Nuclear Power Plant Life Management - Challenges and Proposal for a Unified Model Integrating Safety and Economics

Paolo Contri[a], Bernhard Elsing[a]

European Commission
JRC-Institute for Energy, Safety of Purrent Nuclear Reactors Unit
PO Box 2, 1755 ZG Petten, The Netherlands
Bernhard.Elsing@ec.europa.eu[1]

Abstract. In recent years many electric utilities and nuclear power plants adopted policies for improved coordination of both safety and non-safety programs, called plant life management (PLIM), also in view on plant life extension programs, but mainly for an optimisation of operating costs. The implementation of PLIM programs has followed many different approaches, being intrinsically dependent on the national regulatory framework and technical traditions. In Countries with some experience, the PLIM program proved very convenient, especially when coupled with Maintenance, Surveillance an Inspection (MS&I) optimization: average savings are reported in the range of 20-30% of total (maintenance) costs. A unified European model for PLIM was developed at the JRC-Institute for Energy with the support of a network of stakeholders (SENUF), and validated at some EU nuclear plants. This paper provides a summary of the model features, the result of its validation at some plants and summarises the perceived scientific/technological challenges on which JRC proposes to focus, based upon its competencies and skills, having in mind both the European and world-wide context and its potential evolution.

Keywords: nuclear plants, operation, plant life management, maintenance.

1. INTRODUCTION

The current social and economic framework for the energy production is characterised by the following trends:

- The open electricity market, which is going to be a reality in most of the European Countries in few years. Such economical and financial framework demands for significant reduction of the generation costs, very strict investment planning, outsourcing, controlled reliability of the equipment and components (incl. obsolescensce) and therefore for reliable indicators of the effectiveness of the maintenance programmes
- The generic trend towards the extension of the operating life of the existing plants. Such life extension requires a detailed review of the original design assumptions, also reflected into current maintenance practice, and the continuous monitoring of the component reliability (performance goals) in order to support a suitable trend of the safety evaluation beyond the design life.

As a consequence, in last years many electric utilities and nuclear power plants adopted policies for improved coordination of both safety and non-safety programs, called plant life management (PLIM). Its implementation has followed many different approaches, being intrinsically dependent on the national regulatory framework and technical traditions. The Long Term Operation (LTO) process poses further challenges, particularly in view of the nuclear safety implications as well as the economic strategic and political ones. Therefore in recent years the need for tailoring available safety assessment tools to such needs has become very urgent. However, such adaptation often proved very complex due to the long time perspective of the PLIM (typically 30-40 years), as compaerd to the

[1] The views expressed in this paper are those of the author and do not necessarily reflect those of the EC

typical time framework where the available methods are currently employed (~10 years of the standard periodicity of the Periodic Safety Review process).

In Countries with some experience, the PLIM program proved very convenient, especially when coupled with Maintenance, Surveillance an Inspection (MS&I) optimization: average savings are reported in the range of 20-30% of total (maintenance) costs.

Moreover, in terms of safety, the control of equipment reliability, significantly improved with PLIM models for example through Ageing Management Program (AMP) and Reliability Centred Maintenance (RCM), made a long term asset management of the overall plant possible and the overall safety indicators significantly improved in many cases.

This is why R&D tasks are needed in this phase, not only in the long term extrapolation of the component integrity and behaviour, but also in new management strategies at the plant (PLIM), able to address organisational issues, spare part management, staff ageing, component obsolescence, etc, which are typical components of the PLIM (see for example [1])

The Framework Programme 7 of the EU (FP7 – European Council decision 18/6/2006, [2], in the area dedicated to the reactor systems calls for a research effort "to underpin the continued safe operation of all relevant types of existing reactor systems (including fuel cycle facilities), taking into account new challenges such as life-time extension and development of new advanced safety assessment methodologies (both the technical and human element)".

Consequently, the JRC Multi Annual Work Program (MAWP), in the Nuclear Safety "agenda" under the Euratom Program, developed two main tasks addressing the safety of nuclear installations and the nuclear fuel safety, respectively. The former is addressed in the following, being relevant to this context.

