NUGENIA VISION

July 2023

Main Author(s):
Abderrahim Al Mazouzi (EDF)
Anthony Banford (NNL)
Eric Hanus (CEA)
Luis E. Herranz (CIEMAT)
Pavel Kral (UJV)
Ales Laciok (CEZ)
Bruno Michel (CEA)
Steve Napier (NNL)
Ignacio Real (Iberdrola)

With the contribution of all NUGENIA members and especially the sub-technical area leaders.

SNETP Association

c/o EDF

Avenue des Arts 53B, 1000 Brussels, Belgium

Email: secretariat@snetp.eu

Website: www.snetp.eu

This XXXXXX XXXXX was prepared by the NUGENIA Pillar of the SNETP Association.

LEGAL NOTICE

Neither SNETP nor any person acting on behalf of SNETP is responsible for the use which might be made of this publication.

Additional information on SNETP is available on the Internet. It can be accessed through the SNETP website (www.snetp.eu).

Brussels: The SNETP Association

ISBN xxx-xx-xx-xxxxx-x (pdf)

ISBN xxx-xx-xx-xxxxx-x (print)

ISSN xxxx-xxxx (print)

ISSN xxxx-xxxx (online)

doi: xx.xxxx/xxxxx

TABLE OF CONTENT

Introduction

The deployment of advanced Light Water Reactors (LWR) for electricity production could throughout the 21st century provide the bridge between the ageing nuclear installations currently in operation and/or the Generation III reactor, now under construction, and the Generation IV reactors, proposed by the Generation IV International Forum (GIF) and promoted by the European Sustainable Nuclear Industrial Initiative (ESNII) and Nuclear Cogeneration Industrial Initiative (NC2I). To assess and reinforce the attractiveness of LWRs, there is a need to continuously improve their performance and safety and to propose new technology and/or new concepts with new attributes. Increasingly, nuclear technology and the modern reactors are considering non electrical applications in support of achieving international net-zero carbon emission targets. These include; hydrogen production, direct use of nuclear heat for heating and heat intensive industrial production, synthetic fuel production, desalination.

The current global fleet, mostly Generation II, was developed with plant design lives that were typically either 30 or 40 years. The newly installed fleets, Generation III, are expected to have design lifetimes of at least 60 years operation, with power ranging between 300 and 1800 MW. The economics of nuclear energy are currently characterized by low and stable operating costs, resulting from the low proportion of fuel cost in the total cost structure and this has enabled nuclear power plants (NPPs) to supply reliable, competitive and safe low-carbon power. Once built and commissioned, and assuming a good operational performance, NPPs should be able to carry out this indispensable role for the long term. With high fixed costs and low running costs, average electricity costs for NPPs fall substantially with increased output. It is therefore vital for nuclear operators to achieve high plant capacity factors for long-term operation.

A safe, efficient and economically competitive operation of NPPs is the result of a number of interlinked human, organizational and technical factors. Owners of NPPs, currently mostly operating in deregulated competitive markets, are under pressure to reduce operational costs to be more competitive with other energy production options. To recover the initial investment costs and to maintain necessary level of profitability it is reasonable to prolong operation of existing plants (LTO – long-term operation) where it is feasible, without compromising safety and security. Along with traditional safety and reliability parameters, economic and financial factors need to be considered in new perspectives. Another aspect is that NPPs will be operated in markets with increasing number of decentralized and variable renewable sources (weather conditions derived energy production) and therefore flexibility (higher manoeuvrability) of NPPs will be increasingly important.

It should be noted that operators of NPPs continually improve their assets by various measures, notably i) power uprate (design reserves utilization, efficiency), ii) optimization of maintenance and outages, iii) upgrade and more efficient utilization of nuclear fuel (prolongued cycle length, enrichment, burn-up, reload patterns, multi-recycling….), iv) flexibility of operation (load-following mode), LTO and last but not least v) supply chain optimization.

Improvements in operation are also realized based on inputs from missions and peer reviews that are focused mainly on safety, but also considering operational aspects of NPPs. The most important reviews are organized under auspices of IAEA and the World Association of Nuclear Operators (WANO). The WANO mission is to maximise increased reliability and safety worldwide through common efforts in assessment, benchmarking, mutual support, exchange of information and use of best practice. Areas contributing to improvement of reactor and NPP operation could be divided into management, organisational and human performance measures on the one hand and technical measures on the other hand.

Europe produces about 25% of its electricity through the operation of 131 reactors. Maintaining a high level of safety and competitiveness is a major challenge and requires the establishment of a coordinated R&D programme at European level. NPP operators have joined forces to build R&D programmes since 2011 with research centres, nuclear industry and technical support organisations (TSOs). The support of the European Commission enabled the launch of transnational programmes with major R&D advances in fields as varied as severe accidents or the estimation of the lifespan of critical components. Nevertheless, these advances must now be part of a logic of industrial deployment that will allow Europe to have a globally competitive nuclear sector. The establishment of an ambitious R&D programme will also consolidate a very high-level nuclear science and technology sector whose spin-offs impact the energy, health, production of clean heat and hydrogen, construction and industrial manufacturing industries.

The development of Renewables In Europe, as well as in other parts of the world, leads to the development of new Gridcodes [TA1-9], establishing the new rules for the connection of any type of production to the European Network (ENTSOE)[TA1-10], with wider frequency and voltage ranges compared to the old ones. This may have an impact of the electric LDN (Local Distribution Network) of the NPPs and possibly an impact on safety and reliability of components.

Specific challenge represents higher level of **flexibility** (non-baseload operation) as a response to operational conditions with the increasing portion of Renewables, with the objective of 30 % of Renewables in 2030 [TA0-1]. NPPs should also be prepared to participate in the trading of electricity in more complex conditions and provide various ancillary services such as frequency control, load following or reactive power control.

An analysis of recent technological innovations in the field of manufacturing, digital technology and safety approaches leads us to propose three R&D and innovation priorities for the next FP9 Horizon Europe Framework Programme (2021-2027) [TA0-2].

Innovations and Competitiveness of Nuclear:

In conjunction with the deployment of renewable energies, the production of nuclear electricity is one of the solutions to meet the challenges of climate change. In addition to nuclear power reactors such as the **European Power Reactor (EPR)** (Generation III), Europe needs to broaden the available offer to meet national specificities. The development of **SMRs (Small Modular Reactors),** with power ranging between 10 MW and 300 MW and Micro Nuclear Reactor (0-10 MW), are a possible way for Europe, for the development of the future energy mix in Europe. The establishment of a shared R&D programme at European level will lead to a detailed design by 2025 based on harmonised European safety standards. In order to reconcile the development of safer, accessible, flexible and economic European NPPs [TA0-4], ambitious R&D programmes are also needed to optimize particularly **passive safety systems** or **new nuclear fuels (EATF)** that are more resistant to accidental situations. This is to stay ahead of the international competition and lead to industrial deployments by the end of this decade. The acceleration of the transfer to the nuclear industry of emerging technologies in the field of **additive manufacturing** or **civil engineering** will become effective only through the implementation of applied research programmes based on the construction of demonstration prototypes. By creating European technological competitiveness clusters, the spin-offs go beyond the nuclear sector.

Digital Transition:

The digital transformation of the industry is a reality and nuclear energy is part of this underlying trend. In order to accelerate collaborations between industrial players and European academics, it is essential to build a European digital integration bench in order to achieve a digital twin such as a **Digital Reactor**. Russia (Rosatom), the USA via the DOE and China are fully committed to this approach. A dedicated European federated programme will lead towards the definition of a digital integration bench comparable to the aeronautical industry. This is a major technical and organisational challenge. Concerted integration work at the European level is essential to make progress in terms of **multi-physics and multi-scale modelling and simulation** (High Performance Computing) with better uncertainty quantification, **data analysis** (Data Analytics), **visualization** (e.g., Virtual Reality), **advanced instrumentation** (e.g. IOT) and **control-command**.

The benefits of this ambition go beyond the scope of the nuclear sector and reinforce the programmes already undertaken by Europe on the digital field.

Safety and Environment.

The existing nuclear fleet makes it possible to produce electricity without CO_2 emissions and meet the challenges of energy independence in Europe. Safety is a priority for the nuclear industry and must lead to the establishment of safety standards. For power plants in operation, Europe must continue to share R&D programmes in the areas of **accidents and hazards** (single or combined), such as **earthquakes**, floods, **fires, extreme weather (e.g., droughts) or severe accidents** but also on methodological approaches such as Probabilistic Studies. The programme will strengthen the construction of a pan-European network of experimental infrastructures.

