The European NULIFE research network for plant life management

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Abstract:
The European network of excellence NULIFE (Nuclear plant life prediction) has been launched under the Euratom Framework Programme with a clear focus on integrating safety-oriented research on materials, structures and systems and exploiting the results of this integration through the production of harmonised lifetime assessment methods. NULIFE will help provide a better common understanding of the factors affecting the lifetime of nuclear power plants which, together with associated management methods, will help facilitate safe and economic long term operation of existing nuclear power plants as well as will help in the development of design criteria for future generations. NULIFE was kicked-off in October 2006 and will work over a 5-year period to create a single organization structure, capable of providing harmonised research and development (R&D) at European level. The network consists over 40 partners from leading research institutions, technical support organisations, power companies and manufacturers throughout Europe. The importance of the long term operation of the plants has been recognized at European level, in the strategic research agenda of SNETP (Sustainable Nuclear Energy Technology Platform). In NULIFE, the joint EU-wide coordinated research strategy for plant life integrity management and long term operation has been defined. Discussions of operational model and statutes of the future NULIFE institute have been started. The activity of the NULIFE insitute intends to maintain the sustainability of nuclear power towards 60+ years of safe and economic operation.

1 THE SCOPE AND OBJECTIVE OF NULIFE

The European network of excellence NULIFE (Nuclear plant life prediction) has been launched with a clear focus on the sustainability of nuclear power and on the continued, 60+ years of safe operation of current nuclear power plants. The importance of the long term operation of the plants has been recognized at European level, e.g. in strategic research agenda of SNE TP (Sustainable Nuclear Energy Technology Platform) [1].

Research and development to assess the service life of nuclear power plants is a multidisciplinary enterprise and must therefore take into account many factors. Lifetime assessment requires knowledge not only of the ageing of materials but also of factors such as load effects and reactor water chemistry and the influence of these on plant safety. Research data arising from this work has ultimately to be utilised for the development of safe and economic operation of existing nuclear power plants and the design of new units.

NULIFE's 5-year vision is therefore to create a sustainable NULIFE association with an integrated research and technology development platform embracing all European stakeholders within a completely new structure with improved and efficient use of public and private R&D funding. It will provide the European nuclear power industry and national regulatory authorities with information and methods to assess the service life of nuclear power plant materials and structures, as well as to underpin strategies for upgrades or refurbishment.

In particular, NULIFE will serve to support the harmonisation of lifetime assessment methods and practices for nuclear power plants throughout Europe. Best practices for the prediction of the lifetime of reactors or systems will support strategic management in the decisions on upgrading the plant. The path towards the vision is described in figure 1, proceeding through different phases of integration evolution and finally reaching the NULIFE Institute with a customer-driven programme.

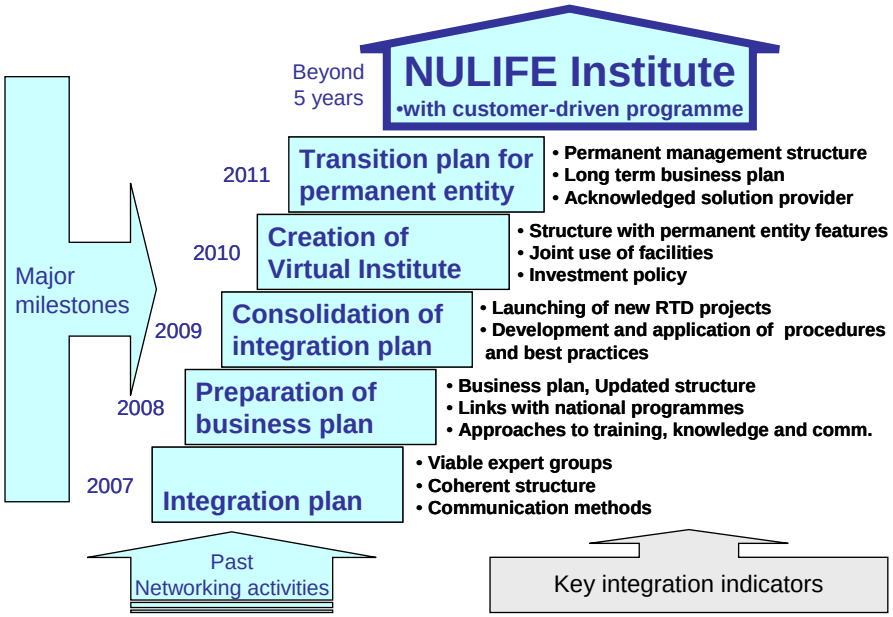

Figure 1. Planned organizational evolution during the five phases of NULIFE (2006-2011).

