supply. Sweden is now facing new challenges such as:

- The expansion of the energy system,
- Its performance when making various energy sources coexist,
- The need for further electrification,
- The necessity to keep power prices as low as possible,
- The reduction of Sweden reliance towards fossil fuel

The Swedish Parliament will vote on the energy mix in the coming months. Restrictions for further NPP development were removed in order to allow for the potential construction of new NPPs.

- **Per Seltborg**, Swedish Radiation Safety Authority, **Challenges and Opportunities about Nuclear Safety and Radiation Protection in Sweden**

P.Seltborg presented the role of the Swedish Radiation Safety Authority (SRSA) and its recent work to ensure safe nuclear production in line with the regulatory framework for nuclear in Sweden.

In the past few months, nuclear has been receiving new political support and increased funding. This development of new nuclear in Sweden underlined challenges and opportunities such as:

- **Challenges**: growing need for qualified personnel; radiation protection, waste management, emergency preparedness; international harmonization.
- **Opportunities**: robust and competent nuclear community, increased funding and growing interest for nuclear at national level, new comprehensive regulatory framework.
- **Carl Berglöf**, Secretary General, Swedish Atomic Forum, **Outlook for new nuclear power in Sweden – Supply chain, R&D and EU cooperation**

In Sweden, 98% of electricity production is fossil free (29% from nuclear with 6 units in operation, 41% hydro, 20% wind, 9% CHP and 1% solar) The country was the largest exporter of electricity in 2022 in Europe (40TWh).

The country managed to partially decouple GDP and emissions (due to nuclear power programme, low-carbon district heating, CO2 tax) and they target carbon neutrality by 2045.

Sweden is likely to face a huge increase of its electricity needs which may double by 2035-2045 posing challenges to the security of supply.

Hence the need for dispatchable power: flexibility & capacity mechanisms are being developed.

The general outlook for new nuclear power in Sweden is the following:

- The political risk is clearly decreased,
- Legislation will be adjusted to simplify for a new programme to allow nuclear reactors at new site,
- Safety adjustments are being planned to customize to SMR specific needs, including licensing process,
- The financial model is not settled to support the development of complements of the electricity market,

The EU needs to balance all low-carbon options, and support nuclear, not only renewables.

- **Björn Linde**, Managing Director, Forsmarks Ktaftgrupp AB. Vattenfall, **Swedish programme for long term operation**

Two Vattenfall's sites were presented:

- Ringhals; focused on pre-study to consider the construction of SMRs and potentially new conventional reactors,
- Forsmark: focused on LTO

Three years ago, Vattenfall started reflecting in terms of fossil-free energy rather than just renewables. This meant that nuclear power was emphasized as a heavy and important part of Vattenfall's future production portfolio, along with wind and hydro power.

Their focal point to understand SSC ageing is on:

- Materials and materials properties
- Stressors and operating conditions
- Ageing mechanisms
- Degradation sites
- Condition indicators
- Consequences of ageing degradation and failures

Vattenfall works with a number of external relevant organisations and companies such as: EPRI, DKC, KTH, Studsvik, SNETP, Uppsala, FROG, VTT. Vattenfall's strategy is to collaborate and thereby build networks and spread our knowledge while bringing in new ones.

- **Ane Håkansson,** Professor and Director of ANitA, **Presentation of the Swedish national competence centre ANItA,**

A. Håkansson highlighted that SMRs are a complementary technology which could reduce the costs and construction time with SMR based on LWR technology.

ANitA aims to bring together Industry, Academia and State. ANitA ensures that realization of light-water SMRs, can be an important part of arriving at Swedish Net Zero 2045 plans. To achieve this, the idea of ANitA is to provide knowledge based information and know-how to the politics and policy makers to create new knowledge and competence.

In this perspective, 14 research projects were launched, including:

- The national context
- Fuel and core
- Legislation, licensing and regulation
- Project and financial models
- Technical and non-technical aspects of safeguards
- Novel reactor monitoring systems
- Safety analysis methodologies
- Structural materials
- Recycling of spent fuel

ANitA established a collaboration with founders and financiers from academia (Uppsala University (host); Chalmers Institute of Technology ; Royal Institute of Technology), industry (Fortum Power and Heat Oy; Studsvik Nuclear AB ; Sydkraft Nuclear Power AB (Uniper) ; Vattenfall AB ; Westinghouse Electric Sweden AB) the Swedish Energy Agency and some observers (The Swedish Radiation Safety Authority; STUK; WiN Sweden).

2.2. Challenges of the nuclear sector to play its role in tackling Climate Change

- **Aline des Cloizeaux,** Director**,** Division of Nuclear Power, Department of Nuclear Energy of the IAEA

The general and actual context is the climate emergency, according to IEA "Global emissions rebound sharply to highest ever level". Nuclear is the energy source with the smallest carbon footprint.

Deployment challenges are being addressed and discussions started in different fora (COP, G20 and CEM) looking at four main topics:

- Policies,
- Public acceptance,
- Costs and access to finance,
- New technologies and initiatives (*more than 20 countries working on new technologies and initiatives*).

A. De Cloizeaux, emphasized on three main points:

- Emergence of the SMR market and offer – more than 80 SMR designs were registered in the 2022 IAEA ARIS Database but mostly not from EU stakeholders / countries.
- The many flexible applications of SMRs: electricity generation, process heat, replacement of ageing fossil plants, integration with renewables, desalination of water. The interest on non-electric applications of nuclear power is growing, driven by a series of factors, including environment, economics, and security of energy supply. SMRs can be adapted to non-electric applications according to their key operating parameters, which in this context is exit working fluid temperature.
- Harmonization and standardization: NHSI – with the NHSI, AIEA is working through 3 working groups on regulatory track and four topics addressing industry track. Results are expected by 2024 with recommendations for future work.

- **Rosalinde Van der Vlies: DG-RTD, Head of Clean Planet for all, European commission**

R. van der Vlies, welcomed SNETP discussion on the most recent technological innovations in the field of SMRs, nuclear safety, waste management, etc… For her, SNETP is playing a crucial role in supporting the creation and implementation of European R&D programmes.

R. van der Vlies, presented some highlights of the EC work:

- RePower EU Plan (especially in the geopolitical context regarding Russia),
- New EURATOM WP 2023-2025 (with a budget of 132M€),
- Preparation of the SMR partnership (potential investment of 20M€ on the next call for proposal) to develop a European SMR design starting by LWR,
- SET-Plan, the IWG nuclear safety will play a key role toward climate neutrality. The revised SET – Plan will go beyond electricity production such as hydrogen production.

- Importance of nuclear expertise for all European nuclear plants for inspection of nuclear power plants, for safety standard, for the management of nuclear waste, for medical application and for exploration.
- Close collaboration with Members states through co-funded partnership under the EURATOM programme (EURAD, PIANOFORTE, EUROFUSION and CONNECT-NM).

These actions are supported by policy development in the EC:

- Approval of the delegated act on the Taxonomy regulation,
- Commission proposal for the NET Zero Industry Act (fusion, SMR and advanced reactors are mentioned as strategic innovative net zero technologies)

- **Zuzana Petrovičová,** Head of Unit, DG ENER, European Commission

Z. Petrovičová structured her speech around three mains topics : policies, challenges and the EC role.

Energy policies remain mostly a national prerogative. Each Member State maintains its right to 'determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply' (Article 194(2)).

Challenges faced by the EU in the field of energy are numerous and a variety of measures aiming to achieve an integrated energy market, security of energy supply and a sustainable energy sector are at the core of the EU's energy policy. DG ENER launched a nuclear ecosystem study, and the results will be presented at Bratislava.

In this context, the EC role will be:

- Set up a clear taxonomy (nuclear belongs to sustainable energy now).
- Promote the Net Zero Industrial act – nuclear is included (SMR) in this act.
- In the Electricity market: nuclear is included.
- The SMR Partnership – launched the pre-partnership with 5 work streams.

- **Manuel MARTÍN RAMOS,** Deputy Head of Unit, JRC, European Commission, **Challenges of nuclear research in the EU**

M. MARTÍN RAMOS started his presentation by setting the scene of the current panorama. Within this context he reminded the legal basis of the JRC and the value propositions based on three axis: anticipation, integration and impact.

The JRC counts a large project portfolio (33) that can be put in line with the Commission priorities.