This paper provides a short summary of selected results obtained at the JRC under the 7th Framework programme (2007-2010) and summarises the perceived scientific/technological challenges on which JRC proposes to focus, based upon its competencies and skills, having in mind both the European and world-wide context and its potential evolution.

2. A UNIFIED PROPOSAL FOR A PLIM MODEL INTEGRATING MAINTENANCE OPTIMIZATION

Previous publications highlighted the main issues behind the development of a PLIM model, its main features and the experience of few European and non-European Countries in this effort (see for example [3]-[6]).

As a consequence, JRC-IE developed a preliminary version of a new PLIM model that is believed to significantly improve the performance of the European plants. A first draft of this model is available at [1].

The model was subsequently validated at one European plant that is believed to have one of the most advanced PLIM model in place. As a result of the validation carried out at Loviisa NPP, a new model was developed and is shortly described in the following.

2.1. PLIM objectives

PLIM can be defined as a program (or even a combination of programs and procedures) aiming at a safe and cost-effective operation of a nuclear power plant in the longest possible time period.
In this sense, it represents a framework for optimised, day-to-day, decision making aiming at a plant long-term operation with optimal utilization of resources (see for example [7])

In other words, PLIM objective is the development of a consistent framework program at the plant which enables the plant

- to produce electricity in a safe and responsible way by continuously improving the power plant operation and safety
- to secure an efficient generation portfolio

This objective is typically achieved with coordination of some key programs at the plant, such as: operation, asset management, maintenance surveillance and inspection (MS&I), ageing management, knowledge management, and nuclear safety.

2.2. Approach to PLIM

In order to achieve the goals set up in the previous chapter, the PLIM program has to consider the following main components:

- Nuclear safety and licensing
- Production and economy (including fuel and waste management)
- Human resources

The long term investment plan is the basic tool for managing the investment portfolio where all the technical programs provide input.
The generic PLIM structure is the result of the integration of selected existing programs at the plant and the development of suitable links and feedback loops.
In particular the following programs are directly coordinated by PLIM:

- Maintenance, surveillance and inspection (MS&I), including control of human factors
- Ageing management, component obsolescence and plant configuration control
- Knowledge management
- Asset management and investment planning

Plant modernization, power upgrading, fuel management may also be part of PLIM, but they are not necessarily implemented at all plants.

This concept is described in Fig.1, where the four main components of PLIM are highlighted in the central program, the input and the output are in the vertical lines and other programs are listed in the lateral boxes.