2 THE UNIQUE CONSORTIUM OF NULIFE

The core of the network comprises eleven leading research institutions, technical support organizations and industrial enterprises from across Europe. Key organizations, contractors of NULIFE are

- VTT, Technical Research Centre of Finland, the Coordinator of NULIFE
- Studiecentrum voor Kernenergie - Centre d'Etude de l'Energie Nucléaire, SCK•CEN from Belgium
- Ustav jaderneho vyzkumu Rez a.s., Nuclear Research Institute Rez plc, NRI from Czech Republic
- Commissariat a L'Energie Atomique, CEA and Electricité de France, EdF from France
- AREVA NP GmbH from Germany
- European Commission Directorate General Joint Research Centre, JRC, from The Netherlands
- British Energy Generation Ltd and Serco Ltd from the UK
- E.ON Kernkraft GmbH from Germany, and
- Forsmark Kraftgrupp AB from Sweden.

The EC (European Commission) funding is specifically targeted at a process of integration between the contributing research institutions and ensuring the long-term sustainability of the network. The contractual arrangement is shown in figure 2. The eleven core organizations (contractors) are signatories to a consortium agreement, which defines the working arrangements and decision-making procedures in NULIFE. They are supported by the contributions of 26 associate contributor organizations from industry and research, which contractually act as third parties under the full responsibility of contractors.

A collaboration agreement mechanism is also applied whereby additional organizations can take part in specific activities on a discretionary basis but without any reimbursement of costs.

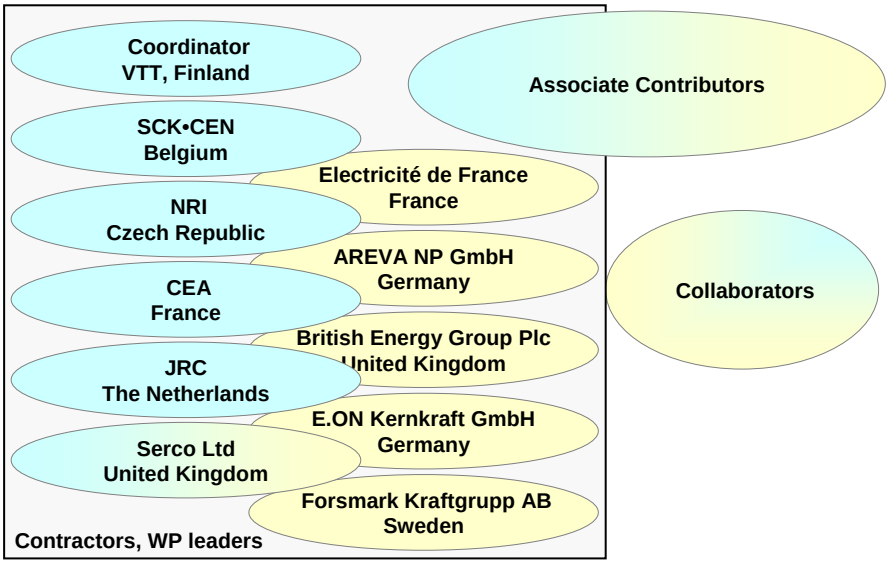

Figure 2. The unique contractual structure of NULIFE consortium with third parties, so called associate contributors and collaborators.

The NULIFE network meeting is organised yearly and the fifth meeting gathered 80 NULIFE members in Les Renardières for three busy days in September 2009. The NULIFE Bulletin related to the 2008 Madrid event is available on the public NULIFE website [2]. The next NULIFE network meeting will be in September 2010 in Stockholm.