Safety concerns all phases of the life of a nuclear installation. **Decommissioning and Waste Management** is an area on which Europe must make progress in terms of research and standards. A decommissioning and waste management R&D programme will enable Europe to master the end of the nuclear installations cycle and also to position the European industry in this growing sector.

Scope and purpose

NUGENIA is a pillar of the Sustainable Nuclear Energy Technological Platform (SNETP) dedicated to innovation, research and development of nuclear fission technologies, with a focus on Generation II and III nuclear technologies. It gathers international stakeholders from industry, research, safety organisations, SMEs and academia committed to cooperate and develop joint collaborative projects in the field.

The activities of NUGENIA are carried out in 8 technical areas (TA), within a general scope defined by the SNETP Strategic Research and Innovation Agenda (SRIA) and technical scope outlined in the NUGENIA Vision (last edition 2015). Harmonisation and cross-cutting issues are tackled within the different technical areas and streamlined by the pillar governance: the coordination board composed by the leaders of each technical area.

The NUGENIA governance, the coordination board, operational teams and technical experts focus on monitoring of R&D&I activities and defining high level challenges and priorities within the context of the European Union policies and its Member States interests. For increased visibility and credibility at international level, a number of cross-cutting initiatives were launched in the past years and formalised interactions put in motion at different levels. This covers relations with other SNETP pillars (ESNII and NC2I), EU bodies, international organisations and national public and private actors. NUGENIA, in its short but intense historical activities started by building upon the existing bricks within the European landscape (merging of NULIFE, SARNET, SNETP Gen II/III TWG, ENIQ networks), followed by the creation of a non-profit association that has gathered more than 100 members from all around the world. Thanks to the EURATOM support (FP7-NUGENIA+ project), it has been able to create services to the community, foster the creation of innovative project ideas and to play an effective role at the international level by co-organising international level and collaborating with international stakeholders such as IAEA, WNA, COG and OECD-NEA …. Up to now, NUGENIA has labelled more than 60 projects, from which more than 2/3 have been launched – either thanks to EU funding or in the in-kind mode. It has published books, guidelines and positions papers increasing the dissemination level of the R&D&I output.

The NUGENIA Roadmap is a major technical document of NUGENIA. It is based on the high-level challenges expressed in the NUGENIA Global Vision document consolidated back in 2015. The first technical roadmap was issued in 2013 and updated in 2021, to identify major R&D&I topics of importance and/or interest for the international community. The NUGENIA roadmap has been serving as an important reference that contributes to the building of the European agenda, Euratom R&T programme as well as the SET-PLAN among others.

Beside safety, additional topics of importance, driven by the need of innovation to tackle new societal, environmental and economic challenges, have been raised. Among others the cyber security, digitalisation, SMRs, new fabrication routes for materials, new fuels that would allow an enhanced tolerance to accidents and last but not least new technologies for dismantling, decommissioning and waste management nuclear plants.

The goal of this document is to highlight the need of a strong international collaboration accompanied with a substantial financial support both from the private and public sector in order to ensure a safe and efficient production of low carbon energy.

Indeed, nuclear must play its role in minimising the carbon emissions that are becoming more and more damaging to the climate.

The scope of the work performed by the coordination board of NUGENIA aims at:

- Fostering collaboration between industry, SMEs, research centres, academia and technical safety organisations
- Building knowledge and expertise
- Facilitating the emergence of innovations
- Achieving projects with high added value to the community,
- Maintaining and developing the needed skills, competences and infrastructures to tackle the up-coming challenges (LTO, new build, SMR, dismantling, ….)
- Sharing and disseminating results

To facilitate the interaction between experts in different areas, this work is structured in 8 different technical areas, namely,

1 Plant Safety and Risk Assessment
2 Severe Accidents
3 Improved Reactor Operation
4 Integrity of Systems, Structures and Components
5 Waste Management and Decommissioning
6 Innovative LWR Design & Technology
7 Fuel Development and Spent Fuel Management
8 European Network for Inspection and Qualification (ENIQ)

The main challenges to be addressed within and between the areas are the following:

- Improve safety in operation and by design
- High reliability and optimized functionality of systems
- High reliability of components
- Improve modelling of phenomena in NPPs
- Increase public awareness
- Efficient integration of NPPs in the energy mix
- Prepare the future to avoid technology obsolescence
- Performance and ageing of NPPs for long term operation

Therefore, the missions of the NUGENIA Coordination Board, defined in its charter, include, but are not limited to:

- Elaborate, consolidate and update the NUGENIA strategic and technical documents
- Contribute to the elaboration, consolidation and update of the SNETP strategic documents
- Initiate and facilitate the creation of project ideas
- Propose mature project ideas for labelling by the SNETP GB
- Monitor NUGENIA's project portfolio

Each technical area is chaired by a TA leader and divided into various subareas. Each subarea is chaired by a subarea leader. Meetings of the individual TAs are organised at least once a year.

TA leaders are elected by the members of the TA. The election mode and the duration of his/her mandate remains at the discretion of each TA, but in the absence of any specific process, the following generic rule should apply: Each TA leader is elected by the identified organisations of the TA for a three-year mandate, renewable.

The missions of the TAs include, but are not limited to:

- Follow-up the progress of projects labelled by SNETP pillars, which fall under their TA;
- Initiate and facilitate the creation of new project ideas.

Each TA has been summarized using, as input, the fully developed NUGENIA R&D roadmap that is available to all NUGENIA members. The R&D topics have been selected in a consensual manner by the experts and the challenges are those which need to be addressed with the widest possible collaboration both at the European and international level.

1. Technical Area 1 (TA1) - Plant Safety and Risk Assessment

Safety of nuclear installations is among the absolute priorities from the very beginning of nuclear reactors construction in 1940s. During the nearly 80 years of designing, construction and operation of research reactors and commercial NPPs, the concept of nuclear safety has developed into a complex and sophisticated system, with the defense-in-depth approach at its core. The main safety assessment tools are still the deterministic and the probabilistic methods, when substantial effort is paid to development and application of advanced tools and methods combining these two original approached, qualifying and quantifying the uncertainties of safety assessment and taking into account new risks and hazards. Nuclear safety is a critical condition for sustainable NPPs operation and therefore SNETP puts significant emphasis on R&D activities focused on increasing safety of NPPs and improving understanding of accident phenomenology and abilities for NPP safety and risk assessment. An accident in any country in any part of the world effects the nuclear sector globally. That is why support of nuclear safety related R&D programmes and harmonization of approaches to nuclear safety is an important aspect of nuclear safety effort.

1.1. Scope

TA1 is devoted mainly to improving the physical understanding and the numerical modelling of the relevant phenomena involved in NPP incidents and accidents, to increase the capacity and comprehensiveness of the plant behavior and to enhance the accuracy of safety margin assessment accordingly.

1.2. Objectives

The main challenges identified are:

- The comprehensive adoption and use of the Probabilistic Safety Assessment (PSA) for understanding and pointing out safety risks, including quantitative aspects for risk and margin evaluation, methodologies to assess shut-down states, and external events, quantification of the risk inherent to spent fuel pool, best practice for probabilistic safety assessment (PSA) application and appreciation of residual risk.
- The deterministic assessment of plant transients, mainly focusing on the improvement and validation of models and tools for plant transient analysis, including reactor physics and thermal hydraulics, design and evaluation of passive safety systems, coupled multi-physics and multi-scale simulations, containment behaviour, and fluid-structure interactions. Non-linear phenomena have also to be investigated, in the frame of the “structural dynamics” in addition to deterministic and probabilistic approaches, within the context of design extension conditions consideration.
- The impact of external loads (including electrical disturbances) and other hazards (including cumulative load sequences and history, possible impact of seismic aftershocks) and internal degradations (e.g., due to ageing) on the safety functions.
- The advanced safety assessment methodologies: safety margins and best estimate methods, integrating the deterministic and probabilistic safety assessments, extended PRA approaches to deal with specific hazard such as seismic.
- The design of new reactor safety systems to comply with new safety requirements.

- The design and protection of equipment of the electrical Local Distribution Network of the NPPs, considering the new Gridcodes due to the development of the energy mix of the future including Renewables [TA10-9], [TA10-10].

