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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

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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

Technical Report

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EXECUTIVE SUMARY

Main objectives of this report, as outcome of the research activities carried out in 2008 and in previous years by the research network SENUF, are the following:

1. To collect the experience of the European Countries in the field of Plant Life Management (PLIM) and Plant Life Extension (PLEX), seen as two crucial programs in safety and cost optimisation at operating plants
2. To settle a model for PLIM also suitable to support a PLEX program, tailored to the European market
3. To validate the proposed model against the European practice.

The basic goal of PLIM, as it is defined in this research, is to satisfy requirements for safe, possibly long-term, supplies of electricity in an economically competitive way. The basic goal of the operating companies is to operate as long as economically reasonable from the safety point of view. PLIM is a management tool for doing that.
Therefore PLIM is a system of programs and procedures developed in many Countries, with some differences due to the national framework, to satisfy safety requirements for safe operation and for power production in a competitive way in a time frame which is rational from both the technical and economical point of view. PLIM programs address both technical and economic issues, as well as knowledge management issues.

This report makes reference to the first part of this study that was completed in 2007, when a PLIM model was proposed and validated at real Nuclear Power Plants. This report adds some important contributions in three areas: definition of the PLIM scope, review of the Ageing Management Program for selected structures, management of contractors and strategic alliances. These contributions were selected after a thorough analysis of the European best practice, also with the contribution of the SENUF network Members.

The validation of the proposed PLIM model, including the improvements described in this report, represents only the first step of a more ambitious program of validation/improvement that will be implemented in the course of 2009.

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1 Introduction

1.1 Background of the research

In recent years the engineering community and the nuclear industry are living a "nuclear renaissance" time. At the same time, the effort to operate the existing reactors in a safe and cost effective mode, even in a long term perspective (such as in a framework for a Plant Life Extension Program), adds new challenges to old design and operation approaches.

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.

In Countries with some experience, the PLIM program proved very convenient, especially when coupled with Maintenance, Surveillance and Inspection (MS&I) optimization: average savings are reported in the range of 20-30% of total O&M (Operation and Maintenance) costs, especially in Central European Countries.
The recent achievement of low production costs (16,8 USD/MWh) in 2007 and 92% capacity factor (in the USA) with no significant safety related event is considered a milestone in the nuclear industry, and a proof of the reliability and safety of the current plants, also thanks to the extensive application of PLIM techniques (in the USA they are mainly referred to the methodology described in the INPO AP-913 [1]).
New challenges are ahead for the new reactors in the same fields: ageing management and operation control should be better integrated since the design phase, the large use of standard/unified projects will have to be localised to this concern, construction control and project management still poses serious unknown.

The need for harmonised PLIM models at least at the European level (where the energy market is rather unified and regulated by general rules) has been recently raised, supported by two main reasons:

- A reliable PLIM model needs to be supported by a consistent analysis of feedback from plant operation, which could be available only at over-national scale (only exceptions are the large nuclear energy suppliers);
- Effective PLIM models need sharing of resources, suppliers, spare parts, O&M techniques among different plants, which therefore must have the same or very similar characteristics to foster such exchanges.

The research for such a unified model focused on the four main components of a PLIM program/model, such as:

1. Life Management of critical structures, systems and components (including ageing program, maintenance program, ISI, etc.);
2. Long Term Investment plan;
3. Long Term Operation and Personnel plan;
4. Continuous safety upgrading of the plant.

The SONIS/POS action, implemented at the JRC/IE since 2007, addressed the above mentioned issues and developed a number of research tasks in the field, which ended up in the issuing of a number of technical reports: "Maintenance rules: improving maintenance effectiveness" [2], "Advanced Methods for Safety Assessment and Optimization of NPP Maintenance" [3] and "Optimization of Maintenance Programs at NPPs - Benchmarking study on implemented organizational Schemes, Advanced Methods and Strategies for Maintenance Optimization - Summary Report" [4]. These studies culminated with the first proposal for an integrated PLIM model contained in the report "A plant life management model including optimized MS&I program –Safety and economic issues" [5] issued in 2007.

In the year 2008 the PLIM model proposed in 2007 was deeply revised and the areas of major concerns were re-developed on the basis of a detailed analysis of the EU state-of-the-art experience. Therefore, this report adds some important contributions to the 2007 model, in the following areas:

- definition of the PLIM scope: informed selection of the SSCs covered by the PLIM program, at different levels;
- review of the Ageing Management Program for selected structures, especially concrete structures, traditionally excluded by refined AMPs focussed on metal components;
- contractor's and strategic alliances management, with emphasis on work control, contractors' training and contract management.

These contributions were selected from a thorough analysis of the European best practice, also with the contribution of the SENUF network Members.

According to the SONIS Work Program for the year 2008, this deliverable answers to the planning, as defined in the SONIS/POS 2008 Workplan [6] for deliverable 1.1a.

This deliverable also represents an outcome of the SENUF (Safety of European NUclear Facilities) network, Workpackage 3 (Benchmarking of optimized approaches to maintenance), according to the SENUF Workplan for 2008 [6].

The follow-up of the research, mainly based on validation and improvement of the proposed models, will take place in the years 2009 and 2010.

1.2 Objectives of the research

Main objectives of this report, as outcome of the research activities described above, are the following:

1. To collect the experience of the European Countries in the field of PLIM and PLEX;
2. To consolidate the PLIM model developed in 2007 [5], developing/improving those sections which showed difficulties in the application to real cases in the last benchmark exercise, such as the management models, to be adapted to the state-of-the-art practice (covering the large use of supplemental workers, set-

up of networks for spare parts, etc.), the scoping process and the AMP for selected structures;
3. To validate the proposed model against the European practice;
4. To disseminate the developed models in the European engineering and research communities in order to get feedback and to encourage a widespread, coordinated improvement of the European practice.

The next phase of the research (2009-2010) will improve the validation of the proposed model.

1.3 Conduct of the research

In the year 2008 the research on PLIM models and maintenance optimization schemes was conducted in three main steps, each containing important tasks, namely:

A) Planning phase
1. Coordinating with the SENUF network members, after the Steering Committee of May 2008 [6], in order to collect their experience in the field, planning the necessary tasks and the contributions.