3 ORGANIZATION AND WORKING METHODS OF NULIFE

3.1 Organization

The main organizational elements of NULIFE are shown in figure 3 and described in the following:

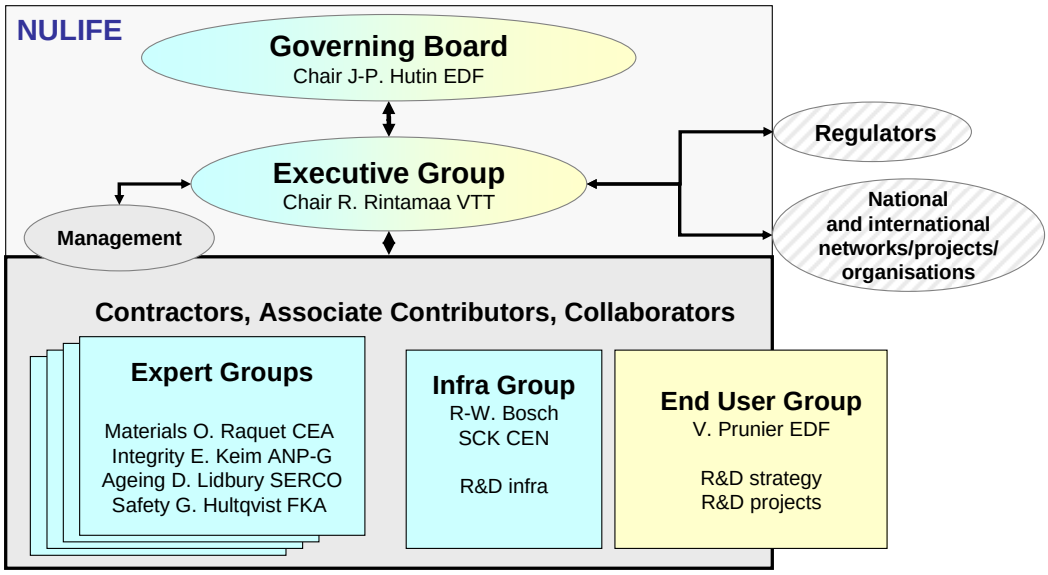

Figure 3. The main organizational groups and decision-making bodies in NULIFE.

- **Governing Board** is the ultimate decision-making body of the consortium and consists of one nominated representative of each contractor. Nominated representatives of the associate contributors also have the right to participate to the Governing Board meetings as observers.
- **Executive Group** is responsible for the execution of the agreed work programme and comprises nominated representatives of the contractor and work package (WP) leader organizations.
- **Infrastructure Group** develops common platforms for experimental testing and investigations, for simulation and analyses, for data management, documentation and software tools.
- **Expert Groups (EG)** provide a mechanism for coordinating and integrate the available expertise of the researchers nominated by each of the participating organizations, for supporting the research projects and for developing advanced technical methods; the EGs may have sub-groups dedicated to specific technical areas.
- **End User Group (EUG)** is composed of representatives of participating utilities, other end-users and manufacturing industry; its role is to give advise on concerning research directions and to select and propose the research priorities together with the NULIFE Executive Group.

3.2 Working methods

The joint programme of activities includes integrating activities (IA), joint research and development activities (RA), spreading excellence activities (SA) and management activities (MA). Specific work packages (WPs) are clustered in three main working areas: strategy, R&D projects and resources(figure 4). All these together aim at advanced PLIM (plant life management) methodologies and are supported by specific WPs for harmonisation and links to ETSON (European technical safety organisations network) and regulators.