The main objectives that have been identified are: advancements in NPP probabilistic assessment and human reliability analysis, further development of computational tools for deterministic plant assessment including coupled codes to progress towards multi-scale and multi-physics computational capabilities, advanced safety assessment methodologies and tools (identification and reduction of all uncertainties), development of methods and tools to better insure complementarity of probabilistic and deterministic assessment, including integration of such methods, extended validation of deterministic computational codes and benchmarking of probabilistic assessment methods (including identification of missing experimental data), improved understanding and modelling of internal and external hazards, application of new tools like Bayesian Networks to PRA and hazard assessment (Figure 1-1), development and application of tools and methods for upgrading of reactor safety systems to handle new safety demands, effective replacement of obsolete components and support to LTO. In order to get reliable computational results, numerical methods and tools should be validated, primarily against experimental data.

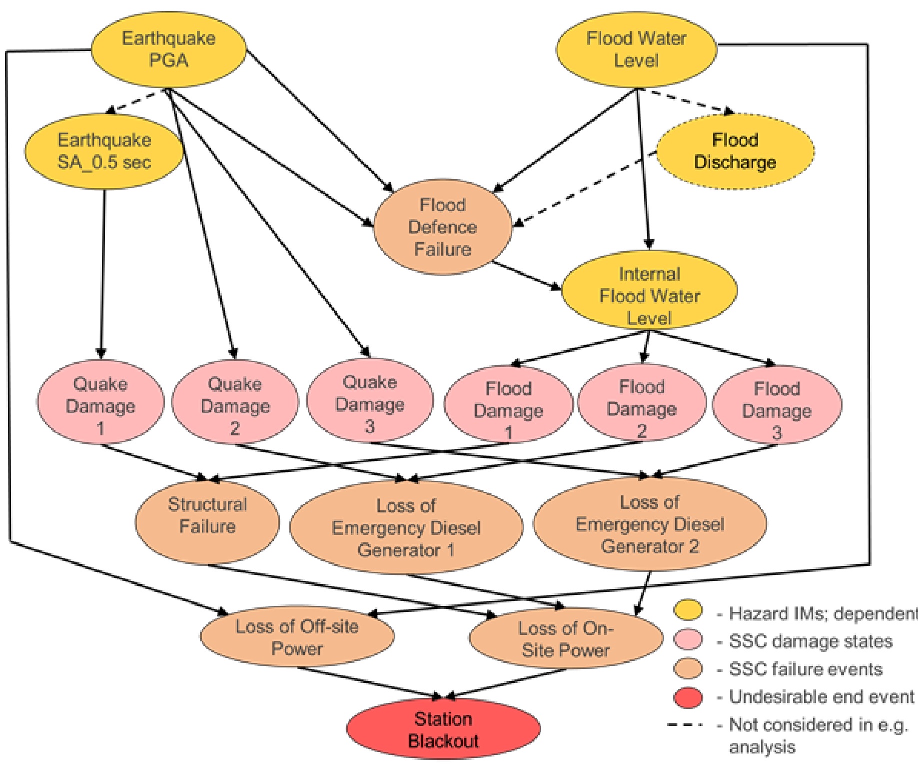

Figure 1-1: NARSIS Toy Bayesian Network for integrated multi-risk analysis and PSA on PWR.

2. Technical Area 2 (TA2) - Severe Accidents

2.1. Scope

The fundamental purpose of nuclear safety is to protect people and the environment from harmful effect of ionizing radiation, particularly under those conditions that pose higher radiation risk, like severe accidents (SAs) as earthquakes, floods, etc…in NPPs . With appropriate site risk evaluations, plant designs and management, current Generation II and III NPPs show high levels of robustness and low probabilities for SAs. However, despite the highly efficient accident prevention measures adopted for the current Generation II and the still more demanding ones for the Generation III plants, some accident scenarios may, with a low probability, evolve in SA, as emphasized with the Fukushima-Daiichi accidents in Japan. This leads to a possible core melting, plant damage and dispersal of radioactive materials outside the containment of the plant, thus threatening public health and the environment.

The residual risk associated to this kind of scenarios can be substantially decreased when state-of-the-art devices currently available for prevention and mitigation of SA are installed. Lessons from the Fukushima-Daiichi accidents and consequences related to accident management provisions from the ENSREG (European Nuclear Safety Regulators Group) stress tests and other national activities are leading to further safety enhancement of current and future NPPs.

Considerable knowledge has been gained about SA phenomenology through research carried out during the last 40 years, also in the framework of the SARNET network [TA2-1] and afterwards in NUGENIA/TA2 [TA2-2]. This research is based on experimentation, mostly out-of-pile but with a few in-pile programmes like Phébus-FP, and on analytical developments that have resulted in computation tools capable of simulating accident key-phenomena like the ones occurred at Three Miles Island (TMI2) in 1979, Chernobyl in 1986, and at Fukushima-Daiichi in 2011 (figure 2-1).

Figure 2-1: Fukushima Daiichi site right after the accident.

Since the latest NUGENIA roadmap in 2013, many European and international R&D projects have started in diverse frames such as Euratom (FP7,H2020 and Horizon Europe), OECD/NEA and IAEA. Some EU Road maps have been proposed in the frame of EU projects, such as SAFEST [TA2-3] (for phenomena involving corium needing complementary R&D studies), and a number of projects are ongoing under the H2020 frame (i.e., MUSA, R2CA, AMHYCO)), and recently under the Horizon Europe programme (i.e., SEAKNOT, ASSAS, SASPAM-SA). No less important, in-kind projects within TA2, like SAMHYCO, ASCOM , have recently finished and some others are still ongoing, like IPRESCA.. Among the entire SA projects portfolio of these years, those related to the Fukushima Daiichi forensic analysis, under the auspices of OECD/NEA, have had particular relevance [TA2-4] (i.e., OECD/BSAF, /BSAF2, ARC-F, and others) and activities are still running within the OECD/FACE project.

2.2. Objectives

The extreme complexity of SA scenarios makes them hard to be thoroughly and accurately characterized, and uncertainties still remain and need to be assessed properly. Complexity goes beyond the numerous phenomena occurring and the broad and extreme range of conditions prevailing, it extends to the strong coupling and feedback among them, which heavily conditions SA research.

The generic objective of TA2 is to reduce such uncertainties as much as feasible for Gen2 and Gen3 reactors, so that an effective enhancement of Severe Accident Management Guidelines (SAMGs) can be achieved.

Specific objectives might be formulated as follows:

- To identify and investigate key-phenomena in NPP SA unfolding and/or their consequences through experimental and numerical platforms.
- To build a European experimental network able to respond to SA key issues for current and future reactors, including long term operation of damaged reactor (till decommissioning).
- To develop and adapt analytical methodologies (i.e., uncertainty quantification, data analysis and machine learning, artificial intelligence) with potential to support a better assessment of safety margins and of giving better insights into the timeliness and effect of SAM actions.
- To enhance efficiency of prevention and mitigation devices (instrumentation included) supporting accident management and to propose innovative ones with high potential in accident management.
- To capitalize the gained knowledge in SA phenomenology , particularly the insights gained from the Fukushima-Daiichi, in powerful SA numerical simulation tools
- To provide the most reliable information necessary to implement robust and long-term management of severe accidents and effective emergency plans.
- To investigate accidental scenarios associated with nuclear innovation, from near-term deployment (i.e., Light Water SMRs and ATFs) to farther-away developments (i.e., hydrogen-nuclear cogeneration), for eventually reducing their risks.
- To spread the gained knowledge on SA to the different stakeholders and, in particular, to new generations of nuclear scientists and engineers, , reinforcing the knowledge and knowhow transfer to the nuclear technology forthcoming workforce.
- To develop mitigation solutions in the case of SMRs, which may require new approaches.

A synthetic view of the recent progress made and the challenges ahead may be reached in [TA2-5; TA2-6].

In order to achieve the TA2 objectives, the six sub- areas below were identified, all of them being more and more directly linked to SA management and in particular to mitigation processes:

- In-vessel corium/debris coolability

- Ex-vessel corium/debris interactions and coolability
- Mitigation of gas explosion risk in containment
- Source term reduction
- Severe accidents linking to environmental impact and emergency situations
- Management of severe accident scenarios

3. Technical Area 3 (TA3) - Improved NPP Operation

3.1. Scope

NPP operators are facing economic pressure in the current competitive market conditions with significant implications for plant operation. The optimization of operation and maintenance costs is therefore a key component of a broader integrated business planning process. Asset management and decision making is integral part of the overall operation strategy. Specific challenge represents higher level of flexibility (non-baseload operation) considering the development of the energy mix of the future, including the rapid development of Renewables. NPPs should be prepared to participate to handle the new operating conditions defined on the European Grid by the ENTSOE and also provide various ancillary services such as frequency control, load following or reactive power control.