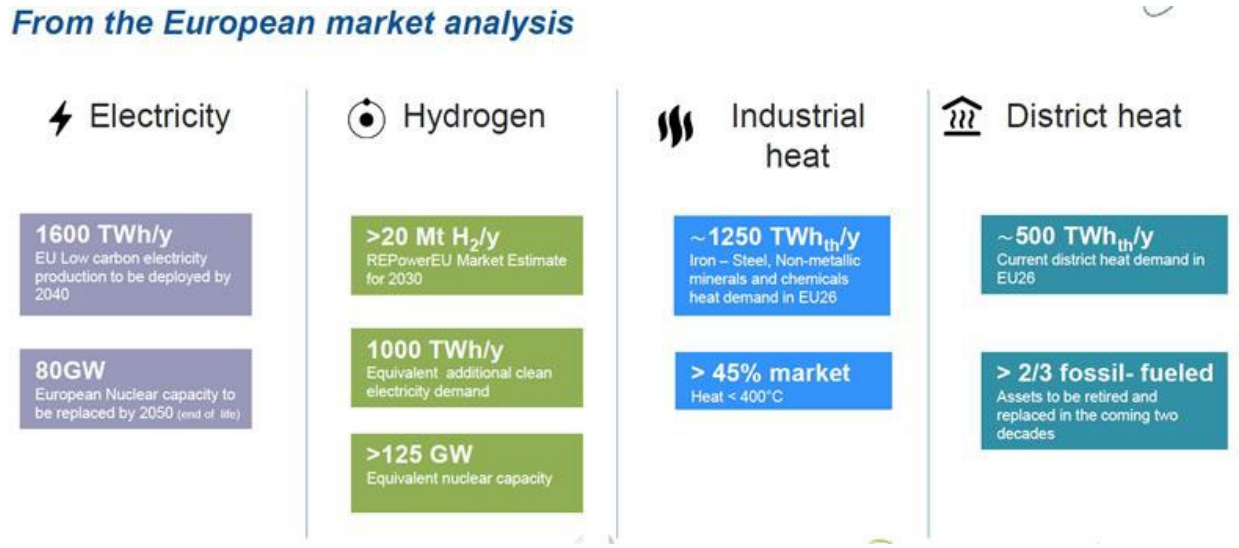
In this portfolio, JRC has Euratom direct actions and a dedicated Research and Training Programme.

He provide a presentation of the Euratom direct actions in the JRC portfolios. JRC is open and looking for partnership.

- **Anicet Touré,** Head of Nuclear Strategy and Innovation – Tractebel ENGIE / Chair of European SMR Pre-Partnership WS1 (market), **EU SMR Market analysis in the EU**

In the SMR Pre-partnership - WorkStream1 on Market analysis, the aim is to assess the future needs of the EU energy / power market in the context of high RES and address the SMR potential in that context.

Market assessment by literature analysis was done with a focus on electricity, hydrogen, industrial heat and district heat.



This analysis led to 3 highlighted scenarios:

- Current projection (little is done to push SMR deployment)
- Boosted deployment (enabling framework enables to get 10 SMRs per years from 2035)
- Net zero 2050 (with a retro-planned ambitious market)

Currently, 8 countries have an SMR programme.

In conclusion, European market needs for low-carbon energy are gigantic. More than 2GW of SMR installed capacity can realistically be expected by 2035 (ca. 10 SMRs). Market upscale is THE challenge to increase deployment rate between 2035 and 2040 (3 to 20 SMRs per year). If we reach approximatively 100GW from Small Modular Reactors by 2050, which is possible, we would facilitate pathways to net zero 2050 .At its peak deployment (around 2040), the European SMR market could represent 7.5 to 20 Billion € in annual revenues for European companies.

- **Peter Baeten,** General Director SCK CEN, **SMR strategy in Belgium**

A new initiative in Belgium for SMR R&D&I is based on innovative concepts with a budget of €100M (4years). The evaluation of SMR concepts was conducted at the national Belgian level.

SCK CEN compared SMRs concept based on 8 criteria organized around 3 pillars:

- Reducing potential impact
- Benefits to the Belgian economy
- Responsible and timely planning of the future energy landscape.

Belgium decided to focus on MYRRHA which is a world class technology complex to serve HLM SMR development. MYRRHA (SMR-LFR) is an added value if you look at a development as soon as possible.

SCK CEN recommended to the Belgian government to choose for SMR-LWR building (instead of a lead bismuth), to develop strategic international partnership from the very beginning of the research process and keep the nuclear know-how in Belgium. Pre-licensing should start in 2024, construction after 2030, and commissioning after 2036

SCK CEN also benefits from other SMR LWR developments for the licensing, construction and commissioning

SCK CEN prepared a work plan for the Belgium government and wait to be implemented.

But currently, the assumptions for the construction of the demonstrator are the need for international consortium, the access to the knowledge accumulated within the MYRRHA programme experience and the access to an existing LFR design.

- **Zbigniew Kubacki**, Senior Policy Adviser in the Polish Ministry of Climate and Environment, Poland

The energy policy in Poland until 2024 is based on three pillars: just transition, zero-emission energy system and good air quality. Focusing on the zero-emission energy system, Poland chooses to focus on:

- Offshore wind: about 8-11 GW to 2024
- Nuclear energy: build 6-9 GW of installed nuclear power capacity
- Distributed and prosumer energy

Poland will replace the coal power plants by NPPs.

SMR is not included yet in the Polish long term plan but will be included in the updated version. Numerous projects led by private companies but not yet included in the Long Term Energy Strategy however, polish government recognizes the potential of SMRs, especially for the polish power industry and for industrial companies' own needs

At the moment, Polish private industries (ZE PAK, PGE) signed with Korea colleagues a letter of intent to build a third NPP with the APR1400 technology. HTGR (for industrial cogeneration) is also officially envisaged; NCBJ was mandated to explore HTGR development.

In regards with public acceptance, Poland benefits of a huge support of the population. 86% of the respondents confirmed their support for construction of NPP in Poland and local societies support the construction of a nuclear plants by 75%

Looking at international collaboration, Czech Republic and Finland are the main support of Poland.

- **Jan Larsson**, Metheus Energy, **The West Atomic Alliance Story**

Pro nuclear parties are an active participant in the new Swedish government since September 2022.

The closure of several NPPs in Sweden was not in favor of consumers because this decision:

- harmed energy security in general
- impacted the electricity prices.

Privately owned electricity production mitigates political risk and upcoming changes in nuclear regulations will create new opportunities. We should ensure they favor SMRs to support SMR deployment.

3. Plenary Session 2

3.1. How nuclear sector can collaborate with other sectors.

- **Ivan Matejak**, EERA Operations Director

EERA counts in 2023 18 pan-european joint research programmes out of which two are dedidated to materials, ten on low-carbon technologies and six on systemic research areas.

Six joint programmes are relevant to collaborate closely with SNETP, the most natural one is on Nuclear materials (JPNM). SNETP has already a close relationship with this joint programme. But the collaboration can also be relevant for five more joint programmes:

- Energy efficiency in industrial processes – coordinated by TNO (Yvonne van Delft)
- Energy systems integration – coordinated by TU Delft (Laurens de Vries)
- Carbon capture and storage - coordinated by SINTEF (Marie Bysveen)
- Fuel cells and hydrogen - coordinated by VTT (Jari Kiviaho)
- Advanced Materials and Processes for Energy Applications: from discovery to innovation – coordinated by CEA (Sawako Nakamae)

EERA and SNETP must work together on the identification of areas of collaboration between nuclear and other energy sources. Materials is a real opportunity for SNETP to work with EERA joint programmes.

Nuclear energy and renewable sources, such as solar and wind, can work together to provide a stable and reliable energy supply (baseload, intermittence, grid stability)

Integration of nuclear and renewable energy can stimulate innovation and drive down costs, making clean energy more accessible and affordable for all.

A new joint programme will be created in the coming months on Digitalisation for energy, coordinated by CIEMAT, but they still need a strong support from the European Commission and Members States to make it happened.

- **Jean Christophe Gariel**, IRSN, Coordinator of PIANOFORTE

PIANOFORTE is a European partnership launched on 14 and 15 June 2022, with a 46M€ budget for 5years

The general objective of PIANOFORTE is to improve radiological protection of members of the public, patients, workers and environment in all exposure scenarios and provide solutions and recommendations for optimized protection in accordance with the BSS. This objective will be reached by multidisciplinary research, innovation and citizen involvement activities in a collaborative approach of scientists, regulators and stakeholders. Research projects focusing on identified research and innovation priorities will be selected through competitive open calls.

The first open call has been launched in 24th April on three topics:

- Developing a knowledge base for a better understanding of the disease pathogenesis of ionising radiation-induced cancer to improve human health risk assessment.
- Individualised diagnostic and therapeutic procedures for optimisation of benefit/risk ratios.
- Development of risk assessment and risk management approaches and technological capabilities to cope with scenarios arising from threats due to war or armed conflict situations or natural disasters taking into consideration social, ethical and legal issues.