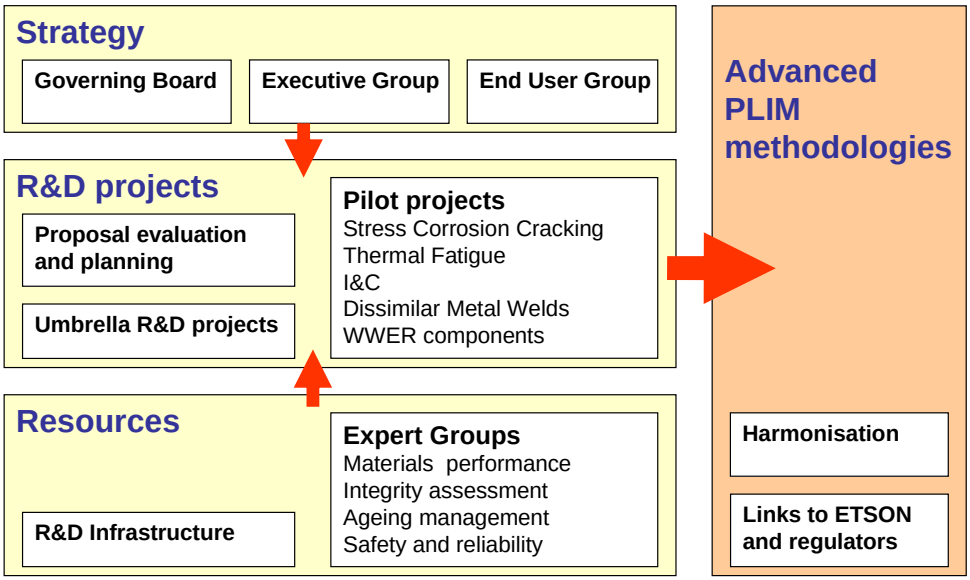

Figure 4. Joint programme of activities and work flow in NULIFE.

3.3 Expert group activities

NULIFE brings together a broad range of scientific and technical competences, facilities, tools, data, operating experience and organizational skills which are integrated into the network structure and work programme. The NULIFE questionnaire for mapping expertise

was launched in the first year. Research organizations and service providers were asked to define the current expertise, and end users and vendors are asked to define strategic needs. This covered different reactor types, experimental conditions, system and component types (like Instrumentation&Control systems, containment, reactor pressure vessel, piping, steam generators, reactor internals, active components such as valves, pumps) as well as material types (like metallic materials, concrete, cable materials, plastics, composites). Life management expertise was broken down into areas such as degradation modes (like microstructural ageing, corrosion modes, fatigue modes and embrittlement modes), load effects, condition monitoring, inspection, integrity assessment and safety management. Testing facilities, organization/process related expertise, dissemination skills as well as design, manufacturing, operation expertise were also all being considered. As a result of this, complementary and overlapping resources were identified, together with 'gaps' that have to be addressed in the expert groups.

Overall the results of the questionnaire confirmed that NULIFE R&D resources are versatile and high quality (according to self-assessment). In addition to the wide range of technical expertise available, these are widely spread at geographical and organisational level. One clear expertise gap was related to facilities for simulated operation conditions and for field testing conditions. Further expertise gaps were connected to I&C systems, concrete, cable materials and plastics. There were major expertise overlaps connected to general corrosion, erosion-corrosion, fatigue, corrosion fatigue and hydrogen embrittlement. It was suggested that specific work packages should follow-up on the specific issues identified in the mapping exercise i.e. the expert groups for expertise levels; End-User Group for needs, Infra Group concerning facilities for plant condition simulations etc.
The coordination of the network's combined expertise is managed principally via a system of expert groups covering the following generic technical areas:

- **Materials performance expert group (EG1)** deals with the material property issues, in particular the mechanisms of materials degradation (environment assisted cracking, thermal ageing, irradiation embrittlement) and characterization of the properties of aged materials, i.e. as a function of in-service conditions.
- **Integrity assessment expert group (EG2)** is concerned with establishing state-of-the-art in methods and tools for of assessing potential damage or failure modes. It deals not only with fracture mechanics methods, but includes also a consideration of existing codes and procedures, non-destructive examination, safety factors and certain special topics (effects of load history, crack arrest, secondary and residual stresses, WPS (warm prestressing).
- In **Ageing management expert group (EG3),** the knowledge gaps identified by the other expert groups will be assessed in terms of their implications for through-life structural integrity. In addition, an assessment will be made of the potential for, and possible implications of, knowledge gaps outside the scope of the other expert groups. Lifetime Expert Group will take a long-term perspective of component integrity, in particular the safety justification of components over the whole of their foreseen operational life, where the demonstration of safety margins becomes dominated by considerations of fatigue (including thermal fatigue and corrosion fatigue), irradiation embrittlement and other ageing processes (including creep and creep-fatigue).
- **Safety and reliability expert group (EG4)** will add to other EGs to support the network by providing advice on identification, characterisation and management of uncertainties in lifetime evaluation, through modelling structural reliability and performing risk assessments to provide added insights into the assessment of safety margins.