TA3 is devoted to improving the technical and economical characteristics of NPP operation by various measures including maintenance strategies, optimization of outages, power up rates and improvement of efficiency, efficient utilization of nuclear fuel (increased cycle length, higher enrichment,…) or application of digital technologies (also for maintenance and personnel training).

TA3 is also dealing with minimization of the radiological impacts on plant workers, the environment and general public during normal plant operation (also covering periods of shut-down, reshuffling, abnormal operational situations and emergency states, but excluding severe accidents).

Commercial nuclear power reactors operating experience is approaching 20 000 reactor-years [TA3-1]. [1]

Due to continuous improvement of operation of nuclear power plants in past tens of years, they reached excellent operational characteristics – (lifetime) energy availability factor usually exceeds 90% and outages are shorter. Exposures of workers [TA3-2] [2]and volume of radioactive waste are continually decreasing (per MWh) and it will be interesting to witness if this trend is continuing despite of average age of reactors in Europe connected it with higher intensity of repairs and modernisations.

3.2. Objectives

The key challenges identified are:

- Economic operation of NPP in changing market conditions (new market design, changing generation mix).

[1] [TA3-1] IAEA, 2022: Operating Experience with Nuclear Power Stations in Member States
[2] [TA3-2] OECD NEA, 2020: Occupational Exposures at Nuclear Power Plants

- Measures for achieving higher level of flexible operation of NPPs [TA3-3]; [3] development of solutions for the minimization of negative impacts (aging, breakdown, etc…) on the lifetime of components.
- Minimization of risks of delays and cost overruns in new-build and modernization projects.
- Application of holistic and integrated systems engineering and human factors engineering processes (e.g., by the application of model-based systems engineering) and application of risk-informed decision making in human factor area and methods, means and tools for improvement of safety culture and operating practices.
- Keeping and improvement of competences of personnel.

- Digital transformation - advanced sensoring (including IoT), high level of automation and robotization, virtual and augmented reality, implementation of digital twins and advanced data analytics and decision making (including machine learning, deep neural network learning and other forms of artificial intelligence) [TA3-4][4].
- Maximize cycle energy production with minimum fuel cost while maintaining sufficient margins to improvement of precision of core calculations and better estimation of their uncertainties.
- Advanced and more accurate chemistry control.
- Improvement of radiation protection and reduction of occupational exposures by application of new tools (real time monitoring of received dose, augmented reality tools,...) and minimization of radiological impacts on the environment and general public.

The above-mentioned topics are addressed within TA3 in six sub-areas:

3.1 Improvement of operational economics and nuclear power plants flexibility
3.2 Human and organisational factors
3.3 Implementation of advanced digital technologies and solutions for cybersecurity
3.5 Improvement of core management modelling tools and core monitoring and instrumentation
3.5 Water chemistry and low-level waste management
3.6 Radiation protection

4. Technical Area 4 (TA4) - Integrity Assessment of Structures, Systems and Components

4.1. Scope

Safety-classified SSCs of a NPP are required to function with a high level of safety and reliability. Safety justifications are supported by methodologies and various assumptions that are generally conservative and need to take account not only of normal operation, but also for anticipated events, transients and

[3] [TA3-3] Nuclear Power Plant Flexibility: P. Morilhat, S. Feutry and al., VGB PowerTech Journal 5, 2019
[4] [TA3-4] Digital Twins, a New Step for Long Term Operation of Nuclear Power Plants: C. Varé, P. Morilhat, Engineering Assets and Public Infrastructures in the Age of Digitalization. Proceedings of the 13th World Congress on Engineering Asset Management

accidents as well as postulated events. These can be classified as Design Basis Events (DBE) and Design Basis Accidents (DBA). Furthermore, SSCs also need to function under postulated conditions beyond DBE and DBA. Such postulated conditions are denoted Design Extension Conditions (DEC) for which less conservative and more realistic methodologies and assumptions can sometimes be considered. Components and equipment in NPPs therefore need to be environmentally and seismically qualified. Long-Term Operation (LTO) of NPPs entails reliable component and equipment function in all safety-classified SSCs. This is ensured via appropriate maintenance, replacement and repair strategies through an appropriate plant life management (PLiM) system, so that components and equipment are able to perform their intended function in a reliable and safe manner throughout their lifetime or intended time of use.

There is a need, particularly for assessing nuclear plant components in terms of LTO, to properly quantify, demonstrate and understand levels of conservatism in current structural integrity assessment methodologies. This is so that well-founded information can be provided such that member states will be able to revise their guidance and procedures so as to be less conservative while still upholding the necessary basis for providing safe and reliable justifications for operation. Unified European guidance in terms of recommended practice (RP) documents, would be a significant advantage. In order to properly understand levels of conservatism, detailed micro-mechanistic modelling, supported by relevant experimental data, is often required, particularly when considering degradation (ageing) mechanisms such as irradiation and stress corrosion effects. Such mechanistic understanding can subsequently be used to develop and apply simulation tools and assessment procedures to structural components in NPPs in order to demonstrate their safe and reliable operation Such aspects as structural features, real or postulated flaws, appropriate loading conditions and relevant material characteristics including ageing effects need to be properly incorporated of course.. It is also important that the external and internal hazard safety assessments of a nuclear installation should include an assessment of consequences of the postulated events.

4.2. Objectives

The objective of TA4 is to improve knowledge, modelling techniques and methodologies in order to ensure high safety, structural integrity and reliability of NPP components. All relevant internal and external loads and material properties need to be included as well as taking full account of through-life ageing (degradation) mechanisms. All such knowledge and information is required in order to be able to maximise availability of NPPs and control the lifetime of their SSCs. While the integrity assessment principles and approaches relating to SSCs are generally similar in European member states (and indeed worldwide), there are differences in technical details, some of which could stem from differences in the various underlying design codes (see [TA4-1] in relation to the reactor pressure vessel). With the longer term objective of European harmonization in mind, it is necessary that the differences in detail are fully understood and for the lessons learned from Gen II NPPs to be considered when developing and/or revising best practice guidance for the safe operation of SSCs with satisfactory, but not over-conservative safety margins (see [TA4-1] and [TA4-2] as examples).

A plant-specific probabilistic risk assessment should be linked to the deterministic structural analyses of the safety-classified SSCs.

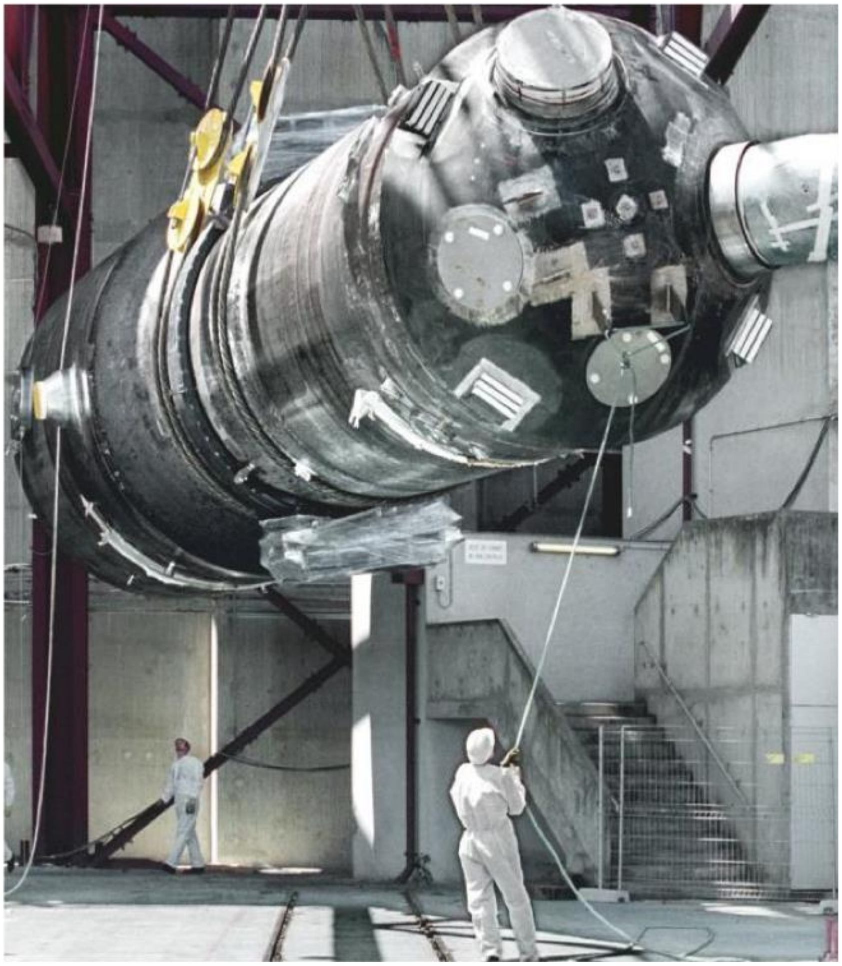

Figure X: Replacement of a steam generator (Courtesy of EDF)

The scope and objectives of TA4 are progressed by way of various sub technical areas, each of which have expertise in the different technical fields as referred to above.