B) Research phase
2. Development of Questionnaire on "Human behavior of contractors and staff in relation to maintenance and ISI", issued to all Utilities/Plants in Europe. Summary and analysis were carried out at the IE.
3. Organizing, in cooperation with the IAEA and Inetec, an International Workshop on "Advanced Approaches to In-Service Inspection, Maintenance and Repair", hold in Zagreb at the INETEC premises, on May 4-9, 2008. The Workshop was attended by 15 experts from Russian Fed., Ukraine, Slovenia, Lithuania, Slovakia, Romania, Bulgaria. Lectures were delivered by four international experts, invited by the JRC (W.Daniels) and by the IAEA (J.J.Nicolais, M.Bolander, T.Batuecas,), N. 8 Lectures were given by Inetec experts on advanced techniques and manipulators for ISI of the RPV, SG (including plugging) and other components of the primary system [7].
4. Organizing (and coordinating a Division), in cooperation with the OECD/NEA/CSNI WG on Concrete Ageing, a Workshop on "Ageing Management of Thick-Walled Concrete Structures, including In-Service Inspections, Maintenance and Repair, Instrumentation Methods and Safety Assessment in view of Long-Term Operation", hosted by the Nuclear Research Institute Rez, on 30 September – 3 October, 2008. N.70 participants from 14 Countries (scientists and policy makers, involved in the field of nuclear safety, invited by the working Group of OECD/NEA on Concrete ageing) attended the Workshop, presenting 26 scientific papers + 3 keynote lectures [8].
5. Coordinating the Division for Plant Operation at the 2008 ASME Pressure Vessel and Piping Conference, Chicago, 27-31 July, 2008, where almost 500 scientists and policy makers from all Countries attended the sessions [9]
6. Organizing a Workshop on "Optimisation of maintenance programs at NPPs with consideration of safety and economical aspects" in Petten at the JRC on November 13-14, 2008. 20 experts from 9 Countries (6 New Members and 3

Neighboring Countries) attended the WS, two external experts were invited as speakers and 4 IE staff members contributed to the lectures [10]

C) Validation Phase

7. Validation of the proposed model with selected SENUF Members, on bilateral basis, during the whole 2008.

1.4 Report content

This report dedicates Chapter 2 to collect and summarize the European experience in relation to the PLIM and PLEX programs; Chapter 3 proposes a new approach to screening of the components in the framework of PLIM, while Chapter 4 addresses Ageing Management issues for selected groups of components and Chapter 5 covers some crucial management issues in relation to PLIM.

Chapter 6 draws the conclusion of the research and sets the new drivers for the future steps.

2 Background on PLIM and PLEX programs

2.1 The PLIM program

As better described in [5], the Plant Life Management (PLIM) problem was raised some years ago when it was clear that technological, safety, regulatory, human and economical issues had to be addressed at once in the overall management of the plant assets [4,11].

However, the PLIM models developed in recent years differ one from another because of the national frameworks and therefore a generalization sometimes appear difficult.

Interesting attempts were carried out by the International Atomic Energy Agency with some technical documents and papers [11], to identify common drivers among the different national programs, but the discipline was never indeed regulated by binding documents to its Member States, by presenting commonly accepted principles, recognized by all the interested parties. Nevertheless, a large number of IAEA documents are available on basic safety concepts that could be relevant to life management programs [12-22].

In particular, a generic misunderstanding still survives in the engineering community among objectives and content of the different programs put in place in the different Countries which developed experience in the PLIM field. Programs such as License Renewal (LR), Long Term Operation (LTO), Plant Life Extension (PLEX), Periodic Safety Review (PSR), Ageing Management Program (AMP), etc. proved to share many technical tasks, but also to meet different objectives and to follow different regulatory frameworks.

The JRC-IE spent some research efforts in last years in the clarification of the many issues addressed by the European Countries' programs and developed some unified models, which received very high consensus in many engineering communities and particularly in the research network of European Countries interested to this discipline, SENUF [2,3,4,5]. A number of scientific papers were also published in order to foster the feedback from the engineering community [23].

As a result of this effort, a harmonized PLIM model could be developed. According to the EU experience, PLIM objectives can be summarized as in the following:

- The basic goal of Plant Life Management (PLIM) is to satisfy requirements for safe long-term supplies of electricity in an economically competitive way. The basic goal of the operating company is to operate as long as economically reasonable from the safety point of view. PLIM is a management tool for doing that.
- PLIM is a system of programmes and procedures developed in many Countries, with some differences due to the national framework, to satisfy safety requirements for safe operation and for power production in a competitive way in a time frame which is rational from both the technical and economical point of view. PLIM programmes address both technical and economic issues, as well as knowledge management issues.

It has to be noted that PLIM should not be necessarily associated with the extension of operational life-time of the NPP. It represents an owner's attitude and rational approach of the operating company to run the business economically and safely since the design stage and during the whole design life of the plant.
In this framework some operational programs play the most crucial role, namely:

- The ageing management program (AMP)
- The maintenance, surveillance and inspection (MS&I) program
- The knowledge management program (KM)
- The asset management program
- Major plant upgrading programs (if in place, such as power up-rating, modernisation, etc.)

In particular, the AMP is a transversal program [5] cross-cutting maintenance, surveillance, and in service inspection programs and other operation related programs. It addresses ageing mechanisms prevention, control and consequence mitigation. The operating experience shows that active and short-lived SSC are in general addressed by existing maintenance programs. Conversely, the performance and safety margins of the passive long-lived SSC are assumed to be guaranteed by design. However, the analysis of the operating experience showed that unforeseen ageing phenomena may occur either because of shortcomings in design, manufacturing or by operating errors, calling for a refined, self-improving program.

The maintenance program for a nuclear power plant covers all preventive and remedial measures that are necessary to detect and mitigate degradation of a functioning SSC or to restore to an acceptable level the performance of design functions of a failed SSC [13]. In this sense, the integration with surveillance and in-service inspection is crucial, as the most advanced types of maintenance do integrate the three programs which have a common objective: to ensure that the plant is operated in accordance with the design assumptions and within the operational limit and conditions. Therefore in the following, MS&I will address all the three programs in an integrated form.

It is clear that the MS&I program is a crucial part of PLIM, being by far the main contributor to both operating costs (after operation) and operation planning. However, in order to support a PLIM framework, MS&I should have a specific list of attributes, making both safety assessment and cost optimization possible. These are the reasons why MS&I are deeply covered in this report and why the PLIM model strongly relies on specific assumptions in the field of MS&I.

Knowledge Management and Asset Management are traditionally isolated programs from MS&I and AMP. PLIM recognizes the need for their integration and sets an overall optimization framework.

In many European Countries, PLIM is accompanied with a PSR program. The combination is not surprising, as PLIM is typically a utility driven program, while PSR is driven by the Safety Authority. Many technical tasks (those safety related) are similar, but objectives, time frame and regulatory implications are definitely different.

The relationship among PLIM and the other programs running at the NPPs is now quite clear in the EU Countries: well known programs such as component integrity, ageing management (AMP), life extension (PLEX), periodic Safety Review (PSR) and Plant Life Management (PLIM) are in fact well connected, but definitely not interchangeable. Despite of the different names, mostly derived from the national regulatory and engineering frameworks, there is a clear hierarchy among them. In particular, component integrity is a basic science dealing with the failure modes of the different components, their detection and their control. The AMP is an operational program in place at any NPP, which integrates maintenance, ISI and organisational issues aiming at controlling the component degradation. PLIM addresses safety as well as economics, knowledge management as well as decision making, and provides an overall framework to keep the whole plant in a safe and economically sustainable condition.

2.2 The PLEX program

Plant Life Extension (PLEX), often called Long Term Operation program (LTO), is a process often implemented in the nuclear Countries, due to the ageing of the plant fleets and the need to secure important energy sources combined with investment protection.

A large number of technical documents is now available at the International Community on basic safety concepts that could be relevant to life extension programmes, and in particular on the requirements of the maintenance programmes in view of LTO programmes [5,15,16,19,20,21,22]. A clear position is common to many documents:

- LTO is a programme that can be implemented only when the plant can demonstrate a suitable safety level in all its statuses;
- The LTO programme are crucially based upon a strong integration of many existing programmes at the plants, such as ageing management, configuration control, predictive maintenance, etc.