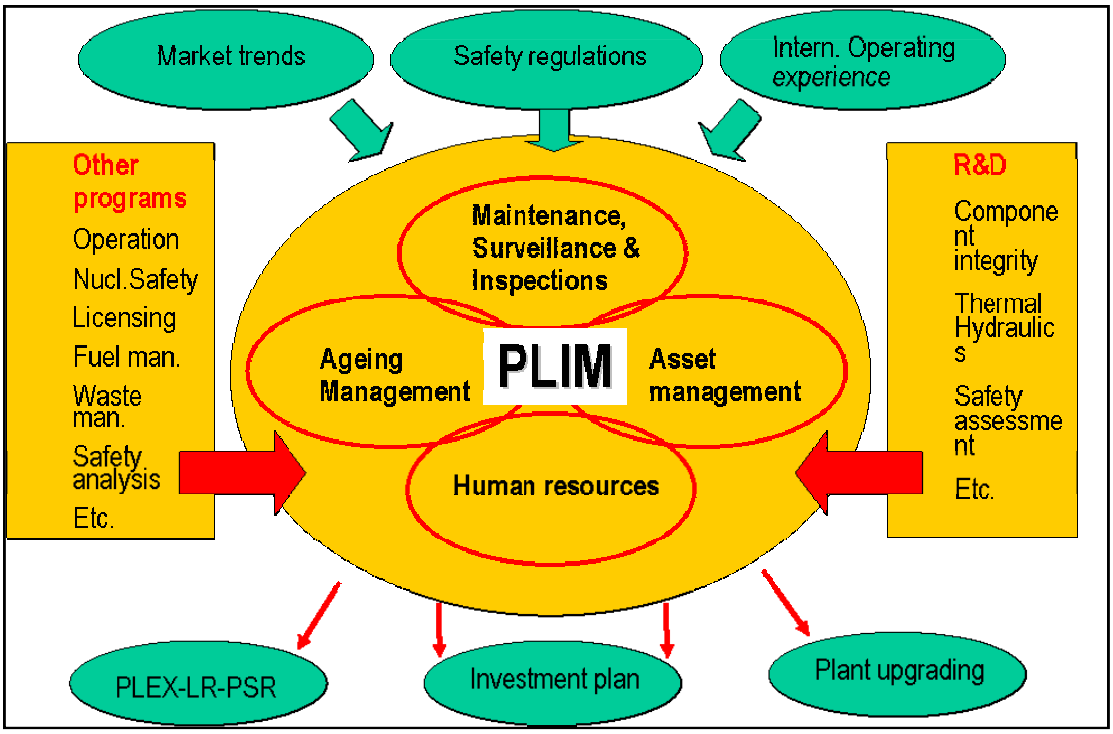

Fig. 1. Approach to PLIM and interfaces with related programs

These programs should also meet specific pre-conditions on their main features, as discussed above and summarised in Figure2.

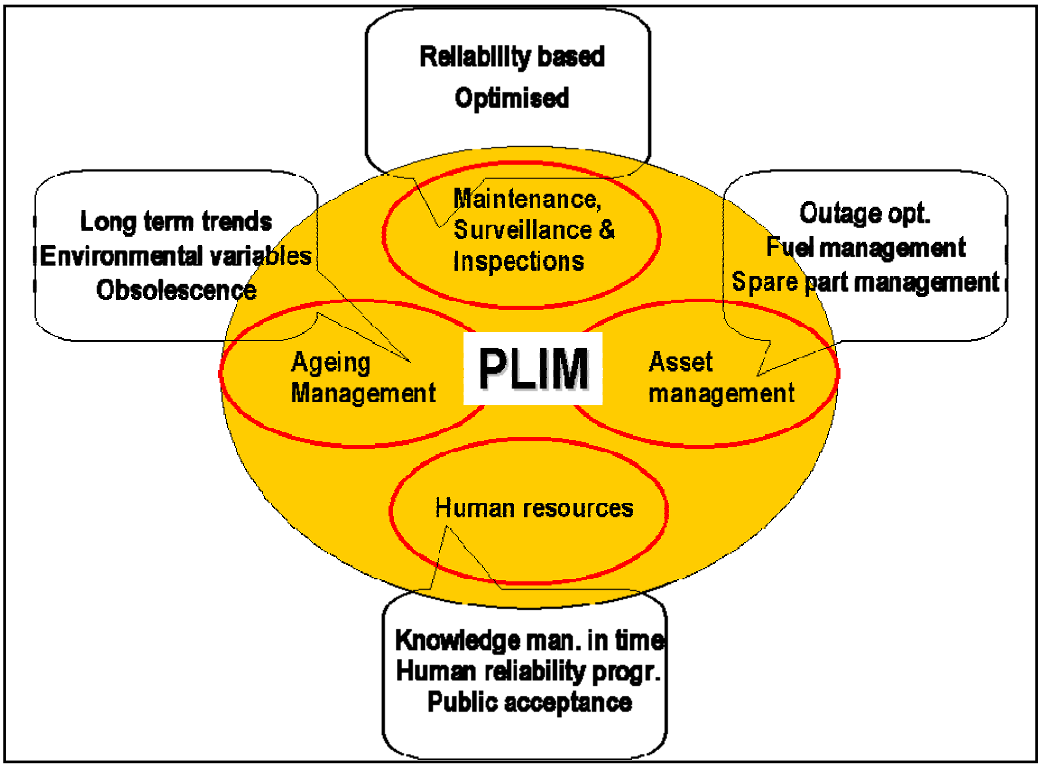

Fig. 2. Preconditions for the key programs to be part of PLIM

Other programs represent a generic background for PLIM, and exchange data with PLIM, but they are not explicitly part of it, such as: operation, nuclear safety, fuel management, waste management, licensing (including the continuous updating of the Safety Analysis Report), engineering, etc.
At last, important programs may be based upon PLIM, but they are not part of it, such as: plant life extension, license renewal, periodic safety review, plant upgrading (including power uprating), public acceptance, etc.