PIANOFORTE took into account SNETP comments on its scope and collaborate closely through the OFFERR project.

- **Andrea Kozlowski** president elect of ENS YGN, **Multigenerational nuclear community: the foundation of a the European nuclear future**

The ENS YGN is a network of networks established in 1995 representing approximatively 4.000 young people from students to young professionals.

The ENS YGN performs multiple actions such as:

- Scientific and technical exchange
- Scholarships,
- Cooperations with IGOs and NGOs
- Bridging generational gaps,
- Knowledge exchange & support of national ideas, projects, etc.
- Sharing opportunities for young people

A way for SNETP to involve young people could be to communicate more in the University about job opportunities and go and meet researchers.

- **Domenico Rossetti di Valdalbero**, Deputy Head of Unit, DG RTC CA, European Commission

Europe is facing a particular political context that force us to strengthen unity & solidarity among Europeans to overcome the energy crisis and to ensure security of supply of nuclear fuels.

To face these new challenges the European Commission worked on the NextGenEU & RePowerEU & Delegated act on EU Taxonomy, defined terminology (Strategic autonomy, Sovereignty, Security, Affordability, Competitiveness) and will invest more on nuclear power generation capacity *(Commissioner Simson (ENEF, 10-11/11/22): The EU will need up to €450 B in investment just to keep the current level of its nuclear power generation capacity).*

For this, the EC will use the Euratom programme and the revamping of the SET-Plan. But the EC needs the Members States to work together and synergies has been found with European co-funded partnerships in EURATOM:

- Fusion with EUROfusion
- Radiation Protection with PIANOFORTE
- Radioactive Waste Management with EURAD
- Nuclear Materials

One step further is the Euratom research in action and the declaration on SMRs signed also by SNETP on 4 April 2023.

On 17 March, the Euratom WP has been published with a budget of 132Millions Euros for 2023-2025.

- **Gumenyuk Dmytro**, Head of the SSTC NRS Safety Analysis Unit, **Main Trends in Safety Analyses for Ukrainian NPPs**

G. Dmytro presented the main trends in safety analysis for Ukrainian NPPs:

- Life-time extension of NPPs;

Over the past 15 years, Ukraine has accumulated significant (unique) experience in long-term operation of different types of VVER-1000 and VVER-440 units. Currently, there are no methodological and technical problems in implementation of activities on long-term operation of NPPs.

- Increasing the safety level of Ukrainian NPPs and implementing the post-Fukushima measures;
    - Qualification of systems and components

- SFP feeding and cooling
- SG feeding
- Essential service water supply
- Mobile DG (low power)
- PAMS
- Prevention of early containment bypass
- Hydrogen removal systems
- CFVS
- SAMG

- Nuclear fuel diversification for NPPs with VVER-1000 and VVER-440 type reactors;

Challenges under new fuel introduction are:

- Reducing licensing time ® Development of common and harmonized approach for new fuel licensing
- New fuel introduction under LTO ® Investigation of different concepts to reduce radiation load on the reactor vessel and reactor internals
- New fuel operation in “mixed” cores ® Enhanced modelling of “mixed” cores

- Licensing of new nuclear installations;

SSTC NRS is involved in the U.S. SMR’s design assessment:

- June 2019: Holtec International, “Energoatom” and SSTC NRS signed the Partnership Agreement
- January 2020: NuScale and SSTC NRS signed the MoU
  - Ongoing SSTC NRS SMR activities:
  - NuScale support in gap analysis;
  - Independent NuScale FSAR review;
  - FIRST activities;
  - SASPAM-SA

- Activities on assessing current state and plans on safety analysis of the Zaporizhzhia NPP as part of restoring regulatory control and its operation.

Nuclear power is most reliable power generation under Russian military aggression. NPPs safety improvement activities are performed despite the war.

4. Technical session 1 – SMRs, AMRs and Advanced Nuclear Systems

This technical session was moderated by Marco Cherubini (NINE), Michele Frignani (ANN), Fulvio Mascari (ENEA), Stephane Sarrade (CEA), Marc Schyns (SCK CEN), and Ferry Roelofs (NRG)

4.1. Scope

Innovative technologies and solutions are needed to ensure that a whole range of competitive and adapted nuclear solutions will be available in convergence with other power generation technologies, providing improved speed of construction and extended implementation possibilities in local systems. In addition to the nuclear reactors in operation and those under construction, Europe needs to expand the range of reactors technologies available to meet national/local specificities. The development of different SMRs, based on most matured technologies or on other advanced technologies, offers the possibility to deploy flexible options for both power and non-power applications and contribute to decarbonization. R&D&I should support the development of SMRs to make them safe and competitive with other means of production as part of a global deployment strategy over the coming decades.

4.2. Summary of technical sessions

4.2.1. Member State Programmes (S. Sarrade, CEA; M. Pukari, Fermi Energia, A. Blennermark, LeadCold)

Member state programmes in France, Estonia, and Sweden were presented. The France 2030 programme aims at strengthening competitiveness and future technologies, including LW-SMRs and AMRs. The budget allocated for the programme is about 1 B€ for a period of 10 years and the programme will be executed in partnerships between the industry, research organizations, and start-ups. The SMR programme in Estonia aims primarily at energy security. The key areas of the programme are site selection, building up the workforce, and the selection of the preferred technology. Currently, the BWRX-300 of GE-Hitachi has been selected as the preferred technology. In Sweden, the AMR programme aims at breakthrough technologies that can decarbonize the industry sector. To that respect, lead-cooled systems are under development. An electric mock-up and a demonstrator are currently being planned.

4.2.2. NUWARD (S. Durand, NUWARD)

The NUWARD reactor design and R&D programme were presented. The design includes an integrated reactor pressure vessel, a wide deployment of passive systems, and aims at boron-free operation. The R&D programme includes test campaigns which aim at demonstration of the performance of new components and/or systems, e.g. mechanical wear, vibrations, and drop time of the Control Rod Drive Mechanism, separate and integral effect tests of the pressurizer, flow mixing in the pumping system, the bottom vessel, the core exit, and the steam generator inlet, performance and control of the compact steam generator, demonstration and code validation of the safety heat removal system, and performance of the cooling system of the spent fuel pool. In general, code validation plays an important role.

4.2.3. SMR Safety Research Needs (O. Marchand, IRSN)

SMRs are under consideration in Europe. This means that TSOs have to prepare safety assessment of such new designs. Important safety implications that need to be checked for SMR innovations are to prove the

performance of passive safety systems under all circumstances, to assess severe accident management, to deal with organizational and human factors, e.g. with respect to common control rooms, to analyze reactor physics and criticality, to check the performance of new steam generator designs, and to deal with the impact of small containments. Dedicated experiments and development and/or adaptation and validation of simulation tools will be a crucial part of this exercise.

4.2.4. SMR Pre-Partnership (S. Takenouti, EDF)

Although the SMR pre-partnership centralizes also on many other topics, in the frame of the SNETP Forum, the focus was on workstream 5 'R&D roadmap for European SMR development' aiming at the definition of an R&D programme for LW-SMR and AMR, taking into account R&D programmes set up by the designers and/or vendors. To this purpose, the programme identifies facility needs and considers an education & training programme. Currently, the focus in the programme is on European SMR designs and international SMR design seriously under consideration in the EU member states. Five designs have been pre-selected for considerations: NUWARD, LDR-50, Rolls-Royce SMR, BWRX-300, VOYGR. The R&D programme considers the following topics: Core/fuel, NSSS Integrated vessel and its internals, Passive systems, Severe Accidents, Modularity, Human Factors and autonomy, and uses beyond electricity. Obviously, this work will provide important input for running and future European collaborative projects.

4.2.5. SMR in Euratom (C. Vaglio-Gaudard, CEA; F. Mascari, ENEA; J. Tissot, EDF)

In short, the activities within two ongoing European collaborative projects were outlined. The TANDEM project is about the assessment of safe and cost-effective integration of SMRs in a hybrid low-carbon energy mix and provide guidance. The project includes the development of methods and tools implemented in case studies, e.g. district heating & power supply in Finland and Czech Republic, and energy hub in Western European harbor area. The SASPAM-SA project investigates the applicability and transfer of knowledge from large LWRs to the deployment of iPWRs with respect to severe accident and emergency planning zone. The project aims at speeding up licensing and siting of iPWRs and includes dedicated actions on ATF and IVMR. Finally, the project uses a combination of experiments and simulations for the analysis of generic submerged iPWR and dry containment iPWR.