The Regulatory frameworks for long-term operation (LTO) differ from country to country in accordance with the licensing system. In countries where the operational license is granted for a well-defined operational lifetime, a formal license renewal is practiced. In some countries the utilities have a license renewal for 20 years. Some other Member States have just started the development of regulations for license renewal and project planning. In the countries where the operational lifetime is not limited by license, the Periodic Safety Review (PSR) is frequently chosen as the regulatory tool for an LTO, but in a ten-year framework only.

However, despite of the differences that affect the regulatory strategy in the countries and the consequent differences in the application/approval process for LTO, the main technical components of the LTO programmes and their basic technical tasks are shared among most of the countries.

A general approach to LTO, independent of the regulatory framework, can be based upon the following assumptions:

1. Separation of “pre-conditions to LTO” and “LTO specific” tasks;
2. Separation between regulatory issues (PLEX, PSR, PLIM, etc.), technological issues (degradation) and economical issues;
3. Clarification of the LTO scope and objectives, and therefore of the interfaces between maintenance, ISI, AMP, etc.;
4. Analysis of the differences between active and passive SSCs, replaceable and non-replaceable components.

This approach leads to the following definitions:

1. **Preconditions for LTO**: tasks needed to reach the required level of plant safety and to prove it. Required also for current operation during design life (see for example the safety factors of the PSR). They may include the following actions/programmes:
   - ✓ Keeping the Safety Analysis Report updated;
   - ✓ Keeping the Equipment Qualification updated;
   - ✓ Keeping the design basis updated;
   - ✓ Update the External Event hazard;
   - ✓ Update the safety analysis;
   - ✓ Appropriate maintenance programme, with monitoring of its effectiveness and trending features in time;
   - ✓ Plant radiological risk assessment;
   - ✓ Integrated Plant Assessment aspects relevant to safety;
   - ✓ Plant Modifications Analysis;
   - ✓ etc.

2. **LTO specific tasks:** tasks needed to maintain the required level of plant safety in the long term in relation to material ageing, technological obsolescence and staff knowledge, beyond the plant life defined at the design phase by the technological limits. They are affected by the extension of the beyond design basis lifetime. They may include the following actions/programmes:
   - ✓ Trend analysis of material and component degradation;
   - ✓ Time Limited Ageing Analysis aspects relevant to nuclear safety;
   - ✓ Management of the staff ageing;
   - ✓ Management of the long term technological obsolescence of SSCs;

- ✓ Public acceptance;
- ✓ Environmental issues (population, installations, emergency planning);
- ✓ etc.

Prior to giving consideration to long-term operation, it is essential to check that the plant has been maintaining an acceptable safety level of the operation (“preconditions”). In particular, the review of the maintenance programme (MS&I) and of the ageing management programme (AMP), which in many countries includes maintenance, should be conducted, in order to check if the trend analysis is adequate to support a decision on the long term. An essential element of the LTO programme is the extrapolation of the detected degradation on the planned operational lifespan. The licensee should demonstrate that for the extended operational lifetime:

1. The safety and ageing analysis remain valid and could be projected to the end of intended operational lifetime;
2. The effects of ageing on the intended function(s) will be adequately managed;
3. There is a mechanism to deal with unexpected ageing mechanisms that can surface.

In many cases, the plant existing maintenance and ageing management programmes can be credited as acceptable programmes for the long-term operation. For the remaining cases, either the plant existing programme can be augmented to satisfy the listed above attributes or new programmes should be initiated.

The results of the trend analysis should be evaluated considering the following:

- The entity of life time extension;
- Time required to implement corrective actions;
- Probabilistic Safety Assessment (PSA) application;
- Expert judgment (risk is often subjective).

One of the following strategies can be implemented in case of non-compliant items:

- Replacing or restoring the component;
- Changing the operational conditions and/or improving ISI;
- Developing additional analyses (eliminating initial conservatism with more refined methods);
- Performing a re-evaluation test (with improved qualification methodologies).

In fact beyond design life the design safety margin can be maintained through accommodation of the new issues into the design conservatism, sometimes built up with rough design methods, conservative environmental conditions and conservative operation assumptions.

2.2.1 MS&I in PLEX

It appears that suitable maintenance programmes are one of the most important pillars of the LTO programmes; many Countries decided to modify their maintenance programmes as a precondition for LTO.

All Countries implementing an LTO programme applied extensive modifications to their requirements on maintenance at first step, setting up mechanisms to monitor the effectiveness of the maintenance activities. In general the engineering community believes that the maintenance programme should have specific attributes in order to support a long-term operation (LTO) programme for the plant. More specifically, the maintenance programmes based on standard preventive maintenance (time based), not oriented to the monitoring of its effectiveness, are not considered suitable to support the LTO programmes. Crucial attributes for maintenance programmes in order to support LTO are considered: the verification of the performance goals, the root cause analysis of failures, the feedback from maintenance to the ISI programme, the feedback on the OLC, etc.

In particular, the following features are believed to be indispensable for a state-of-the-art maintenance programme, even if the LTO process is not urgent in the Country:

1. Monitor the performance of the SSCs which may have impact on safety during all operational statuses of the plants;
2. Assess and manage the risk that may result from the proposed maintenance activities in terms of planning, prioritisation, and scheduling.

Therefore, systematic approach to the improvement of the maintenance effectiveness is a generic tendency in Countries where LTO programmes are in place; however, the progress in this field depends on both the maturity of LTO project and on the specific regulatory framework.

In some countries requirements exist on the evaluation of efficiency of the maintenance with respect to safety criteria (Maintenance Rule, MR). In these countries the utilities have to develop and implement systematic approach to the planning, performing and evaluation of the maintenance in response to the MR. A common example of the proof of efficiency of the repair work is for example the leak-test and/or function test. The key aspect is the integration of existing programmes such as: ISI and monitoring, trending, maintenance, replacement, to ensure a long term plant operation.

In this sense the experience of the USA, Spain, Hungary, Finland and other countries with an LTO programme in place are a confirmation of this generic statement: all these countries modified their regulatory requirements on maintenance, in the direction mentioned above, as one of the preconditions for the LTO of their plants. Therefore the analysis of these LTO programmes becomes essential to understand the requirements on the state-of-the-art maintenance programmes posed by the International Community.

More details are provided in the following on the position developed at the IAEA, in Spain, Finland and in the USA, for reference.

2.2.2 Ageing management in PLEX

In general, ageing management is addressed in procedures for maintenance, surveillance, in service inspection programme, etc. as one of the irreversible physical degradation processes, which could lead to failure. The operating experience shows that active and short-lived SSC are in general addressed by existing maintenance programmes. Conversely, the performance and safety margins of the passive long-lived SSC are assumed to be guaranteed by design. However, the analysis of the operating experience showed that unforeseen ageing phenomena may occur either because of shortcomings in design, manufacturing or by operating errors. Therefore the implementation of an AMP and a predictive MS&I programme is definitely a condition for the operation within the limits of design or licensed lifetime and is a pre-condition for an LTO as well. Moreover, the ageing management is intended to provide a crosscutting connection among all maintenance and inspection activities carried out on active components also, to provide a unified understanding and treatment of the degradation phenomena. In conclusion, both the AMP and MS&I programmes could be accepted if the following actions are completed:

- Programme scope is defined;
- Preventive actions are developed;
- Parameters to be monitored or inspected are detected;
- Detection of ageing effects is ensured;
- Monitoring and trending is performed;
- Acceptance criteria are defined;
- Corrective actions confirmation process are defined;
- Administrative control is fixed;
- Operating experience of the programme is considered.