From the technical standpoint, the approach to plant life management consists of:

- Identification of critical systems, structures and components (SSCs) from the standpoint of the plant operation and safety
- Classification of the identified SSCs
- Identification of loadings and ageing mechanisms
- Development of method for the lifetime prediction
- Identification and implementation of applicable ageing countermeasures
- Feedback to MS&I programs and other relevant programs
- Development of the investment planning

2.3. PLIM Scope - Component classification

The scoping of the PLIM program is still an issue under debate, also because of the heavy implications with the existing engineering and safety traditions at the plants. The proposed model is compatible with any of the scoping models presented below, taken from Countries/Plant with deep experience in PLIM.

3. APPLICATION CASES

3.1. The Finnish model (VVER)

According to the experience at the Loviisa plant (see [1], [8]), all structures, systems and components at the plant, regardless of their safety relevance, should be covered by such classification. A suitable grading of measures may be applied and therefore different levels of MS&I and AMP, economic analysis etc. may be assigned.

The model (see Fig.3 from [1]) groups different classes as in the following:

- Class A: critical components and structures directly limiting the plant life with their availability/integrity, non replaceable. Example: reactor pressure vessel, steam generator, pressurizer, main coolant pump, containment structures. Example of MS&I strategy: full scope monitoring and analysis of the degradation;
- Class B: critical components, systems and structures from the standpoint of their importance to safety and their cost of replacement/reparation. Examples: primary circuit, high and low pressure safety injection systems, feed water system, condensers, turbine, generators, Diesels. Example of MS&I strategy: condition based MS&I;
- Class C: sensitive components, systems and structures. Examples: nuclear intermediate cooling, sprinkler, drainage and vents, main steam line, residual heat removal, circulating and service water systems, condenser cooling system. Example of MS&I strategy: preventive (time-based) MS&I;
- Class D: other components and structures. Example: condenser purification system, auxiliary boiler plant, drinking water supply, sewerage. Example of MS&I strategy: run-to-failure.