For the upcoming Euratom call, a proposal is being prepared linked to the European LW-SMR projects NUWARD and LDR50 designs. The tentative work programme includes acceptability, environmental impact, co-location near cities, integration in hybrid systems, passive systems, additional test campaigns for validation and demonstration, human factors (e.g. main control room for a multi-unit operation), application of additive fabrication, and new materials and/or powders beyond 316L. The proposal is open for participation.

4.2.6. AMR (F. Franceschini, WEC; M. Schyns, SCK CEN; J. Sobolewski, NCBJ, F. Mascari, ENEA)

The SNETP pillars ESNII and NC2I shortly presented their goals and programmes. ESNII aims at deployment of fast neutron systems and more specifically ALFRED, ALLEGRO, and SFR. The lead-bismuth cooled system MYRRHA is considered an important asset as a testbed for fast neutron reactor technology. Recently, also MSR systems are included within ESNII as emerging technology. NC2I aims at deployment of cogeneration systems. Apart from district heating applications which can be achieved by almost any kind of nuclear reactor, specific attention is being paid to addressing the decarbonization of the industry by not only

providing electricity, but also high caloric hear. To that respect the GEMINI HTR programme and the Polish prismatic HTR are important assets.

The recently established OECD/NEA Expert Group on SMRs was also presented. Apart from LW-SMRs, this expert group especially also considers advanced technology SMRs (AMRs). The expert group is roughly prioritizing safety knowledge gaps and putting up recommendations to address these gaps. Finally, Westinghouse presented it's AMR design based on a lead-cooled system aiming at decarbonization of the industry sector, closing fuel cycle, enhancing siteability, ad including a thermal energy storage system to increase flexibility.

4.2.7. Round Table on Start-ups (V. Tulkki, VTT; L. Cinotti, Newcleo; S. de Groot, Thorizon; P. Gauthe, Hexana; A. Blennermark, LeadCold)

A round table was organized inviting European start-ups in the SMR field. The main messages from the interesting discussion were:

- Start-ups have a common aim to design an economic, safe and reliable reactor. However, their solutions are different.
- Start-ups typically have a positive attitude which raises enthusiasm and makes them attractive, e.g. to attract new employees.
- Security of supply is becoming more and more important and sooner than we think.
- A reactor should not only be manufacturable and licensable, but above all also 'sellable'.

As hurdles or challenges towards deployment, the following was mentioned:

- (Local) public acceptance and support
- New business models
- Material qualification
- Qualification of innovative components
- Component reduction to remain economic
- Fuel fabrication
- Back-end of the fuel cycle, incl. recycling
- (Passive) Safety demonstration
- Severe accident management
- Development and validation of simulation tools and design codes

The start-ups were asked to provide feedback towards SNETP. First and above all, they mentioned that start-ups emerge from past experience and to that respect it is clear that SNETP members are the foundation on which they build. Further, they advise to be open and to embrace the start-ups, to create a clear goal (like John F. Kennedy's goal: to the moon and back), to support advancing the regulatory framework, to act as a bridge between start-ups and established sector (vendors, supply chain), to support improvement of codes and standards, and to promote cross-cutting R&D.

4.2.8. Key Learnings

The session highlighted the significant efforts and budgets being directed towards SMR/AMR deployment in member states and companies. The major R&D&I topics which were identified are:

- Construction

    - Siting
    - Modularity
    - Additive manufacturing

- Safety
    - Harmonization of regulation
    - Passive system
    - Experiments and simulation tools
    - Multi-scale, multi-physics
    - Multi-unit effects
    - Severe accident management
    - Cyber security
- Operations
    - Human factor
    - Fuel (enrichment, geometry, ATF, triso)
    - Fuel cycle development
    - Core (boron free, small, baffle)
    - Transportation
    - Education and training
- Integration in energy mix
    - Integration in the energy mix, incl. non-electricity applications
    - Business models
    - Public acceptance

A common understanding was that the 'Nuclear sector should be dynamic, innovative and trustworthy'.

5. Technical session 2 – Safety Research and LTO & Improved Plant Operation & Maintenance

This technical session was moderated by Pavel Kral (UJV), Sanjeev Gupta (BT), Jean Dhers (Framatome) and Szavai Szabolcs (Bay Zoltan).

5.1. Scope

The enhancement of high safety standards is a must for the nuclear industry. In order to assure the optimum performance of the running nuclear reactors and the development of even safer and more competitive European reactors, ambitious R&D&I programmes are needed. Recently, there are two elements that draw the attention of a good part of the international community: passive systems (to a good extend related with SMRs, but not only) and new nuclear fuels (EATF), potentially capable to perform better under both even more demanding nominal conditions (I.e., higher power rates; longer irradiation times) and off-nominal conditions. For power plants in operation, nuclear must continue to develop R&D&I programmes in the areas of accidents and hazards such as earthquakes, fire or severe accidents but also on methodological approaches such as Probabilistic Studies. Climate change and its consequences should also be considered in the way the sector envisage safety and resilience of nuclear power plants more globally.

5.2. Summary of technical sessions

5.2.1. Nuclear safety: What research for what objectives (P. Giordano, IRSN)

In the view of the IRSN, the main objectives of nuclear safety research are connected with 2 tasks: extension of reactor operation (LTO) and commissioning of new reactor types.

Regarding LTO, scientific questions should concern in-depth knowledge of the alteration processes of the key components of nuclear facilities (in order to identify the possible modes of degradation), the development of more relevant innovative techniques in non-destructive testing and online monitoring (to better characterize the condition of equipment).

Regarding new reactor designs, nuclear safety research should be oriented to prepare their safety assessment and encourage the taking into account as early as possible of the requirements in this field to facilitate the subsequent assessment process. Research needs would concern behaviour of new material (i.e new fuels -ATF, properties of additive manufactured material), behaviour of new systems (i.e. passive systems), and Human Factors & Organisation to handle new questions (i.e. question on new operating process).

5.2.2. KIT safety-related activities for LWR, LW-SMR and potentials applications to research reactors (V. Sanchez, KIT)

There is an increased interest to deploy both European SMR-designs (NUWARD, LDR-50, etc.) and non-European SWR like NuScale, BWRX-300, etc. in different European countries. Among other, the safety demonstration based on the current EU regulatory framework is an important challenge. For this purpose, validated numerical simulation tools and dedicated tests (single effect, integral, etc.) are urgently needed. This presentation will discuss the KIT safety research Activities for LWR and LWR SMR with potential

applications to research reactors. The focus is on the numerical tools based on multi-physics and multiscale methods by combining different solvers neutronic (diffusion, transport, Monte Carlo) and thermal hydraulics (system, subchannel and CFD) to improve the simulation of key safety parameters when evaluating design basis accidents such as RIA, SLB, Cold Water Injection in LWR and LW SMR. Selected results are presented to show the capabilities of high-fidelity simulation tools for the analysis of the core behaviour, including the one of research reactors with plate-type fuel under accidental conditions.

5.2.3. AC2/FENNECS – a Finite Element Diffusion and SP3-based Coupled Code System for the Safety Assessment of SMRs, AMRs and Advanced Nuclear Systems (A. Seubert, GRS)

The Finite ElemeNt NEutroniCS code FENNECS is a 3-d few-group finite element-based neutron kinetic code devoted to the safety assessment of SMRs, AMRs and advanced nuclear systems which are frequently characterized by geometries that deviate from regular lattice structures. The required geometric flexibility is accomplished by FENNECS through a continuous Galerkin weighted residual finite element approach for the diffusion and the Simplified P3 (SP3) transport equation. FENNECS uses triangular prisms with linear basis functions as spatial elements. Fully implicit time discretization is used for solving the transient diffusion equation. Thermal hydraulic feedback is accounted for by a coupling with the thermal-hydraulic system code ATHLET which is a module of the GRS AC2 code system. For the spatial meshing of the problem geometry, the Python External Meshing Tool with Yaml input (PEMTY) is applied. Beyond regular cartesian and hexagonal lattices, PEMTY allows the meshing of, e.g., control drums peculiar for micro reactors. Apart from an overview of the features of FENNECS, this presentation aims at demonstrating the range of applications of FENNECS including AMR, SFR (Sodium-cooled Fast Reactor) and VVER. The high-fidelity coupled simulation capability of FENNECS is shown for SFR minicore models with pin cell-wise and subchannel resolution. Future applications may also include research reactors.