All four EGs have provided state of the art -type reports for the basis of work in the projects (all reports are at the moment for NULIFE internal circulation only)

- EG1 Materials: Priority R&D and harmonisation areas and Guideline for the development of high quality stress corrosion crack growth data

- EG2&3 Integrity and Ageing: Structural integrity assessment and lifetime tools and procedures
- EG4 Safety: Reactor safety and risk assessment practices.

4 RESEARCH AND DEVELOPMENT PLANNING

Effective developing of R&D projects to meet stakeholder needs is essential to NULIFE's strategy. The simplified outline of the project creation process is shown in figure 5. The network work programme has a dedicated work package (RA-1 Proposal evaluation and planning) that is tasked to

- set up and implement a systematic and clear process for identifying necessary research topics for NULIFE (e.g. yearly call for proposals)
- define the necessary work programmes
- make recommendations to the Executive Group for implementation.

The process underlines key role of the End User Group in setting priorities. Theme-specific ad hoc groups are created for project optimisation. The ad hoc groups consists of members from both utilities (and vendors) and research organisations.

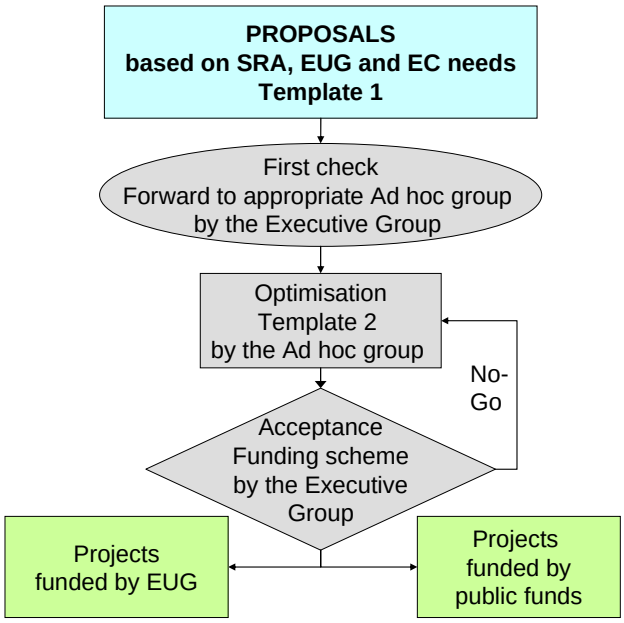

Figure 5. Simplified outline of development, evaluation and approval of R&D and harmonization projects

By providing research excellence and fostering common approaches in nuclear power plant lifetime prediction, NULIFE will contribute to the electric power utilities' decision making in terms of plant operation and investments. Safety authorities will also benefit from the knowledge in their duties to grant plant licenses for the continued operation of plants.

The ability of the network to deliver procedures and best practices documents on ageing issues will be an important measure of the network's impact. At the highest level, NULIFE will support the development of a European common safety justification framework. Since lifetime management tools are only one element in such a framework, its development will require support from other stakeholders than R&D organisations. The broad composition of the network is a major advantage in this respect.

NULIFE will also benefit from other European and national activities, collected and communicated widely in R&D forums. E.g. in Finland nuclear plant life prediction research is carried out in national nuclear safety programmes, today in SAFIR2010 programme, aiming at training of new scientists and linking international co-operation with the Finnish research as well [3]. SAFIR2010 programme is a Finnish national tool to meet national challenges but benefiting and contributing to European activities. The national programmes and networks are vital for the success of the EU network NULIFE.