Some of these attributes are inter-related. Particularly the frequency, the trending and the number of locations to be monitored may reflect the operating experience from past operation.

3 PLIM Scope - Component classification

3.1 The Finnish model (VVER)

According to the experience at the Loviisa plant [24], 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 also Fig.1 from [24]) 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.

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.

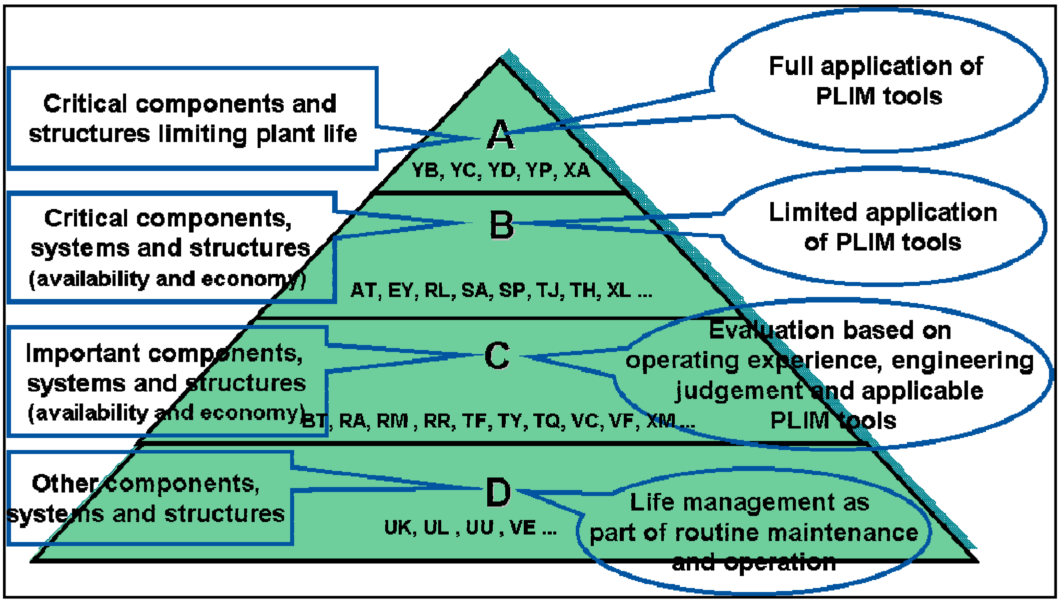

Figure 1 – Proposal for PLIM oriented component classification

3.2 The Spanish model

The Spanish approach to PLIM follows closely the US regulation, as stated in the 10CFR54 [25] Code. In its compulsory part ageing management is applied to both active and passive components; however it is the Component Reliability program [1] that addresses Maintenance, ISI and Ageing evaluation under a single integrated program (see Fig.2).

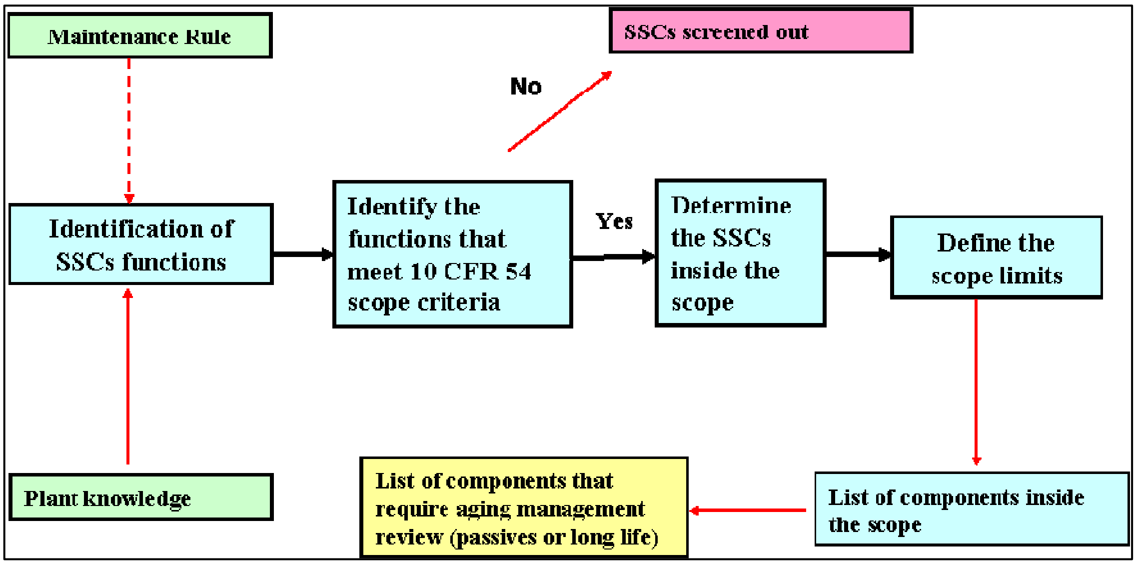

Fig.2 – Summary of the Spanish approach to PLIM and to component screening.

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 [10].

The AMP scoping process goes through a systematic application of a number of criteria, as summarized in Fig. 3