5.2.4. Safety Case for SMR and MMR (J. Hyvarinen, LUT)

The presentation described a possible way in implementation of Defence-in-Depth and safety functions on Small Modular Reactors and Micro Modular Reactors where safety justification rests largely on the structural features of the designs and processes that inherently arise during transient and accident situations, instead of the traditional dedicated safety systems. The presentation proposes a transparent assessment model based on IAEA SF-1 DiD line definitions, and also incorporates insights from recent study, carried out by LUT, for the Finnish Government to support Nuclear Energy legislation revision to properly recognize the needs of efficient licensing of SMRs.

5.2.5. Towards a harmonization of BEPU application in Severe Accident analysis (Herranz, CIEMAT)

The presentation covered main results of the MUSA project and innovative research agenda to advance the predictive capability of Severe Accidents analysis codes by combining them with the best available/improved Uncertainty Qualification tools and embedding accident management as an intrinsic aspect of Severe Accidents analyses. Main outcomes of the project are identifying and quantifying uncertainty sources in Severe Accidents analyses, reviewing and adaptating Uncertainty Qualification methods and testing such methods against reactor and Spent Fuel Pool accident analyses, including accident management.

5.2.6. Severe accident research (L. E. Herranz, CIEMAT, P. Piluso, CEA)

Main outcomes of the EC-MUSA project aiming for a harmonization of BEPU application in severe accident analyses and corium research at CEA for GEN. II, III and IV reactors were presented. The ongoing R&D activities have specific focus on continuous safety improvement and mitigation of severe accident. Efforts towards "uncertainty reduction" in severe accident analyses involve developing systematic "harmonized" methodology and preparing a database with the important uncertain phenomena (leading to identifying uncertain parameters) affecting the source term.

The focus of ongoing corium research activities at CEA was mentioned on the identification of safety margin for future GEN IV, long term operation of GEN II & III, as well as R&D related to post-accident damaged reactors and decommissioning. The related efforts including experimental research and identification of critical experimental infrastructure were highlighted with examples of ongoing projects, namely EC/ SEAKNOT and OECD/NEA COPs.

A new project called INNOMUSA is currently under preparation by CIEMAT for the upcoming Euratom call. The proposal aims for consolidation of uncertainty analyses methodology in severe accident with specific focus on accident management and new technologies (e.g. near-term ATF, LW-SMRs).

5.2.7. CFD code development and validation (E. Komen, NRG, A. Manera, ETH/PSI)

The presentations highlighted the use of CFD (computational fluid dynamics) codes for LWR nuclear thermal hydraulics including both single-phase and two-phase flows. Application of CFD for the analysis of flow and heat transfer phenomena in the reactor core and in the reactor pressure vessel was discussed with the selected examples. While discussing possibilities and limitations of CFD tools for LWR safety analyses, further research needs were also underlined. It was mentioned that for the post-CHF regime, CFD codes require improved closure models for sub-channel and thermal-hydraulic system codes. In this context, proposal for a new project on Improved closure models for post-CHF regimes is currently under preparation by NRG.

In addition to CFD calculation for reactor application, requirement of validation database for CFD codes was highlighted. Development and further improvement of measurement techniques for producing "CFD-grade" database was discussed with examples of high-speed/high resolution laser-based optical, radiation-based tomography, among others. The importance of considering "representative" conditions for reactor-application was underlined and the related ongoing efforts were mentioned, e.g., extension of wire-mesh sensors for high pressure application.

In addition to current fleet of nuclear reactors, experimental activities towards producing CFD-grade database for SMRs/AMRs application involving two-phase flow in helical coil, (sodium) heat pipe studies were presented with some examples.

5.2.8. Advanced high-resolution instrumentation for CFD-grade experiments of single-phase and two-phase flows (Manera, ETH/PSI, Switzerland)

Validation of Computational Fluid Dynamics (CFD) models require a new paradigm in experimentation. In the presentation, advanced instrumentation will be discussed specifically developed for high-resolution measurements that can be used for CFD validation. Applications to two-phase flows in bundle geometries, high-pressure experimental facilities and buoyant flows was presented. The main topics of the presentation were as follows: stratified single-phase flows, optical methods PIV/PLIF in presence of density

differences, novel refractive index matching technique, high-resolution measurements for CFD V&V and subchannel codes, radiation-based measurements, void-fraction distribution in fuel bundle, fuel relocation in fuel assembly of SFR, void-fraction in high-pressure steam/water facility, two-phase flow in helical coil, and sodium heat pipes microreactors.

In addition, the second part of this session was dedicated to the discussion of the R&D needs towards long term operation of the existing NPPs. The following 8 presentations have been delivered:

- Overview of IRSN activities in the LTO: Ageing of Concrete, Polymers, and metallic components (F. Ribeiro, IRSN)
- Beyond 60 years: the new R&D challenges for EDF, (C. Vare, EDF)
- Experiences using a software product for AMR, IGALL implementation, and AMP validation (U. Wildner, Framatome)
- Long-Term operation of WWER's pressure vessel internals in Ukraine (YaroslaDubyk, IPP)
- SMILE –Supporting Long Term Operation and Ageing Management of LWRs (M. Bjurman, Studsvik Nuclear AB)
- APAL -Advanced PTS analysis for LTO –overview and results of APAL project (Sz. Szavai, BZN)
- NUGENIA/TA4 vision (P. Kadecka, UJV)
- Repair of the pressurizer in Ringhals4, (P. Efsing, Vattenfall)

These presentations have highlighted the following major R&D needs:

- Ageing of Concrete, metallic and polymers components….:
  - ✓ For Concrete: Pathologies (Internal Swelling Reaction). Understanding the mechanism and modelling, thanks to an experimental platform
  - ✓ For Polymers: experimental ageing platform (mechanical and chemical characterization) for understanding the ageing mechanism. Development of specific tests …..
- Extension beyond 60 years of EDF NPP fleet. LTO Programme (Grand Carénage):
  - ✓ R&D focused on Non replaceable components associated with their main ageing mechanism, for example RPV and irradiation damage.
  - ✓ Replacement Refurbishing of big components Projects as well as main Maintenance Programmes with associated R&S such as SG digital twin, Asset Management models to optimize maintenance…
- Software development for ageing management:
  - ✓ Development of a Software tool for degradation assessment: COMSY Ageing Management Software.
  - ✓ AMR: Automatic Degradation Mechanism, assessment software assessing the relevant degradation mechanism...
- Development of tools for LTO and structural integrity degradation evaluation in WWER RPV Internals: Calculations are developed for:

- ✓ the Irradiation induced swelling of the Core Baffle, which affects related PVI elements (pins, Barrel)
- ✓ Dynamic stability of PVI, during Large Break LOCA

- Supporting LTO and ageing management:
  - ✓ Improving and validating the knowledge of materials ageing phenomena and their kinetics
  - ✓ Extract and test real plant aged materials and components, focus on:
    - irradiation embrittlement of RPVs,
    - irradiation embrittlement and IASCC of RVIs –including welds,
    - SCC of DMWs and SS welds, PWSCC resistance and thermal stability analysis
  - ✓ Establishment of a materials library
- Advanced PTS assessment:
  - ✓ Development of advanced probabilistic PTS assessment and quantification of safety margins of LTO improvements
  - ✓ Development of best-practice guidance for deterministic and probabilistic RPV integrity assessment
- R&D&I for safety justification of the functionality (integrity), Special emphasis and more focus on:
  - ✓ Digitalization (digital twins, IA, IoT) for LTO
  - ✓ Health monitoring of components
  - ✓ New fabrication methods of components
- RCS pressurizer analysis:
  - ✓ Analyse the Cu-contamination effect on RCS, the effect of copper sputter relating to non-energized heaters
  - ✓ Focus on structural integrity assessment, material integrity analyzes, operability assessment
  - ✓ How would remaining copper affect the structures?

6. Technical session 3 – Waste Management and Recycling

This technical session was moderated by Gérald Senentz (Senior Manager of R&D at Orano) and Anthony Banford (Chief Technologist at NNL).

6.1. Scope

The current and projected fleet of plants consists largely of water-cooled, water-moderated reactors. These reactors have over time achieved a high degree of maturity in terms of economic performance and safety. To achieve major steps in terms of sustainability (reduced high-level waste production, better use of resources and higher thermal efficiencies) and to open the way for high-temperature non-electricity applications, new types of reactors based on other coolant technologies should be envisaged combined with more advanced fuel cycles. The use of fast reactors in a closed fuel cycle approach will allow a large decrease in natural resource (uranium) consumption, allowing therefore a more sustainable implementation of nuclear energy. One of the major concerns of society regarding the implementation of nuclear energy is also the high-level nuclear waste. Fast spectrum reactors with closed fuel cycles will allow a significant reduction in high-level nuclear waste radiotoxicity and volume. Advanced reprocessing and fuel manufacturing techniques are needed to recycle the minor actinides. This session shall discuss the how the sustainability in terms of resource utilization and high-level waste minimization can be gradually increased.