Sub TA 4.1 is concerned with Integrity Assessment and as such is focused on what may be termed as engineering methods. These are methods that enable engineers to be able to undertake structural integrity assessments of SCCs. Such methods may be incorporated in and form part of codes and standards, or may be procedure document in their own right. As previously noted, the methods generally contain inherent conservatisms and one of the main aims is to properly understand the levels of conservatism with a view to providing well-founded information such that member states will be able to revise their methods to be less conservative while still upholding the necessary basis for providing safe and reliable structural integrity assessments. A significant part of TA 4.1 is associated with fracture mechanics concerned with the behaviour of known or postulated flaws (cracks) in SCCs. In regard to this, it is important that TA4 maintains strong cross-cutting links with TA8 (European Network for Inspection and Qualification). This link is particularly important for developing revised less-conservative methods for defining qualified flaw (defect) sizes.

Sub TA 4.2 is concerned with materials performance and ageing. The identification of the SSCs that are subject to ageing (degradation mechanisms) is a key issue for plant life management and plant life extension justifications. It is essential that analyses are performed for understanding and modelling the main ageing mechanisms concerning each SSC (potential or encountered). Finally measures have to be set up to justify the integrity of each SSC based on nuclear codes & standards, regulatory requirements and regulations, specifications and guidelines and scientific knowledge of the ageing mechanisms.

For efficient identification and evaluation of new ageing effects for operated SSCs it is necessary to put emphasis on harvesting of materials from decommissioned reactors (mainly with the task to evaluate material properties of very high dose materials) and development and standardization of miniaturized specimen test techniques for the NPPs structural materials degradation assessment.
Several issues have been revealed recently in connection with obsolescence and repair needs. These issues affect not only core components that have long been the focus of research for safety reasons, but also materials such as concrete and cable polymers, the degradation of which, in an LTO framework that take into account 60+ NPP operation, is a point of attention. The introduction of new materials or manufacturing processes to solve the problem needs coordinated effort of the expert community therefore a close cooperation with Joint Programme on Nuclear Materials (JPNM) of the European Energy Research Alliance (EERA) is expected.
Sub TA 4.3 is focused to ageing monitoring, prevention and mitigation that consist the important part of reliable ageing management (AM) necessary for NPP LTO. Increasing operational experience brings new challenges in the SSCs AM that are successfully addressed. This even show that NPP LTO behind 60 years of operation can be fully feasible. New monitoring methods, diagnostics and monitoring simulation tools that can greatly increase the ageing management efficiency has to be developed. Efficiency of the monitoring and evaluation process can be significantly enhanced by application of the AI and ML methods. In the area of the ageing prevention and mitigation the activities are aimed at the development of efficient and applicable preventive measures and repair technologies should capitalize advanced manufacturing. Open sharing of operating experience that enable new preventive measures development is necessary.

Sub TA 4.4 is concerned with equipment qualification, harmonization and pre-normative research. Equipment and components in a NPP have to function with a high level of reliability not only for normal operation, but also for DBEs, DBAs and DECs. This needs to be demonstrated when a NPP is in the design phase via equipment qualification procedures and rules as they are laid down in nuclear codes & standards (NC&S) and related guidance documents. Equipment qualification involves tests in certain environments and under certain loading conditions (e.g. seismic). LTO of NPPs entails reliable equipment function in all NPP SSCs throughout their lifetime or intended time of use. This is ensured via appropriate maintenance, replacement and repair strategies, which also have to follow certain rules according to NC&S.

So one aim of TA 4.4 is to strive for harmonization of equipment qualification procedures, to allow transfer of equipment qualifications between countries. The further development of NC&S and development of harmonized procedures & guidelines based on findings, results and conclusions of TA4 projects is a major task of TA4.4.

Another aim of TA4.4 is to foster pre-normative research. This could be R&D on a new structural material that is intended to be used in a NPP or the introduction of a new material characterization test or further evolution of an existing material characterisation test to allow its wide use to access properties of structural materials. A good example is the small punch test, for which a EN standard was introduced in 2021 and which is subject to enhancements and experience building in various ongoing NUGENIA projects.

5. Technical Area 5 (TA5) - Waste Management and Decommissioning

5.1. Scope

TA5 focuses on sustainability within waste management and decommissioning. Broadly this covers the management, treatment and disposal of materials (fuel and waste) arising from operations across the nuclear fuel cycle (including fuel fabrication, power generation and fuel recycling/reprocessing). Beyond waste management the area incorporates the dismantling and decommissioning (D&D) of nuclear facilities as the last step in their lifecycle. The emphasis is on the identification of best practice from the international community, development and maturation of innovative technology and methods that drive towards improved safety, enhanced environmental performance, sustainable solutions and project efficiencies, through a holistic lifecycle approach.

We maintain strong interactions with relevant Euratom projects; including recently SHARE [TA5-1] and PREDIS [TA5-2].

5.2. Objectives

As decommissioning and dismantling activities proceed across the globe, significant experience is being gained. For D&D, the focus is on development of pre-planning for decommissioning, decommissioning strategies, and the transition phases between operation and decommissioning. Key technical areas that underpin the D&D activities are plant characterisation, decontamination techniques, dismantling equipment, remote operations (including robotics) and land remediation.

Furthermore, it is also essential to focus on the implementation of the waste hierarchy in the context of radioactive waste management. This involves characterisation of waste, innovative approaches for treating waste (decontamination and revalorisation of radioactive materials), waste storage, waste form development, long term condition monitoring and disposability. Innovative approaches can reduce the burden of waste management activities and lead to a more sustainable long-term approach. As with all areas, active demonstration of new technology is vital to increase the technology readiness and demonstrate the maturity of new approaches.

Some of the major TA5 objectives are summarised below and as research themes in figure 5-1:

- Application of an ‘Integrated Waste Management’ approach for legacy facilities and crucially to current and future nuclear operations. Utilisation of tools such as Life Cycle Assessment (LCA) to support decision making.
- Application of the waste hierarchy to avoid/minimise waste generation: through smart design, appropriate material selection, operational measures, and designing for decommissioning.
- Underpinning spent fuel management, including long term storage, recycle and disposal.

- Establishment of improved (Predisposal) treatment technologies (thermal or other) to reuse/recycle materials, minimise waste volumes and to develop robust and passive waste forms. Specific waste focus areas include, organic wastes, metallics, contaminated concrete, irradiated graphite, etc
- Development of characterisation techniques for waste inventory assessment, and plant/facility assessment to aid planning for decommissioning and waste management
- Development of waste segregation/sorting, advanced decontamination techniques and optimized measurement/assay methods to enable a circular economy where appropriate.
- Application of transformative technologies to optimize decommissioning scenarios: for example, digitalization, digital twins, supercomputing, artificial intelligence, in-situ characterization and robotics.
- Identification of synergy effects for multi-unit sites or fleet-wide D&D projects, standardization of approach, use of mobile treatment facilities and optimization of post-operational phase.
- Identify the waste issues associated with the fuel cycle for the new SMRs/reactors of the future, which will differ from the Gen II and Gen III cycles.