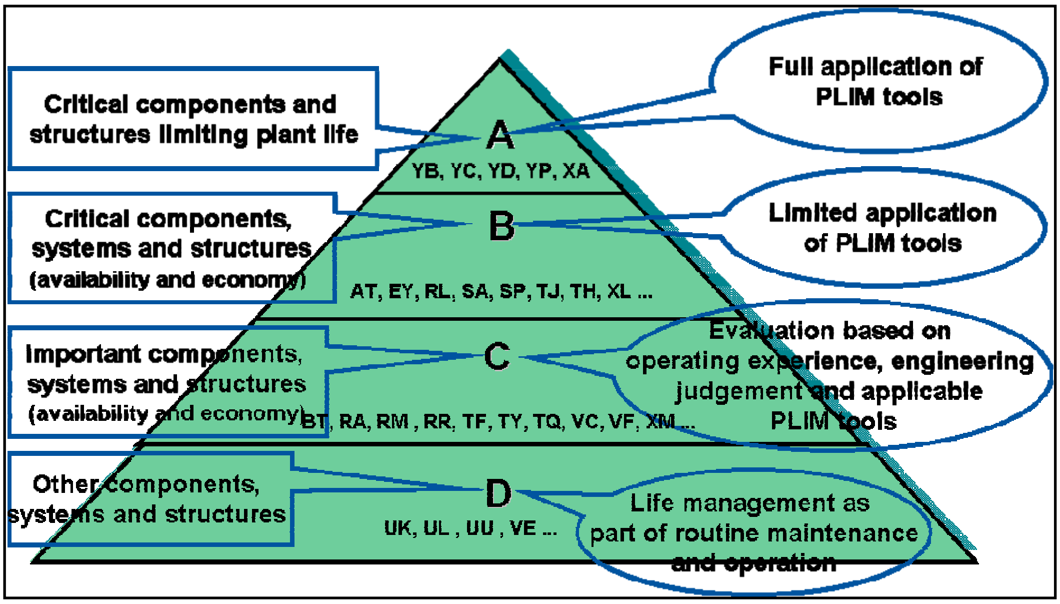

Fig. 3. Proposal for PLIM oriented component classification

It is noted that such approach is still quite heterogeneous, as it mixes up components, systems and special equipment. Therefore the proposed classification may be reviewed to provide a more homogeneous approach that would make the interfaces with the maintenance classification or spare part classification much easier and traceable, because more homogeneous.

For components in classes A,B,C, a sort of component "health certificate" is recommended for continuous review and upgrading by the system engineers. The certificate should make reference to the design basis and should collect the results from the AMP, the operation ad the ISI programs, including the pending issues detected by previous tasks.

3.2. The Spanish model

The Spanish approach to PLIM follows closely the US regulation, as stated in the US 10CFR54 Code. In its compulsory part ageing management is applied to both active and passive components; however it is the Component Reliability program (see [9]) that addresses Maintenance, ISI and Ageing evaluation under a single integrated program (see Fig.4).

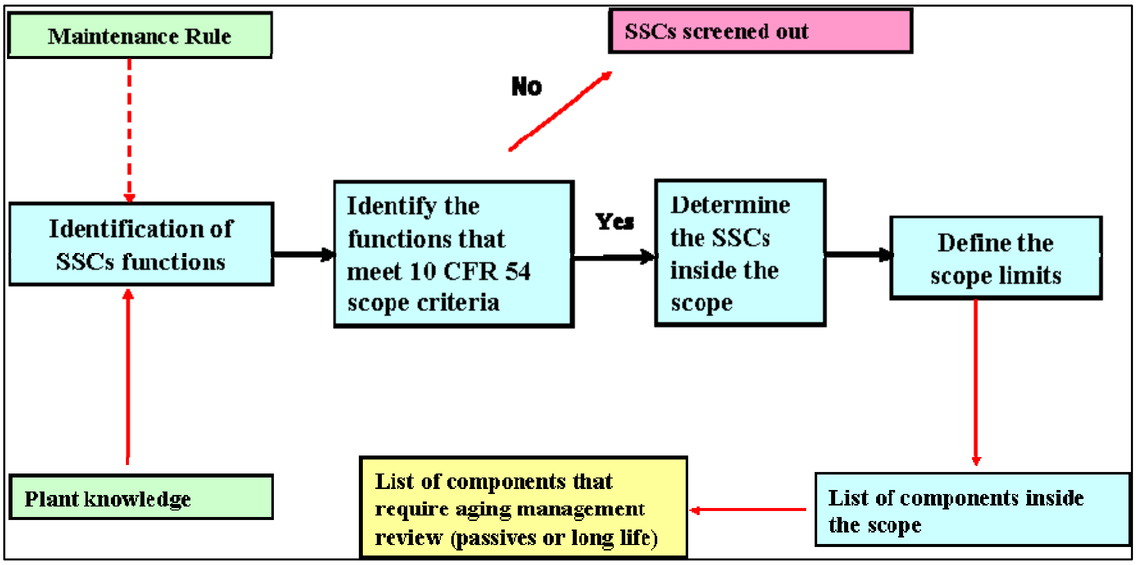

Fig. 4. Summary of the Spanish approach to PLIM and to component screening.

3.3. The Romanian model (CANDU Plant)

The Romanian model is discussed in the following and it represents a consistent application of a generic approach to a CANDU type plant (see [8]).

The AMP scoping process goes through a systematic application of a number of criteria, as summarized in Fig. 5.

Level 1 of application of PLIM – Life limiting SSCs, those SSC for which:

- it must be assured their integrity and functional capabilities during operating life and while in shutdown states;
- there is no replacement possibility;
- it's estimated a total control over plant life;
- Life Assessment analyses, or a Life Cycle Management plan must be realized.