5 RESEARCH PROJECT PORTFOLIO

In the scope of NULIFE, new joint projects are being identified and prioritized to meet future trends and needs. The original two NULIFE research projects were started in order to test the NULIFE structure in creating and implementing pilot projects. The consequent two pilot projects are feasibility studies for the possible independent research projects, so-called umbrella projects. Several other project ideas, via RA-1 Proposal evaluation and planning, are developed to umbrella projects.

5.1 NULIFE pilot projects

In the planning phase of NULIFE, the interest shown by the End User Group for stress corrosion cracking and thermal fatigue lead to these topics being chosen as the two pilot R&D projects. Stress corrosion cracking (SCC) pilot project is complete [4]. SCC is defined as the cracking of a material produced by the combined action of corrosion and tensile stresses (residual or applied). It can cause loss of integrity of a component without clear visual damage as the cracks are usually very small. SCC is caused by certain material, environment and stress combinations, many of which are well known. SCC of nickel-based alloys like inconel 600 (used for steam generators) and alloy 182 (used as weld metal to connect stainless steel piping to the carbon steel reactor pressure vessel) is a concern. Therefore, a pilot study on SCC of Ni-based alloys was organized in the framework of the NULIFE project. The focus of this pilot project was to

- define a good practice for the development of high quality stress corrosion crack growth data
- review the data on SCC propagation in alloy 600 and 182, according to the proposed practice for testing
- assess the disposition curves (= crack growth rate as a function of stress intensity factor K).

The SCC pilot project resulted in the following conclusions and recommendations:

- A number of reliable disposition curves for inconel 600 and alloy 182 are already available and so it is not necessary to define other disposition curves. In addition the data provided by the partners was plotted together with these curves for comparison. Generally there was good agreement with the provided data and the existing disposition curves.
- In all disposition curves, there is a lack of *crack growth rate data with low K values*. Major reason for this is the long test time and so the tests are expensive. These data is however, valuable and it seems a good topic for a joint project as data sharing in this case is essential.
- The crack growth rates of Ni-based alloys are quite high. Therefore the life time of a component is mainly determined by the time to crack initiation i.e. the moment a crack is formed means end of life. Therefore *crack initiation* is a relevant topic to work on.

Thermal fatigue (TF) pilot project is concluding its work and several reports are in progress

- Synthesis of the available mock-up tests devoted to thermal fatigue analysis
- Recommendations for high cycle fatigue tests of austenitic stainless steels.
- Status on the knowledge on cracks under loadings from a thermal spectrum

- Summary of available tests and computational capabilities for thermo hydraulic load determination.

Planning the second year two additional pilot projects were identified:

- Instrumentation & Control, I&C (on-going)
  - Databases (I&C-failures and tools to be used for degradation mechanism) developed within MAGIC (EU funded project) shall be taken over by NULIFE as well as the work performed to develop courses on I&C-management
- Dissimilar metal welds, DMW (on-going)
  - Provide NULIFE recommendations on good practice approach for assessment of DMWs, as part of an overall LBB (leak before break) procedure.

Planning the third year one new pilot project was identified:

- Unified procedure for WWER(russian design water/water reactor) components, VERLIFE (on-going).

5.2 NULIFE umbrella projects

The current NULIFE umbrella projects are

- PERFORM60: Prediction of effects of irradiation for RPV (reactor pressure vessel)
  - To predict the effects of radiation for reactor pressure vessel and in-core materials using multi-scale modelling – 60 years foreseen plant lifetime
- STYLE: Structural integrity assessment of reactor coolant systems, piping and components (non-RPV) (proposed to the EU FP7 call in April 2009)
  - To identify realistic failure modes relevant to the ageing and lifetime management of pressure boundary/pressure circuit components in LWR (light water reactor) and WWER systems as well as gas-cooled reactors -
- LONGLIFE: Treatment of long term irradiation embrittlement effects in RPV safety assessments (proposed to the EU FP7 call in April 2009)
  - Summary of boundary conditions for long term operation of 80 years (fluences, plant specifics, materials, core configurations, …)
  - Systematic (re)evaluation of prediction tools for irradiation embrittlement in context to safety assessment for long operation times
- NESC VII: A European project for application of WPS in RPV assessment including biaxial loading

The umbrella projects under planning are

- CFD Validation: Benchmark for CFD validation focused on the heat transfer from the fluid to the wall end
- CABINET: Constraint and biaxial loading effects and their interaction considering thermal transients
- ACCEPT: Aging of concrete and civil structures in nuclear power plants

The project ideas are related to the I&C components, multi-metal components, safety issues, annealing of reactor pressure vessel and crack initiation.

