ROADMAP

NUGENIA Roadmap 2013

NUGENIA

NUclear GENeration II & III Association

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Foreword by the President

Since its official establishment in 2011, NUGENIA has achieved very important steps towards the consolidation of its structure, the clarification of its vision, the deployment of its strategy and last but not least the increasing of its visibility and the strengthening of its position. The main accomplishments are summarised as follows:

- NUGENIA highly qualified experts have been organised and structured in technical areas to develop, short, mid and long term scientific challenges.
- Expert groups of NUGENIA members have been active in elaborating an R&D roadmap which contributed to the updating of the 2013 SNETP Strategic Research Innovation Agenda (SRIA), and is the basis of this document.
- NUGENIA's ExCom and its secretariat have been active in defining a project creation process aimed at the identification of the most promising research ideas to be shared, discussed within the NUGENIA community and elaborated into proposals endorsed for their high quality level.
- NUGENIA community has contributed significantly in the building of a common prioritisation process based on high level priorities which are aligned with the existing proposals expressed in the full roadmap; this prioritisation process contributed to the roadmap coherency and highlighted the main initial objectives of NUGENIA.
- NUGENIA is now a reality, thanks to the effort of all members but especially the ExCom, Technical areas and the secretariat members who are taking care of the daily activities on a voluntary basis.

Its ambitious character will continue to drive its progress to become the reference association concerning R&D on Gen II and III. The road is clear ahead of us, allowing NUGENIA to play it's expected role in the co-programming of Gen II and III Nuclear R&D of public-public and public-private interest aimed at ensuring the safe and efficient long term operation of the existing NPPs, recognised as a sustainable and valuable contribution to the energy mix scenario under consideration in Europe and worldwide.

NUGENIA, based on the long standing expertise of its members, will have to play a significant role in harmonising the knowledge concerning safety culture, increasing the awareness of the public, facilitating the education of the young generation of future experts and more importantly integrating the European R&D in the field of Gen and III.

In addition to its own activities, NUGENIA will be supported by the new project NUGENIA+ partly funded by the European Commission, DG RTD under Euratom-FP7, expected to kick off in October 2013, with the aim to strengthen our position and enlarge our ability to provide technical and scientific solutions based on collaborative R&D.

J.P. West, President

EXECUTIVE SUMMARY

This publication - NUGENIA roadmap, challenges and priorities - has been produced to provide a single reference document for NUGENIA members and the wider nuclear generation II and III R&D community in Europe and around the World.

NUGENIA was established on the 14th November 2011 and now includes and embraces the technical objectives of all the EU Generation II and II R&D networks (NULIFE, Gen II/III TWG, SARNET, ENIQ) under the umbrella of SNETP (the Sustainable Nuclear Energy Technology Platform). In less than 2 years it has defined a clear technical structure for generation II and III research, developed a detailed technical roadmap based on 6 technical areas and 2 cross cutting areas:

1. *Plant safety and risk assessment,*
2. *Severe accidents,*
3. *Improved Reactor Operation,*
4. *Integrity assessment of Systems, Structures and Components,*
5. *Fuel Development, Waste and Spent Fuel Management and Decommissioning,*
6. *Innovative LWR design and technology,*
7. *Harmonisation,*
8. *In-service Inspection and Non Destructive Examination.*

Technical area leaders (TAL) and sub area leaders (SAL) are appointed for each area. In addition, The ExCom has appointed a coordinator to ensure completeness and coherency between topic areas. The full roadmap allows for the identification of key challenges and major technical issues.

NUGENIA has identified high level objectives in order to help the prioritisation of the main R&D issues, these also help in initiating, following and valorising projects related to each of the areas as well as identifying possible cross-cutting topics:

- Improve safety in operation and by design,
- Reach high reliability and optimised functionality of systems,
- Reach high reliability of components,
- Improve modelling of phenomena in NPPs,
- Increase public awareness,
- Efficiently integrate NPPs in the energy mix,
- Prepare the future to avoid technology obsolescence, and seek for innovation,
- Manage performance and ageing of NPPs for long term operation.

NUGENIA has developed an organisation and structure which supports these objectives and allows all members to participate yearly through General Assembly and the various technical Fora. Daily organisation and management are carried out by the Executive Committee (ExCom) and Secretariat.

In order to maintain the efficiency and effectiveness of NUGENIA, the ExCom has developed a set of rules and procedures covering all aspects of its operation from membership applications, through to administration and financial processes, to an online project creation process and innovation platform (NOIP). Project performance and progress will be monitored and supported throughout by the ExCom and fully public reports will be published and made available on the knowledge management platform currently being developed. NUGENIA also manages a website for member and public communication.

This document provides a summary of the 8 technical area roadmaps detailing the technical challenges for today and for the future. It also launches the list of prioritised cross – cutting challenges to meet the objectives of NUGENIA - to coordinate and support R&D for the safe and efficient operation of Gen II and development of Generation III NPPs in Europe and beyond.

NUGENIA is one of the "three pillars" of Sustainable Nuclear Energy Technology Platform (SNETP), as shown in Figure 2, these are:

1. Current technology and its evolution (Generation II & III),
2. Future technology (Generation IV, Fast Breeder Reactors),
3. Cogeneration of power and heat.

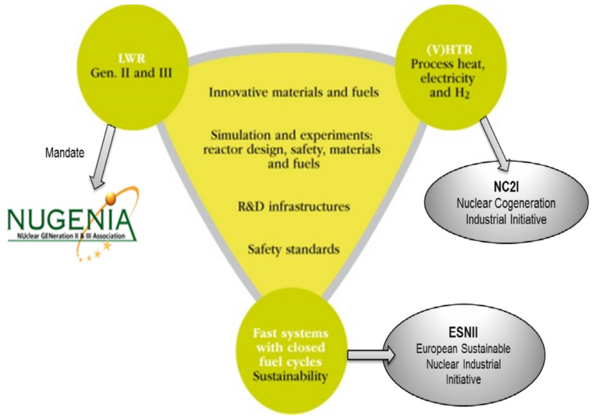


Figure 2: The Position of NUGENIA as one of the three pillars of SNETP.

I. Introduction to NUGENIA

I.1. History and objectives

NUGENIA ("NUclear GENeration II & III Association"), an international non-profit-making association according to Belgian law, was established on 14th November, 2011 to become the unique framework for collaborative R&D in the scope of Generation II & III nuclear systems. The main mission of NUGENIA is to be the integrated framework for programming collaborative R&D between industry (e.g. manufacturers, vendors, utilities, small and medium enterprises), research organisations (e.g. universities, national research centres, technical safety organisations) and member states public bodies (see Figure 1). All collaborative R&D is carried out in order to enhance the safety, reliability and competitiveness of Generation II and III nuclear power plants in Europe and around the world.

Figure 1: NUGENIA based membership.

SNETP mandates NUGENIA to act as the body in charge of coordinating at EU level the implementation of the R&D within this technical scope. Under this mandate NUGENIA is responsible for the following activities:

- Define detailed roadmaps and R&D priorities,
- Facilitate the emergence of projects implementing R&D in the field of Gen II & III,
- Identify all relevant funding sources for Gen II & III R&D,
- Generally promote European nuclear Gen II & III collaborative R&D,
- Facilitate cooperation with international counterparts on Gen II & III R&D.

The mandate under the umbrella of SNETP gives NUGENIA rights as well as obligations: NUGENIA is acting as the driving force to represent the Gen II/III pillar of SNETP and is supported by SNETP to facilitate the dialogue with high level stakeholders and forums (such as ENEF, ENSREG, and other Technology Platforms). On the other side, NUGENIA periodically reports to the management bodies of SNETP, including brief reports on projects launched under its umbrella. NUGENIA contributes to the production and updating of SNETP's strategic documents and acknowledges SNETP in its public communication.

Since its creation NUGENIA has been successful in integrating several European Networks of Excellence such as NULIFE on Plant Life Prediction, SARNET on Severe Accident and ENIQ the European Network on Inspection and Qualification and the SNETP GenII/III TWG. It gathers together the major European nuclear stakeholders with members from the industry, utilities, research institutions, SMEs, universities and technical safety organisations.

To summarise the historical emergence of NUGENIA, the following steps have been successfully achieved:

2006-2010: the building blocks in Europe

- Development of several Europeans networks addressing different aspects of Gen II & III research: FP6-NULIFE, FP6/FP7-SARNET, SNETP Gen II/III TWG… that achieved international reputation and recognition.

2011: the consolidation process

- March: First joint meeting of SNETP TWG Gen II&III, NULIFE and MMOTION.
- March: SNETP Governing Board supports **full integration between TWG Gen II& III and NULIFE.**
- November: **Legal establishment of NUGENIA** with 7 initial members.

2012: the birth of NUGENIA

- February: ENIQ supports the joint integration with NUGENIA.
- March: SARNET supports the joint integration with NUGENIA.
- March: **Official launch and First General Assembly.**
- March: Signature of mandate from SNETP to NUGENIA.
- March: First NUGENIA Plenary meeting.
- April: NUGENIA reaches its 50th member.

2013: NUGENIA is a reality

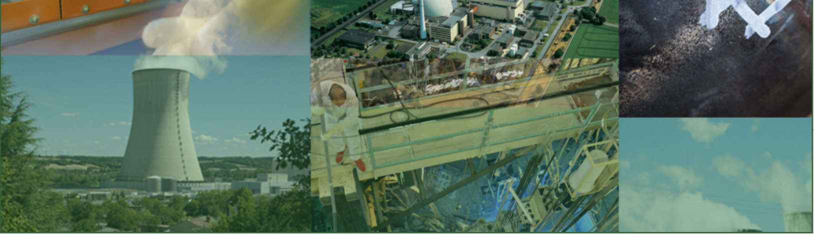
- February: Publication of the first NUGENIA vision within the SNETP SRIA.
- February: Identification of emerging project ideas.
- March: Consolidation of the first NUGENIA project portfolio.
- March: second NUGENIA General Assembly and election of a new ExCom.
- March: second annual NUGENIA FORUM.
- April: Launch of NUGENIA Open Innovation Platform (NOIP).
- June: Identification of cross-cutting issues between different technical areas.
- September: publication of the NUGENIA roadmap.

I.2. TECHNICAL AREAS AND HIGH LEVEL OBJECTIVES

Joining forces to reach scientific and technical excellence is the main value of NUGENIA. In order to bring to all members the best available competences, facilities and technologies, the work of NUGENIA is organised along the main stakes into eight Technical Areas (TAs):

1. Plant safety and risk assessment,
2. Severe accidents,
3. Improved Reactor Operation,
4. Integrity assessment of systems, structures and components,
5. Fuel Development, Waste and Spent Fuel Management and Decommissioning,
6. Innovative LWR design and technology,
7. Harmonisation,
8. In-service Inspection and Non Destructive Examination.

The main challenges related to each of these technical areas are described in Chapter III. Several technical domains are interconnected with more than one area; in particular area 7 and 8 are cross cutting areas over all other areas; for clarity of the document, the inter connections and cross cutting aspects are not described but they are considered with great attention in the daily work. High level objectives are described in chapter IV, and are



defined as the most important topics to which each of the technical areas should significantly contribute. Both these are key inputs to the prioritisation procedure described in Chapter II and IV.

I.3. Organisation and Responsibilities

For its legal creation, NUGENIA has adopted a general status according to the requirement of the Belgian law which are supplemented by internal rules that define the way that each of its constitutive body interact with each other.

The NUGENIA Association is represented by the President and Vice-president. The roles of NUGENIA decision making bodies, namely the General Assembly and the Executive Committee are presented in the scheme below and can be described briefly as follows.

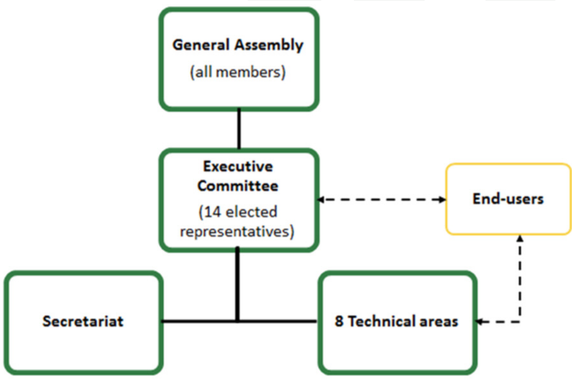


Figure 3: NUGENIA governance

- **General Assembly**: is the highest decision making body of the Association and approves the changes to the purpose, the mission, the general policy and the strategy of NUGENIA. The General Assembly is composed of one legal representative for each Member. It elects a President, a Vice president and the members of the Executive Committee from among its members for a two–year period and appoints the members of the Secretariat. It is also its duty, to appoint business auditors, approve the annual activity plan and related budgets, approve the annual report of activities, approve the annual accounts, ratify the membership of the Honorary Members, among others. All the decisions are validated during its annual meeting hosted on a voluntary basis by one of the members.

- **Executive Committee (ExCom)**: is composed of maximum 14 elected individuals on the basis of 50 % of the members represent R&D organisations, technical safety organisations or public bodies and 50 % of the members represent the industry. The Executive Committee is responsible for the operational management and administration of NUGENIA, by:
  - proposing and implementing internal rules,
  - producing the annual activity plan and related budget,
  - taking operational decisions to follow and implement the activity plans and strategy,
  - implementing the decisions taken by the General Assembly,
  - coordinating the evaluation, planning and monitoring of the endorsed R&D projects.

The Executive Committee is supported in its tasks by the Secretariat for the daily administration of NUGENIA.

I.4. Role of Technical Area Leaders

Each Technical Area (TA) is coordinated by an expert appointed by the Executive Committee. This TA leader (TAL) is mandated to:

- Develop with the help of sub-area leaders (SAL) and all the members the content of the technical and scientific roadmap, highlighting the common understandings, the gaps and the challenges.
- Review, with the help of SALs, the project ideas submitted by NUGENIA members.
- Communicate with other TA leaders on cross-cutting issues and projects.
- Report to ExCom on status on each area and associated projects.

In order to strengthen the coherency between the areas, a coordinator has been appointed by the ExCom to fulfil the following tasks:

- Harmonising TAs approaches through TALs periodic meetings.
- Development of the cross-cutting challenges facing NUGENIA.
- Assuring homogenous position on focused technical topics throughout TAs.
- Representing NUGENIA technical area leaders where relevant.
- Report to the ExCom at least twice a year.

I.5. Members

NUGENIA has 2 types of membership categories - Full members and honorary members.

All members shall comply with the applicable laws, the NUGENIA Statutes, the NUGENIA internal rules and decisions taken by the General Assembly and the elected Executive Committee.

Full members

Any legal entity having expertise in the nuclear field can apply for membership and becomes a member if it is accepted by the ExCom.

1. Industry (non-SME)
    a. Utility
    b. Vendor, supplier, engineering / construction company, other industrial company
    c. Service company
    d. Energy-intensive industry
2. R&D organisation
    a. Research & technology organisation
    b. Academia
    c. TSO: technical safety organisation (based on ETSON definition)
3. SME: small and medium enterprises (based on European Commission definition)
4. Public authorities (Safety authority, Ministry, National agency, ...)
5. Others are considered cases by case.

Honorary members

Groupings such as: joint research centres of the European commission, consortia, standardisation bodies, associations, networks, clusters, platforms, federations, organisations with particular status such as NGO's, may apply to become honorary members of the association.

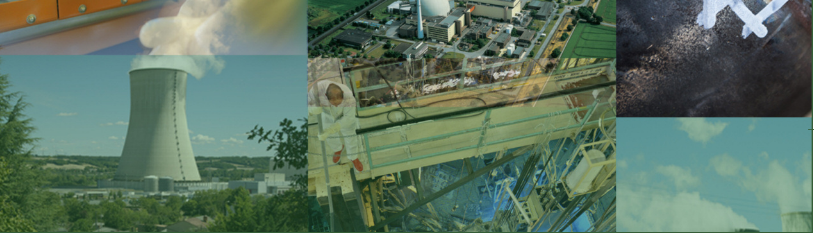
The status of a NUGENIA honorary member shall allow having access to the same flow of information within NUGENIA as a full member, especially regarding the road mapping, setting up of priorities and monitoring the project creation process within the open innovation platform. The honorary member is invited to participate in the general assembly as an observer.

I.6. End Users

The primarily end users of the results obtained from the NUGENIA endorsed projects are its members. In addition and in order to facilitate the harmonisation of knowledge on one hand and to take into account the needs of the society, market, economy and policy, on the other hand, NUGENIA has been establishing a global strategy for collaborating with various European and international active groups such as FORATOM, IAEA, OECD, KIC-inno-energy etc. The interaction between NUGENIA and the end users is based on the following principles:

For each user, NUGENIA undertakes to assume the general responsibility with regard to:

- Organisation of periodical dissemination meetings to share privileged information on the submitted proposals and work performed in on-going projects of the NUGENIA portfolio.
- Organisation of information exchanges (including topical meetings, web-communication etc.) between the end users and the consortium of a specific project upon bilateral agreement.



Each end user is invited to:

- Be informed on the project's objectives, progress and success indicators,
- Provide recommendations to NUGENIA and its projects,
- Provide R&D input to a specific NUGENIA project from separately funded initiatives and finance additional R&D work they consider useful to expand a project scope.

It shall be noted that, to ensure the protection of the intellectual property rights of each of its members, NUGENIA encourages the establishment of a consortium agreement between the active partners of each project. This would ensure the possibility of any user (member or non member of NUGENIA) to collaborate under separate agreement with each project consortium.

II. NUGENIA PROCESSES

The management of an international association needs clear and transparent rules and procedures to ensure traceability of decisions and engagements.

II.1. MEMBERSHIP APPLICATION PROCEDURE

To become a NUGENIA member, the authorised representative of the interested organisation has to apply online. Thereafter, details on the organisation should be provided as well as the contact details of the authorised representative(s) and administrative/financial contact persons. The NUGENIA Executive Committee examines the application and informs the contact person of the decision.