6.2. Summary of technical sessions

P1: Keynote presentation on the management of nuclear waste in Sweden (Mathias Karlsson, SKB)

Irrespective of the question of the future of nuclear power, today there is nuclear waste that must be dealt with in the short and long term to protect mankind and the environment. That is SKB's task.

The Swedish system was presented for all types of waste. Since the mid-1980s, both the Final Repository for Short-Lived Radioactive Waste (SFR) and Central Interim Storage Facility for Spent Nuclear Fuel (Clab) have been in operation. Safe transport of radioactive waste from the nuclear power plants takes place using our ship the M/S Sigrid.

Sweden is preparing for the components of this system that will deal with the encapsulation and final deposition of the spent nuclear fuel.

In the beginning of the 1990s, SKB also began to search for suitable sites. Finally, two good alternatives remained, Forsmark and Oskarshamn. In June 2009, Forsmark was selected. The reason was that our investigations showed that this was where the rock was most suitable for the purpose.

In 2011, SKB applied to the Radiation Safety Authority and the Land and Environment Court for permits to build the Spent Fuel Repository at Forsmark.

After being approved by the municipalities of Oskarshamn and Östhammar in 2018 and 2020, the Swedish Government approved SKB's application in January 2022.

P2: Predisposal Waste Management R&D in the European PREDIS Project (Maria Oksa, VTT)

PREDIS, "Predisposal management of radioactive waste", is a EURATOM 4-year project targeted to develop and assess new and improved treatment and conditioning technologies for low and intermediate level waste. This collaborative effort is performed by 47 European organisations from 17 countries.

The project focuses on treatment of metallic wastes, liquid and solid organic wastes, including for example optimization of decontamination and immobilization processes, characterization and procedures for waste minimization and recycling, studies on conditioning matrix performances and economic and environmental analyses.

One area of interest is testing and evaluating innovations in cemented waste handling and predisposal storage, including utilization of different monitoring techniques, data collection and digital twins. The project has also developed the predisposal strategic research agenda for future activities and gathered global information on waste acceptance criteria.

PREDIS targets also to develop and transfer knowledge and competences via a Knowledge Management Programme.

This presentation gave the current status of project's achievements on the predisposal management activities, focusing on the engagement with end users to have impact from the results. Information will also be shared about the PREDIS Strategic Research Agenda, identifying topical needs for future collaboration.

P3: EURAD Programme Update and EURAD 2 Preparations (Louise Théodon, ANDRA)

EURAD is a European Joint Programme on Radioactive Waste Management, co-financed by the European Commission. Launched in 2019 to help the Member States in developing and implementing their national R&D programmes for the safe long-term management of their full range of radioactive waste, it gathers 115 RWM organisations across 23 countries.

The presentation gave an overview of the outcomes of the programme one year before its end, with a more specific focus on the update of its Strategic Research Agenda, collaboration between the 3 Colleges (Waste Management Organisations, Technical Safety Organisations and Research Entities) and lessons learned.

The European Commission published on March 17th, 2023 the EURATOM Work Programme for years 2023 to 2025. In this Work Programme, the EC has established a Grant to Beneficiary for a co-funded European partnership on radioactive waste management. This partnership aims for the continuation and merge of EURAD programme and PREDIS project.

A Core Group, formed by 6 representatives of the Colleges (2 per College) (Waste Management Organisations, Technical Safety Organisations and Research Entities) and one Coordinator has been established in September 2022, to steer the activities to be carried out until the submission of the proposal.

Made on behalf of the EURAD-2 Core Group, this presentation informed on progress status about the EURAD-2 partnership and present the process of definition of the technical content of the proposal.

P4: The EURADSCIENCE and Engagement (Vanessa Montoya, SCK-CEN)

EURADSCIENCE is a "cross-disciplinary, inclusive network ensuring scientific excellence and credibility to radioactive waste management". Founded in 2018 in Berlin, it aims to maintain a holistic view of relevant scientific disciplines, provides scientific excellence to advance the progress of national radioactive waste management programmes (RWM) and assure scientific credibility to contribute to societal acceptability of waste management concepts and decision making on RWM. It brings innovation and optimization along the whole value chain of the RWM and integrates the scientific advances, regardless of national implementation status, waste type or national inventory.

Terms of references had been distributed to the partners in April 2023: it is a formal collaboration agreement between EURADSCIENCE partners composed of different actors (general public, WM organisations, waste producers, research organisations and regulators. Its structure is based on the three pillars “safety”, “implementation driven” and “scientific innovation” within a transnational frame.

P5: The FREDMANS Project (Christian Ekberg, CHALMERS)

In the FREDMANS project we will show that the recyclability of advanced nuclear fuel can be done in a safe, efficient and industrially suitable way. Our model fuel will be the nitride fuel since in that case there is not only the recycling of the fissile material that is needed to handle but also the isotopically enriched N-15. By doing this there is a clear reduction of the radioactive footprint of the nitride fuel usage.

The main issues of advanced nuclear fuel recyclability is handled through dedicated work packages handling: advanced manufacturing, recyclability, waste management and industrial applications. Overall of these the red thread of safety concerns is held high. In addition, it is considered that the real safety of future nuclear systems is achieved by people with a complete and correct knowledge who have actually handled the materials and questions in reality. To support this the FREDMANS project has an extensive training and education work package where safety and a holistic view of the whole system is in focus

P6: Regain project (Mathilde Guilpain, ORANO)

During treatment and recycling of nuclear fuels, irradiated fuel assemblies are sheared into sections called hulls. The nuclear material contained in the hulls is dissolved in nitric acid. The structural and cladding elements are rinsed, then compacted and packaged in CSD-C (French acronym for Standard Container of Compacted Waste). They are currently considered Intermediate Level Waste Long Life (ILW-LL) in the French waste classification and will be stored in the CIGEO French geological disposal.

The REGAIN project (recycling of nuclear hulls) proposes the study of an alternative solution, consisting in reducing the radiological source term of the hulls through a succession of decontamination operations with the aim of limiting the volume of final waste to be sent to CIGEO. The expected results of the project will make it possible to direct the treated and conditioned hulls to a storage center other than the geological disposal. If all goals are met, it would lead to full zirconium recycling to manufacture new nuclear fuel cladding and structure.

For this, several innovative technological bricks, of different initial maturity, will be studied and developed. Technical, economic and life cycle assessments, of each elementary bricks and of the overall process, sized at an industrial scale, will be used to validate the feasibility of a zirconium recycling system, reducing consumption of mineral resources, and optimising the volume of ILW-LL.

P7: Lessons learned from LILW Safety Case projects in Finland (Otso Manninen, FORTUM)

In Finland, the waste producer has the responsibility to manage nuclear wastes produced, including the final disposal. The Finnish nuclear power companies, Fortum and Teollisuuden Voima, dispose their own low and intermediate level wastes (LILW) in the repositories located at the nuclear power plant sites at Loviisa and Olkiluoto at the depth of approximately 100 meters. The disposal of spent nuclear fuel at Olkiluoto is carried out by Posiva, an expert organisation owned by the two nuclear power companies.

Demonstration of the long-term safety is a precondition for the final disposal and therefore it has been

studied for decades in Finland. The long-term safety is addressed in a safety case, a report portfolio demonstrating compliance with the regulatory requirements. For instance, the safety case for Loviisa LILW repository 2018 considers the operational and decommissioning wastes arising from Loviisa nuclear power plant. The Finnish radiation and safety authority approved the safety case in 2019. It has been utilised in periodic safety review for the repository in 2020 and in the operating licence application for the extension of the repository and its operating period in 2022. This presentation focused on the lessons learned from the Finnish safety case projects - including the key uncertainties that are utilized in the further planning of the final disposal as well as in the on-going R&D-programme.

6.3. Key learnings

The session highlighted the need to take a holistic approach to radioactive waste management, focussed on the application of the waste hierarchy principles, to minimise waste destined for ultimate disposal and to implement safe disposal for those materials that require geological disposal. Overall, the discussion focused on the sustainability of the back end of the nuclear fuel cycle.