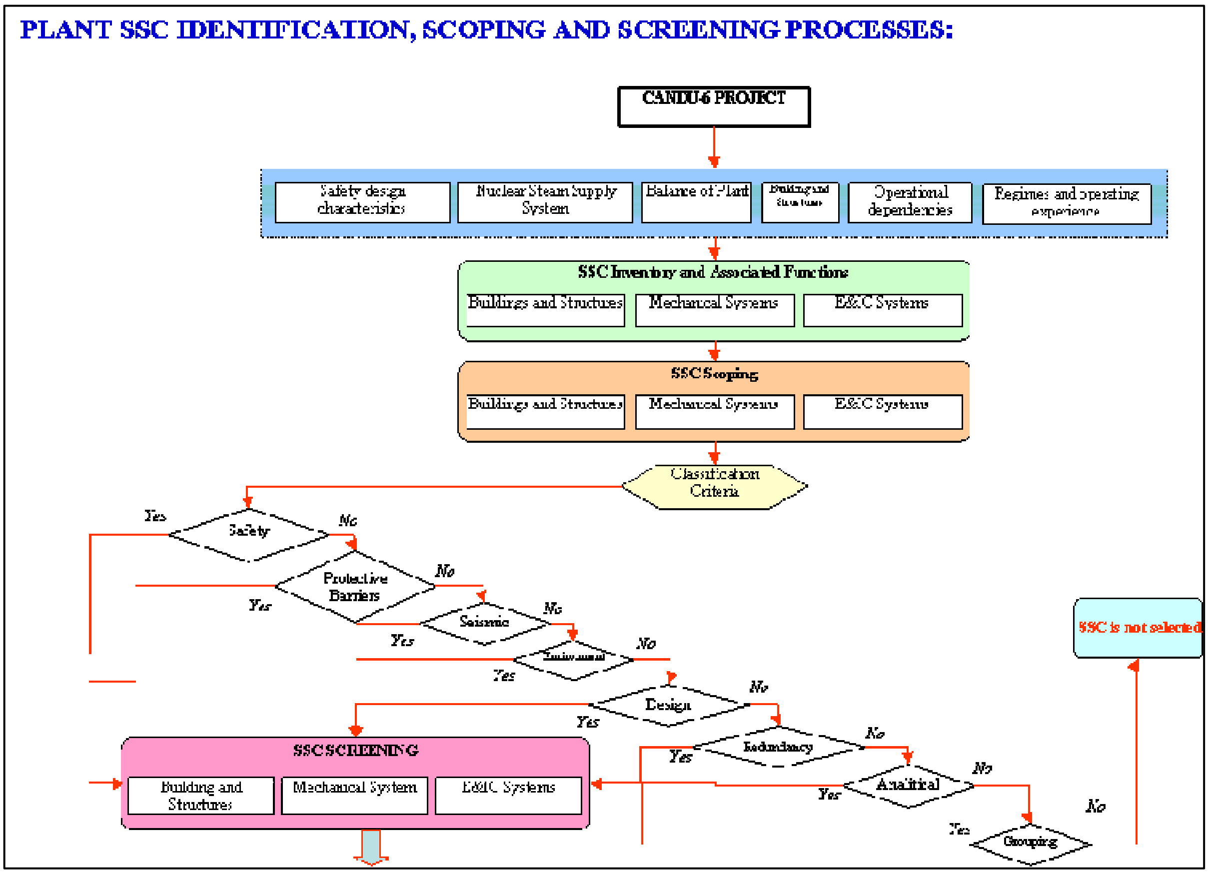

Fig. 3 – Summary of the procedure developed at Cernavoda NPP for PLIM and for component screening.

In particular the screening process relies on the following criteria:

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

The full-scope application of PLIM in view of the PLEX program envisages the following:

- Evaluation 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.

The flow chart is shown in Fig.4.

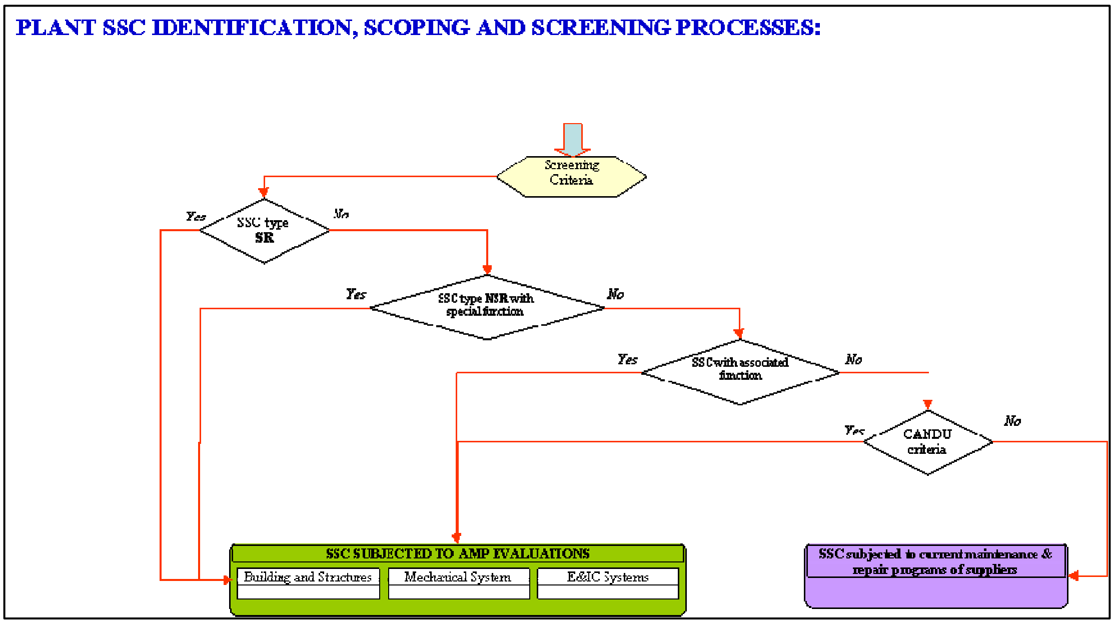

Figure 4 – The screening process applied at Cernavoda [10]

The outcome of this process is the following list of life-limiting components, for which the PLIM model is applied in the different levels:

Level 1 SSCs

* Calandria vessel
* ESCS components
* Calandria tubes
* In-core Reactivity Mechanism Control components
* MMS pipe spools inside calandria vault
* Containment and essential internal structures

Level 2 SSCs

* PHTS equipment and pipes
* Pressure Tubes
* Steam Generators
* PHTS pumps
* PHTS feeders
* ECCS pipes and equipment
* SDCS pipes and equipment
* MMS pumps and heat exchangers
* Special safety systems
* Structures with essential or safety related functions
* High capacity heat exchangers
* Others SSC in a variable number (10 - 20)

Level 3 SSCs

* ESCS pipes and equipment
* Calandria vault cooling system components
* PHTS feed system pumps
* Turbine-Generator system
* Service water systems pipes and equipment
* BFWS pipes and equipment
* Medium and low capacity heat exchangers
* Diesel generators
* Power supply and distribution systems
* Battery cells system

Level 4 SSCs

* Compressors and compressed air system components
* Instrument air system
* D_2O vapour recovery dryers
* Air exhaust system fans
* Transformers
* Power cables and I&C systems

The application of the above mentioned criteria to structures and buildings may lead to the following actions:

– intermediate wastes storage facility extension
– metal and concrete structures repairs
– coatings and epoxy liner partial replacement and repairs
– bays metallic plate coating

- furnishing elements replacement
- walls and floors finishing replacement and repairs
- floors elements replacement and repairs
- Rompan walls replacement and repair
- covers replacement and repair

and to the following costs

- Human effort: 350 m x h
- Estimated period: 2.5 y
- Conventional wastes: 930 t
- Radioactive wastes: 410 t

The application of the above mentioned criteria to the reactor and mechanical systems may lead to a number of actions on the following systems (taken from the experience in Cernavoda):

- Mechanical absorber units
- Adjuster units
- Liquid zone control units
- Liquid injection shutdown units
- Ion chamber casings
- Calandria vessel assembly
- Flux detector units
- ESCS system
- Pressure tubes
- PHTS feeders
- Pressurizer
- Steam Generator
- SDCS heat exchanger
- Instrument air system
- PHTS purification inter-cooler
- PHTS purification heat exchanger
- Primary circuit
- Shutdown cooling system
- PHTS purification system
- MMS heat exchanger
- F/M head
- F/M auxiliary ports
- F/M auxiliary and support systems
- Spent fuel transfer and storage system
- Main steam system
- Service water systems (RCW,RSW)
- Spent fuel bay vent system
- Reactor building vent system
- Local air coolers system

And to the following costs

- Average human effort:
- 468 m x month
- Low and medium radwastes: 2980 t

- Conventional wastes: 2441 t

In the experience of Cernavoda, the application of the above mentioned criteria to the turbine and generators led to the following costs:

- Human effort: 72-90 m x month
- Estimated period: 1.8 y
- Conventional wastes: 160-190 t

According to the experience in Cernavoda, the overall amount of resources involved can be summarised as in the following:

- ✓ Estimated average duration of reactor systems refurbishment is approx. 30 months.
- ✓ Estimated average duration of turbine-generator refurbishment is approx. 20 months.
- ✓ Estimated average duration of steam generators repairs is approx. 30 months.
- ✓ Estimated average duration of structures and buildings repairs is approx. 30 months, if work conditionings are foreseen.
- ✓ Spent fuel bay metallic plate coating can not be started earlier than 2 years from the plant shutdown and fuel transfer to intermediate spent fuel storage facility.
- ✓ Estimated total duration of plant life extension project is between 4 ÷ 5 years, including plant commissioning and grid connection phases.
- ✓ Expected maximum human effort during development of plant life extension project is between 2200 ÷ 3100 m x month.
- ✓ Estimated maximum wastes quantities vary between 3427 t and 3725 t (low and medium radioactive wastes) and between 2929,2 t and 3662 t (conventional wastes).