To become officially a NUGENIA Honorary member, the organisation or the person has to be invited by the Executive Committee and ratified by the NUGENIA General Assembly.

Each member is invited to appoint technical representative(s) for each technical area of interest to his activities.

II.2. ADMINISTRATION

The NUGENIA Secretariat manages the day-to-day back-office of the association. The secretariat appointed representatives to interact with various external services, providers or public authorities (lawyers, accountants, auditors, tax administration, bank representatives), following well established procedures decided by the ExCom.

II.3. PROJECT MANAGEMENT

NUGENIA manages for its members an open innovation platform (NOIP) that is a web based interactive working platform with the aim to increase visibility, support transparency and assure the traceability of new R&D projects ideas.

Any member registered in NOIP, can submit an idea by using the so-called "Template 1" form. The technical area (TAL) and sub-area (SAL) leaders then review and evaluate this idea and provide feedback to the proposer.

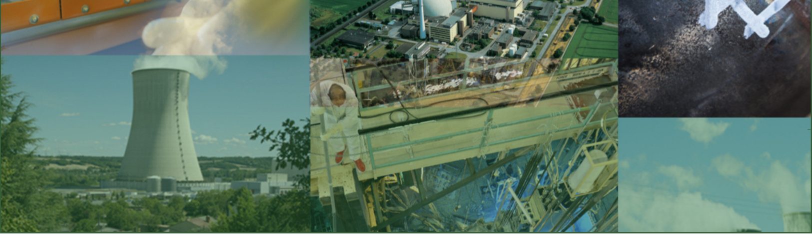
The main points to be reviewed and evaluated before the publication of the project idea under Template 1 to the NUGENIA community are the following:

- Coherency with the priorities of the roadmap (according to its latest status).
- Quality of the proposal: scientific/technical challenges.
- Impact of the proposal: on NUGENIA community and on the harmonisation of knowledge.

Upon approval of the proposal, any member may express its interest in participating/contributing to the proposed project idea and/or provide technical comments.

This feedback in hand, the idea can be developed further into a project proposal description, including its budget and partners, allowing the submission of the so called "Template 2" form, to be reviewed by the corresponding technical area(s) representatives in order to evaluate:

- The Quality of the consortium in term of competences and the facilities identified for the accomplishment of the proposal objectives.
- The pertinence of the deliverables to be monitored by the appointed member of the ExCom.



Depending on the readiness level of the project proposal the NUGENIA Executive Committee provides recommendations, including guidance on possible funding sources, if necessary. Most importantly, the ExCom decides on the attribution of NUGENIA label, the guarantee of a high-level quality research proposal and a clear sign for potential private and public funders.

Each labelled project will be attributed an ExCom contact with the role to assist in the project monitoring and to valorise its results by enhancing the visibility through publications, credibility through the scientific and technical quality of the publications and sustainability through the strengthening of existing networks and building new ones.

II.4. Knowledge and Information Management

All documents related to NUGENIA administration and management meetings are available on the NUGENIA collaborative platform (Members area).

A NUGENIA library (Knowledge Management Platform) is under development to facilitate the sharing and transfer of scientific data resulting from the research work within the NUGENIA project portfolio via databases, reports and other suitable means.

It will contain a public section for full public reports and a restricted area for storage of reports that are reserved to NUGENIA members and/or consortia running projects within the NUGENIA project portfolio.

The scientific output resulting from R&D projects will be stored and managed within specific databases, such as STRESA (JRC database for data from severe accident experiments), based on mutual agreements between the result owner(s) and the database administrators and respecting the clauses of the agreement of each consortium. It is understood that the intellectual propriety rights shall be dealt with at the level of each project consortium.

II.5. External Relations and Communication

NUGENIA uses modern communication tools to inform its members about its activities.

For public communication, the NUGENIA website (www.nugenia.org), delivery of quarterly online Newsletters and other public communications (PowerPoint presentations, brochures, posters, articles in focused publications, press releases etc.).

For internal communication, the NOIP offers a continuous track of all projects under development. The secured Members area contains documents related to the on-going activities of NUGENIA bodies.

In addition, the Annual Forum provides the opportunity for member's management and technical representatives to share views on R&D matters.

II.6. Road-mapping and Prioritisation Processes

Straight after the foundation of NUGENIA, the TA leaders in close collaboration with experts from different member organisations started considering their common needs to be part of the roadmap for each technical area. The roadmaps are organised to contain the objectives of each TA, based on the state-of-the-art, allowing the identification of the main consensual challenges for the future accompanied with R&D needs.

After the Fukushima-Daiichi accident SNETP decided to revise its Strategic Research Agenda (SRA) to take account of the lessons learned and the initiatives taken from re-viewing the safety of present and future LWRs. NUGENIA has therefore issued comprehensive summaries of each TA roadmap for the revision of the "Strategic Research and Innovation Agenda (SRIA)" of SNETP, which was published in February 2013.

Following its second Forum (March 2013), NUGENIA decided to consolidate its detailed roadmap and to issue a condensed version, aligned with the published part of SRIA, with the goal to harmonise its objectives, to clarify its challenges and to prioritise its R&D needs in a consensual manner. For this purpose, each TA leader has initiated focused discussions with the appropriate experts from member organisations to define their interests and the national/international framework in which the defined activities are being pursued. Thus, the technical experts identified the gaps in their technical field of competence integrating the knowledge gained through national and international programmes and seeking common interest. This bottom-up exercise allowed an almost exhaustive listing of the R&D topics to be considered in each technical area.

Subsequently, the ExCom and the TALs have initiated a top-down prioritisation exercise, in order to establish a global vision of NUGENIA overall program and to provide high level objectives. This exercise improved the consistency and collaboration between the different TAs and highlighted cross cutting challenges.

The comparison of both approaches showed that bottom-up identified challenges are necessary to achieve the high level objectives strengthening the cohesion of the NUGENIA community and the coherency of the overall methodology, whilst recognising that the accomplishment of high level objectives would need complementary effort in several research fields.

Processes

III. Technical area objectives and challenges

This chapter is based primarily on the SNETP SRIA, amended by TALs and SALs to take into account the relevance of each topic when it comes to ensuring safe and reliable operation of Gen II and III nuclear power plants, not only existing plants, but also those under construction or consideration for the future.

Each TA has been summarised 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 at the international level.

III.1. Technical Area 1 (TA1), Plant safety and risk assessment

III.1.1. Scope

The TA1 is devoted to improving the physical understanding and the numerical modelling of the relevant phenomena involved in Nuclear Power Plants (NPPs) incidents and accidents, to increase the capacity and comprehensiveness of the plant behaviour and to enhance the accuracy of safety margin assessment accordingly. The main challenges identified within the TA1 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 focussing 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 simulations, containment behaviour, and fluid-structure interactions.
- The impact of external loads (including electrical disturbances) and other hazards on the safety functions.
- The advanced safety assessment methodologies: safety margins and best estimate methods, integrating the deterministic and probabilistic safety assessments.
- The design of new reactor safety systems.

Figure 4: Grohnde power plant (Source: E.ON)

III.1.2. Objectives

In the TA1 roadmap, the above mentioned issues are addressed either in specifically identified sub-technical area, as it is the case for PSA, the impact of external loads and disturbances, the advanced safety systems and methodologies or in cross-cutting topics, as it is the case for human factor and organisational issues. The main objectives that have been identified are:

1.1 Data, Methods and Tools for Risk Assessment,
1.2 Deterministic Assessment of Plant Transients,
1.3 Impact of External Loads and Hazards on the Safety Functions,
1.4 Effect of Electrical Grid Disturbances,
1.5 Effects of Human Errors and Reliability Evaluation,
1.6 Advanced Safety Assessment Methodologies,
1.7 Design of Reactor Safety Systems.

III.1.3. State of the art

The R&D activities on safety approach and risk evaluation have relied, for a long-time upon wide support from international organisations, such as the European Framework Research and Development Programmes (FP), the programs of the OECD working-groups and several others. The main issues that have been addressed are related to the probabilistic and deterministic methods, the impact of external loads and hazards on the safety functions, the consequences on the safety function reliability of external electrical disturbances and the advanced methodologies for safety assessment and their harmonisation, for example: the OECD Working Group-risk, addressing risk assessment methodologies, the European FP6 and FP7 seeking for harmonisation among practices on PSA2 and addressing man-machine interface and ergonomic aspects. As for the deterministic assessment of plant transients several international and European programs have been performed or still ongoing either to address the transient and severe accident phenomenology, mainly for Light Water Reactors (LWR) assessment methodologies and to improvement of the computation tools and chains. The impact of external loads and hazards on the safety functions has been the subject of several national and international programs, as well.

However, the proper assessment of safety and risks needs a continuous effort to reduce the uncertainties and gaps in the existing methodologies and validate them at the appropriate level but also to develop a harmonised safety culture that takes into account the latest R&D results.

III.1.4. Challenges

III.1.4.1. Data, Methods and Tools for Risk Assessment

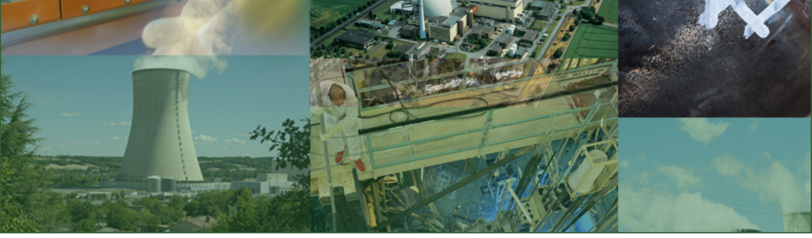
As far as the quantitative aspects of the probabilistic safety assessment (PSA) are concerned, the following major challenges should be addressed:

- Methodologies to quantify initiating event frequencies for low probability events with severe consequences, including external events, Common Cause Failures (CCF) events and combination of events (including internal and external ones).
- Methods to establish component failure rates - with specific care to components with low failure rates and failure due to specific loads (such as loads due to fire, severe accident conditions…).
- Data and methods to assess CCF inside system and among systems.
- Methods to assess human reliability and establishing a database with reference cases for assessments of human performance.
- Methods to account for time-dependence in PSA.
- Methods and data to quantify the effects of aging on PSA-outputs.
- Methods and data to assess the failure frequencies of digital components.
- Methodology and data for fire PSA.

For the PSA concerning source term issues (level 2 PSA), recommendations on the best strategies to couple level 1 and level 2 PSA should be made, and methodologies to assess shut-down state or external events should be developed.

R&D topics:

- **Developing methodologies and tools to allow the consideration of several plants simultaneously affected, notably, in the case of external events.**
- **Benchmarking existing PSA-studies to check their comparability and support adoption of risk-aimed approach in plant management.**
- **Developing guidance for safety assessments.**
- **Assessing the risk related to spent fuel pool.**



- **Developing techniques to model the functional dependencies in electrical and safety instrumented systems.**
- **Establishing methodologies for level 3-PSA (up to health effects) including integration with level 2-PSA.**

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Even if advanced PSA tools are widely available and extensively used, it is still extremely important to check their correct application in specific Risk Informed Decision Management (RIDM) strategies. If good methodology for development of "basic" PSA is necessary the need of a large practice of well-developed and harmonised RIDM methodology is even more necessary.

III.1.4.2. Deterministic Assessment of Plant Transients

III.1.4.2.1. IMPROVED THERMAL HYDRAULICS EVALUATION FOR THE EXISTING PLANTS

Plant behaviour is the result of complex tightly coupled multidimensional physical phenomena. In the assessment of transients, new challenges are now arising, but recurrent studies still need large efforts.

Figure 5: Safety assessment at Cruas NPP, France (Source: IRSN)

To fulfil the current and new goals, the main pending challenges in thermal-hydraulics are:

- A better understanding and modelling of the multi-dimensional phenomena, in particular in vessels and pools.
- A better understanding and modelling of the multiphase (steam/water, non-condensable gases etc.) phenomena.
- The interaction with neutronics (in particular in reactivity transients), mechanics (fluid-structure interaction in steam generator for example), and thermo-mechanics.
- Containment phenomena in dry-well like stratification and heat transfer into the condensation pool and load assessment from source to loads on walls under different voiding conditions in the condensation pool with the aim of reducing uncertainties.
- Develop modelling of 2–phase flow in the core.

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R&D topics

- **Stratification in pools and vessels, in particular for BWR- condensation pools when steam flow is low.**
- **Mixing in pools and vessels, in particular at low flow rates, including vessel pressurised thermal shock and boron mixing in reactor vessels.**
- **Instability in BWR-cores.**
- **3D flows in the reactor pressure vessel (BWR/PWR/VVER).**
- **Effects of non-condensable gases in pipes for scenarios with gas intrusion.**

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III.1.4.2.2. DESIGN AND EVALUATION OF PASSIVE SAFETY SYSTEMS

The major challenge to a generalised adoption of passive systems for safety purposes is the achievement of a convenient and exhaustive full scale demonstration of their reliability in transient conditions.

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R&D topics

- **Provide evidence of the system reliability despite the approximations and assumptions in the validation experiments and to clear the way to extrapolation.**

■

III.1.4.2.3. COUPLED MULTI-PHYSICS SIMULATIONS

Development of coupled multi-physics simulations is a widely acknowledged need. Such methodologies are already well advanced, but they require further effort to address specific problems such as the re-criticality scenarios and the instability in BWR-cores.

III.1.4.2.4. Fluid structure interactions

■

R&D topics

- **Turbulent flows and its effects on component aging.**
- **Fluid-structure interaction in steam-generator.**
- **Water hammer assessment.**
- **Coupling between CFD (Computational Fluid Dynamics) and system codes.**
- **Heat transfer along piping and vessel walls during turbulent flows.**

■

III.1.4.2.5. Fire risk

■

R&D topics

- **Comprehensive characterisation of different fire loads.**
- **Fire suppression models and suppression technologies.**
- **Methods and criteria to assess malfunction of electrical equipment considering combined effects of soot and thermal stress.**

■

III.1.4.2.6. Containment behaviour

■

R&D topics

- **Non condensable gas flows in the containment with and without spraying.**
- **Heat transfer in the gas phase of the containment including the interaction with walls and pipes leak rates through containment up to containment break.**
- **Clogging phenomena in strainers and fuel and associated assessment methodology.**
- **Fire and gas explosion simulation methods and applications to reactor safety.**

■

III.1.4.3. Impact of External Loads and Hazards

The external events have to be characterised by loads and frequency as well as by the risk for co-incident occurrences and the effects on non-safety systems on the safety system. The potential for successful preventive and mitigating human actions has to be considered.

■

R&D topics

- **Methods for frequency/magnitude assessment for events with short and long return periods (from 100 to more than 1000 years) need to be further developed in view of the major uncertainties involved. Estimates of the effects of climate change also indicate substantial impacts on the frequency and magnitude of certain natural external events. even in the near future, which needs to be considered in the analysis of external events.**
- **Methods and methodologies to identify single and multiple external events are also necessary to assess effects on a multi-unit plant, as well as how the effects of external events on non-safety systems could affect safety systems.**

■

III.1.4.4. Effect of Electrical Grid Disturbances on the safety functions

■

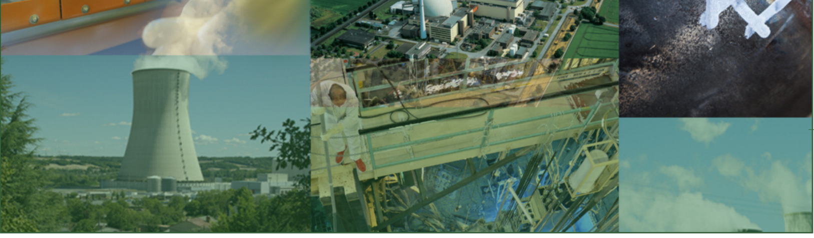
R&D topics

- **Grid disturbance effects on the plant through the internal electrical buses and other electrical components important to safety. It includes assessment of the effects originating either from lightning or from motor magnetic fields on modern electronics and/or digital equipment which are far more sensitive to magnetic fields than components used in the past. Other equipments like plant electrical and Instrumentation and Control (I&C) equipment, or diesel generators for emergency power may be also affected.**
- **The design of plant control and protection systems has to be based on an increased understanding of these effects and the sources of these effects have to be investigated.**

■

III.1.4.5. Effects of Human Errors and Reliability Evaluation

Typically, deterministic assessment relies on automatic functions in short term (30 minutes). Human is supposed to handle actions where more time is available for decisions. Human interactions in short term will anyhow have impact on scenario developments.



Operators and maintenance actions that are not covered by procedures are not assessed, neither in deterministic, nor in most of the risk assessments performed so far. Actions are taken to include such effects in the risk assessments. Issues related to quantification of risk related to human failures in PSA assessment are the main subject for this sub-area.

More research shall be envisaged to extend the end of cycle (EOC) analysis from the full power to the scenarios where EOC is more possible and important, e.g. shutdown situation, fire analysis.

Several methods are developed and applied for assessing human reliability for supporting common risk assessments of human performance but there are still large uncertainties in these assessments. There is also a crucial need to develop detailed human reliability assessment (HRA) guidance for specific applications.

■

R&D topics

- **Issuing a guideline for a state of the art HRA for PSA purposes, based on performed assessments, ensuring that plant specific properties are properly taken into account in the HRA.**
- **Selecting methods should be used for different types of operator actions.**
- **Collecting human performance data from plant near-miss reports, incident/accident reports, digital systems and simulator exercises. Detailed human performance data would help understanding the important PSFs and sufficient human performance data would greatly help in the quantification of the human failure events in PSA.**

■

III.1.4.6. Advanced Safety Assessment Methodologies

The general challenge in this sub-area is to increase knowledge about the existing safety margins of a plant. Several methodologies can be further developed in order to improve the accuracy of evaluations. The research will also develop common understanding on how to use best estimate methods for safety margin assessments.