Level 2 of application of PLIM – Critical SSCs, those SSC for which:

- it must be assured their integrity and functional capabilities during the operating life and while in shutdown states;
- it is extremely difficult to replace them;
- there are estimated high costs, long terms operation in shutdown state, radiation exposure significant risk;
- Life Assessment analyses or Systematic Assessment of Maintenance studies must be realized.

Level 3 of application of PLIM – Important SSCs, those SSCs for which

- there is the possibility of their replacement in an orderly manner;
- the programs of preventive maintenance, in-service inspection and components status/surveillance evaluation are applicable;
- it must be realized Systematic Assessment of Maintenance (for structures and components) and a Life Cycle Management program (for systems), both used in plant condition evaluation.

Level 4 of application of PLIM – Not important SSCs, those SSCs for which

- could represent a residual risk for Ageing Management Review analyses;
- have support functions for safety related SSC;
- can be periodically replaced without difficulty;
- are subjected to the preventive maintenance, in-service inspection and assessment/surveillance programs prescriptions for components

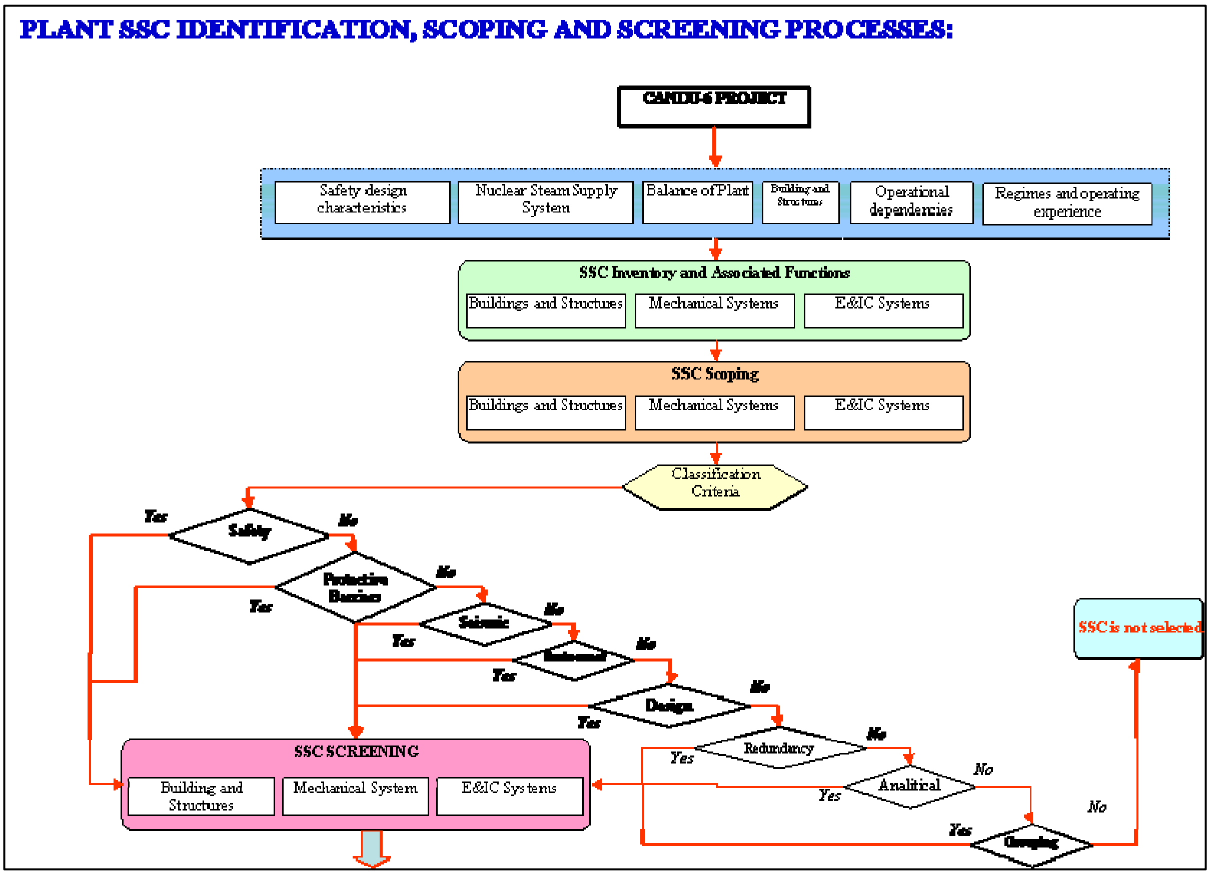

Fig. 5. Summary of the procedure developed at Cernavoda NPP for PLIM and for component screening.

In particular the screening process relies on the following criteria:
The full-scope application of PLIM in view of the PLEX program envisages the eEvaluation of the Actual plant condition, including:

- Technical aspects overview and tasks schedules of PLEX project.
- Existing environmental operating conditions.
- Details on environment components affected by wastes and toxic and dangerous materials.
- Time limited ageing analyses (TLAA) descriptions required for degradation evaluation:
- TLAA analyses (pressurizer, reactor inlet header, pressure tube and calandria vessel)
- Industrial experience
- Methods and models of probabilistic assessment (PSA, PRA)
- Nuclear specific civil-work experience
- Plant condition assessment after 30 years of operation: Buildings and Structures, Reactor and Mechanical systems, Electrical and I&C systems.

4. CONCLUSION

The European Commission, especially in the framework of the EURATOM programme, identified specific R&D priorities to be mainly addressed by "direct actions" managed by the Joint Research Centre (JRC) in the field of the Plant Life Management of its nuclear facilities. The best chance for implementation is given by the Framework Programme 7 (FP7), where large coverage is given also to the nuclear safety issues. The activities under the current 7th FP (2007-2011) combine continued effort in the area of component structural integrity with several new initiatives in the areas of maintenance optimisation and risk-informed approaches.