- Major R&D&I topics
  - HLW and ILW disposal industrialisation activities in Sweden and Finland continue
  - Research on material recycling is required to achieve sustainability goals.
  - European research ecosystem on waste and disposal is collaborating. €80M worth of all encompassing collaborative research activities focus on predispsoal and disposal projects
  - EURAD-2 will combine disposal and pre-disposal activities in one Euratom partnership

- Research needs
  - Alternative treatments and recycling to reduce the need for final disposal (not only HLW, but also ILW)
  - Reuse of materials to reduce waste and save resources (LCA, less mining activities) – enabling circularity.
  - SNETP (TA5) has a role to play in helping defining reasearch priorities (and is doing so through position papers – it gets noticed) – Now is the time (definition of EURAD-2 WP finalised by mid-July)
  - Increase the R&D focus on predisposal to minimise waste arisings
  - Continue joint working on spent fuel management and high level waste, including long term storage, disposal and other options.

Whilst decommissioning was not featured in the annual forum this year it remains a crucial issue for Nugenia TA5. Details of priorities inthis field are detailed in the Nugenia vision.

7. Technical session 4 – Fuel Elements and Core Design

This technical session was moderated by M. Bertolus and L.E. Herranz

7.1. Scope

Industry stakeholders target to improve further the safety of nuclear reactors, while adapting it to more flexible operation modes and to smaller reactor sizes. Another important objective is to enhance the sustainability of nuclear energy by making progress in nuclear fuel recycling, which would increase the available resources, reduce the ratio of waste per produced energy unit and optimize the fuel cost contribution to the nuclear levelized cost of electricity (LCOE). Innovative core designs and nuclear fuel elements are key elements to reach these goals.

The development qualification and full introduction of new fuel technologies requires advanced performance codes based on a thorough understanding of the fuel element behaviour obtained by complementary post irradiation experiments, separate effect experiments and multiscale modelling.

7.2. Summary of technical sessions

Nine papers were presented in the session, which was attended by about 30 to 40 people permanently. The session was split in two, which dealt, respectively, with: collaborative activities on core design and fuels (PUMMA; ESFR-SIMPLE; OperaHPC; PATRICIA), and ongoing and planned activities in flagship organizations in the area (IRSN; CVR; Chalmers; Westinghouse; Framatome).

Along the different presentations, some key learnings were delivered:

- Ongoing activities on fast reactors address the full cycle of MOX fuels to sustainably optimize Pu inventory in a flexible way.
- There persist the European interest in sodium fast reactors, also under the current trend towards the design of a simplified and small scale SFR. Fundamental investigations as well as large experiments and full-scale design are being addressed, with particular attention to training of young researchers and social aspects.
- Preservation of experimental capabilities and knowledge should be paid necessary attention, so their lack do not hinder the European momentum being built now.

Development of physically-based fuel performance codes involves combining experimentation (separate effect and integral) and advanced modelling (uncertainty quantification and machine learning).

- CONNECT-NM is being structured to integrate all the research on nuclear materials in the coming years. Bridges will be built between materials families (material types and different reactor types) and analytical methodologies; links with fusion and other energy technologies are in the scope.
- Research on safety assessment and qualification of advanced technology fuels (ATFs) is being conducted across the entire research community (from academia to TSO and industrials) on two timelines: short-term (evolutionary with respect to the current fuels; i.e., coatings, doped oxide fuel matrix, etc.) and mid-term (i.e., nitride fuels, SiC/SiC claddings and others).
- Access to facilities and research reactors for fuels testing (i.e., CABRI; LVR-15 and others) to enable fuel modelling tools addressing new fuel systems should be kept, probably through international frameworks.

Research was defended to be an efficient way to preserve knowledge and, in particular, a few insights into that research were given:

- Fuel databases should be populated to allow further validation of existing and advanced technology fuels and even to allow a better application of advanced modelling methods (AI).
- A new approach to materials research by “designing what is required” instead of testing multiple options to find out the best match to what searched for.
- No fuel and core design development can be envisioned if research reactors are not looked at as indispensable tools. And, at the same time, analytical developments should pace up to allow the required qualification.
- ATFs testing under transient and accident conditions should be considered a must to support their use in commercial reactors beyond leading fuel test assemblies.

8. Technical session 5 – Non-Electric Applications Including Hybrid Energy Systems

These technical sessions were prepared by Józef Sobolewski, Dominique Hittner and Michael Fütterer

Organized by NC2I in 3 panel sessions with presentations, discussion and Q/A

Number of presentations: 19

Number of attendees: 40-50 in all sessions

8.1. Scope

In a context of high prices for energy, stringent emission reduction targets and reduced availability specifically of natural gas, nuclear energy has the potential to provide dependable solutions for low-carbon cogeneration of heat and electricity, and for hydrogen production. Dialogue and collaboration with other sectors such as chemical, cement, steel, paper, etc. industries and with regulators and investors are key to address these challenges from the end-user perspective.

Nuclear power can serve as a reliable technology for low-carbon, baseload electricity production. Today's industrial nuclear power plants produce 26% of all electricity. However, electricity represents only 24% of the European energy consumption, while heating and cooling for residential and industrial uses account for 50%. Almost unnoticed by the public, close to 100% of heat is delivered by combustion of large amounts of fossil fuels, which implies that an effective European decarbonization strategy must address this sector with high priority. In a context of climate change and geopolitical constraints, nuclear energy has considerable potential to reduce greenhouse gas emissions (GHGs) worldwide by providing a secure supply of electricity, district heating and high temperature heat for industrial processes including for the required large-scale production of hydrogen. Many of the envisaged non-electric applications can produce storable energy carriers and are thus considered enabling technologies for Hybrid Energy Systems including large fractions of variable renewables.

The topic was addressed by 3 panel sessions to promote information exchange between all stakeholders with particular focus on end-users, vendors and supply chain companies, regulators and business developers.

9. Summary of technical sessions

TS5.1: End-user Panel

moderated by Paul Nevitt, UK NNL

Panelists:

1. Daniel Bergkvist, Arctic Paper, Sweden & Poland
2. Hanna Uhl, PKN Orlen, Poland
3. Lars Ydreskog, LKAB, Sweden
4. Adam Kanne, Perstorp, Sweden
5. Ted Lind, UNIPER Sweden
6. Carl Berglöf, Energiföretagen, Sweden

Six panellists from end-user industries expressed their views on the way forward for nuclear cogeneration.

- **Strategy:** Industry has challenging decarbonisation commitments and are looking for solutions, need to ensure visibility of opportunities with nuclear so that they can be included in forward strategies for industrial organisations.
- **Engagement and PR:** Need to ensure stakeholders are aware of the opportunities, talk about the opportunities of non-electric applications of nuclear energy and advertise more.
- **Integration:** Industrial stakeholders are balancing lots of inputs and outputs to ensure economic viability; we need to help them understand how nuclear can fit in this landscape.
- **Viable solutions:** Industry wants to see demonstration of viable solutions now, need to get on with industrial demonstrations together with industry.
- **Demonstration:** Viable demonstrations of industrial cogeneration for end users should be the priority, less research, but more demonstration working with industrial users. Industry and other stakeholders should convince the EC to support construction of the first EU AMR/SMR First-Of-A-Kind.
- **Deployment:** There is a need to accelerate deployment of nuclear energy.

TS 5.2: Concepts for non-electric applications and their potential role in hybrid energy systems

moderated by Dominique Hittner, Hit Tech Relay

Panellists:

1. Mariusz Dąbrowski, NCBJ, Poland
2. Frederik Reitsma, USNC Europe, France
3. Jeff Harper, X-energy, United States
4. Jean-Marie Hamy, Framatome, France
5. Tomáš Melichar, CVR, Czech Republic
6. Christophe Schneidesch, Tractebel, Belgium

Summary:

For vendor concepts to be successful, they have to meet market needs, in particular:

- Suitable power output: It appears that there is room for different sizes of reactors, from the range of micro-reactors (~ 10 MW) to bigger ones in the range of 100-200 MW.
- Flexibility: For achieving the required flexibility in power output for specific applications, thermal storage is sometimes already included in the design. Hybrid systems, which allow managing together different types of energy sources and different types of energy users, are expected to provide practical solutions.

To achieve competitiveness of non-electric applications, three points were raised:

- The usual approaches are simplification, use of proven technologies, modularization, benefit of production in large series etc., but there is still no clear evidence that these advantages can produce real benefits, at least in a relatively short term.
- European energy policies impose decarbonisation, also on energy-intensive industries to mitigate climate change. There is, however, the risk of “carbon leakage” with industry escaping to regions of the world with fewer constraints.

- It can be assumed that the cost of risk of smaller projects is significantly lower than for a large nuclear power plant.