6 STRATEGIC RESEARCH PLANNING

The preparation of the long term strategy and business plan was started very early in NULIFE. The current business plan includes the creation of an international association type NULIFE institute according to the vision of NULIFE. The expected benefits of NULIFE Institute are to

- trigger innovation and promote new ideas

- support the launching of new R&D projects
- implement support to all PLIM related issues.
- find and link funding partners and find R&D capabilities from the NULIFE competence pool
- support project agreement and management
- support integration and harmonisation.

Strategic research planning was started together with business plan and has been strongly related to the preparation of the Strategic Research Agenda (SRA) of the Sustainable Nuclear Energy Technology Platform (SNE-TP). NULIFE members participate in the SNE-TP Strategic Research Agenda Group (Chair of subgroup Gen2/Gen3, EdF, Valery Prunier), Executive Committee (Chair, VTT, Rauno Rintamaa), Deployment Strategy Group (EdF, Olivier Marchand), Governing Board (several NULIFE organisations).

The SNE-TP SRA defines the strategic targets in long term operation (LTO), performance improvement and external factors. In the long term operation area, safety justification, ageing mechanisms of systems-structures-components, ageing monitoring and prevention and mitigation of ageing are important subjects. In addition some generic cross-cutting focus areas like structural materials, prenormative research, codes and standards, modelling, simulation and methods are considered. The near future action will be the preparation of road maps and specific short, medium and long term research topics for each strategic focus areas identified in the SRA.

It is seen that nuclear energy's contribution, as part of an overall energy mix, is securing the energy supply and combating climate change. NULIFE is a key instrument in implementing PLIM related topics of the SNE-TP and other EU wide strategies. NULIFE is focusing on the sustainability of nuclear power by providing safety-oriented research and the continued, 60+ years of safe operation of nuclear power plants. The recognition of NULIFE's position in EU wide strategy implementation will assist the establishment of the NULIFE Institute and providing the sustainable LTO and PLIM related research and harmonised procedures.

In order to reach even wider harmonisation, NULIFE members have also actively participated in the international collaboration between Euratom and Rosatom, with IAEA (International Atomic Energy Agency) and OECD/NEA (Organisation for Economic Cooperation and Development/Nuclear Energy Agency. Also collaboration with Chinese CAEA (China Atomic Energy Agency) is foreseen.

7 CONCLUSIONS

The European network of excellence NULIFE (Nuclear plant life prediction) has been launched with a clear focus on integrating safety-oriented research on materials, structures and systems and exploiting the results of this integration through the production of harmonised lifetime assessment methods.

NULIFE is foreseen as evolving in 5 phases. The third phase, which has now been completed, was the consolidation of integration plan. The NULIFE consortium was strengthened and is now composed of the 11 contractor organisations, all key players in R&D in the area of plant life management. They represent seven nuclear countries in Europe and include utility, vendor, TSO (technical safety) and research organisations. The consortium is supported by contributions of over 30 organisations from industry and research, acting as third parties.

It is foreseen that the NULIFE goal to create a sustainable NULIFE institute will be achieved during the fourth year. NULIFE intends to be a key instrument in implementing the strategic research agenda (SRA) and the deployment strategy (DS) of the sustainable nuclear energy

technology platform (SNE TP) in PLIM related R&D topics. NULIFE improves the delivery of best-practice life assessment methods to end-users to support optimized ageing management programmes for existing nuclear power plants and also for new builds.

A firm and active link between research organisation and end users as well as to regulators is created. NULIFE intends to use of public and private R&D funding in an optimized way to launch new projects. Funding sources for optimised project proposals are sought actively. NULIFE will also benefit from other European and international activities, collected and communicated widely in R&D forums. Synergy with international organisations and third countries is seen important and kept up.

ACKNOWLEDGEMENTS

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