■

R&D topics

- **Risk informed methodologies, usually developed by operators, based on decision-making theory and/or economic models can still be improved in order to optimise the risk accuracy evaluation.**
- **Harmonised and accepted methods to perform best estimate assessments.**
- **Safety margins and best estimate methods by integrating the deterministic and probabilistic safety assessments. This includes development of methodologies (such as Dynamic PSA and Monte-Carlo assessments or a combination) to be used in parallel with existing methods for probabilistic and deterministic assessments.**

■

A challenge for these methods is to better model/predict the dynamic behaviour of the system including also time dependent scenarios without affecting the assessment of uncertainties, which is to remain independent.

Application of these developments should address better evaluation of safety margins for Reactor Pressure Vessels (RPV)s, main containment, passive system and pipes in case of LOss of Coolant Accident (LOCA) or Pressurized Thermal Shock (PTS) events, but also for beyond design situations or natural circulation conditions.

III.1.4.7. Design of Reactor Safety Systems

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R&D topics

- **Design of digital system with integration into existing plants.**
- **Increased diversification and robustness of safety systems.**
- **Use of passive system for safety function.**
- **Methods for reactivity measurements under accident conditions.**
- **Design of level measuring systems to withstand high temperatures.**

■

III.2. Technical Area 2 (TA2), Severe Accidents

III.2.1. Scope

The main public safety goal for nuclear power is to prevent a societal calamity and huge economic loss. With appropriate site risk evaluations, plant designs and management, current Generation II and future Generation III NPP show high levels of robustness and low probabilities for severe accidents (SA). But, 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, result in SA, as recently emphasized with the Fukushima-Daiichi accidents in Japan. This SA can result in core melting, plant damage and dispersal of radioactive materials outside of the plant containment, thus threatening public health and the environment.

This risk can be substantially decreased when state-of-the-art devices currently available for prevention and mitigation of severe accidents are installed. Lessons from the Fukushima-Daiichi accidents and consequences related to Accident Management provisions from the recently completed ENSREG (European Nuclear Safety Regulators Group) stress tests and other national activities will lead to further enhancement of the safety of NPPs.

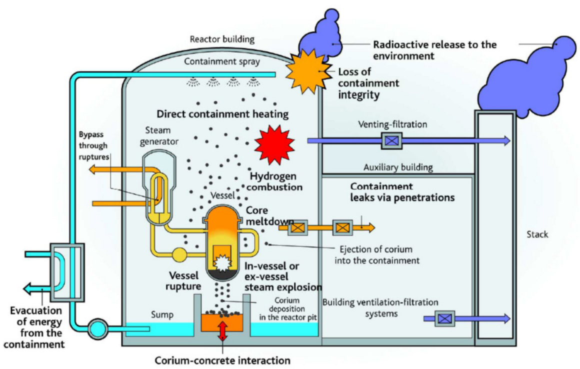


Figure 6: Phenomenology of severe accidents in a reactor (Source: IRSN)

III.2.2. Objectives

Some predominant phenomena require a better understanding in particular to improve Severe Accident Management Guidelines (SAMGs) and to design new prevention devices or systems for mitigation of SA consequences.

Seven sub-technical areas address the topics listed here below, among which, topics 1 to 3 are directly linked to mitigation processes, topics 4 to 6 to the assessment of the impact of the transients on the environment, and the last one to their management and prevention. The main objectives that have been identified are:

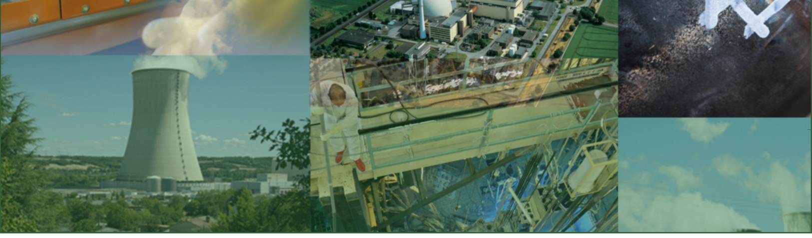
- *2.1 In vessel corium/debris coolability,*
- *2.2 Ex-vessel corium interactions and coolability,*
- *2.3 Containment behaviour, including hydrogen explosion risk,*
- *2.4 Source term,*
- *2.5 Impact of severe accidents on the environment,*
- *2.6 Severe accident scenarios,*
- *2.7 Emergency preparedness and response.*

New experimental efforts will be needed in most sub-areas accompanied by modelling development and validation. The knowledge gained and the modelling improvements will allow the optimisation of SAMGs and the improvement of prevention and mitigation systems such as core reflooding systems, filtering systems, venting systems or recombiners in the containment.

III.2.3. State of the art

Considerable knowledge has been gained about SA phenomenology through studies carried out during the last 30 years. It is based on experimentation, mostly out-of-pile, with a few in-pile programmes like Phebus, and theoretical simulations, as the accidents at Three Miles Island (TMI2) in 1979 and at Chernobyl in 1986 were the only major NPP reference cases until the Fukushima-Daiichi accident.

Since 2004, the state of the art is periodically updated in the frame of the SARNET network (Severe Accident Research NETwork of Excellence), (see www.sar-net.eu). In particular, the ranking of R&D priorities has been recently reviewed to take into account early feedback from the Fukushima-Daiichi accident. The identified challenges account also for the results of all past and on-going international programmes (Euratom-FP7, OECD/NEA , ISTC/STCU …).



III.2.4. Challenges

The highest priority safety challenges are described in the following sub-areas: In-vessel corium/debris coolability, Ex-vessel corium interactions and coolability, Containment behaviour including hydrogen explosion risk, Source term, SA impact on the environment, emergency and preparedness management. One transversal sub-area concerns the SA scenarios.

III.2.4.1. In-vessel corium/debris coolability

Substantial knowledge exists concerning cooling of intact rod-like core geometry. The main challenge for long term R&D will be to address the remaining uncertainties concerning the efficiency of cooling a degraded reactor core, with presence of corium and/or solid debris, by water addition to limit or terminate the SA in-vessel progression.

The impact of the further analysis of the Fukushima accident will be taken into account, and, conversely, R&D will be important for the plants decommissioning.

R&D topics

- **Debris bed formation and cooling; for in-vessel melt retention, corium pool coolability in the reactor pressure vessel (RPV) lower head, especially for BWRs with presence of control rod and instrumentation guide tubes; critical heat flux and RPV external cooling conditions.**

III.2.4.2. Ex-vessel corium interactions and coolability

For ex-vessel corium situations after vessel lower head failure, the major safety challenge is to preserve containment integrity against rapid failure (steam explosions, Direct Containment Heating or DCH) or slower basement melt-through (by Molten-Core-Concrete-Interaction or MCCI) and/or containment over-pressurization.

R&D topics

- **Fuel-water premixing and debris formation and coolability; complementary MCCI research to cover oxide-metal layer interaction and all reactor concrete compositions; assessment of MCCI top flooding; and finally analytical work to transpose MCCI experiments to reactor scale.**
- **Reduce uncertainties in assessment of steam explosions.**

III.2.4.3. Containment behaviour, including hydrogen explosion risk

The containment represents the ultimate barrier to prevent or limit the release of fission products to the environment during a SA. If local concentrations of combustible gases (hydrogen and carbon monoxide) are present, gas combustion might occur and cause a pressure increase that could eventually lead to containment failure.

Efforts in the short and mid-term should focus on extensive simulations of gas distribution in the presence of mitigation systems using both Lumped-Parameter and CFD (Computational Fluid Dynamics) codes in order to interpret a whole set of different experiments with consistent models. More reliable models of deflagration and deflagration-to-detonation transition should be developed in order to improve the present modelling mainly based on empirical correlations.

R&D topics

- **Containment atmosphere mixing (including BWR containments with nitrogen atmosphere) and gas combustion, which imply the following phenomena: gas distribution in the containment with the influence of mitigation systems, pressure increase during hydrogen combustion, and deflagration to detonation transition. Scaling (qualitative and quantitative) of phenomena from experimental facilities to actual containments should also be addressed with priority.**

III.2.4.4. Source term

The source term to the environment refers to the amount, chemical speciation and isotopic speciation of all radio-elements that can be released to the environment. At present, the increased safety requirements in both existing plants and new designs aim at reducing the source term by proper measures for limitation of uncontrolled leaks from the containment and for improvement of the filtering efficiency of containment venting systems. The Fukushima accident underlined the need for studying the impact on the source term of the filtered containment venting systems which are important radionuclide-removal processes.

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R&D topics

- **Impact of filtered containment venting systems on source term and development of improved devices; oxidizing environment impact on FP release from fuel, in particular for ruthenium, i.e. under oxidation conditions or air ingress for high burn-up and MOX fuels; high temperature chemistry impact on FP behaviour in the Reactor Cooling System (RCS), i.e. improving predictability of iodine and ruthenium species exiting RCS towards the containment; containment chemistry impact on source term, i.e. improving the predictability of iodine and ruthenium chemistry in the containment.**

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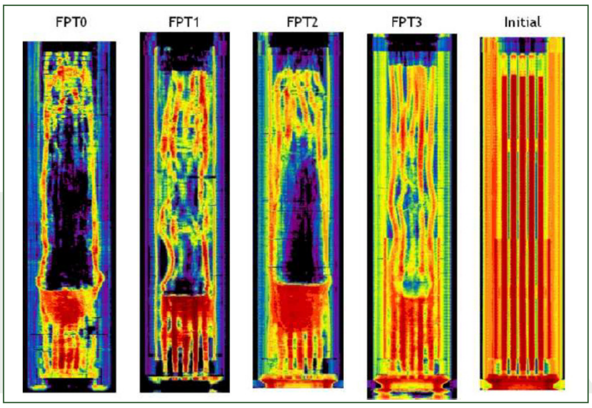


Figure 7: Phebus.FP degraded bundles for real source term (Source: IRSN)

III.2.4.5. Impact of severe accidents on the environment

The SA impact on the environment in the near-field around the NPP must be assessed as part of the Environmental Impact Assessment (EIA) of a NPP in accordance with European and national legislation. Here only the atmospheric dispersion of radio-nuclides is addressed. This will allow an interface between PSA Level 2 and assessment of radiological consequences and it will improve the emergency planning and zoning and the post-accidental situation management.

Strong links should be established in the future with the NERIS platform (European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery: see www.eu-neris.net).

■

R&D topics

- **Accurate atmospheric dispersion models, in particular accounting for chemistry of radio-elements (integrating on-site experiments and use and development of specific CFD models); adaptation and development of "ensemble computations" (i.e. variations of calculations for different initial weather data) for atmospheric dispersion of radio-elements from NPP.**
- **Effect of using different venting strategies in severe accident. Better understand and quantify leakages from the containment and its dependence on pressure, humidity and temperature. This should also include an increased understanding of the containment integrity, which is related to topics in TA 4.**

■

III.2.4.6. Severe accident scenarios

Integral codes (or system codes) are essential for simulating all SA scenarios including the evaluation of the source term into the environment, as well as the evaluation of SAM measures and the efficiency of mitigation systems. The highest priority is to continue to capitalise knowledge inside these codes, particularly the ASTEC code (IRSN-GRS) considered as the European reference tool, and to feedback the interpretation of the Fukushima accident in the coming years. Attention should be paid in particular to models of BWR core degradation and to their validation.

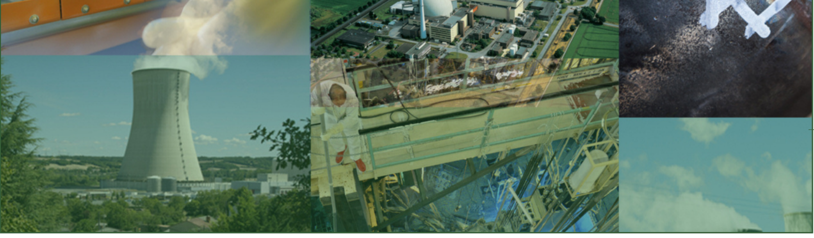
In addition, the Fukushima accident has underlined the importance of the modelling of the behaviour of spent fuel pools in case of loss of cooling. The criticality risks in case of spent fuel pool dry-out or of damaged NPP core should also be assessed.

Another essential issue is the need to store in reliable and durable databanks the results of the huge amount of SA experiments that were performed over more than 30 years. They should remain available for any further analysis of SA phenomena and for validation of simulation codes.

■

R&D topics

- **Continuous capitalisation of knowledge in the integral codes, particularly ASTEC, and improvement of their applicability to spent fuel pools. The latter will need further R&D on the following phenomena: large-scale flow convection, impact of partial dewatering**



of fuel assemblies on thermal runaway and fuel degradation, clad and fuel mechanical behaviour in air-steam atmosphere.

■

III.2.4.7. Emergency prparedness and response

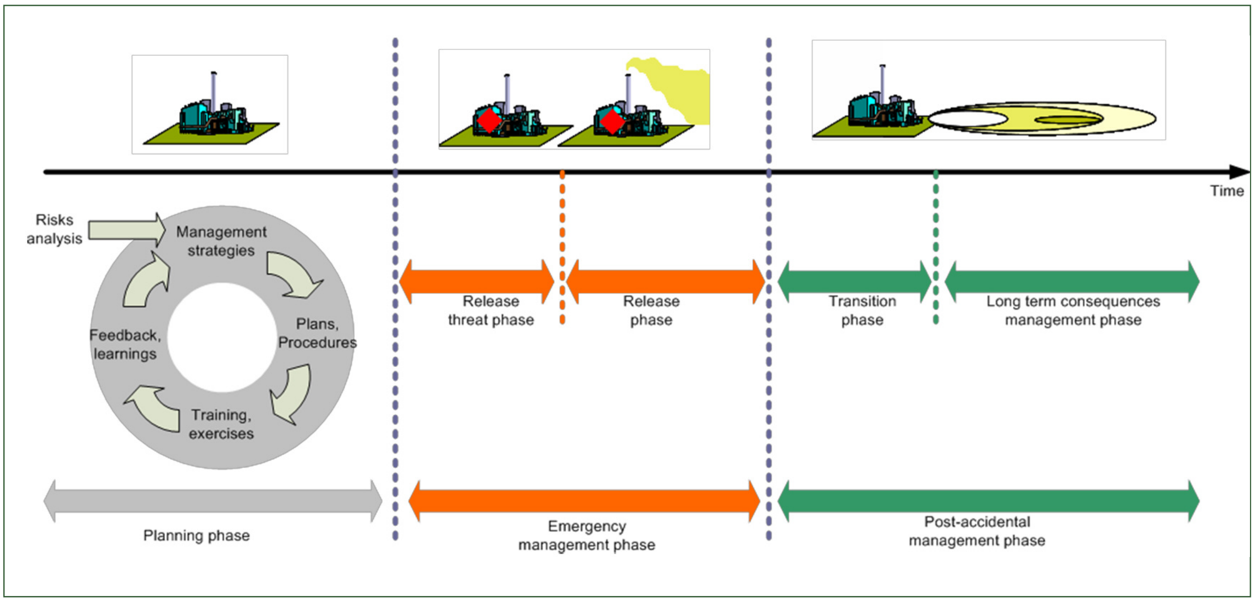
In the emergency preparedness and response area, an accidental sequence can be roughly broken down into two phases: the emergency phase (composed of a threat phase and a release phase) and the post-accidental phase.

In the threat phase, the objective of the emergency management is to analyse the behaviour of the plant and to take actions or complementary means in order to restore control on the heat generation, on the cooling capacity and on the radioactivity containment. In a more degraded situation, this phase requires well established and shared methodologies as well as tools to evaluate the time before radioactive release, the consequences of further palliative actions and to mitigate the consequences of the accident, both for the environment and for protection of the population around the plant. This requires the availability of reliable information from the plant, the capacity to operate correctly under high stress and harmful conditions, and the availability of efficient and reliable tools. The latter encompass well exercised information systems and emergency organisations, instrumentation, fast computer systems to study multiple future scenarios, highly trained and complementary teams with experts in informatics, reactor physics, reactor operation, meteorological data, and integration of all the different aspects.

In the beginning of the release phase, the measurement of the radioactivity around the plant is necessary to comfort the diagnosis of the plant accident scenario and to improve the prognosis concerning the source term. The management of the plant accident can extend a long time, like for the Fukushima Daichi accident, because actions on the plant may be required even if the source term emission is started for a long duration already.

The post-accidental phase needs information on the source term in order to estimate the consequences on the long term; this is addressed in the NERIS project, so that the scope dealt with in this paragraph includes also addressing the environment and making the bridge between NUGENIA and NERIS activities.

Figure 8: Emergency management phases (Source: IRSN)



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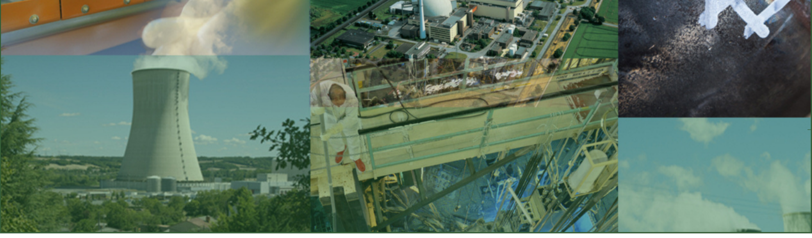
R&D topics

- Concerning the threat phase, beyond well established and tested methodologies and emergency organisations, fast running tools are necessary to make the diagnosis and the prognosis of the reactor behaviour, under several recovery strategies, and to evaluate the time to release and the amount released. If the time to release increases more sophisticated tools might be useful.
- Development of fast running tools for source term evaluation, relying upon accurate environmental data and benchmarks with similar codes in use, mainly focussing on an evaluation of source term to the atmosphere (by using inverse atmospheric modelling and comparisons with the environmental measurements).
- Development and/or improvement of suitable instrumentation and information transmission tools for SA diagnosis and management. This instrumentation should include measurement devices and data transmission, collection and elaboration tools, as well. The implementation of a suitable mobile measurement device, able to operate in the hostile environment of a degraded site to provide information on the reactor status, should also be considered. In such circumstances, precision is not the prime objective: robustness and reliability should be preferred. Accordingly, the device should be: quite small; easy to handle, robust and reliable in such extreme conditions of radiation, temperature and pressure, activity and humidity.
- Improvement of organisation-dealing aspects (partly addressed in the STATIC project), e.g. to extend redundancy among teams without slowing down the engineering capacity, and improvements of knowledge on human behaviour under stress conditions.