4 The Ageing Management Program for selected SSCs

4.1 NDE issues

The Ageing Management Program (AMP) aims at the evaluation of the component degradation, based upon the results of inspections and analyses. The NDE program plays a crucial role to the AMP. Based on the state-of-the-art practice, some considerations are collected in the following on the capabilities of modern NDE to support AMP.

Some recent surveys of the reliability of modern NDE techniques [26] highlighted the following:

(1) Some plants show very complex inspection works at areas not covered by inspections in similar plants in other Countries. Examples are the baffle bolts at Loviisa, and the vessel head (the welding around the penetrations of the CRDM) in South Ukraine. This fact raises the issue for a better communication among plants, for a systematic collection and redistribution of the feedback of operating experience, in the interest of safety.

(2) The importance of qualified ISI systems, inspired for example to the ENIQ model, is generally recognised. Qualification costs are in Europe too high and

harmonisation of the national practice would bring enormous benefit to the industry, saving costs and guaranteeing a uniform level of reliability throughout the European Commission.

(3) Repair techniques are becoming very important: the qualification of the durability of the repair in some cases is difficult.

(4) Risk informed ISI (applied to all safety related components and piping) and in general PSA applications represent natural evolution of the traditional approach. However, still not too much practice was accumulated in Europe and guidelines would be welcomed. In addition, emphasis has to be given to the quality of the PSA studies supporting such applications (the TECDOCs of the IAEA are of great help to this concern).

(5) The evaluation of the component reliability values as function of the MS&I system is still a challenge and additional R&D should be developed, also to cover the structure of the databases where similar data can be processed.

In conclusions, and according to [26], flaw detection by available NDE techniques still are very much influenced by the orientation of the probe and the defect, by the stress orthogonal to the flaw, by the hysteretic effects due to the crack closure and re-opening. Therefore NDE is still very much skill and experience dependent and the strategy, also drawn by ENIQ [27], of a full integration and assessment of process, technology and personnel is very up-to-date.

All NDE models still have troubles in capturing the "anomalous" behaviours triggered by construction and mounting, as they refer to the "ideal" design case.
The experience in recent years showed that the NDE programs are still too much oriented to capture defects which are expected in terms of generation, location and size. All recently discovered ageing mechanisms were not detected by NDEs (either because not included in the inspection programs or because not requested by the codes), but by failures (a new one every 7 years in average). Therefore many scientists emphasise the idea of developing "proactive" NDE plans, able to "detect the unexpected", improving the concept of NDE effectiveness and fostering the concept of on-line monitoring and RI-ISI to try to capture unexpected degradation mechanisms.

The following measures have been taken to support optimal NDE programs in new plants: fewer welds in critical areas, use of degradation resistant materials, provide good access for inspection, design welds for inspection in components that need to be inspected, prepare ID and OD at best, use on-line monitoring, build self-monitoring systems, do performance demonstration before construction.

4.2 AMPs for concrete structures

Nuclear power plant operators have recognized many challenges to maintenance, repair and more in general for PLEX in relation to concrete structures. One of these is the ability to detect and predict the extent of internal damage and ageing effects. Modern NDE methods and instrumentation are thought to provide potentially useful techniques for the detection and measurement of the extent of internal damage and provide information on the construction quality. However, still a lack of consolidated experience affects the reliability of the AMP for concrete structures.

Moreover, despite of the large choice of inspection techniques available, the engineering community still employs different practices in the management of concrete ageing, especially in the use of ISI, their integration with the safety assessment and their optimization. This issue has become urgent in recent years, when the degradation mechanisms affecting concrete structures have shown their potential to jeopardize structural reliability, thereby challenging the safety of the installation.

The international community (see for example [26]) considers that there is a need to ensure that the methods used for the inspection and monitoring of safety critical containment structures are reliable and that their capabilities and limitations are properly understood. In particular, the main issue seems to be related to the determination of which additional information is needed to assure that non-readily replaceable components and structures (e.g., concrete structures) will retain their integrity and reliability during their projected years of service.

The following notes summarize the state-of-the-art practice to this concern:

1. Concrete structures are plant life limiting, being mostly irreplaceable. Therefore PLIM should address safety, durability and cost control at the same time. Broad choice of techniques are now available for monitoring and a PLIM program is feasible

2. Two technical objectives for PLIM of concrete structures should be considered:
   - **Monitor** degradation, for durability and planning covering the whole life, from design to construction and operation
   - **Proof safety** (leaktightness, integrity), even in absence of visually evident degradation

3. Especially for new reactors durability is considered since the design phase (either implicitly, through prescriptions on water content, concrete cover, etc. or explicitly)

4. New types of instrumentation (vibrating wire strain gauges and fibre optic sensors) have been used together with real time monitoring

5. Monitoring from short and long term purposes may be different and needs optimization since the design stage

6. Environmental variables: they are crucial in driving the degradation and should be carefully monitored

7. ISI results and design data need well designed IT tools to support any PLIM evaluation and optimization of ISI, maintenance, and repair

8. A global correlation between overall strain field and leak rate is now possible, provided creep effects are screened out

9. Most of leak rate is still concentrated around penetrations, gaskets, discontinuities

10. Liner configuration, behavior and repair technology may deeply affect leak rate

Despite of the good understanding of concrete degradation mechanisms and of the large availability of ISI techniques, few steps are still needed to close the gaps to comprehensive ageing management programs:

1. Which **degradation mechanisms** are the most relevant to safety (and should be considered since the design stage)? At which locations?
   - The environmental stressors may be crucial for such choice and adequate monitoring should be suggested.
   - Compilation of material property data for long-term performance (also at elevated temperature and radiation) and trending, evaluation of environmental effects and assessment and validation of non-destructive evaluation methods.
2. Which **ISI techniques** are the most suitable to monitor degradation? At which locations? At which time interval? Which cost benefit? (Reference to technology, procedure and personnel)
   - A safety case with a sample AMP plan may be useful (on shut-down plants?).
   - Risk-informed approaches may provide a useful framework, as “monitoring for everything” is neither feasible nor cost effective. Include provisions for “detecting the unknown”.
   - Non-destructive methods for thick-walled, heavily reinforced concrete structures and basements may be improved. Round robin may be beneficial
   - Personnel training and qualification guidelines (the “metal” world covers it already)
3. How to correlate ISI and monitoring result to **containment fragility**?
   - Improved constitutive/damage models and acceptance criteria for use in assessments of current as well as estimating the future condition of structures
4. How to **repair**?
   - Data on application and performance of repair materials and techniques should be collected

5 Management issues

Organisational aspects in Maintenance and ISI are more and more important: a better control of subcontractors is needed in countries where 80% of MS&I tasks are contracted to external companies, as compared to the past tradition in Central Europe, where only 10% was contracted. The type of contracts for ISI, qualification of contractor personnel and the ownership of the qualification dossier (i.e. either the plant or the contractor) need homogenisation in Europe.

