Institute for Energy

SONIS Action n. 52103

A plant life management model including optimized MS&I program –Safety and economic issues

Technical Report

Paolo CONTRI, Bernhard ELSING, Povilas VAISNYS

DG JRC – Institute for Energy

December 2007

SENUF

Safety of European Nuclear Facilities

EUROPEAN COMMISSION
DIRECTORATE GENERAL
Joint Research Centre

EUR-23232 EN

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Printed in the Netherlands

EUR 23232 EN
ISSN - 1018-5593

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Report EUR-23232 EN
2007/11

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EXECUTIVE SUMARY

Main objectives of this report, as outcome of the research activities carried out in 2007 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 maintenance optimisation, seen as two crucial programs in safety and cost optimisation at operating plants
2. To settle a model for PLIM and maintenance optimisation suitable for 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 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.

The first chapters of the report contain a survey of the engineering practice in the EU in relation to PLIM. The main issues behind the development of a PLIM model, its main features and the experience of few European and non-European Countries are highlighted.
Based on this survey, the JRC-IE researchers together with the SENUF members developed a preliminary version of a PLIM model that they believe could significantly improve the performance of the European plants.
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 described in the last chapters of this report, with special emphasis to the maintenance optimisation approaches which represent one of the most important part of the PLIM models.
The validation of the proposed PLIM model represents only the first step of a more ambitious program of validation/improvement that will be implemented in the course of 2008.

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1 Introduction

1.1 Technical and economical 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, adds new challenges to old design and operation approaches. Some of these challenges may be listed as in the following:

1. Safe and efficient operation, possibly beyond the design life, despite of the differences in operating tradition in the different countries
2. Ageing degradation and technological obsolescence affecting all plant components pose challenges to the optimization of the maintenance systems
3. Ageing of the workforce, availability of workforce, public acceptance
4. Protection of the plants to new scenarios (e.g. large aircraft crash and very severe earthquakes)
5. Public opinion issues, difficulty in opening new sites
6. Capacity of the industry to cope with the rising demand of new plants: in particular, the forging of large components (requested in order to reduce critical welds) and large supply of rare raw material (e.g.zyrchonium, etc.) appear the main bottle neck for future orders
7. Licensing issues (time, process, certification), execution issues (time, etc.), innovation of the design (gen. IV), globalized standardisation of design and certification of plants
8. Need to incorporate the lesson learned from 50 years of operation all over the world in the design codes: too often their text did not change in recent years
9. Globalisation: more countries involved means difficulties in coordination and optimization of the design configurations

Most of these challenges are related to the current social and economic framework for the energy production, which is characterised by the following main trends, especially in Europe:

1) An 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. obsolescence) and therefore for reliable indicators of the effectiveness of the maintenance programmes

2) A 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.
It is noted that the need for tailoring available operational programs and procedures to the new framework often proved very complex due to the long time perspective of the PLIM (typically 30-40 years), as compared to the typical time framework which the available programs and procedures are traditionally set up for.
Nevertheless, 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.

As mentioned above, many Countries addressed the PLIM issue through specific programs, though with different overall objectives. This often un-coordinated approach led to some inconsistencies in the engineering approach to the technical issues. In particular, some confusion was raised on the technical content of the following programs:

- PLIM (Plant Life Management)
- AMP – TLAAs (Ageing Management Program – Time Limited Ageing Assessment)
- Component integrity
- PSR (Periodic Safety Review)
- Licence renewal
- LTO (Long Term Operation)
- PLEX (Plant Life extension)
- Power uprating
- Plant modernisation (mainly I&C)
- Etc.

This is why it was widely recognised [1] that R&D tasks are needed in this phase, starting from clear definitions and objectives for all the mentioned programs, not only in the long term extrapolation of the component integrity and behaviour, but also in the development of new management strategies at the plant (PLIM), able to address organisational issues, asset management, human reliability and ageing issues [2], all at once, in a coordinated approach.

1.2 The SONIS action and the SENUF network

The technical issues raised above triggered research actions also at the JRC-IE level, which have been managed in the framework of the SONIS (Safety of Operating Nuclear FacilitieS) action.

The SONIS action (n.52103) represents and answers to the Euratom Multi-annual Framework Programme (FP7) [3], being one of the EC “Direct Actions”, which aims at satisfying the R&D obligations of the Euratom Treaty and to support both

Commission and Member States in the field of safeguards and non-proliferation, waste management, safety of nuclear installation and fuel cycle, radioactivity in the environment and radiation protection.
More in detail, the FP7 (Council decision 18/6/2006) 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 1) the safety of nuclear installations and 2) the nuclear fuel safety, respectively.

The SONIS action addresses the former agenda, covering all aspects of operation safety of NPPs with a very complex research program [4]. Task 1 addresses PLIM models and MS&I optimization schemes in a time range of 5 years starting in 2007.

The first year of the SONIS research started where the previous SENUF reports ended, namely: "Maintenance rules: improving maintenance effectiveness" [1], "Advanced Methods for Safety Assessment and Optimization of NPP Maintenance" [5] and "Optimization of Maintenance Programmes at NPPs - Benchmarking study on implemented organizational Schemes, Advanced Methods and Strategies for Maintenance Optimization - Summary Report" [6]. In all these reports recommendations were issued on the continuation of the research in relation to three main areas in the field of integration of MS&I programs at the plants, decision making process, organizational aspects.