■

AL AREA 2



III.3. Technical Area 3 (TA3), Improved Reactor Operation

III.3.1. Scope

TA3 is devoted to improving the technical and economical characteristics of reactor operation by various measures and also to minimising the radiological impacts on the plant workers, the environment and general public during normal reactor operation (covering also periods of shut-down, reshuffling, abnormal operational situations and emergency states, but excluding severe accidents).

The various R&D areas have been identified supporting improvement of reactor operation and minimising impacts of its operation, many of them being in tight connection and relationship to the topics addressed primarily in TA1, TA4 and TA5, but also in other TAs:

- The impact of all key aspects related to human behaviour and decisions, and organisational factors on the safe and secure operation of the plant, including the interaction between the control room operators and the plant.
- The implementation of innovative approaches, measures and tools to improve economics of operation of nuclear power plants (including optimisation of outages and lifetime management).
- The integration of advanced technologies which can support the operators in their duty, namely the advanced digital information and control technologies.
- The core management as a subject of ongoing R&D activities, since it has direct impact on the economy of the fuel cycle. It encompasses core and fuel system design related calculations and numerical modelling, evaluation of uncertainties, core reload optimisation and core monitoring and instrumentation.
- The water chemistry influencing corrosion and degradation of components and consequently their life time.
- The impact of the plant on the environment and public through minimisation of emissions to the air, effluents to watercourses and radioactive waste to be disposed into the appropriate final repositories. The minimisation of radiation dose received by plant workers as a balance of the latest science-based quantification of impacts of radiation on human health and economic justification of protection measures.

III.3.2. Objectives

A safe, efficient and economically-competitive operation of the nuclear power plants is the result of a number of interlinked human, organisational and technical factors. Owners of nuclear power plants currently mostly operating in deregulating competitive markets are under pressure to reduce operation cost to be more competitive with other energy production options. To recover huge initial investment cost and to maintain necessary level of profitability it is reasonable to prolong operation of plants where it is feasible, naturally without compromising safety and security. Along with traditional safety and reliability parameters, economic and financial factors are needed to be taken into account in new perspectives nowadays that is incomparable with former regulated markets where utilities provided complex service with inclusion of all reasonable costs.

Various areas thus can contribute for improvement of reactor and nuclear power plants operation.

Human and Organisational Factors (HOF) are key subjects of analysis made with the aim to improve safety, performance and efficiency characteristics of nuclear power plants operation. After the Fukushima accident, the focus of studies on HOF has been moved towards the importance of the preparedness for emergency management, but area of prevention still need to be maintained (safety culture, safety versus efficiency, impact of automation etc.).

Implementation of modern digital technologies offers a unique opportunity for improving operational performance, enhancing nuclear safety and supporting life extension of NPPs. Although some European plants have gone through relevant modernisation programs, many interventions still have to be performed under the constraint of minimising the impact of the traditional way of operating, maintaining and managing the plant.

Improvements in core management are currently based on the continuous updating of the design and analysis tools, with the aim of achieving higher accuracy with well-established uncertainty evaluation, through a strengthened understanding of the underlying physics and associated modelling requirements, combined with enhanced computational efficiency. This task can be directly translated into large challenges in basic nuclear data, neutronics, material science, thermo hydraulics, fuel fabrication and fuel storage. Coupling all these aspects (multi-physics) with the help of up-to-date advanced software is the driver for replacing the current systems of codes used for simulation of processes related to reactor operation.

Water chemistry and LLW management activities have the main target in optimisation of chemical parameters of the primary, secondary and auxiliary cooling systems and in development of the optimum technologies for LLW treatment. Water chemistry is actually one of the most powerful tools, the operators can use to improve the lifetime of plant components and systems. Suitably designed water chemistry can significantly reduce "randomly" occurred operational problems, including corrosion, erosion, deposition of corrosion products etc.

Radiation protection is a specific area to protect both human beings and environment against negative impact and/or consequences of ionisation radiation. The main goal here is to keep the ALARA principles, i.e. to limit the exposure "as low as reasonably achievable".

The above-mentioned topics are addressed within TA3 in six specifically identified ST-A, addressing, a topic each, as follows:

- *3.1 Improvement of the operation economics,*
- *3.2 Human and Organisational Factors,*
- *3.3 Integration of Advanced Digital Technologies and solutions for cyber-security,*
- *3.4 Improvement of core management modelling tools and core monitoring and instrumentation,*
- *3.5 Water Chemistry and LLW (Low Level Waste) Management,*
- *3.6 Radiation protection.*

III.3.3. State of the art

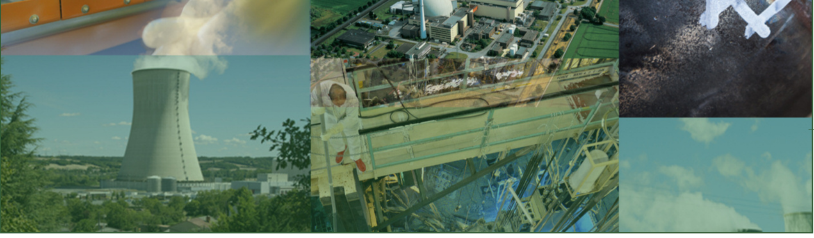
During last two decades, the human and organisational factors community has been solving various R&D topics in several international subjects and platforms, for example, in the OECD/NEA Working Group of Organisational and Human Factors (WGHOF), IAEA, in international cooperation organised by IFE Halden etc. A new roadmap for the area of human and organisational factors (HOF) has been recently developed as a part of the FP7-MMOTION project. It is worth mentioning that HOFs are usually subject of safety missions and peer reviews thus giving inputs for improvements at nuclear power plants. These improvements are quite frequently typical with high worth/cost rate from safety point of view, i.e. relatively inexpensive measures taken in the human factor area may lead to fairly significant decreasing of risk of NPP operation.

Defining a strategy for the implementation of full digital systems into the processes of NPP operation control is becoming a more and more urgent issue for the life extension of the generation II reactors, as well as for the deployment of the Generation III. A various aspects are touched by EPRI, US DoE programme and EU projects (for example FP7-HARMONICS).

Core management is divided into four distinct areas: core and fuel system design related calculations and numerical modelling, evaluation of uncertainties, core reload optimisation and core monitoring and instrumentation. Core design covers neutron-physical design, thermal-hydraulic design and fuel rod and mechanical design. In engineering practice these topics are yet treated either independently or with very simplified interrelated feedbacks. The activities to be envisaged here are similar to those described in TA1.2 and TA1.6.

The water chemistry topics were the subject of large basic and applied research programmes in earlier years. Recently, the most comprehensive programme has been carried out by the EPRI (materialised mainly in the water chemistry guidelines). Radioactive waste management technologies are subject of rather national and engineering companies' effort than EU projects, the state-of-the-art in this field is well documented by the OECD NEA and IAEA. Innovative chemical methods and technologies usually used in other industries offer big potential for effective use in nuclear power plants.

A strong focus put on radiation protection recently has led to the establishment of the Multidisciplinary European Low Dose Initiative (MELODI) platform,



with the overall aim of consolidating European initiatives on researching and better understanding the health effects of man's exposure to low dose radiation. New approach of ICRP, documented by ICRP guidelines 103 and 109, started the new point of view on designing and application of the limits for both personnel and population protection. A lot of activities worldwide (e.g. OECD-HRP) are focused on virtualisation of real world with added information ("Augmented Reality") with the goal to serve as tool for optimisation of maintenance and repairs of equipment in contaminated areas, for training of the personnel with the aim to reduce and/or eliminate human failures and, finally, for optimisation of interventions and radiation monitoring activities during emergencies.

III.3.4. Challenges

The TA3 encompasses quite variable spheres contributing to improvement of efficient, reliable also safe and secure operation of nuclear reactors. The following six main challenges and subordinating research areas and topics were identified.

III.3.4.1. Improvement of the operation economics

Operators of NPPs are under strong pressure in the current competitive market conditions with significant implications for plant operation. The optimisation of operation and maintenance costs is a key component of a broader integrated business planning process. Asset management and decision making is integral part of the overall operation strategy.

R&D topics

- **Optimisation of outages.**
- **Advanced and integrated approaches to maintenance and lifetime management of components and systems.**

III.3.4.2. Human and Organisational Factors

The aspects which are considered as utmost priority in this field are human reliability analysis, operational culture and work practices. Important challenges are to strengthen the objectivity of safety judgments by using methods of risk-oriented decision making in the human reliability area, to improve the effectiveness of safety provisions, to harmonise operational principles across Europe and to minimise the negative impacts of complexity on operation and safety. Since organisational safety culture and operating practices strongly influence the safety level, new research should help in defining of the conditions required for ensuring the robustness of the organisations in charge of operating NPPs, based on a deep understanding of work practices and safety culture. It will be particularly important to consider how individuals, teams and organisations function and interact within the plant under a specific safety culture, and how they are supported by tools, artefacts, procedures, rules etc.

R&D topics

- **Application of risk informed decision making in human factor area.**
- **Improvement of safety culture and operating practices for safety analysis.**
- **Development of socio-technical approach to improve management of human resources under circumstances with dynamic features.**
- **Improvement of training based on simulation of plant processes.**
- **Development of tools and methods from collection, acquisition and analysis of human factors related data (plant events, including low level events and near misses; data from full scope simulator exercises).**

III.3.4.3. Implementation of advanced digital technologies and Cyber security management

Digital technologies are nowadays deployed in all modern power generation plants and also in large industrial plants and devices characterised by a non-negligible risk level. The situation in the nuclear power sector differs from the rest of the industry in the following key aspects:

- Use of analogue systems is being extended beyond their expected service lifetime.
- Regulatory uncertainty and associated business risk concerns are delaying the deployment of new technologies.

■

R&D topics

- **Innovative I&C design and architecture.**
- **New technologies in I&C (smart instrumentation, modern communication means – wireless, field programmable gate arrays, irradiation resistance, electromagnetic compatibility etc.).**
- **Advanced diagnostics (equipment condition monitoring, reliability prediction etc.),**
- **Cyber security (policy, guidelines and templates for NPPs, etc.).**
- **Human performance support (highly integrated digitalised control rooms, field workers support etc.).**
- **I&C life cycle management.**

■

III.3.4.4. Improvement of core management modelling tools and core monitoring and instrumentation

The goal of the management of a LWR core with fuel assemblies and associated systems is to maximise cycle energy production with minimal fuel cost while maintaining sufficient margins to relevant safety criteria. It can be achieved through improvement of precision of core calculations and better estimation of their uncertainties.

Nuclear instrumentation is still mainly based on safe but conservative technologies. Present and future level of competitiveness with the other power sources depends also upon accurate and predictive knowledge of core behaviour. Advanced instrumentation and measurement methods, and efficient signal analysis, can increase reliability, performance and competitiveness.

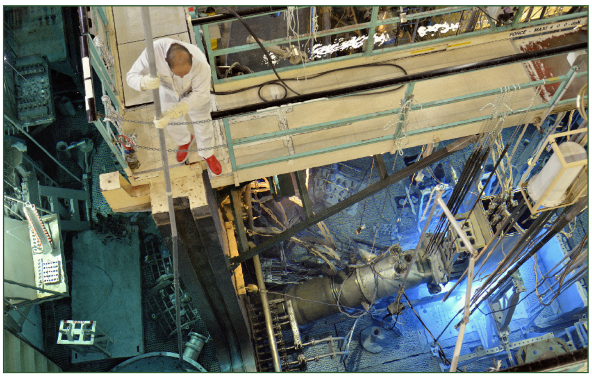


Figure 9: OSIRIS reactor at CEA Saclay (Source: CEA)

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R&D topics

- **Improvement of precision of core calculation and numerical modelling.**
- **Improvement of core monitoring and instrumentation.**
- **Improvement of robustness and precision of uncertainty estimations.**
- **Multi-cycle core reload optimiation, combined optimisation of fresh fuel profiling and fuel assembly emplacement in the core and improvement of reliability of the optimisation process.**

■

III.3.4.5. Water Chemistry and LLW (Low Level Waste) Management

Water chemistry in primary circuit significantly influences generation of radioactive waste and radiation fields and consequently personal dose. In addition, in all systems, it influences aging and life-time of components (due to corrosion, erosion) and performance of components (for example decreased heat transfer due to depositions).

The pressure to reduce the radiation exposure of the workers as well as the radioactive release into the environment requires constant improvement of processes and technologies for LLW treatment and for conditioning of liquid waste, potentially able also to reduce the costs. Priorities in the treatment of liquid radioactive waste are to obtain higher decontamination and volume reduction factors, lower on-site processing costs, reducing solid radioactive waste generation rates and minimise corrosion.

■

R&D topics

- **Purification and radiation reduction of primary water coolant.**
- **Crevice corrosion sampling and measurement.**
- **Boric acid purification and LLW reduction (advanced filtration and innovative removal processes to monitor, control and limit activated corrosion product transport; tritium, carbon 14C and boron management).**
- **Improvement of secondary water chemistry and in auxiliary systems (prevention of deposition of scales, bio-fouling and bio-corrosion etc.).**

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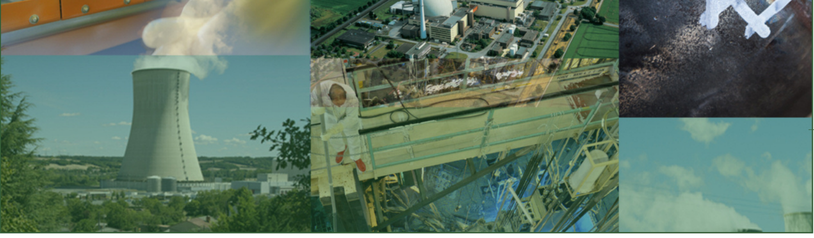


III.3.4.6. Radiation protection

Exposure to external and internal irradiation resulting in doses to personnel is an inevitable consequence of the operation of NPPs, but it can be minimised through various means, like procedures for maintenance, instructions for movement of personnel, etc. Cost effective solutions and application of new tools are highly demanded including more accurate dosimetry. Risk remains in the potential tightening of radiation limits for personnel and the environment leading to further new measures and requirements for new measurement tools. Large uncertainty in assessment of risk also arises from the fact that co-exposures typical of most real situations (radioactivity and other stressors such as chemicals and physical stressors) have been very poorly considered so far.

Figure 10: Personal dose measurement (Source: IRSN)

Discharged radionuclides from NPPs during normal or abnormal operation (liquid and gaseous) may cause long-term impact to the general population and the environment by various irradiation pathways and therefore it is a sensitive issue which influences public opinion of the nuclear industry.

- **Improvement of radiological protection and reduction of occupational exposures by application of new tools (real time monitoring of received dose, augmented reality tools, better dosimetric measurements (especially for actinides) and interpretation, etc.).**
- **Improvement of public and environmental radiological protection (improvement of organisational and technical issues for minimising the release of radioactive substances into the environment under normal operational conditions from NPPs, improvement of models and risk assessment methods for quantifying the impacts to the population and the environment, including input data).**
- **Development of generic and harmonised process for data base construction throughout Europe in support to more robust and conclusive epidemiologic studies based on smartly designed workers cohorts.**
- **Development of new concepts and supporting strategies, methods and tools allowing to take into account co-exposure to mixtures of stressors and their resulting impact on populations of human beings and other biota.**
- **Development of platforms, methods, guidelines and tools necessary for realisation of credible and useful PSA Level-3 as an essential pillar of emergency preparedness and response.**

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

III.4.1. Scope

Structural assessments are an important part of NPP management programs (e.g. ageing management, maintenance and design changes). These assessments are one requirement for the effectiveness of periodic safety reviews. Aspects that need to be considered include definition of integrity assessment over the whole life cycle, the various degradation mechanisms, ageing issues, safety margins and harmonisation issues.

The Structures, Systems and Components (SSC) that need to be considered are those important for safety and availability, those that require high costs to replace and those that cannot be replaced without a significant long term refurbishment program. Components like Instrumentation and Control (I&C) which are of high safety significance also need to be addressed

III.4.2. Objectives

While the assessment principles relating to SSC are generally comparable in Europe, the actual methodologies and codes are different in the various European countries. With the longer term objective of European harmonisation in mind, it is necessary for the differences to be fully understood and for the lessons learned from Generation II nuclear power plants (NPPs) to be taken into account when developing and/or revising best practice guidance for the safe operation of SSC with sufficient, but not over-conservative safety margins. This is required to ensure high integrity and high performance in the case of internal and external loads. Post-Fukushima lessons imply that investigations of beyond design loads are also required to be considered.

This technical area is split into the six sub-technical areas listed below:

4.1 Integrity Assessment,
4.2 Description of Loads,
4.3 Material Performance and Ageing,
4.4 Ageing Monitoring, Prevention and Mitigation,
4.5 Equipment qualification,
4.6 Qualification.

III.4.3. State of the art

Integrity Assessment of SSC takes into account material properties, component geometry, loading and degradation mechanisms and degradation effects. It mainly relies upon fracture mechanics methods, e.g., the integrity assessment of the Reactor Pressure Vessel (RPV) under a Pressurized Thermal Shock (PTS) loading, and the analysis of Leak Before Break (LBB) in pipes is mandatory for the safe operation of nuclear power plants. Codes, standards and procedures are commonly used for integrity assessment. These are generally well founded and validated but in many cases they can have inherent levels of conservatism, particularly when considering plant life extension.

III.4.4. Challenges

III.4.4.1. Integrity Assessment

There is a need to properly quantify and understand the levels of conservatism in the current integrity assessment methods with a view to revising the guidance and procedures. Such aspects as effects of load history, crack arrest, treatment of thermal and weld residual stresses and warm pre-stressing effects need to be considered with regards to this aim. Lessons learnt from Generation II NPPs in terms of integrity assessment validation should be considered and implemented.