The main issues behind such needs seem to be the management of maintenance contractors, including good practice on qualification of suppliers, the contract management (long term contract, training included, etc.), the availability of contractors in the long term, the strategic alliances with contractors, the contractor qualification and audit.

However, there is still workshop highlighted that there is still a big gap between Western European Nuclear Utilities and some Eastern European ones in the field of the maintenance management. In particular, very few show structured maintenance optimization systems in place, network to share spare parts, reliable control of the supplemental workers (more and more used), integration with the asset management of the plants, proper set of maintenance effectiveness indicators.

These delays in adopting robust modern techniques for plant life management as a whole make the outages still long, and the overall management of the plant asset far from optimized.

5.1 Summary of the questionnaire

Not all Countries/Utilities have a Human factor control program for maintenance and ISI; in most Countries, the issue of the HF has been implicitly addressed through improved techniques (better planning, automated welding, IGSCC control, RI-ISI, RCM, etc.) and better work control.

In relation to the number of contractors/workers involved (average per Unit), results are summarised in the following table 1.

Table 1 – Summary table on the questionnaire outcome

Country	# contractors involved in maintenance	# workers at the plant during maintenance	# plant workers
LT	6	100	0
H	0	600	
UKR	0	600	
UKR	7	340	50
BG	8		
RO	170	100	
SK	19	270	625
ARM	6	600	
RF	200	870	30%
CZ	35	1400	60

In relation to the incidence of human factors on operational events, the following two examples looked informative:
In Romania

- out of 2471 events (2006), 9% are HF related
- out of 2682 events (2007), 7% are HF related

In Armenia

- 17% are HF related

The most widely used indicators of maintenance effectiveness are the following:

- Failure rates
- Generic safety indicators
- Control of loose parts
- Percentage of rework
- N. of claims
- Repeated Maintenance
- Time/task
- N. of unplanned work orders
- Etc.

According to the sole Czech experience [10], a special set of indicators was developed:

- Work conformance to specifications
- Delivery schedule to plan
- Work to agreed cost
- Response/reaction time, for Single/Project
- Quality of performance, for Frame work contracts
- Workforce utilisation
- Safety (number of accidents, lost time injury (LTI), rate of absenteeism, etc.)

The survey highlighted the following preventive/corrective actions implemented in relation to the above mentioned indicators:

- Training and re-training
- Supervision
- Access control

- Improved work procedures
- Detailed work planning
- Use of Simulator
- No-blame culture
- Improved labelling
- Etc.

In relation to the practice on contractors' management, the questionnaire highlighted the following:

- The average length of the contracts is 2-4 years
- In some cases, a general contractor is identified and encouraged as a practice
- Contractor training is not always organised by the Licensee
- Contractor qualification could well be from foreign Bodies, and ISO

5.2 Work control

In many Countries the procedures for work control are quite stringent, also in consideration of the growing involvement of supplemental workers that requires even more stringent procedures (see previous chapters).

A key role in the work control is played by the maintenance manager, which has very well defined functions in all Countries. An example of such functions is summarized in the following from the European experience [4]:

1. Technical mission: anticipate and control the technical risks, capitalizing the experience, manage the OLC margins without reducing the safety (through changing inspection intervals, etc.), is ready with contingency plans
2. Team management: managing competences, managing staff ageing and knowledge management, control of contractors experience (+ licensing and training), monitoring the contractors, check the safety culture, carry out effective communication
3. Economic management: undertaking the overall objective (deciding the overall strategy on cost, availability, etc.), manage the maintenance optimization, decide the subcontracting policy and the type of contracts, appoint the appropriate staff number and competences, manages the connection with the ISI team

A very urgent issue, as raised by all the Countries involved in the research, is the control of supplemental workers, which poses new concerns, particularly in the new European Member Countries, traditionally used to employ large numbers of maintenance staff. The issue is addressed in the following chapters.

5.3 Roles and responsibilities

The PLIM program requires important changes in the traditional plant organisation. In particular, the following preparatory organizational tasks should be implemented:

- Development of a PLIM supervision and coordination Unit

- Nomination of System Engineers, full time in charge of selected systems, especially for Class A or Class 1 for CANDU-6 power plants
- Identification of research and engineering specialists in different disciplines at the TSO organisation, ready to cooperate with the system engineers to address methodological issues, interpretation of results, interfaces with the scientific and engineering community, etc.

The identification of System engineers (typically 10-15 people for two power units) in the typical Technology Unit at a plant is considered an important contribution to a good PLIM implementation. They are responsible for the life management of a particular system, structure or component. They represent the system "owners". These engineers are responsible for the following tasks:

- Preparation and control of inspection, monitoring and maintenance activities related to life management of systems, structures and components critical to safety
- Detection and assessment of aging mechanisms and effects
- Preparation and implementation of improvements in the field of proactive maintenance.
- Maintain and populate the life management system
- Update the information in the long range planning system
- Keep updated the records of the component/system health status in the reference documentation system
- Guarantee the reporting

Some interfaces between the system engineers and other groups/depts. are particularly important in the PLIM framework, namely:

1. The operators: plant TS and OLC may be discussed and changed (with the due authorizations) as a consequence of detailed analysis of the operating experience and of the MS&I outcome.
2. The MS&I technicians: objectives, periodicity, scope and other attributes of the programs may be agreed and modified
3. The Safety specialists (either on site or at the TSO): they own the plant safety analysis and therefore all the acceptance criteria for ageing and degradation should be agreed and reviewed with them
4. The technical support group: the decision to repair/replace/maintain a component or structure is taken jointly and approved by the management group of the PLIM.

5.4 Work process

Work planning and control should be defined in the relevant procedures. One example is shown in Fig.5 [5].