Decommissioning and dismantling

- **Decommissioning strategies, end-points and evaluation**
- **Plant characterisation, Laser-scanning, 3D modelling,**
- **Digital planning options for decommissioning –**
- **Remote operations**
- **Improve automation of tools**

Waste treatment and recycling

- **Circular economy**
- **Lifecycle assessment**
- **In-situ waste and effluent treatment: Modular, mobile technology**
- **Challenging wastes**
- **Sort and segregation**
- **Technology demonstration**

Decontamination & release

- **Increase automation in decontamination tasks**
- **Improve techniques for decontamination**
- **Intelligent tools for decontamination characterization & control**

Waste storage and disposal requirements

- **Reducing hazard**
- **Minimizing waste volumes**
- **Develop recycling options**
- **Improve disposal options for med /low active waste**
- **Digital tools**

Figure 5-1 : Focus areas for Waste Management and Decommissioning (TA5)

6. Technical Area 6 (TA6) - Innovative LWR Design and Technology

6.1. Scope

Innovative technology will be developed along with a transverse view for fulfilling the needs and requirements of the currently operating LWRs and new designs. On the one hand, this will provide new solutions and/or use of new methods and techniques for addressing key issues pointed out in the other

TAs which will be used as input. On the other hand, this will support the development of advanced LWR concepts with improved sustainability making better use of uranium resources and multi recycling capabilities of fissile materials. This will also allow the development of small modular reactors (SMRs), which offer simpler design, inherent safety advantages and modular construction. Progress should also be achieved both in the field of economics particularly when developing cogeneration, nuclear flexibility in a changing energy mix and in the field of public understanding and awareness, especially following the Fukushima accident and considering a diverse use of nuclear energy for district heating, industry and hydrogen production.

6.2. Objectives

Innovation is the key driver for addressing technology, methods, testing and computation capacities, with the objective of supporting the competitiveness of LWRs (figures 6-1 and 6-2). The main challenges are the following:

- The development of new materials, manufacturing and assembly technologies will result in the fabrication of highly reliable components for LTO. In this domain, the challenges are to promote technologies like hot isostatic pressing, additive manufacturing and to develop new or improved materials for LWRs.
- Alternative LWR concepts benefiting from the experience gained in the field of LWR technology are for instance high conversion ratio LWRs which better use fissile material and LWRs which favour multi-recycling of plutonium.
- SMRs [see SMR booklet TA6-1] have smaller core size, smaller footprint and lower capital cost compared to large LWRs. Their simpler design and the integration of passive safety systems combined with smaller residual heat allow improvements in safety. Developing numerous smaller reactors facilitates standardization and series effect but requires harmonization in the licensing process [see ongoing ELSMOR project TA6-2]. Besides SMRs are clear candidates for modular construction with modules manufactured and tested in factories.
- Even though less mature than LWRs, supercritical water-cooled reactors (SCWRs) operate at significantly higher pressures and temperatures compared to current LWRs and therefore have higher plant efficiencies.
- Deployment of innovative NPPs (LWRs based Gen III or Gen IV), SMRs, Micro NPPs) in a changing energy market with carbon neutrality consideration: Techno-economic studies are necessary to provide economic NPPs, which may eventually compete with Renewables; they will constitute the energy mix of the future, also considering the architecture of the new networks being developed, as imicrogrids, etc…, in addition to the classical ones. In that context, nuclear energy can serve new applications, in MV electrical networks or even LV ones like district heating, desalination, clean hydrogen production, building lighting, industrial applications, etc…
- Building public awareness, understanding and social acceptance: Studies in these areas are particularly helpful for the construction of new nuclear facilities, like NPPs, storage or disposal facilities or new applications with nuclear plants closer to local demands.

Figure 6-1 : NUWARD^{TM} small modular reactor (©TechnicAtome).

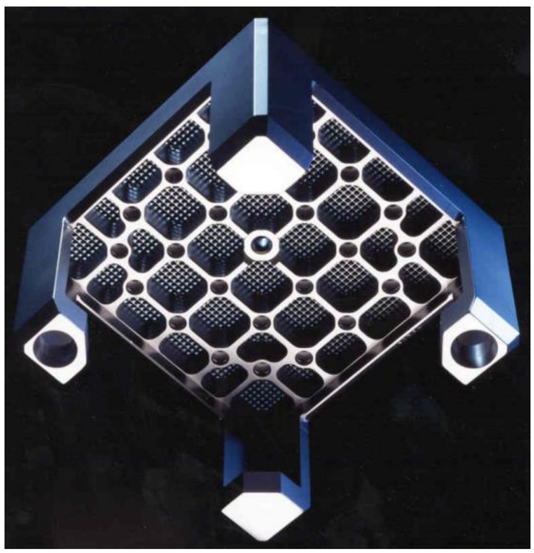

Figure 6-2: Debris trapper considered within additive manufacturing NUCOBAM project (Framatome courtesy).

7. Technical Area 7 (TA7): Fuel Development, Fuel behaviour in the reactor and Spent Fuel Management

7.1. Scope

TA7 covers the research on nuclear fuel elements for existing, advanced and innovative core designs including fuel assembly and control rod considerations. As defined in [TA-1], it includes the development of new fuel elements, manufacturing, fuel elements use in reactors, intra-core instrumentation and pre-disposal management of spent fuel.

In spite of the large knowledge base on existing nuclear fuel types, mainly UO_2 and $(U,Pu)O_2$ pellets with zirconium based alloy for cladding, there are still data gaps, which necessitate dedicated material property measurement and modelling. In addition, there are many challenges for a number of innovative nuclear fuel element types under development, in particular with enhanced accident tolerant fuel.

The focus is first on the safety requirement criteria for the fuel rod behaviour in the core under normal, transient and accident conditions, as well as for the fuel cycle. Of particular importance is that the roadmap takes account of lessons from the Fukushima accident to propose research, development and innovation to improve the safety and resilience of the existing and new build LWR reactor fleet. A second focus is to improve the economics and sustainability of nuclear power, through optimization of the use of available fissile and fertile nuclear material resources, reduced fuel costs, increased burn-ups and development of SMRs. Finally, in relationship with a more varied energy mix, fuel flexibility also has to be improved.

7.2. Objectives

Numerous R&D programmes were carried out to qualify fuels and fuel performance codes for current fuel rod designs and from operating conditions. A transposition of this knowledge to new conditions requires a thorough understanding and detailed description of the fuel behaviour. Physics-based validated fuel performance codes capitalizing the results of a combination of irradiation experiments, post-irradiation examinations, separate effect or integral tests experiments and multiscale modelling approaches are the way forward to answer these new questions. This knowledge must then be transferred in industrial simulation tools and undergo verification, validation and uncertainty analysis.

The priority topics are as follows.

- **extend the validity of the fuel performance codes for new designs and materials from operating conditions to accidental ones**
  - ✓ Consolidated multiscale modelling approaches and associated physical property databases,
  - ✓ Description of a large range of phenomena such as clad ballooning, pellet fragmentation, fuel relocation, fuel creep, pellet-cladding interaction, fission gas behaviour
- **develop accident tolerant fuel elements for the increase of safety margins under operation and accident conditions**
  - ✓ Innovative fuel pellet and cladding microstructures to improve power evacuation and reduce the fuel temperature
  - ✓ Innovative fuel claddings to lower high temperature steam oxidation and the associated hydrogen production,
  - ✓ Innovative fuel rod designs and fuel element materials to reduce the mechanical and chemical pellet cladding interaction

- **guarantee the fuel development for SMRs**
  - ✓ Evolution of fuel cladding and pellet microstructure and properties, as well as fission gas behaviour, at lower power and temperatures with a reduced irradiation defects annealing rate
  - ✓ Development of fuels with higher concentrations of burnable poisons for boron free reactors
  - ✓ Impact of the small core size and of the power level operation with control-rods on the safety margins for pellet-cladding interaction
- **improve spent fuel management: long term storage**
  - ✓ Long term fuel rod behaviour assessment and physically based modelling.
- **enable multi recycling of fuels**
  - ✓ Extend the knowledge obtained on single recycling of MOX fuels with new data regarding the impact of a higher content in Pu or minor actinides and of degraded isotopic composition on fuel thermal and mechanical properties, as well on fission gas behaviour

It is also critical to maintain key experimental facilities, in particular experimental irradiation devices in research reactors, hot cells and hot laboratories, and to expand their capabilities to meet future requirements regarding advanced characterization techniques or online data acquisition in irradiation experiments.