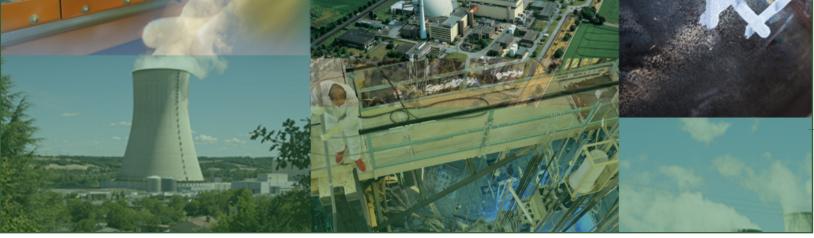
The modelling of integrity assessment is important in order to be able to translate the mechanistic understanding to simulation tools and assessment procedures to predict theoretical margins for the safe operation of NPPs, taking into account structural features, real or postulated flaws, loading conditions and relevant material characteristics including ageing effects.

■

R&D topics:

Metallic components:

- **Update of design curves including fatigue and environmental effects, indicators and surveillance programs for materials behaviour for long term operation.**
- **Validated models for the assessment of structural integrity of in-vessel components under high doses of irradiation, including integrity of RPV**



internals for long term operation.

- Assessing, optimising and developing the use of advanced tools for the structural integrity assessment of non RPV components.
- Development of best practice procedures for assessing structural performance of multi-metal components, including cladded components.
- Development of a probabilistic approach of RPV and other safety critical systems integrity assessment for long term operation and harmonisation of probabilistic safety assessment to achieve improved justification for safety factors (in close link with TA1).
- Implementation of lessons learnt from Generation II NPPs in terms of integrity assessment validation.
- Benchmarking of safety assessment methodologies including comparison of outputs from deterministic versus probabilistic methods and integration into the safety assessment.
- Development of a probabilistic approach of Leak Before Break (LBB) analyses for long term operation.
- Gaining an understanding of LBB procedures and engineering assessment procedures employed in different European countries.
- Treatment of secondary and residual stresses (including crack closure and load history effects).
- Developing and experimentally validating warm pre-stressing assessment and analytical tools for conditions beyond the present experience & data.
- Fracture mechanics for thin sections.
- Treatment of non-crack like defects (corrosion, thinning, pitting, erosion, flow induced corrosion, crevices).
- Development of a methodology to include high temperature ageing effects in plant assessments.

Civil works:

- Gain understanding of modeling approaches adopted in different European countries on life time evaluation of civil structures.
- Modeling of cracks opening in pre-stressed concrete and air and air/steam mixture flow rate through cracks according to different loads, including severe accidents loads.
- Develop probabilistic and deterministic methodologies to evaluate the impact of internal hazards (hydrogen explosion, pipe whip impact) and external hazards (seismic event, aircraft impact and explosion).

■

III.4.4.2. Description of Loads

Accurate knowledge of applied loads and resulting stresses (and strains) is needed for SSC's reliability. Increased computing power over recent years, coupled with advanced modelling capabilities, has resulted in enabling the accuracy to be evaluated in greater detail. Examples of this include piping system loads and stresses resulting from pressurized thermal shock loading or fluid structure interaction.

■

R&D topics:

Metallic components:

- Investigation of combined fatigue and tearing fracture resistance under high asymmetry cycles and random high cyclic loads.
- Improved methodologies for thermal stratification and mixing assessments (pipings and t-junctions).
- Harmonisation of load evaluation methodologies.
- Development of guidance in order to more accurately predict fluid to component wall heat transfer (CFD, Computational Fluid Dynamics) for thermal fatigue analysis.
- Dynamic response of reactor internals to Loss of Coolant Accidents (LOCAs).
- Methodologies for establishing the significance and ranking of external loads for deterministic and probabilistic assessments.
- Fluid structure interaction under turbulent flow conditions (resulting impact force).
- Development of improved guidelines for lifetime extension of bolts and flanges (including defect tolerance).

■

III.4.4.3. Materials Performance and Ageing

The major challenge is to justify properly that all components affected by an ageing mechanism remain within the design and safety criteria. Indeed, properly understanding the performance of materials relevant to structural components and the effect of ageing mechanisms on their performance are key issues from the start to the end of life of each NPP. Basically, ageing management should follow a well-defined procedure that consists of following key aspects:

- Identification of the SSCs that are subject to ageing.
- Performing analysis, comprising the understanding and modelling of the main relevant ageing mechanisms concerning each SSC (potential or encountered).
- Setting up of measures to justify the integrity of each SSC based on codes & standards, regulations, specifications & guidelines and scientific knowledge of the ageing mechanisms.

Figure 11: X-ray control of a tank welding (Source: IRSN)

III.4.4.3.1. Material Properties

Knowledge of many material properties is required in relation to SSC. Examples of material properties required for "start of life" assessments include tensile properties, fatigue stress versus number of cycles (S-N) data and fracture toughness data for defect tolerance evaluations. In addition, and particularly for in-service evaluation of SSC, properties relating to aspects like irradiation creep (for high temperature operation), corrosion and environmentally assisted fatigue (EAF) may be required. Data are fairly widely available on all these materials properties for materials of interest but there remains some concern and debate regarding e.g. the treatment of scatter, in corrosion and environmental fatigue data, to correctly apply in integrity assessments. Beyond that, operational effects potentially prolonging SSC's lifetime are not considered in general. In addition, there is the complex issue of how manufacturing processes (including welding, thermal and mechanical treatments and coatings) may affect materials and materials' properties and how such processes may be improved in the future.

■

R&D topics:

Metallic components:

- **Development and testing of accelerated (SCC) test methods for life time prediction.**
- **Establishing guidelines and rules for the manufacturing conditions of crucial SSC's (e.g. cold work, surface finish, welding procedures, metallurgical heterogeneities, heat treatment, ...) on material performance.**
- **Further develop testing and qualification procedures for miniaturised specimens.**
- **Effect of dynamic strain ageing on fracture toughness of materials.**
- **Improve identification of radiation-resistant materials.**
- **Investigation of the fatigue endurance roots.**
- **Development of characterisation methodologies and qualification procedures for dissimilar metals welds (DMWs).**
- **Guidance for manufacturing processes based on material performance studies.**
- **Creation of materials database including coolant (primary and secondary), thermal, mechanical and irradiation effects (single and combined effect).**
- **Development of joining and welding procedures (including mixed welding, welding of thick components etc.).**

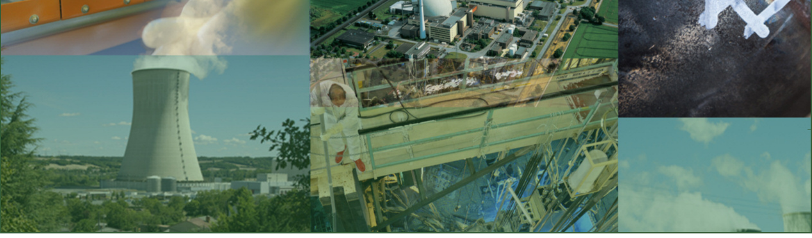
Polymer materials:

- **Development of acceptance criteria for replacement taking into account correlations of all properties (composition versus performance).**
- **Irradiation ageing of polymers: Investigate the influence of dose rate and irradiation time when performing accelerated irradiation.**
- **Synergistic effects of stressors at polymers: Investigate synergistic effects of irradiation, heat, moisture (water), vibration and other existing stressors affecting the environmental impact of polymers with special considerations taken for elastomers. Establishment of methodologies for testing and characterising polymers used in nuclear power plants.**

■

III.4.4.3.2. Ageing and Degradation Mechanisms

Ageing management addresses physical ageing that could result in degradation of SSC such that



safety functionality could be impaired. Thus, degradation modes, including fatigue, irradiation embrittlement, stress corrosion cracking, irradiation assisted stress corrosion cracking, thermal ageing, general corrosion, erosion-corrosion, strain ageing, environmental fatigue, creep, creep-fatigue and thermal fatigue, need to be fully understood to ensure a good SSC status. It is therefore very important to be able to properly evaluate their positive or negative effect on "start of life" properties as they may become limiting factors for the safe and reliable operation of NPPs. Important as well is that the effects of the ageing and degradation mechanisms should be considered for the specific type of SSC material being assessed. Guidance and/or data are generally available for the projected lifetime but very scarce for allowing beyond design long term operation. There is clearly a need for further R&D to be undertaken in several of the areas referred to in order for a better fundamental understanding of the ageing and degradation mechanism to be realised and to lead to realistic assessment guidance.

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R&D topics:

Metallic components:

- **Investigation of micro-structural and mechanical effects in RPV steels caused by long term irradiation leading to the improvement of RPV safety assessment of existing European LWRs under long-term operation and Generation-III reactors under construction (supporting RPV ageing management and plant life extensions).**
- **Improving the knowledge regarding stress corrosion cracking (SCC) initiation with respect to the field requirements, including experiments with relevant advanced characterisation.**
- **Investigation of the fabrication process and initial surface condition of a metallic component on the SSC time-to-failure.**
- **Evaluation of methodologies to determine and optimise fatigue endurance of safety critical components with the aim of gaining a better knowledge of environmental fatigue effects in PWRs.**
- **Investigation of crack initiation by irradiation assisted stress corrosion cracking (IASCC) and the creation of a database of experimental data.**
- **Investigation of corrosion and hydrogen embrittlement for structural materials.**
- **Investigation of thermal ageing in austenitic stainless steels.**
- **Investigation of irradiation in tough low activation V alloyed steel for future RPVs.**
- **Study of the crack morphology and its influence on leak rates for provision of defined parameters and further improvement in the accuracy of leak-rate/LBB models.**

Polymer and Electrical Equipment:

- **Irradiation ageing of polymers: Investigate the influence of dose rate and irradiation time when performing accelerated irradiation.**
- **Synergistic effects of stressors at polymers: Investigate synergistic effects of irradiation, heat, moisture (water), vibration and other existing stressors affecting the environmental impact of polymers with special considerations taken for elastomers.**

■

III.4.4.3.3. Modelling of ageing

The high variability of ageing and degradation mechanisms necessitates predictive tools to allow transferability and interoperability of the knowledge gained from limited experimental/empirical data (surveillance, in-field monitoring…). In this regard, one long term aim is to develop fully validated multi-scale based models that link the nano scale through to the macro (i.e. structural) scale based on a multi-disciplinary approach. Better understanding of the physical mechanisms affecting the ageing of metallic materials combining advanced experimental investigations with the use of up-to-date modelling methods, such as those developed through the multi-scale approach. Important is to investigate in depth the local phenomena and their interaction by using powerful numerical tools allowing an accurate prediction of ageing, not only of the components that are accessible for inspection, monitoring and repair but of all others that are not easy to reach. This extrapolation needs to be based on experimentally validated models using data from both in-pile and out of pile experiments.

■

R&D topics:

- **Better understanding of physical mechanisms driving the ageing of materials, by combining advanced experimental characterisation of ageing materials with the use of atomistic and nanostructure evolution modelling tools, that should include the effect of local phenomena and the interaction between them, by using powerful numerical tools,**

including those required to homogenise in time and space.

- **Development/improvement of models to predict crack initiation under various ageing mechanisms.**
- **Performance of representative in-pile experiments and subsequent materials characterisation for the validation of the modelling tools.**
- **Investigation of ageing effects, especially irradiation hardening and subsequent embrittlement, of reactor components, especially the vessel, by multi-scale modelling.**
- **Investigation of mechanisms determining irradiation creep and swelling in austenitic steels and development of relevant predictive physical models, based on a multi-scale modelling approach.**
- **Simulation of welding and manufacturing processes with a view to evaluating ageing effects.**
- **Investigation of the correlation between microscopic properties and macroscopic mechanical behaviour of aged materials on the basis of combined experimental and theoretical analysis of dislocation dynamics.**

■

III.4.4.4. Ageing Monitoring, Prevention and Mitigation

SSC ageing needs to be monitored over the nominal and extended service life of SSC in order to be able to correctly determine or anticipate the relevant ageing mechanisms and to evaluate the extent of degradation that may occur. In principle it is possible to monitor ageing effects (as flaws, thinning, material properties change etc.), function performance or its changes, operating conditions (including loading history) and efficiency of preventive measures applied to mitigate SSC ageing. For particular monitoring measures it is necessary to clearly state parameters to be monitored and their acceptance criteria.

SSC ageing mitigation is aimed on replacement, maintenance, refurbishment, operational condition change and other measures, which can influence the degradation rate.

R&D topics in this subchapter are focused to the development of effective and practical methods for monitoring and mitigating ageing of the SSC.

III.4.4.4.1. Ageing Monitoring

New operational experience and progress in understanding of material ageing phenomena enables to develop new monitoring methods, diagnostics and monitoring simulation tools that can greatly increase the ageing management efficiency.

■

R&D topics:

Concrete:

- **Development of methods for assessing the current state of concrete structures by way for example of retrofitting embedded humidity sensors for monitoring the quality of the concrete with respect to penetration of boric acid (and other liquids) in to the SSC.**

Polymers and Electrical Equipment:

- **Detection of local and global degradation of cables and establishing a correlation for residual life estimation by using in-situ non-destructive electrical techniques for in-service full length measurements (for medium and low voltage cables.**

■

III.4.4.4.2. Prevention and Mitigation of Ageing

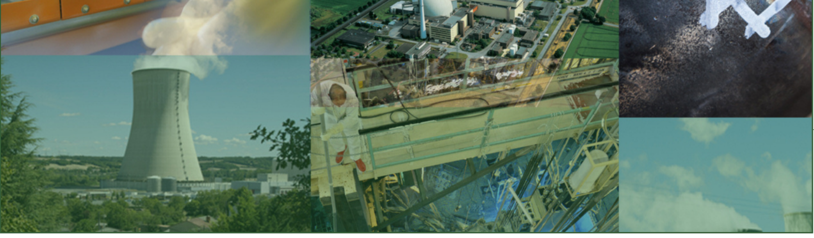
Prevention and mitigation of both ageing mechanisms themselves and their resulting damage and failure has been a long term challenge for engineers and scientists in many industries. However, this is an area where further studies and developments are required. The issue is associated with components that are usually very difficult and expensive to replace and may not be readily observable.

Main challenges for this sub area cover development of efficient and applicable preventive measures and repair technologies. Other mitigating measures are topics of the following sub areas.

■

R&D topics:

- **Simulation of residual stresses and development of mitigation measures including overlay welding.**
- **Investigation into annealing of RPV materials.**
- **Investigation of the effect of water additives on vessels, piping and components in the primary loop of the reactor coolant systems in BWR, PWR and VVER plants.**
- **Development of improved mitigation techniques for inter-granular stress**



corrosion cracking (IGSCC): e.g. modified water chemistries or development of other new techniques.

- **Assessment of low temperature crack propagation susceptibility for primary circuit and core materials (welds, cast materials: Inconel 182, alloy 690 cold worked etc.) in transient conditions with the aim of optimising the water chemistry.**

■

III.4.4.5. Equipment qualification

III.4.4.5.1. Equipment Reliability

The reliability of equipment turns out mandatory even if it has no direct impact on the system safety as almost no SSC is operating in a stand-alone manner. Thus, the incremental development of each NPP to implement the improvement of the safety approaches necessitates a great R&D effort to establish if the SSC are able to perform their intended function in a reliable and safe manner throughout the lifetime of their required use.

Figure 12: Arrival of EPR main vessel at Olkiluoto, Finland (Source: VTT)

■

R&D topics:

- **Investigation of the reliability of relevant equipment for long term operation.**

■

III.4.4.5.2. Industrial Obsolescence

NPPs are per definition designed to operate for a long time period during which a substantial technological and societal changes occur. Obsolescence essentially refers to SSC that are no longer manufactured or maintained properly during the lifetime of an NPP. A common European approach should be developed with the help of NUGENIA either to create versatile technologies, possibly with other industries, or to adapt nuclear procedures to even faster evolving domains.

■

R&D topics:

- **Establish a common position on the relevance of qualification tests and on their extension to cover longer-term operation.**

■

III.4.4.6. Qualification

The qualification of methods used for the integrity assessment of SSC is mandatory which necessitates the establishment of verification and validation of structural integrity assessment and lifetime procedures for SSC and the development of specific materials or component tests. Often an overall qualification approach for structural integrity assessment and lifetime procedures requires a combination of advanced analytical and experimental qualification to comply with the functionality requirements for each component and system.

Qualification is inherent in performing R&D studies on the various issues relating to SSC.

■

R&D topics:

- **Develop structural integrity assessment procedures for dissimilar metal welds including numerical prediction methods for residual stresses and develop a test standard for toughness measurement for multi-metallic specimen and components.**
- **Development of an accelerated test for stress corrosion cracking initiation in LWR conditions.**
- **Assessment, optimisation and further developments of advanced tools for structural integrity assessment of piping systems.**
- **Understand and quantify constraint and bi-axial effects in metallic components and investigate the effect of warm pre-stressing in combination with the effect of crack tip constraint and bi-axiality.**
- **Comparison of existing codes and standards for the estimation of K and J values of various crack configurations in**

pipes and other standard geometry components to quantify the conservatism of the single methods.

- Development of a radiation embrittlement database and development of trend curves RPV life assessment based on the collected data.
- Development of empirical/semi-empirical models for prediction of stress corrosion cracking (SCC) initiation in LWR and super critical water conditions.
- Comparison of different numerical methods on microstructure evolution of irradiation creep and swelling.
- Upgrade and extend the existing VERLIFE Procedures (structural integrity and lifetime assessment procedures for VVER type reactors) with appendices on structural integrity assessment for RPV internals, LBB procedures for piping, NDE qualification.