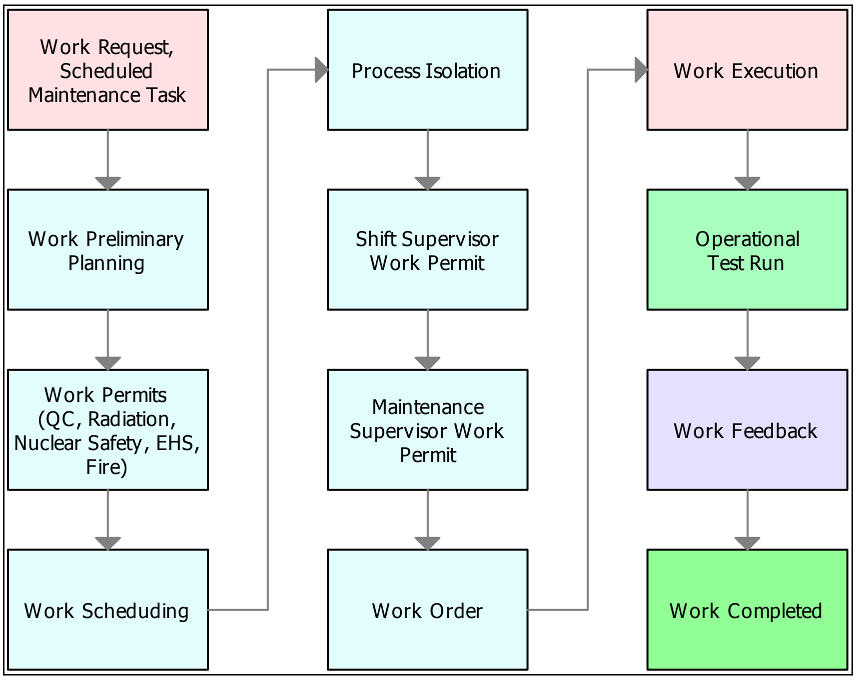

Figure 5 - Work planning and control procedures

This process is typically fully computerized in a maintenance information management system. These systems typically consist of the following modules:

- Work management
- Service management
- Contract management
- Materials management
- Procurement management
- Asset management

A very sensitive issue is represented by the work control, more and more relevant in a very competitive market of suppliers and in regimes of growing subcontracting by the European plants. To this extent, some measures can be applied:

– Involvement of subcontractors in yearly meetings, with detailed analysis of the follow-up from maintenance, with recording of their performance in special dedicated records

– Involvement of the subcontractors in training initiatives, to assure the perfect alignment of competences

– Preference for long term (3-4 years) contracting, which provides better guarantees to the contractors, improving the mutual confidence and encouraging the contractor to invest in training of its personnel

– Stringent assessment of the qualification of the single staff member of the contractor, on a yearly basis

– Audits at the suppliers site on their quality system.

In general the influence of human errors in the failure rates is very high: measures should be taken to minimize such contribution (from both staff and contractors). Detailed recommendations are available in [28].

The quality of the maintenance tasks should be subjected to stringent QA requirements. In particular, post maintenance quality inspectors, calibration specialists, tagging controllers and auditors should not be hierarchically connected with the maintenance teams who implement the job.

5.5 Spare parts: networks and policies

The management of the spare parts is a crucial contributor to the PLIM and to its optimization. The availability of spare parts for every critical SSC should be agreed between the managers of the warehouse, the system engineers and the maintenance engineers.

Possibly, networks for spare parts should be settled between similar plants, even in different countries.

The stocks of spare parts should be properly modeled in the economic planning, at least for the foreseen period of plant operation, including depreciation factors as function of time and environmental conditions.

In case of lack of suppliers, the system engineers should recover the design basis and identify equivalent parts, to be further agreed with the maintenance engineers.

6 Conclusions

The research on PLIM models developed at the JRC identified some areas where some R&D effort is needed to support the development of original PLIM models, integrated with maintenance optimization programs.

The research concluded that there is a potential, very important role for the IE network on safe operation of nuclear installation (in the research field) in the coordination of the efforts among the European Countries to promote a full implementation of maintenance optimization programs and PLIM, especially in the framework of PLEX.

Therefore the research refined the first proposal for a PLIM model completed in 2007 and took the best practice of the European Countries, integrating both safety and economic aspects in a global optimization effort.

The reason to keep the R&D effort at the European level is clear: the implementation of PLIM methods requires the availability of component data, well established probabilistic techniques of appropriate quality etc. that cannot be developed at the Country level only. In this framework, any future action in the

EU/FP7 would be most probably very welcomed and will provide concrete support to the enhancement of the safety of the European Plants.

The next steps of the research will address the following priorities in relation to PLIM

1. PLIM processes: interfaces between plant programs and asset management
2. Classification of SSCs in relation to PLIM and interfaces with other classification approaches at the plant (safety, maintenance, ISI, etc.)
3. PLIM organizational structures
4. Interfaces between PLIM and spare part managements: relevant models, including obsolescence effects
5. Financial modeling to optimize resources in the long term
6. Integration between maintenance strategy and generic PLIM experience on component reliability (AMP), failure rates, performance, etc.
7. Develop models for interaction between PLIM and PSA (safety analysis in general), especially during shutdown modes, for optimal outage planning.

and the following priorities in relation to MS&I

8. Comparison of SFW for M optimization
9. Maintenance effectiveness indicators: their acceptance level and corrective actions to be taken for each of them. Study the combination of indicators and their potential interaction.
10. Collection of potential degradation mechanisms, acceptance criteria and trend curves for the most common and sensitive European components
11. Human factors reduction
12. Conditions for on-line maintenance
13. Simulation tools for M opt: they may save time in the planning!

The research will continue in the year 2009 with a robust validation and improvement of the proposed model at real plants.

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8 List of Abbreviations

ACC	Acceding and Candidate Countries
AMP	Ageing management program
CFR	Code of Federal Regulations
CIS	Commonwealth of Independent States
CM	Corrective Maintenance
EPRI	Electric Power Research Institute
EU	European Union
IAEA	International Atomic Energy Agency
IE	Institute for Energy
ISI	In-Service Inspection
I&C	Instrumentation & Control
LTO	Long Term Operation
MS&I	Maintenance, Surveillance and Inspection
NPP	Nuclear Power Plant
PLEX	Plant Life Extension
PLIM	Plant Life Management
PM	Preventive Maintenance
PSA	Probabilistic Safety Assessment
PSR	Periodic Safety Review
RBI	Risk Based Inspection
RCM	Reliability Centred Maintenance
RG	Regulatory Guide
RIM	Risk-Informed Maintenance
SENUF	Safety of Eastern European Type Nuclear Facilities
SSC	Systems, Structures and Components
TS	Technical Specifications
VVER (or WWER)	Water-Cooled Water-Moderated Power Reactor

European Commission

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Abstract

Main objectives of this report, as outcome of the research activities carried out in 2008 and in previous years by the research network SENUF, are the following:

4. To collect the experience of the European Countries in the field of Plant Life Management (PLIM) and Plant Life Extension (PLEX), seen as two crucial programs in safety and cost optimisation at operating plants
5. To settle a model for PLIM also suitable to support a PLEX program, tailored to the European market
6. To validate the proposed model against the European practice.

The basic goal of PLiM, as it is defined in this research, is to satisfy requirements for safe, possibly long-term, supplies of electricity in an economically competitive way. The basic goal of the operating companies is to operate as long as economically reasonable from the safety point of view. PLiM is a management tool for doing that.
Therefore PLiM is a system of programmes and procedures developed in many Countries, with some differences due to the national framework, to satisfy safety requirements for safe operation and for power production in a competitive way in a time frame which is rational from both the technical and economical point of view. PLiM programmes address both technical and economic issues, as well as knowledge management issues.

This report makes reference to the first part of this study that was completed in 2007, when a PLIM model was proposed and validated at real Nuclear Power Plants. This report adds some important contributions in three areas: definition of the PLIM scope, review of the Ageing Management Program for selected structures, management of contractors and strategic alliances. These contributions were selected after a thorough analysis of the European best practice, also with the contribution of the SENUF network Members.
The validation of the proposed PLIM model, including the improvements described in this report, represents only the first step of a more ambitious program of validation/improvement that will be implemented in the course of 2009.

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