To shorten the time to market two statements were made:

- The technology and the designs of a number of vendors are ready.
- Nevertheless, a demonstration is necessary to de-risk deployment projects, not mainly for technical reasons, but to convince industrial end-users and investors.

TS 5.3: Incentives and Risks in Business Development and Licensing

moderated by Gabriel de Scheemaker, TriGen and Michael Fütterer, JRC

Panellists:

1. Sander de Groot, THORIZON, The Netherlands
2. Marek Ruščák, SURO National Radiation Protection Institute, Czech Republic
3. Norbert Kohtz, TÜV Rheinland, Germany
4. Andrei Goicea, nucleareurope, Belgium
5. Fabio Nouchy, Tractebel, Belgium
6. Fiona Reilly, FiRe Energy, United Kingdom
7. Jan Prašil, Ministry of Industry and Trade, Czech Republic
8. Giuseppe Sangiovanni, Exergon, France

Summary:

Nuclear cogeneration and non-electric applications of nuclear energy have found in the meantime their way into many energy policy documents and national strategies as well as into the specifications of almost every innovative nuclear reactor design, in particular Small Modular Reactors of various types. At the same time, incentives to replace fossil fuel in industry have further increased due to price increases and reduced availability, in particular of natural gas, and owing to further sharpened emission reduction targets.

However, implementation of this technology has so far not happened while potential end-users and investors keep evaluating incentives and risks prior to making investment decisions. With technical risks being increasingly well understood, risks related to licensing and business development have so far not yet been systematically dealt with. This panel session was meant to provide a contribution to change this and, therefore, deliberately included the views of a broad variety of panelists, who identified specific risks and pointed at the required mitigants on the way to demonstration and deployment (cf. related presentations). It was noted that a lot could be learned from other industries, such as Oil & Gas and Wind. Also, customers for non-electric applications, i.c. heat, have different requirements than electric power customers and do not want to take the risks of operating a nuclear facility. To our knowledge, this was the first time that the notion of risk minimization was explicitly addressed in such a broad context. Of particular interest was the viewpoint of investors (with extra attention for the private investor) towards near-term demonstration and deployment, including a transparent analysis of the value chain. Many of the identified risks are actually not on the radar of technologists and often beyond their competence, e.g. financial, socio-economic or legal aspects, stakeholder attitude and others. It was also found that for some players in the value chain, innovation is an asset while others rather considered it a risk. Deficiencies in communication could cause further risks. Perceived Risk is typically greater than Actual Risk. For instance the occasional but persisting misunderstandings about certain technical capabilities (e.g. waste minimization of SMR, need for certain reactor types for specific applications) are calling for closer cooperation between technologists and business developers beyond due diligence, and a step-up in Public

Relations activities. It was also commented that more often than on other continents, European companies have difficulties to be first adopters because of relatively widespread risk aversion. It could be concluded that a more systematic and holistic approach would be required for successful business development. New and additional competences are required including the willingness to deal with non-technical topics, also within SNETP (possibly in the form of a Working Group or Task Force) in concert with GIF, OECD/NEA and IAEA, and to devise appropriate mitigation actions, including in targeted R&D.

Next steps could include:

- A step-up in Public Affairs (in particular for non-electric, nuclear, energy products) to
  - Reduce the gap between perceived risk and actual risk re Nuclear industry
  - Explain non-electric, nuclear energy products and their risks to the general audience (and possible customers)
- Creation of a Business Development task force for non-electric, nuclear energy products to
  - Connect and discuss with relevant stakeholders (customers, suppiers, investors, govt, EU)
  - Study the approach of non-EU nuclear companies entering the EU market
  - Identify the top Risks (perceived) by investors and customers
  - Identify mitigants to these risks
  - Allocate the risks to the appropriate risk-owners, in other words: develop appropriate business models
  - Make findings transparent working closely together with the Public Affairs activity

10. SNETP Forum programme

15 May	16 May	17 May
9.00 Coffee and fruit. (Restricted to morning participants) Room: Volvo Foyer **9.30** SNETP GENERAL ASSEMBLY MEETING (Restricted to SNETP members) Room: Ascom/Catella	**8.00** Registration will open. **9.00 – 10.30** Technical Sessions – 1st Part I Room: see below	**9.00** How nuclear sector can collaborate with other sectors- Roundtable, moderated by Bernard Salha, President of SNETP – Ivan Matejak, EERA Operations Director – Jean Christophe Gariel, IRSN, Coordinator of PIANOFORTE – Andrea Kozlowski president elect of ENS YGN, Multigenerational nuclear community: the foundation of the European nuclear future Room: Palmstedt
12.00 Forum registration will open. **12.30** Lunch (Restricted to morning participants) Room – Volvo Foyer	**10.30 – 11.00** Coffee Break Room: Volvo Foyer	**10.00** – Domenico Rossetti di Valdalbero, Deputy Head of Unit, DG RTC CA, European Commission – Gumenyuk Dmytro, Head of the SSTC NRS Safety Analysis Unit, Main Trends in Safety Analyses for Ukrainian NPPs Room: Palmstedt
14.00 Welcome and Opening of the SNETP FORUM 2023 by Christian Ekberg, Professor Nuclear Chemistry, Chalmers University of Technology, Håkan Eriksson, Deputy Lord Mayor, Gothenburg Town, Maja Lundbäck, Political Adviser Energy to Deputy Prime Minister of Sweden and Minister for Energy, Business and Industry Bernard Salha, SNETP President. Room: Palmstedt	**11:00 – 12:30** Technical Sessions – 1st Part ii Room: see below	**10.40** Coffee Breaks Room: Volvo Foyer
14.15 Presentation of the Swedish energy mix and strategy toward nuclear. – Maja Lundbäck, Political Adviser Energy to Deputy Prime Minister of Sweden and Minister for Energy, Business and Industry – Per Seltborg, Swedish Radiation Safety Authority, Challenges and Opportunities about Nuclear Safety and Radiation Protection in Sweden	**12:30 – 13:30** Lunch Room: Volvo Foyer	**11.00** Wrap up of technical sessions – moderator Abderrahim Al Mazouzi • TS1: SMRs; AMR & Advanced nuclear systems (20') • TS2: Safety Research, LTO & improved plant operation & maintenance (20') • TS3: Waste management & recycling (15') • TS4: Fuel elements & core design (15')

– Carl Berglöf, Secretary General, Swedish Atomic Forum, Outlook for new nuclear power in Sweden – Supply chain, R&D and EU cooperation – Björn Linde, Managing Director, Forsmarks Ktaftgrupp AB. Vattenfall, Swedish programme for long term operation – Ane Håkansson, Professor and Director of ANItA, Presentation of the Swedish national competence centre ANItA, Room: Palmstedt		• TS5: Non-electricity applications from the end-user perspective including Hybridization (20') Room: Palmstedt
15.35 Challenges of the nuclear sector to play its role in tackling Climate Change – Aline des Cloizeaux, Director, Division of Nuclear Power, Department of Nuclear Energy of the IAEA – Rosalinde Van Der Vlies, Director, DG RTD, European Commission (by Video) – Zuzana Petrovičová, Head of Unit, DG ENER, European Commission – Manuel MARTÍN RAMOS, Deputy Head of Unit, JRC, European Commission, Challenges of nuclear research in the EU Room: Palmstedt	**13:30 – 15:00** Technical Sessions – 2nd Part i Room: see below	**12.30** Q & A Room: Palmstedt
16.20 Coffee break Room: Volvo Foye	**15.00 – 15.30** Coffee Break Room: Volvo Foyer	**12.50** Closing Remarks
16.50 Challenges of the nuclear sector to play its role in tackling Climate Change – Anicet Touré, Director SMRs at Tractebel/ENGIE, SMR-Market analysis in the EU – Peter Baeten, General Director SCK.CENSMR strategy in Belgium – Zbigniew Kubacki, Senior Policy Adviser in the Polish Ministry of Climate and Environment, Poland – Jan Larsson, The West Atomic Alliance Story Room: Palmstedt	**15:30 – 17:00** Technical Sessions – 2nd Part ii Room: see below	**13.00** Lunch Break and End of the SNETP FORUM 2023 Room: Volvo Foyer
17.50 Exchanges with participants	**17.00** End of the day	
18.15 End of the programme	**18.00**	

18.15 Welcome reception in cooperation with City of Gothenburg at Chalmers Conference Centre Room: Volvo Foyer	Departure from Chalmers Conference Center for Gala Dinner to Marstrand **19.00** Gala Dinner at Carlstens Fästning at Marstrand **22.00** Departure from Marstrand with ferry and bus **23.00** Return to Chalmers Conference Center	

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