The paper provides an analysis of the research actions already in progress at the European Commission-Joint Research Centre (EC-JRC) in the specific field of maintenance optimisation, through the most recent results of the research on a unified PLIM model in the EU, and intends to provide a basis for a review of the research priorities.

From the preliminary results, a confirmation can be drawn on the unique capability of the EC for coordinating European R&D in support of harmonised best practices for plant life management. The continuous support of the EC managed SENUF (Safety of European Nuclear Facilities) network participants (increased in some cases of 50% in the year 2007) show that the selected activities do reflect the priorities of the stakeholders, in particular plant operators and national safety authorities, coherent with the JRCs mandate under the Euratom framework programmes.

REFERENCES

[1] JRC (2008), EUR 23232 EN, "A plant life management model including optimized MS&I programme –Safety and economic issues", JRC EUR report, January 2008.

[2] EU (2007), Work Programme 2007, EURATOM for Nuclear Research and Training Activities, European Commission C(2007) 564 of 26.02.07.

[3] M.Bièth et al. (2007), “Plant Life Management Models with special emphasis to the Integration of safety with non-safety related programs”, PLiM, Shanghai 15-18/10/2007.

[4] P.Contri et al. (2007a), "Needs in R&D Supporting Nuclear Power Plant Life Management”, PLiM, Shanghai 15-18/10/2007.

[5] P.Contri et al. (2007b), “Maintenance optimisation issues in the EC” - ISEM 2007, Lansing, 10/09/2007

[6] P.Contri (2007c), “Maintenance issues in long term operation of Nuclear Power Plants”, ENC2007, Bruxelles, 19/09/2007.

[7] IAEA (2006), Principles and Guidelines on Plant Life Management for Long Term Operation of Light Water Reactors, IAEA Technical Reports Series- 448 (2006).

[8] JRC (2009), EUR 24231 EN, "A plant life management model as support to Plant Life Extension programs of Nuclear Installations - Effective integration of the safety programs into an overall optimization of the operating costs ", JRC EUR report, January 2009.

[9] INPO (2004), INSTITUTE OF NUCLEAR POWER OPERATIONS, Equipment Reliability Process Description, INPO AP-913, Atlanta, 2004.