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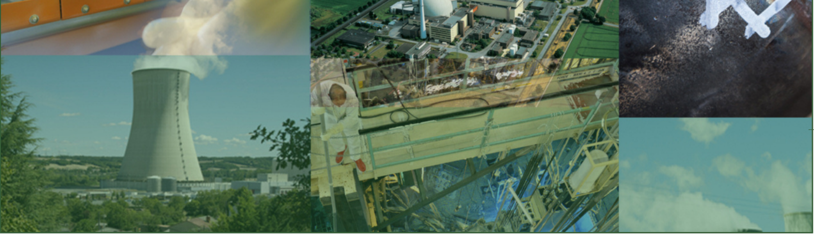


III.5. Technical Area 5 (TA5), Fuel Development, Waste and Spent Fuel Management and Decommissioning

III.5.1. Scope

Technical area 5 (TA5) covers development of nuclear fuel for existing, advanced and innovative core designs, aspects of fuel use in reactors (nuclear fuel behaviour mechanisms) and the fuel management steps – manipulation, transport and interim wet and dry storage. It also includes factors relating to the generation and management of radioactive waste, and the dismantling and decommissioning of nuclear power plants. It includes the safety issues linked with: fuel behaviour in normal operation and accident conditions, and the safety of the fuel cycle, including the investigation of criticality accidents and radioactive material dispersion.

TA5 has connections mainly with TA3 in parts of core optimisation and chemistry and to a lesser extent with TA6 regarding fuels for innovative LWRs and with TA1 for NPP safety and risk, including criticality. TA5 has an important interface with TA2, which deals with severe accident, while TA5 covers normal and off normal behaviour, exclusive of major core degradation.

Outside of the scope of TA5 is radioactive waste disposal since IGD-TP is in charge of the research agenda and deployment plan for this topic.

The scope also takes account of emerging lessons from the Fukushima accident and proposes research, development and innovation to improve the safety and resilience of the existing and new build LWR reactor fleet.

III.5.2. Objectives

The rationale of TA5 is to improve the safe, reliable and economic operation of Generation II and III NPPs (specifically in-reactor and out-of-reactor nuclear fuel management and radioactive waste management) and to maintain the sufficient level of safety defined by the regulatory bodies and reflecting the recommendations of the relevant international organisations.

Nuclear fuel production and use have reached a relatively mature state; nevertheless there is motivation to improve existing fuel types and to establish safety operating limits of developed innovative fuel:

- To increase fuel safety margins and improve behaviour under operation and accident conditions,
- To reduce reactor operating costs (including fuel costs),
- To reduce the amount and/or radio-toxicity of spent fuel,
- To recycle existing waste (uranium, plutonium) from reprocessing operations,
- To increase sustainability,
- To improve the safety of fuel management and decommissioning/dismantling and more generally to the fuel cycle (such as criticality and re-suspension and transfer of radioactive materials),
- To improve proliferation resistance.

The general R&D needs for all fuel types are:

- Development of manufacturing techniques, improving safety as well as out of spec material.
- Collecting data on fuel and material irradiation properties.
- Performing post-irradiation examination (PIE) and collection of in-pile data on fuel performance (fuel thermo-mechanical and thermo-chemical behaviour under irradiation) and fuel resilience either during normal and accident conditions, and long term storage.
- Understanding and modelling of fuel performance and behaviour in accident conditions.
- Providing data to evaluate criticality risk in the fuel cycle, including the burn-up credit.
- Implementing source term determination and mitigation strategies in case of accidental dispersion of radioactive materials (re-suspension, filtering etc.).

Fuel behaviour in both normal operation, storage and accident conditions currently is, and will continue to be, a major issue for the safe, secure and economic operation of nuclear power plants.

Despite the considerable knowledge base, there are still unknowns, necessitating dedicated fuel and material property, separate effect and semi-integral and integral testing to provide experimental data on fuel safety performance behaviour. These data can then be used to inform fuel development and to improve understanding and simulation of fuel performance and in parallel provide improved tools for regulatory bodies.

An understanding of fuel behaviour in normal and abnormal conditions is underpinned by fuel R&D, which must address new design and safety requirements, increases in uranium enrichment, uranium and plutonium recycling (and potentially in the future minor actinide recycling), power up-ratings, and increased cycle length and burn-up and post discharge storage timescales. It must also address differences in behaviour engendered by incremental changes in the fuel components: that is, of the fuel pellets (composition / geometry), cladding and assembly structural components.

Both spent nuclear fuel management and radioactive waste management have achieved a widely agreed maturity, however lack of progress on a final disposal solution is leading to increased storage times and the need to relicense storage facilities, that creates new needs, but there is still room for progress, including the optimisation of loading strategy and the introduction of more efficient and reliable technologies leading to an improvement of the safety of processes, to a reduction in cost and lower environmental impacts.

The number and variety of nuclear facilities in the decommissioning stage will increase greatly in future years and therefore development of remote dismantling techniques and dose minimisation approaches are needed along with more reliable methods for the reuse and recycle of valuable materials and the release of other materials to the environment.

Accordingly, the TA5 comprises the following five ST-A's:

5.1 *Fuel Development for Existing, Advanced and Innovative Designs,*

5.2 *Fuel Behaviour Mechanisms and Computational Codes,*

5.3 *Fuel Treatment, Transportation and Interim Storage (Spent Fuel Management),*

5.4 *Waste and Spent Fuel Management,*

5.5 *Dismantling and Decommissioning.*

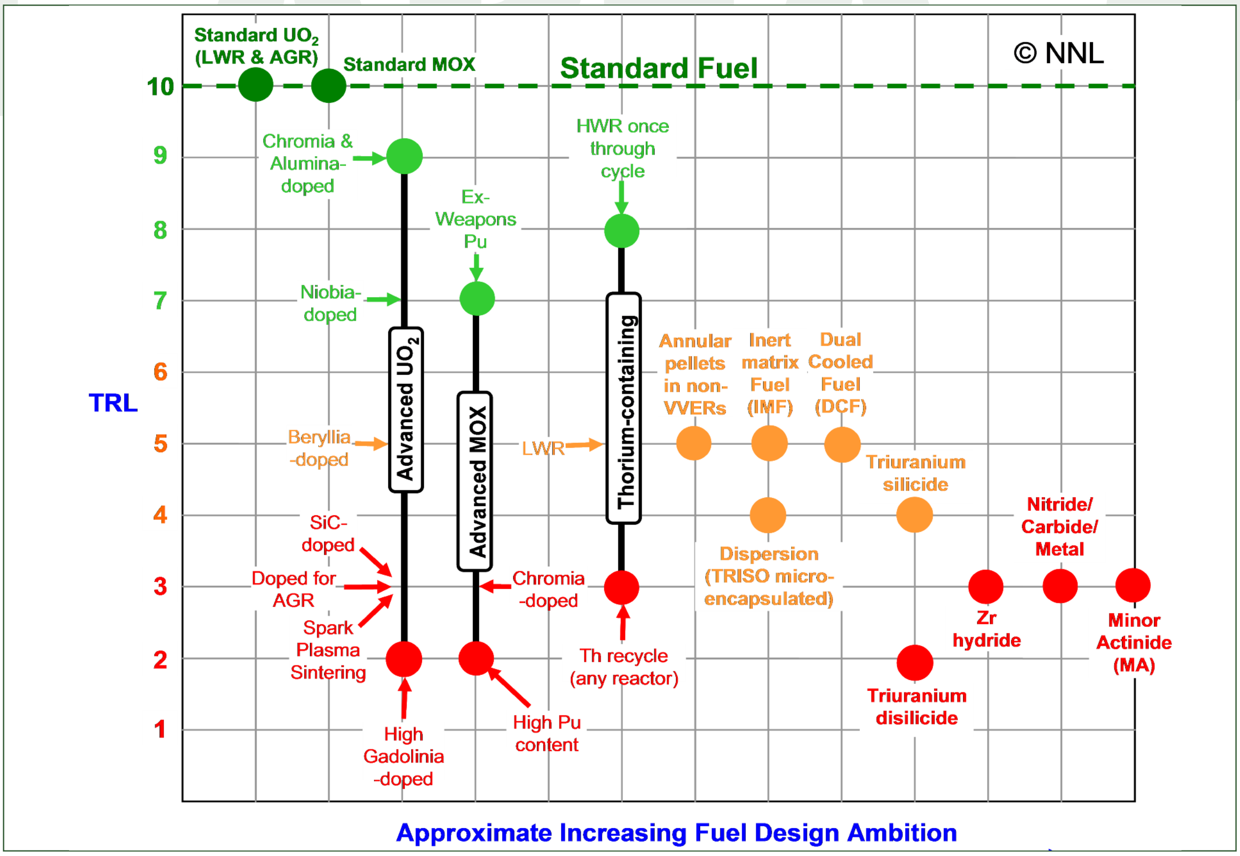
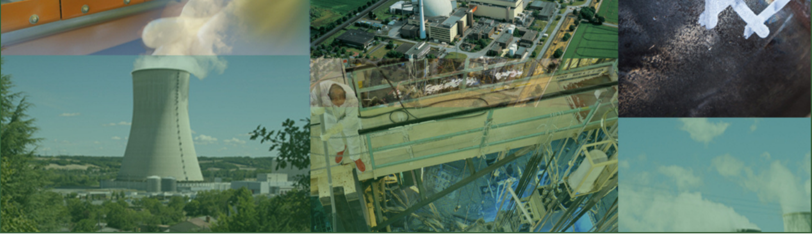


Figure 13: Technology Readiness Levels (TRL) of Advanced Fuels (Source: NNL/DECC)



III.5.3. State of the art

UO2 enriched up to 5% in the form of solid or annular pellets in zirconium alloy cladding remains the most used fuel in European reactors. The main nuclear fuel suppliers in Europe are currently Areva, Westinghouse, GNF and TVEL (LWR fuels). MOX fuel is used in limited quantities mainly in France where processing is available. The existing expert and experimental base consists of vendors own R&D, and operational experience from utilities, research entities and international organisations (mainly IAEA, OECD NEA).

Figure 14: C5 cell of the LEFCA laboratory at CEA, Cadarache (Source: IRSN)

Burnable absorbers integrated into the fuel matrix (Gd and Er) are routinely used to control excess reactivity. Modifications to fuel microstructures have been recently introduced by incorporation of additives or by use of advanced manufacturing techniques. Fuel behaviour mechanisms are currently well known for UO2 fuel in Zr cladding and AGR fuel for burn-ups up to 60 000 MWd/t. The fuel performance codes have been developed and validated (utilising data from operation and dedicated experimental programmes) and are routinely used for simulation of normal operation and accident scenarios.

Experimental facilities (research reactors, hot cells and laboratories) are still available for research and testing, but this valuable infrastructure is decreasing, driving the need for greater cooperation.

Spent fuel management (with various nuclear fuel types for both commercial and research reactors) is undertaken and has benefited from the accumulated knowledge and experience of the past decades. Nevertheless, there is significant room for improvement and optimisation in various areas which would result in improved safety, security (proliferation resistance), and economic and environmental characteristics. The spent fuel management chain is carefully regulated by rules established by national regulators usually reflecting the recommendations of international organisations (IAEA). Within the EU a range of spent fuel storage arrangements are employed, in some countries fuel is stored primarily at the reactor stations/site where it is generated, whereas in other countries centralised storage is used for interim/long term storage after an initial cooling period at the reactor site. Transport of spent fuel is a well-established and regulated operation. With increasing longer interim storage periods, knowledge on the fuel and cladding behaviour needs commensurate advancement.

Fuel recycling of UO2 and metallic fuels is generally well established within the EU, nevertheless development of knowledge is still required at process level.

A number of decontamination, waste treatment and conditioning methods and technologies have been developed and are used. The management of special categories of waste has also been addressed (tritium and C-14 waste, Be, graphite, mixed radioactive and chemically toxic waste, etc.). Nevertheless, the potential for improvement to reduce costs, risks and impacts is still far from exhausted. Methods of reuse and recycling of various materials (metals, concrete) have also been introduced. Experience from decommissioning and dismantling of nuclear facilities is being continually accumulated allowing drafting of guidelines and the use of best practices.

This knowledge is shared under the umbrella of international organisations (IAEA, OECD NEA – Working Party on Decommissioning and Dismantling).

III.5.4. Challenges

Several key challenges remain for the short term such as the improvement of nuclear fuel allowing higher burn-ups and increased safety margins, but also the development of accident resistant fuels, innovative fuels and fuels allowing the burning of Pu and minor actinides (including non-UO2 fuels). At the same time, improvement of nuclear fuel reliability, improvement (reduction of uncertainties) and extending experimental data on fuel behaviour at high burn-ups and in accident conditions are vital.

To meet future requirements it is essential that the fuel performance codes are continuously improved and validated. For this validation also the nuclear facilities need to be maintained, and expanded. It is therefore essential that support is provided to irradiation facilities, hot cell and laboratories, both for maintaining the current fleet and support for expansion and new facilities.

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R&D topics:

- **Handling and storage of leaking fuel assemblies (spent fuel pool and interim wet and dry storage) and handling of fuel and casks after longer term storage including the interface with a deep geological repository.**
- **Improving understanding of ageing mechanisms, inspection requirements and ageing management plans for interim storage facilities, so as to avoid hidden legacies for future generations.**
- **Addressing the burn-up credit challenges (code validation and licensing issues).**
- **Optimising the spent nuclear fuel cycle and reprocessing and recycling of high burn-up and advanced fuels.**
- **Improving the fuel management safety (including long interim storage periods), of dismantling operations and of fuel cycle processes, regarding the risk of re-criticality and of dispersion and release of nuclear materials particularly under beyond design basis conditions.**
- **Using advanced I&C tools for development of integrated waste management strategies.**
- **Minimising waste production by design and material selection and operational measures as well as development of advanced waste treatment and conditioning technologies.**
- **Developing efficient dismantling technologies for structures and components, including remote dismantling techniques.**
- **Elaborating and proposing waste minimisation strategies for decommissioning, including safe release of material to the environment (including assay methods), recycle/reuse, disposal to LLW repositories along with reliable and cost effective activity measurement techniques.**
- **Developing advanced radiation and temperature tolerant adhesives and sealants.**
- **Developing improved filtration methods to reduce legacy radioactive burden at end of life.**

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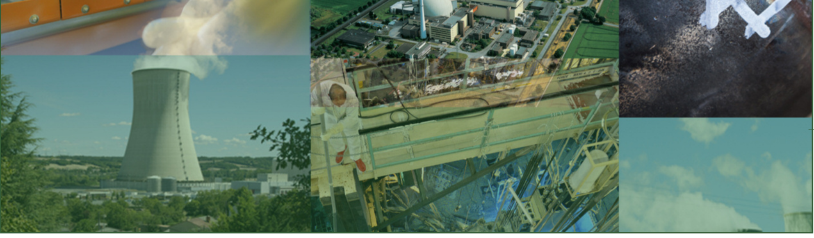
AL AREA 5



III.6. Technical Area 6 (TA6), Innovative LWR design and technology

III.6.1. Scope

The deployment of advanced Light Water Reactors (LWR) for electricity production could valuably make the bridge throughout the 21st century between the ageing nuclear installations currently in operation and/or the Generation III ones, now under construction, and the Generation IV reactors proposed by the GIF and promoted by ESNII. For assessing and reinforcing their attractiveness, there is a need to continuously improve performance and safety, and to propose new technology and /or new concepts with new attributes.

Innovative technology will be developed along with a transverse view for fulfilling the needs and requirements of the currently operated LWR, and new designs as well. 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 data. On the other one, this will support the development of advanced light water reactor concepts that would feature improved sustainability with a better use of uranium resources and capabilities of fissile materials multi recycling, or be sized for smaller generated thermal power and modular construction techniques, etc.

Both existing and new LWR designs will profit from the expected R&D programmes in TA6 through the progress which should be achieved in the fields of safety & commissioning, operability, sustainability, economics and public acceptance, especially following the Fukushima accident.

III.6.2. Objectives

Innovation is the key driver of the TA6 for addressing technology, methods, testing and computation capacities, with the objective of supporting the competitiveness of light water reactors.

The development of new materials, manufacturing and assembly technology will result in the fabrication of high reliable components and for long term operation. This will be applied to the replacement of currently operated LWR components, as well as to the fabrication of new component which should comply with new LWR concepts.

Other LWR concepts will be investigated for proposing new possibilities while benefiting from the experience gained in the field of LWR technology. High conversion ratio reactors offer a better use of fissile material and in the same time, the possibility of Plutonium multi recycling instead of storage in spent fuel. Small modular reactors offer lower initial capital investment and the possibility to progressively increase electricity generation capacity through the addition of elementary modules.

Whatever the LWR design is, inherent and passive safety should be continuously assessed and improved to the maximal possible extend. This is a first step towards public acceptance. Lastly, in an evolving context regarding electricity production sources and rationale for nuclear energy use in the European countries, LWR integration in the energy mix should be analysed for deriving new potential requirements. They will be used as input data for the development of new material and component fabrication technology.

Knowing that new technology deployment at the industrial scale could be a long time duration process, the following time lines will be considered:

- Proposing evolutionary technology for mid-term application.
- Supporting the development of new LWR designs such as with higher conversion ratio or small modular reactors, expected to be ready for commercial operation by fall of the next decade.
- Investigating breakthrough technology for preparing the future.

Accordingly, the TA6 roadmap is organised in five sub-areas corresponding to R&D challenges in line with the objectives mentioned here above:

6.1 Innovative Technology for Reactor Component Design & Technology,

6.2 Innovative LWR Concepts including: High Conversion LWRs, Small Modular Reactors, etc.,

6.3 Innovative LWR Specific Safety Issues,

6.4 Key Success Factors for Innovative LWR deployment,

6.5 Public Acceptance Drivers for New Builds.

III.6.3. State of the art

Synergies with all the other NUGENIA areas will be exploited for taking benefit from operating experience feedback from the current reactor fleet, prior to develop innovative technology that will result in improved performance. That will include enhanced requirements for safety and performance, reduced maintenance and long term operation, material ageing related issues, inspection, control and repair, operation, and plant power upgrade, as well.

The main material grades which are used in nuclear reactors components are mostly used as monolithic structural materials, or may be coated. Recent studies have shown evidence that combining different materials and manufacturing routes may result in multi-functional materials. Large power generation components are commonly fabricated using conventional methods, such as forging, casting and grinding as finishing operations. Recent studies have highlighted the major attributes of powder metallurgy technology, especially high isostatic pressing, which can form near net shape components with limited finishing operations.