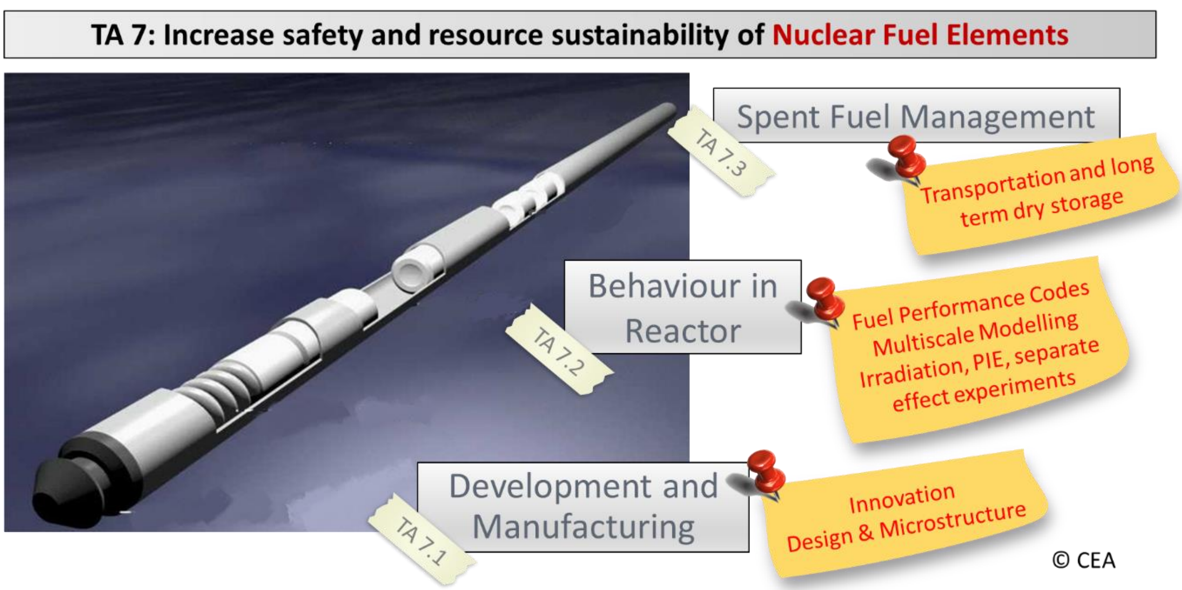

Figure 4 : TA7 methodology.

8. Technical Area 8 (TA8): In-service Inspection and Inspection Qualification

8.1. Scope

The European Network for Inspection and Qualification (ENIQ) was created in 1992 and is a utility-driven network deals with the reliability and effectiveness of non-destructive testing (NDT) for NPPs. ENIQ is working mainly in the areas of qualification of NDT systems and risk-informed in-service inspection (RI-ISI). ENIQ is recognised as one of the main contributors to today's global qualification guidelines for ISI.

The ENIQ methodology has been developed with regard to the inspection of pressurised metallic components and is used in European LWRs and CANDU Reactors and accepted by IAEA and WENRA as recommended practice to follow for inspection qualification.

ENIQ has two sub-areas in which the technical work is performed, the Sub Area for Qualification (SAQ), and the Sub Area Inspection Effectiveness (SAE). ENIQ members come from utilities, ISI vendors, Qualification Bodies (QBs) and research organisations in Europe with additional members from Canada, Japan and the USA. The ENIQ steering committee (SC) is the decision-making body of ENIQ and its members come from utilities of EU member states plus observers from Canada, Japan, USA and the leaders of the two sub-areas. In 2012 ENIQ was integrated into NUGENIA, becoming Technical Area 8 of NUGENIA.

8.2. Objectives

By coordinating expertise and resources, ENIQ aims at supporting licensees (utilities) and stakeholders in:

- Addressing issues where the practice and implementation of NDT will ensure the safe and reliable operation of NPPs through inspection qualification, the application of risk-informed approaches, and other processes;
- Providing recommendations and guidance to optimise and harmonise processes;
- Continually improving the processes for inspection qualification and RI-ISI for increased effectiveness and efficiency;
- Responding to the new challenges resulting from plant life extension (PLEX), new Build, including Small Modular Reactors (SMRs), and the application of the advanced manufacturing processes;
- Promoting ENIQ approaches outside Europe and in non-nuclear industries;
- Maintaining links with other Technical Areas, especially TA4 and TA6.

Accordingly, the corresponding R&D challenges are:

- Qualifying NDT Systems that make Use of machine learning and Artificial Intelligence; an ENIQ recommended practice on the topic will be published in 2021 that will also identify the gaps.
- Supporting the application of Machine Learning and Artificial Intelligence pursuant to ENIQ Recommended Practice 13 and the developments in the field.
- Use of virtual flaws on qualification: Practical trials or technical justificationUnderstand the technical barriers that preclude the transport of qualifications between countries and find methods or procedures on how to overcome these. A related benchmark project on re-qualification of inspections was completed in 2020.
- An independent assessment to verify the accuracy of NDT inspection simulation software

- Use of structural health monitoring systems in NPP to complement ISI
- Evaluating the latest NDT technologies to determine the qualifiable applications for nuclear inspections.
- Review of risk-informed pre-service inspection (PSI) for new build and modifications of existing plants.
- Extension of RI-ISI to all mechanical components, i.e. beyond piping. ENIQ SAE completed a technical report on topic which will be published in 2021.
- Benchmarking of RI-ISI approaches worldwide to harmonize them and improve credibility

Way forward

Nuclear energy is an important contributor to all three main pillars of EU energy policy set out in the SET-plan: i) environmental sustainability, ii) security of supply and iii) economic competitiveness.

Nuclear energy is a key asset for achieving the EU's 2050 carbon-neutral target in an affordable, reliable economic and safe way as

- It is low carbon over its entire life cycle;
- It is a proven industrial technology and is a major employer, supporting skilled high value-added jobs and local economic activity;
- It has the smallest land and resource footprints of any energy source;
- It does not contribute to air pollution such as NOx, SOx, heavy metals and particulate matter;
- It provides 24/7 reliable power for future new infrastructure and Industry growth, but can also load follow if needed;
- It is resilient, and decreases vulnerability to extreme weather phenomena and external threats;
- It provides rotational inertia that helps to stabilise the grid and regulate frequency;
- It enables stockpiling of fuel, which boosts security of energy supplies;
- It can provide isotopes and support for research, medicine, industrial and agricultural purposes;
- It is improving, with new technologies offering greater efficiencies and opening up new applications to enable decarbonisation of heat, industry and transport sectors.

Several major events occurred during the last decade, with the tsunami in Japan effecting the Fukushima-Daiichi NPP in 2011 and the financial crisis in 2008-2009 which triggered the evolution of energy policy in European member states. As a result, public acceptability has been weakened and the financing community together with local authorities have lost part of their trust in the competitiveness of new projects and in the life extension of existing reactors.

The nuclear sector needs to innovate to overcome these challenges. It shall:

- Develop the NPPs of the future, that need to be safe, economic, reliable and flexible
- Continue increasing its safety and security standards despite its already excellent records;
- Minimise and manage efficiently its waste by providing long term solutions;
- Enhance public awareness and acceptability by engaging multilateral dialogue;
- Improve the economic performance of new builds;
- Continue safe, efficient and competitive long-term operation of existing NPPs;
- Define more accurately the end of life of existing NPPs, including their maintenance in the last years, in order to define the Business Plan of the future and anticipate their replacement.
- Develop, attract and retain skills and competences, and the new competences needed for the new projects (SMRs, etc….) which may be different from older ones.

NUGENIA as a pillar of SNETP needs to pursue its evolution by:

- Strengthening and clearly define the positioning of nuclear energy in today's and tomorrow's European energy mix and consolidate European research, development, demonstration and innovation on fission technologies;
- Defining proprieties on innovative topics of high added value to the fission technologies in compliance with our long-term strategy namely the nuclear will continue to play a major role in the energy mix in Europe;

- Promoting and strengthening the collaboration between all stakeholders including industry, SMEs, research centres, academia around its priorities;
- Developing links and crosscutting topics with the actors towards the objective of neutrality promoted by the European commission for 2050: renewable energy platform (such as EERA, …) and also with those acting in the so-called “Digital transformation”;
- Establishing close and “win-win” collaboration with international agencies and other legal entities;
- Maintain and develop the needed skills and competences to tackle the up-coming challenges (LTO, decommissioning, dismantling, new build, ….);
- Building open knowledge and expertise in the highly demanding technological/scientific fields;
- Managing in a project driven way all the activities in order to get results rapidly and in an efficient way, through openness on the new topics;
- Liaise with all the European Research community and Organise an active participation in European/international events;
- Communicate in a proactive and open way on the perspectives opened by the R&D and innovation activities.