The concept of a high conversion light water reactor has gone on being studied over the 80's in the aim at combining the advantages of LWR technology with the use of uranium – plutonium fuel, the achievement of high burn up and low nuclear fuel consumption.

Small modular reactors are expected to share simplicity of design and reduced sitting cost compared to a current LWR. This results in a revival of interest worldwide.

The focus of the studies has to be placed on the safety issues in light of the Fukushima event and of the "EU Stress Tests specifications".

Innovative LWR designs requires further enhancement of inherent safety features and passive safety on component and system levels.

The development of knowledge, safety requirements, criteria and rules for innovative technologies should facilitate and accelerate their implementation in the nuclear field.

III.6.4. Challenges

The main challenges for NUGENIA in the field of Innovative LWR design and technology can be identified in the five sub areas which address all the necessary stages of LWR technology implementation. The R&D projects proposed in TA 6 will combine innovative technology and progress made in any domain for reinforcing the competitiveness of LWR reactors.

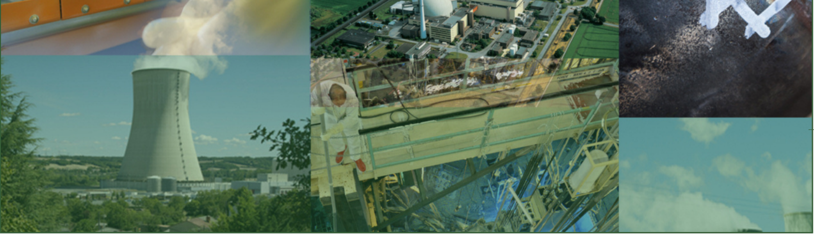
III 6.4.1 Innovative Technology for Reactor Component Design & Technology

As a common theme for all LWR reactor concepts, advanced and breakthrough technologies for reactor component design and fabrication will be investigated. Synergies will be exploited to benefitting from the more demanding requirements and the progress made in basic technologies. Safety issues will be considered at the early stage of the design. Moreover, the overall performance of the component will be assessed adopting new methods.

All the necessary stages for reactor component design and fabrication will be addressed, while seeking for innovation. Safety issues will be considered at the early stage of the design. Finally, the overall performance of the component for the related reactor concept will be assessed using new methods benefiting from the recent progress in testing capacities, physical modelling and numerical simulation.

R&D topics:

- **Development of new materials and processing methods for reaching tailored properties:**
  - **multi-layer material e.g. with high resistance to corrosion and enhanced elasticity,**
  - **surface engineering e.g. for stress corrosion cracking, nano-materials,**
  - **composite materials and hybrids e.g. combining high mechanical stress and other functionality, to achieve properties suitable for high-performance nuclear components.**
  - **multi scale modelling will provide guidance for the evaluation of new alloyed materials e.g. resistance against irradiation damage, swelling, creep**
- **Development of new manufacturing and assembly process, such as using powder metallurgy and predictive modelling on the resulting material microstructure, metallurgical properties, and macroscopic behavior of the component; application to existing**



component for coating, dissimilar metal assembly, near net shape fabrication, and focus on compact heat exchanger for Small Modular Reactors.**

- **As a transverse approach for all reactor concepts, the development of engineering simulator tools will be considered to assess the overall reactor system performance, including the environmental impact. This will first require the development of in-depth knowledge of local phenomena leading to degradation mechanisms**

■

III 6.4.2 Innovative LWR Concepts including : High Conversion LWRs, Small Modular Reactors, etc.

The development of new concepts which could broaden the functionalities of Light Water Reactor and be ready for commercial operations for the next decade will arise new requirements and provide guidance for implementing R&D work in many fields.

■

R&D topics:

- **Concept screening: High conversion ratio, small modular reactors etc. for identifying the main requirements in technology development**
- **Material and component with enhanced properties as required by the related concepts, such as compact heat exchanger fabrication for small modular reactor, performance of heat removal systems**
- **Core design based on available concepts: reactor physics, robust nuclear data, heterogeneous core,**
- **Reactor core cooling: The tight lattice core of high conversion core makes the cooling very specific and raises new challenges in thermal hydraulic evaluation**
- **Investigation on various separate thermal hydraulics phenomena, specific to the reactor technology: natural and mixed convection conditions, boiling heat transfer of Steam generator as plate or tube, flow induced vibration in compact SMR**
- **Analysis of modular construction techniques**
- **Assessment of overall reactor system performance, in operating and accidental conditions.**

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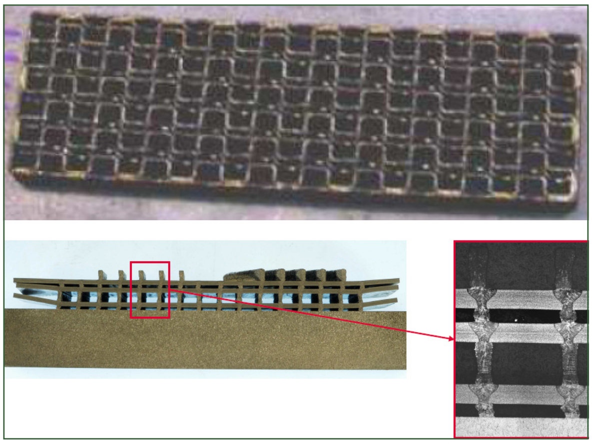

Figure 15: Plate heat exchanger to be fabricated for Small Modular Reactor

III 6.4.3 Innovative LWR-specific safety issues & approach

The development of innovative materials, component fabrication processes, as well as the evaluation of new reactor concepts, could require specific safety approaches and the incorporation of passive system which should be integrated at the early stage of design. Harmonisation with EU Directives establishing a common framework for the nuclear safety of nuclear installations, likewise to Western European Nuclear Regulators Association (WENRA) statements and to IAEA safety publications is to be achieved.

■

R&D topics:

- **Exploitation of pre-normative research results to implement the safety requirements, including site selection and evaluation.**
- **Development of more sophisticated instrumentation and control systems for safety applications.**
- **Integration of the safety issues highlighted after the Fukushima Daiichi accident and by the EU stress tests specifications.**

■

III.6.4.4 Key success factors for innovative LWR deployment

Key success factors for the deployment of new and/or innovative LWR reactors must be investigated vs. the deployment strategy of

Generation IV systems and to the growing contribution from the renewable energy sources. Flexible fuel cycle scenarios will be evaluated using a wide range of combinations of electricity sources for a transition period: current and innovative LWR technologies, thorium cycle, fast reactors, and wind energy which are intermittent and should be complemented.

Enhanced operability of LWRs will be considered along with two objectives that could be separate or complementary:

i) Conventional plant operation and

ii) Facilitating LWR integration within a regional fleet of mixed electricity sources.

Innovative solutions for minimising the environmental impact of LWRs will be evaluated.

■

R&D topics:

- **Evaluation of flexible fuel cycle scenarios relying on a wide range of combinations of electricity sources for a postulated transition period, such as current and innovative LWR technologies, thorium cycle, Sodium fast reactors, and renewable energy sources. Establishment of criteria for scenario analysis (mass inventory, radiotoxicity, ultimate waste, etc.). The outcome from ENEF analysis will be used as an input.**
- **Search for the enhanced operability of LWRs, including potential benefit for either load following or combined mode, and innovative technology for plant operation simplification.**
- **Evaluation of innovative solutions for minimising the environmental impact of LWRs.**

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III.6.4.5 Public acceptance drivers for new builds

In this subarea, it is proposed to address the rationale behind nuclear energy acceptance by the public, notably for new build. European policy is to provide with key elements for guidance.

■

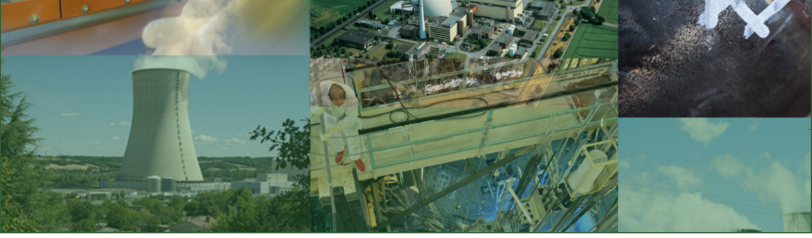
R&D topics:

- **Identification of the main drivers towards public acceptance for new builds, taking into account the specific requirements of different countries.**
- **Harmonisation of the communication policies, taking into account the differences in the public awareness and acceptance, which exist among the European countries.**
- **Organisation of the information dissemination.**

■.

AL AREA 6

NUGENIA NUclear GENeration II & III Association



III.7. Technical Area 7 (TA7), Harmonisation

III.7.1. Scope

Harmonisation, and standardisation, its subsidiary, are crucial cross-cutting objectives within the NUGENIA technical scope. Interest for standardisation and harmonisation - shared by designers, operators R&D organisation and TSOs - is growing every day.

Despite its cross-cutting nature, harmonisation has been identified within NUGENIA as a full-scope TA to:

- Emphasize the needs for a progress in the field within Europe,
- Support and supply help to valorising projects from different technical areas that contribute to harmonisation issues,
- Drive attention to the R&D programs and activity underway which can contribute to the improvement of rules, codes, standards and practices.

III.7.2. Objectives

The objectives of harmonisation in NUGENIA include three different fields of endeavour:

- Supporting the competitiveness of European nuclear energy through setting-up the technical basis for an effective standardisation of reactor systems and components.
- Improving the safety level of the nuclear installation through shared design approaches and common safety assessment methodologies.
- Benefiting in the public acceptance through its better information and involvement.

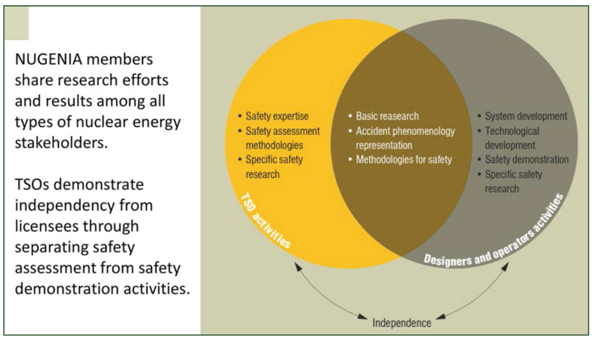


Figure 16: Increasing research domain covered by all stakeholders enlarges the field of technical consensus (Source: IRSN)

The process of harmonisation in the nuclear industry at European - and international - level is supported by several professional or international organisations; some of them gather the operators (FORATOM, WANO), others illustrate the safety efforts (WENRA, AEN/CSNI, ETSON), but few of them gather similarly nearly all stakeholders in the nuclear industry as NUGENIA does. Orienting NUGENIA's research towards selected issues, may contribute sensibly to improve harmonisation. The NUGENIA technical area 7 will therefore support activities in four complementary fields:

7.1 Perform pre-normative research for new design and operating conditions, but also for establishing operating limits, improving safety criteria and promoting of best practices.

7.2 Develop improved methodologies and provide technical basis for design and assessment of reliable NPPs.

7.3 Contribute to the establishment of shared codes and standards through oriented research.

7.4 Adopt a harmonisation strategy with smooth and efficient methods to enlarge progressively the field of consensus among stakeholders.

III.7.3. State of the art

Many projects and industrial initiatives Many projects and industrial initiatives concerning more or less directly harmonisation are already going on, mainly in the fields of pre-normative research (even if the outcomes of such programs are not fully fed-back to practices and rules), design and assessment methodologies (fields in which a wide effort is currently done to harmonise practices for new reactors), and codes and standards, mainly for digital systems and components.

Several national nuclear codes are also available in Europe (like RCC-M and RCC-MRx in France, KTA in Germany) and should be used as input for European codes.

TA7 is intended to support initiatives already underway, emphasizing their potential contribution to the improvement of rules, practices and methodologies. It also aims at stimulating initiatives and proposing cross-cutting projects and coaching projects within other technical areas which present side interest and can be valorised for harmonisation purposes.

III.7.4. Challenges

The main challenges for NUGENIA in the harmonisation field can be identified along its four main fields of endeavour:

III.7.4.1. Pre-normative research

The pre-normative research can be defined as both:

- The preliminary phase of an experimental research aimed at better characterising new technologies and the related safety aspects by applying well established procedures and methodologies.
- A research the results of which are to be used to develop guidelines, standards and technical codes.

Therefore, any technical domain and any NUGENIA project may provide data for pre-normative activities, data that can also be useful for other standardisation organisations.

The pre-normative approach can also apply to safety criteria that were defined once to comply with a given list of transients and for specific types of reactors. It could appear useful to generalise these criteria to several kind of design and to express them in general terms such as control of the thermal power, cooling of heated parts of the plant, and keeping the structural integrity of the different barriers between the fission products and the environment.

III.7.4.2. Design and assessment methodologies and practices

Several plant performance evaluation methodologies have been developed and are still under continuous improvement:

- The defence-in-depth approach, declined in the INSAG 10, provides a functional analysis through identification of systems and components, their failure modes and the mitigation needs. It allows assessing the robustness of the plant design against the risk of dispersion of nuclear materials in the environment and contamination of the human being.
- The risk-informed methodology allows increasing the robustness of design through feed-backing the estimated contribution of the accidental sequences to the risk. It applies in particular to in-service-inspection and maintenance optimisation, and in assessment of plant risk and benefits of plant modifications.
- More recently, studies have been engaged on the safety margins approach, which is intended to account for all major potential contributions to the risk, independently from their ranking and expected issues. The safety margins evaluation approach is the subject of a common challenge.

Several projects in NUGENIA should help clarifying and improving those methodologies.

III.7.4.3. Codes & Standards

Many organisations are editing standards relevant to nuclear industry: ISO and IAEA for example. At the European level three standardisation organisations are active: the European Committee for Standardisation, the European committee for the standardisation of the electro-technical domain and the European Telecommunication Standard Institute.

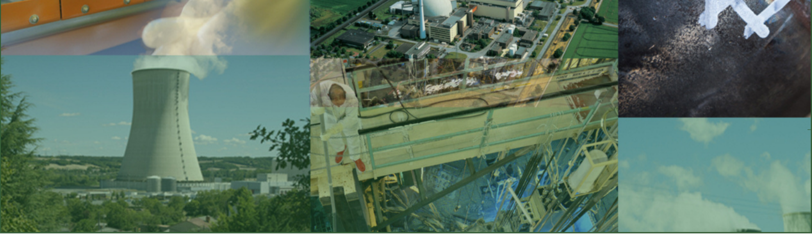
Gathering and synthesising the already existing knowledge to single-out the methodologies and practices that need to be harmonised is a preliminary exercise in NUGENIA. The prerequisite to participate in codes and standards development consist in establishing liaisons with the main harmonisation organisations in order to offer them technical support to back up the standardisation process.

III.7.4.4. Harmonisation strategy

The valorisation of the NUGENIA projects will include exploitation of results in terms of standardisation and preparation of formatted data for standardisation activities.

Sharing projects in the field of methodologies, design, technology and systems will be a source of better harmonisation orientation for all participants; NUGENIA should propose and realise research projects to bring technical basis to all stakeholders in other standardisation organisations.

In the field of safety, NUGENIA efforts will rely on a systematic and continuous dialogue among the stakeholders and should lead those developing practical ways to reach the objectives settled by the safety authorities.



III.8. Technical Area 8 (TA8), In-Service Inspection and Non Destructive Examination

III.8.1. Scope

The European Network for Inspection and Qualification (ENIQ) deals with the reliability and effectiveness of non-destructive testing (NDT) for nuclear power plants (NPP) and is a network driven by European nuclear utilities working mainly in the areas of qualification of NDT systems and risk-informed in-service inspection (RI-ISI). Since its establishment in 1992 ENIQ has performed two benchmark studies and has issued nearly 50 documents. Among them are recommended practices, technical reports, discussion documents and the two ENIQ framework documents, the "European Methodology for Qualification of Non-Destructive Testing, EUR22906EN" and the "European Framework Document for Risk-Informed In-Service-Inspection, EUR21581EN". ENIQ is recognised as one of the main contributors to today's global qualification guidelines for ISI.

ENIQ has three task groups in which the technical work is performed, the Task Group for Qualification (TGQ), the Task Group for Risk (TGR) and the Task Group for inspection qualification Bodies (TGIQB). Their members come from utilities, ISI vendors, IQBs or research organisations in Europe with additional members from Canada and the USA. Beside the task groups ENIQ has a steering committee (SC), which is the decision making body of ENIQ. The SC has twelve voting members, one for each EU member country (with operating NPPs) and Switzerland. SC members come entirely from European utilities. Beside the voting members the SC has non-voting members (observers) from Canada, USA, the chairpersons of the three task groups and additional representatives of European utilities, ISI vendors, IQBs or research organisations. In 2010, the ENIQ SC recognised that the European nuclear industry was entering a period of significant change and thus initiated an internal discussion to determine its vision and objectives regarding ENIQ's future role and activities. This exercise resulted in the issuing of a strategy document, entitled the "ENIQ 2020 Roadmap" and the decision of ENIQ voting members to integrate ENIQ into NUGENIA, making ENIQ the 8thTechnical Area of NUGENIA.

III.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) and new build.
- Promoting ENIQ approaches outside Europe and in non-nuclear industries.

Accordingly, the technical content of TA8 is subdivided into four ST-A, as follows:

8.1 NDT Qualification,
8.2 Risk-Informed In-Service Inspection,
8.3. Inspection Qualification Bodies.

III.8.3. State of the art

III.8.3.1. NDT Qualification

The ENIQ Methodology is established as one of the main contributors to providing assurance that NDT of nuclear safety critical components is fit for purpose. This approach assembles theoretical and experimental evidence and combines this with formal practical demonstrations to ensure that specific performance objectives are met. As such, ENIQ has always been playing a first order role on qualification state-of-the-art, creating the first qualification methodology based on technical justifications, issuing recommended practices (RP) and carrying out pilot studies.

The ENIQ TGQ is responsible for having developed the inspection qualification methodology that is now being used as a basis for all European methodologies and for CANDU type reactors. The ENIQ inspection qualification methodology is also accepted by the IAEA as recommended practice to be followed for nuclear inspection qualification all over the world. After publishing the third issue of the European Qualification Methodology Document in 2007, TGQ has recently issued a recommended practice on personnel qualification and a document giving an overview of inspection qualification for the non-specialist. Currently TGQ is involved in a number of projects and preparing new ones.

III.8.3.2. Risk-Informed In-Service Inspection

ENIQ TGR published the "European Framework Document on RI-ISI, EUR21581EN" in 2005 and since then has been developing a series of supporting Recommended Practices (RPs) and initiating a number of other work-streams to advance the principles of RI-ISI and maximise the overall risk benefit. Amongst these are RPs on the verification and validation of structural reliability models and guidance on the use of expert panels together with discussion documents on the application of RI-ISI to the inspection of reactor pressure vessels and updating of RI-ISI programmes. Also ENIQ TGR members were heavily involved in the RISMET benchmark project on RI-ISI that was organised by OECD-NEA. Currently TGR is drafting a technical report on the lessons learned from the application of RI-ISI to European NPP.

III.8.3.3. Inspection Qualification Bodies

Structural Integrity claims for safety critical NPPs often depend upon having a high level of confidence in NDT results, performed either during manufacturing of NPP components or ISI of the operating NPP. The inspection qualification process that provides this confidence requires the functioning of the IQB as a recognised assessment organisation (second or third party assessment organisation in accordance with ISO 17020). As such IQBs that are established by each country are in the best place to provide advice to licensees on the processes and application of inspection qualification. Consequently, the licensees represented in ENIQ have decided in 2012 to set up a separate task group for IQB to improve qualification practice and to provide a consensus view to licensees. The role of TGIQB is to provide a forum for the free exchange of information between qualification bodies and to identify and conduct R&D and harmonisation activities that are targeted at improving the efficiency and effectiveness of approaches for establishing confidence in NDT.

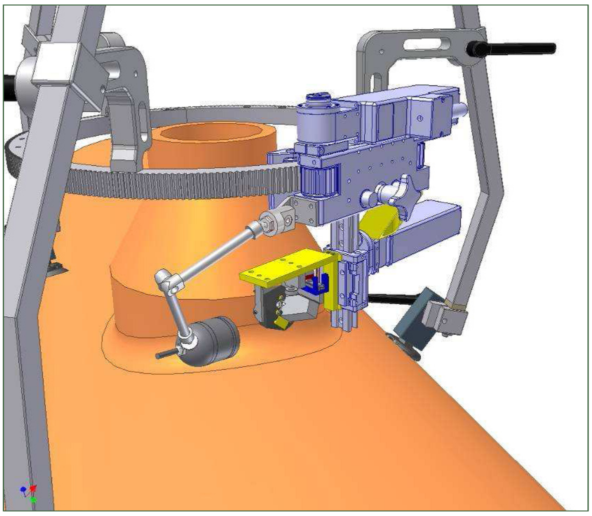


Figure 17: Instruments for inspection of the Boron Injection nozzles (Source: EdF)

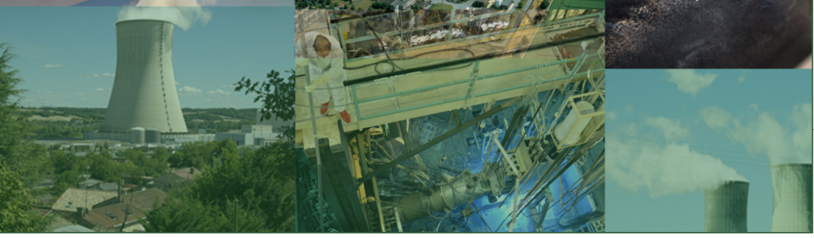
III.8.4. Challenges

III.8.4.1. NDT Qualification

At present, the main challenges for qualification are mutual recognition of qualification approaches between countries and the qualification of new NDT systems such as those based on phased array ultrasonic testing, time of flight diffraction ultrasonic testing and computed radiography. This also includes the qualification of NDT techniques for materials and plant items that have hitherto not been considered in any great depth such as concrete and high density polyethylene. The accuracy and validity of NDT inspection simulation software will continue to be an important area of activity due to its increasing role in NDT design and qualification.

R&D and harmonisation topics:

- **A comprehensive investigation into the performance of computed radiography (CR) aimed to identify the essential parameters that affect the performance of CR thereby providing a consistent approach to inspection design and the production of technical justifications.**
- **Develop a recommended practice for computed radiography qualification and**



Phased Array qualification under ENIQ type Methodologies.

- **An independent assessment of the accuracy of guided waves ultrasonic testing (GWUT) for NDT inspections.**
- **Understand the technical barriers that preclude the transport of qualifications between countries and find methods or procedures on how to overcome these.**
- **Improve the consistency in inspection specifications between countries including format, content type and technical details.**
- **An independent assessment to verify the accuracy of NDT inspection simulation software,**
- **Develop accurate and reliable inspection methods for high-density polyethylene (HDPE) piping.**
- **Develop a process for evaluating the reliability of commercially available inspection techniques and to implement a qualification process for these techniques for concrete components.**

■

III.8.4.2. Risk-Informed In-Service Inspection

The present challenges on the RI-ISI field are RI pre-service inspection (PSI) for new build and RI-ISI for new build in general, the development of probability of detection (PoD) methodologies and risk reduction quantification and optimisation of ISI intervals.

■

R&D topics:

- **Producing specifications for the use of probability of detection (PoD) curves, performance of a pilot study on the application of the Monte-Carlo approach for producing PoD and define the role of quantified PoD in risk reduction.**
- **Analysing the role of RI-ISI for defence in-depth and to assess the achievable level of risk reduction with RI-ISI.**
- **To review RI pre-service inspection (PSI) for new build.**

■

III.8.4.3. Inspection Qualification Bodies

The main challenges for TGIQB are the mutual recognition of qualified inspections and the improvement of inspection qualification practices.

■

Harmonisation topics:

- **Development of a consensus on the design of practical trials and production of test pieces for qualification of ISI procedures and personnel.**
- **Investigate the wider aspects of NDT model validation.**
- **Establish consistent approaches for the re-qualification of NDT personnel.**
- **Provide a consistent approach to the assessment of NDT simulation.**

■

IV. PRIORITISATION OF AREA CHALLENGES ALONG MAIN OBJECTIVES

Prioritisation is an important exercise in the NUGENIA roadmap because:

- All identified projects cannot be launched simultaneously,
- Consistency between the different TAs should be ensured through a global vision,
- Some of the usual financers of the projects (European Commission, Larger industry companies, TSOs) ask for identification of the most important subjects to be supported.

The prioritisation will be regularly updated after taking into account the progress of the R&D.

Using the process described in chapter II.6, 15 objectives appear to be correlated with a higher number of challenges than the others; therefore these objectives can be considered as cross cutting the technical areas. In other words, the technical experts identified challenges that contribute to fulfil the high level objectives, but some objectives could require more research topics to be defined in the future.

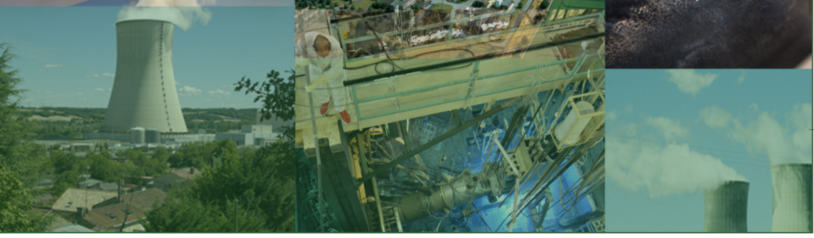
As a consequence, the prioritisation process realised through the correlation of high level objectives with the identified challenges allows drawing several conclusions:

- The existing roadmaps challenges and topics fit globally with the high level objectives,
- Some objectives deserve to be further developed in the roadmaps,
- Cross-cutting objectives can be identified to cover several challenges and might be considered as the main objectives presently covered by the NUGENIA roadmaps.

IV.1. MAIN INITIAL OBJECTIVES

The comparison of high level objectives with sub-area topics shows that, the main priorities covered by the technical experts include:

- Improve safety in operation and by design for existing plant through safety and reliability assessment based on lessons learnt, as well as for new builds through improved diversity of systems and independence of defence in depth levels.
- Assess the performance and ageing of NPPs for long term operation, by investigation the ageing degradation and conditions for long term operation, demonstrating structural integrity of NPP components continuously, and optimising equipment qualification, functionality and maintenance by ageing management.
- Reach the highest reliability and optimised functionality of systems, including I§C, and improve resilience of systems to aggressions, up to strong aggressions, as well as their capacity to mitigate severe accidents, This will only be reached if the boundary conditions for each component are better understood.
- Increase the reliability of components through development of new materials, manufacturing and fabrication processes, better reliability of fuel, and increased safety and reliability predictability as well as control efficiency,-develop better condition monitoring methods.
- Improve modelling of phenomena in NPPs in order to reduce uncertainties in the models and increase their predictability, obtain appropriate validation of the tools,



and develop fast running tools to support real time action.

- Develop coupled computational tools for advanced prediction of phenomena (neutronics-thermalhydraulics, fluid-structure interactions by coupling classical thermal-hydraulic approaches with industrial fluid dynamics calculations, resolve structure issues while using local approaches) and for multi-scale approaches.
- Increase public involvement in the research in order to increase public awareness and contribute to public acceptance.
- Realise an efficient integration of NPPs in the energy mix, in particular considering combinations of different electricity sources that may modify NPP operations and affect the usage factor for materials, and mode of disturbances.
- Prepare the future for avoiding technology obsolescence and in developing innovation, prepare for integration of new technologies in existing plants.

Realising all these technical objectives should favour long term operation of existing NPPs, considering also their permanent upgrading for compensating possible degradations and improving the global safety level.

This initial list of research objectives for NUGENIA community does not prevent identification of new objectives in the future, in particular when the corresponding projects have been performed and exploited.

IV.2. Limitations of the prioritisation exercise and future directions

Doing the prioritisation exercise, the time scale assigned to the challenges and topics in the areas and sub-areas was difficult to maintain because different time scale challenges were contributing to the same objective. As a consequence, it can be understood that those challenges are intended to be realised in the short or in the medium term.

Considering now the completeness of the exercise, and considering that all the objectives have to be achieved up to the same level, NUGENIA intend to monitor the progress towards each of these objectives.

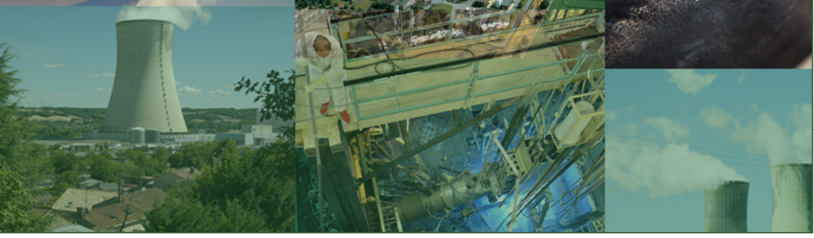
Therefore, to avoid disparity and confusion among the different project proposals, an open knowledge platform will be developed to help establishing a common background and initiating challenging projects of benefit to all members.

In conclusion, in order to improve and confirm the results of the first prioritisation exercise, while meeting the high objectives and challenges of NUGENIA overall program, it appears useful to exchange first more knowledge between members, and second to carry out in depth discussion to improve convergence on common technical priorities, deploy the necessary effort for education, training and dissemination of new knowledge that results from R&D projects.

The Table 1 is the result of the first prioritisation exercise identifying the scientific and technical objectives (second column of the table) needed for the accomplishment of the high level objectives defined by the NUGENIA ExCom, TALs and SALs (first column of the table). The numbers in the third column are relative to the subareas described in detail in the chapter III of this publication, where the objective will be considered for initiating, monitoring and valorizing R&D efforts.

Table 1: Relations between objectives and challenges.

High level objectives	Objectives	Challenges
Improve safety in operation and by design	• Plant safety and reliability assessment based on lessons learn	1.1_1.2_1.3_1.5_3.1_3.2_3.5_3.6_4.1_4.2_4.3_4.4_4.5_4.6_7.2_7.3_7.4_
	• Risk assessment methodologies to support daily operation of NPPs, modifications, evaluate ageing effects	1.1_1.5_4.1_4.3_4.4_4.5_4.6_5.4
	• Safety of new builds: improve diversity of systems and independence of defence in depth levels	1.2_1.5_2.1_2.2_2.3_2.4_2.5_3.4_4.5_6.2_6.3_7.1
	• Implementation of best estimate NDE techniques effectiveness, development and inspection	4.4
	• Improve on line monitoring, data collection and interpretation : uncertainties, procedures, transients	3.3
	• Links to Fukushima task force of SNETP	1.1_1.2_1.3_1.4_1.5_1.6_2.1_2.2_3.3_4.2_4.3
High reliability and optimized functionality of systems	• Take lessons learnt from existing NPPs	2.1_3.1_3.2 4.1_4.3_4.4_4.6
	• Improve systems safety and reliability, including I&C	1.1_1.5_1.6_2.1_2.2_2.3_2.4_3.2_3.6_4.1_4.2_4.3_4.4_4.6_5.2
	• Improve system for mitigation of SA	4.3_6.2_6.3
	• Improve resilience of systems to aggressions, including strong aggressions	1.2_1.6_2.1_2.2_2.3_2.4_2.5_2.6_2.7_4.5
	• Reduce human reliance	1.6_2.1_2.2_2.3_2.4_2.5_2.6_2.7_7.1_7.2
	• Optimization of chemical regime: improve reliability and life time and minimize wastes and radiation doses	3.1_3.4_ 3.5_3.6_4.3
High reliability of components	• Develop new materials and manufacturing and fabrication processes	2.1_2.2_2.3_4.3_6.1_6.2
	• Take lessons learnt from existing NPPs	2.1_4.3_4.6
	• High reliability of fuel	3.4_5.1_5.2_5.3_5.4_7.2
	• Optimisation of waste disposal and immobilisation: reduced volume of waste and relations with IGDTP and ESNII	3.5_5.5_5.6_5.7



High level objectives	Objectives	Challenges
	• Improve safety and components reliability predictability and control efficiency	1.5_1.6_2.1_2.2_2.3_3.3_4.1_4.4_4.6_6.2_6.3_7.3_7.7
	• Improve decommissioning safety and reduce decommissioning cost	4.3_5.5_5.6_5.7
Improve modelling of phenomena in NPPs	• Reduce uncertainties and increase their predictability	1.2_2.1_2.2_2.3_2.4_2.5_2.7_3.4_4.1_4.2_4.3_5.4_7.1
	• Appropriate validation of the tools	1.2_2.1_2.2_2.3_2.4_2.5_2.7_3.4_4.1_4.2_4.3_4.6_5.3
	• Develop fast running tools to support real time action	1.2_2.1_2.2_2.3_2.4_2.5_2.7_3.4_7.2
	• Development of coupled computational tools for advanced prediction of interactions: coupling TH and CFD, structure issues, fill modelling gaps, local approaches	1.2_1.6_2.1_2.2_2.3_2.4_2.5_2.7_4.1_4.2_4.3_6.1_6.2
Increase public awareness	• Apply the Aarhus convention, Increase openness to the public on safety , Increase public involvement in the research, Contribute to public acceptance	2.6_3.1_3.5_4.1_4.3_4.6_6.3_6.4_6.5_7.1_7.2_7.3_7.4
Efficient integration of NPPs in the energy mix	• Usage factor for materials	3.4_4.2_4.3_6.2_6.3_7.2
	• Operating with non stable grid	1.4_4.3_4.4_4.5
	• Disturbance of NPPs operability	4.3_4.4_4.5_5.1_5.2_6.4
	• Power manoeuvrability Innovative LWR design	6.2
Prepare the future to avoid technology obsolescence	• Innovative technology and practices	3.2_4.3_4.6_6.1_7.1_7.2_7.4
	• Knowledge management and development of competences and skills through training and tutoring, succession planning	1.6_4.6_5.2_5.4_6.5
Performance and ageing of NPPs for long term operation	• Assess ageing degradation and conditions for long term operation	1.1_4.1_4.3_4.4
	• Demonstrate structural integrity of NPP components periodically	1.6_1.7_2.3_4.1_4.2_4.3
	• Optimise equipment qualification, functionality and maintenance by ageing management	1.6_2.3_3.3_3.4_3.5_4.4_4.5_4.6

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List of acronyms

Acronym	Definition
BWR	Boiling Water Reactor
CFD	Computational Fluid Dynamics
EIA	Environmental Impact Assessment
ENSREG	European Nuclear Safety Regulators Group
FP	Framework Programme for Research and Development of European Commission
GRS	Gesellschaft für Reaktor Sicherheit
IFE-Halden	Institute For Energy - Halden (Norway)
IRSN	Institut de Radioprotection et de Sûreté Nucléaire
ISTP	International Science Technology Programme
MCCI	Molten-Core-Concrete-Interaction
NEA	Nuclear Energy Agency
NERIS	European Platform on Preparedness for Nuclear and Radiological Emergency Response and Recovery
NOIP	NUGENIA Open Innovation Platform
NPP	Nuclear Power Plant
OECD	Organisation for Economic Cooperation and Development
PSA	Probabilistic Safety Analysis
PWR	Pressurised Water Reactor
RCS	Reactor Cooling System
RPV	Reactor Pressure Vessel
SA	Severe Accidents
SAL	Sub-Area Leader
SAMG	Severe Accident Management Guidelines
SNETP	Sustainable Nuclear Energy Technology Platform
SRIA	Strategic Research and Innovation Agenda (SNETP)
SSC	Systems, Structures and Components
ST-A	Sub-technical area
TAL	Technical Area Leader

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