References

[TA - 0] NUGENIA GLOBAL VISION. Version April 2015 Rev 1.1

[TA0-1] Renewable energy directive (europa.eu)

[TA0-2] Horizon Europe - 2021-2027 (welcomeurope.com)

[TA0-3] "European Technology Platform", "Vision and strategy for Europe's electricity networks of the future", European Commission, Directorate-General for Research, Sustainable Energy Systems, Ref. EUR 22040, 2006

[TA0-4] SNETP Strategic Research and Innovation Agenda (SRIA) 2021, https://snetp.eu/wp-content/uploads/2021/09/SRIA-SNETP-1.pdf

[TA - 1] NUGENIA GLOBAL VISION. Version April 2015 Rev 1.1

[TA1-1] Development and Application of Level 1 Probabilistic Safety Assessment for Nuclear Power Plants. IAEA Safety Standards Series SSG-3. 2010.

[TA1-2] Development and Application of Level 2 Probabilistic Safety Assessment for Nuclear Power Plants. IAEA Safety Standards Series SSG-4. 2010.

[TA1-3] Deterministic Safety Analysis for Nuclear Power Plants. IAEA Safety Standards Series SSG-2. Rev.1. 2019.

[TA1-4] WENRA Statement on Safety Objectives for New Nuclear Power Plants. 2010.

[TA1-5] WENRA Reactor Safety Reference Levels for Existing Reactors 2020.

[TA1-6] Main Benefits from 30 Years of Joint Projects in Nuclear Safety. OECD NEA 2012. https://www.oecd-nea.org/jcms/pl_14784

[TA1-7] NURESAFE – Project Final Report. 2015. https://cordis.europa.eu/project/id/323263/reporting

[TA1-8] Final Report Summary - ASAMPSA_E (Advanced Safety Assessment: Extended PSA). 2016. https://cordis.europa.eu/project/id/605001/reporting

[TA1-9] Network Codes Home (entsoe.eu)

[TA1-10] Home (entsoe.eu)

[TA1-11] M. Rioual, F. Duffeau, I. Marcelles, S. Ruiz, K. Kopsidas, R. Preece, W. Geissler, J. Lorange**,** « INTEGRID - Impact of new Grid Codes on the local distribution network of Nuclear Power Plants »**,** *IEEE 2017 GM, General Meeting, PES GM1546, Chicago/IL, 16-20 July 2017*

[TA2-1] J.P. Van Dorsselaere, A. Auvinen, D. Beraha, P. Chatelard, L.E. Herranz, C. Journeau, W. Klein-Hessling, I. Kljenak, A. Miassoedov, S. Paci, R. Zeyen, "Recent severe accident research - Synthesis of the major outcomes from the SARNET network", Nuclear Engineering and Design, vol. 291, pp 19-34, September 2015

[TA2-2] L.E. Herranz, A. Bentaib, F. Gabrilli, S. Gupta, I. Kljenak, S. Paci, P. Piluso, F. Rocchi, "NUGENIA/TA2 Achievements in Severe Accidents Research 2015-2020", Revista Nuclear España, September 2020

[TA2-3] S. Bechta et al./Annals of Nuclear Energy 124 (2019) 541–547

[TA2-4] M. Pellegrini, L. Herranz, M. Sonnenkalb, T. Lind, Y. Maruyama, R. Gauntt, et al, 2020. "Main Findings, Remaining Uncertainties and Lessons Learned from the OECD/NEA BSAF Project", Nuclear Technology, https://doi.org/10.1080/00295450.2020.1724731.

[TA3-1] IAEA, 2022: Operating Experience with Nuclear Power Stations in Member States

[TA3-2] OECD NEA, 2020: Occupational Exposures at Nuclear Power Plants

[TA3-3] Nuclear Power Plant Flexibility: P. Morilhat, S. Feutry and al., VGB PowerTech Journal 5, 2019

[TA3-4] Digital Twins, a New Step for Long Term Operation of Nuclear Power Plants: C. Varé, P. Morilhat, Engineering Assets and Public Infrastructures in the Age of Digitalization. Proceedings of the 13th World Congress on Engineering Asset Management

[TA4-1] European Technical Safety Organisations Network (ETSON), Comparison of Rules-Making and Practices concerning Reactor Pressure Integrity Assessment, Technical report no. 2018-001, 2018.

[TA4-2] ASME Standards Technology, LLC, Code Comparison Report for Class 1 Nuclear Power Plant Components, report no. STP-NU-051, 2012.

[TA4-3] AFCEN, Design and Construction Rules for Mechanical Components of PWR Nuclear Islands – RCC-M, 2018 Edition.

[TA4-4] AFCEN, In-Service Inspection, Installation and Maintenance Rules for Mechanical Components of PWR – RSE-M, 2018 Edition.

[TA4-5] AFCEN, Design and Construction Rules for Electrical and I&C Systems and Equipment – RCC-E, 2019 Edition.

[TA4-6] https://www.stuk.fi/web/en/regulations/stuk-regulations

[TA4-7] IAEA, Ageing Management for Nuclear Power Plants: International Generic Ageing Lessons Learned (IGALL), IAEA Safety Reports Series no. 82 (Rev. 1), 2020.

[TA5-1] Share: A roadmap for research in decommissioning, https://share-h2020.eu/

[TA5-2] PREDIS: Pre-disposal management of radioactive waste, https://share-h2020.eu/

[TA6-1] https://aris.iaea.org/Publications/SMR_Book_2020.pdf

[TA6-2] https://www.ats-fns.fi/images/files/2019/syp2019/presentations/TSMR1_VTulkki_Elsmor-TowardsLicensingEuropeanSmallModularReactors.pdf

Glossary

ATF	Accident Tolerant Fuel or Advanced Technology Fuel
D&D	Dismantling and Decommissioning
DBA	Design Basis Accident
DBE	Design Basis Events
DEC	Design Extension Conditions
DHR	Decay Heat Removal
EATF	Enhanced Accident Tolerant Fuel
EC	European Commission
EERA-JPNM	European Energy Research Alliance – Joint Program on Nuclear Materials
ENIQ	European Network for Inspection and Qualification
ENSREG	European Nuclear Safety REgulators Group
ESNII	European Sustainable Nuclear Industrial Initiative
EU	European Union
EUR	European Utility Requirements
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
IEA	International Energy Agency
IGDTP	Implementing Geological Disposal Technology Platform
IPCC	International Panel on Climate Change
ISI	In-Service Inspection
JHR	Jules Horowitz Reactor
LCOE	Levelized Costs Of Electricity
LLW	Low Level radioactive Waste
LTO	Long-term Operation
LW-SMR	Light Water – Small Modular Reactor
LWR	Light Water Reactor
MOX	Mixed Oxide
NC2I	Nuclear Cogeneration Industrial Initiative
NDE	Non-Destructive Examination
NDT	Non-Destructive Testing
NEA	Nuclear Energy Agency
NPP	Nuclear Power Plant
ODS	Oxide Dispersion Strengthened
OECD	Organisation for Economic Cooperation and Development
PIE	Post Irradiation Examination
PINC	Nuclear Illustrative Programme
PLiM	Plant Life Management
PWR	Pressurized Water Reactor
R&D	Research and Development
RI-ISI	Risk Informed In-Service Inspection

RPV	Reactor Pressure Vessel
SAMG	Severe Accident Management Guidelines
SAR	Safety Analysis Report
SET	Strategic Energy Technology
SNETP	Sustainable Nuclear Energy - Technology Platform
SSC	Structures, Systems, and Components
TA	Technical Area (of NUGENIA)

NUGENIA
Nuclear Generation II&III Alliance

ABOUT NUGENIA

The **Nuclear Generation II & III Alliance (NUGENIA)** is dedicated to the research and development of nuclear fission technologies, with a focus on Gen II & III nuclear plants. It provides scientific and technical basis to the community by initiating and supporting international R&D projects and programmes.

NUGENIA is one of the three pillars of the Sustainable Nuclear Energy Technology Platform (SNETP) that was established in September 2007 as a R&D&I platform to support technological development for enhancing safe and competitive nuclear fission in a climate-neutral and sustainable energy mix. Since May 2019, SNETP has been operating as an international non-profit association (INPA) under the Belgian law pursuing a networking and scientific goals. It is recognised as a European Technology and Innovation Platform (ETIP) by the European Commission.

The international membership base of the platform includes industrial actors, research and development organisations, academia, technical and safety organisations, SMEs as well as non-governmental bodies.

secretariat@snetp.eu **www.snetp.eu** **SNETP** **SNE_TP**

9 782919 313389