Therefore, according to the SONIS Work Program for the year 2007, a deliverable was planned on the following:

D1.1.2a EUR Technical report developed with the support of specialised consultants on the reference organisational models able to support optimised MS&I programs and with effective integration of the safety programs into an overall approach for the optimization of the operating costs.

As expected, this deliverable also represented 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 2007 [7].

The follow-up of the research, mainly based on validation and improvement of the proposed models, will take place in the years 2008 and 2009.

1.3 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 maintenance optimisation (see Chapters 2 and 3 for a summary of European experience)
2. To settle a model for PLIM and maintenance optimisation suitable for the European market (see Chapter 4 for the model description)

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 will improve the validation of the proposed model.

1.4 Conduct of the research

In the year 2007 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 2007 [7], in order to collect their experience in the field, planning the necessary tasks and the contributions.

B) Research phase

2. Organizing, in cooperation with the IAEA, an International Workshop on "Optimisation of Maintenance, Inspection and Testing with Insights of Risk, Reliability and Performance", hold in Karlsruhe at the FZK/FTU, on July 9-13, 2007. N.20 participants attended the WS from 8 European Countries with nuclear program (Russia, Ukraine, Lithuania, Slovakia, Czech Rep., Bulgaria, Romania, Armenia) and n. 7 invited Experts from JRC (M.Ugalde, K.Laakso), IAEA (E.W.Grauf, J.-P. Raoul), and FTU (C.Heil, R.Buschart, F.Kostroun) [8].
3. Organizing, in cooperation with the IAEA, the Second International Symposium on Nuclear Power Plant Life Management (PLiM), in Shanghai on October 15-18, with 270 attendees from all Countries, 175 papers presented, 35 Member States and 3 International Organizations represented [9]
4. Coordinating a Division at the 19th International Conference on Structural Mechanics in Reactor Technology (SMiRT 19), Toronto, August 12-17, 2007, where almost 500 attendees from all Countries attended the sessions [10]
5. Developing an invited lecture at the ISEM 2007 - Session on Maintenance Engineering, at Lansing (USA) on September 9-12, 2007, with 170 participants from all over the world; the researchers coming from the nuclear industries were mainly involved in NDE issues [11]
6. Organizing a Workshop on "Organisational Models and tools for optimised maintenance programs at Nuclear Power Plants (NPPs)" in Petten at the JRC on December 6-7, 2007. 20 experts from European Countries attended the WS, two external experts were invited as speakers and 4 IE staff members contributed to the lectures [12]

C) Validation Phase

7. Validation of the proposed model with the Loviisa team of experts during a technical Meeting on "Maintenance Optimization issues and Plant life management", organized at Loviisa NPP on December 11-14, 2007 [13]

1.5 Report content

This report dedicates Chapter 2 to collect and summarize the European experience in relation to the PLIM programs and to setting the PLIM problem; Chapter 3 highlights the main issues in relation to maintenance optimization programs, with refernce to some European Countries' experience.
Chapter 4 provides a description of the PLIM model developed at the JRC-IE, as validated according to the feedback from SENUF members and the technical seminar with the Loviisa nuclear plant staff and managers.
Chapter 5 draws the conclusion of the research and sets the new drivers for the future steps.

2 The PLIM problem

2.1 Setting the problem

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 [1,2].
It is a fact that new global approaches have been triggered in recent years by a combination of factors such as:

- The generic trend towards plant life extension beyond the original design life, in order to exploit the plant design at the maximum level
- The market economy, which is pushing for a more stringent management of the economic assets
- The detection of significant ageing phenomena which were challenging the original design assumptions
- The need for preservation of the human knowledge in time, particularly in Countries with growing opposition to nuclear expansion
- The more stringent regulatory requirements in terms of safety assessment and monitoring

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 [2], 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 is available on basic safety concepts that could be relevant to life management programs [14-24].

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 [1,5,6]. A number of scientific papers was also published in order to foster the feedback from the engineering community [25-30].

As outcome of this effort, a list of generic considerations was developed as support to the development of a more unified approach to the common issue of managing the plant assets in time, meeting the highest safety standards:

1. The PLIM program appears the type of program most suitable to address long-lasting safety and economical issues and to present the most comprehensive approach to the plant asset management
2. The PLIM program is neither necessarily related to plant life extension, nor to license extension of any plant. It is a logical framework on which strategic thinking may find the appropriate answers in relation to safety, economy and human asset management.
3. Related programs such as LR, AMP, PSR, each with its own objective, may find in the PLIM framework the answers and the background information that they need to meet their specific objectives; however, they definitely represent separate programs, different from PLIM itself.
4. The PLIM program is crucially based upon a strong integration of many existing programs at the plants, such as asset management, life extension, ageing management, configuration control, predictive maintenance, etc. that share common assumptions and contribute to the same overall objectives.
5. Some special features are required to standard programs and also some specific programs are needed to be in place at NPPs in order to feed a PLIM program adequately. These features/programs creates the pre-conditions for a PLIM program to be successfully applied, such as: the maintenance program should be mostly reliability based, the ISI program should be possibly risk informed, a fuel management program should be in place, an outage optimization program should make available all data in relation to the economic implications of the outage duration, a knowledge management program should be in place, public acceptance analysis should be available, etc.
6. In order to manage the very complex structure of a PLIM program, specialized software tools and databases are highly recommendable, also for the management of the daily work, due to the huge amount of data to be processed and stored.

One example of approach to PLIM is shown in Fig.1, taken from the Finnish practice.

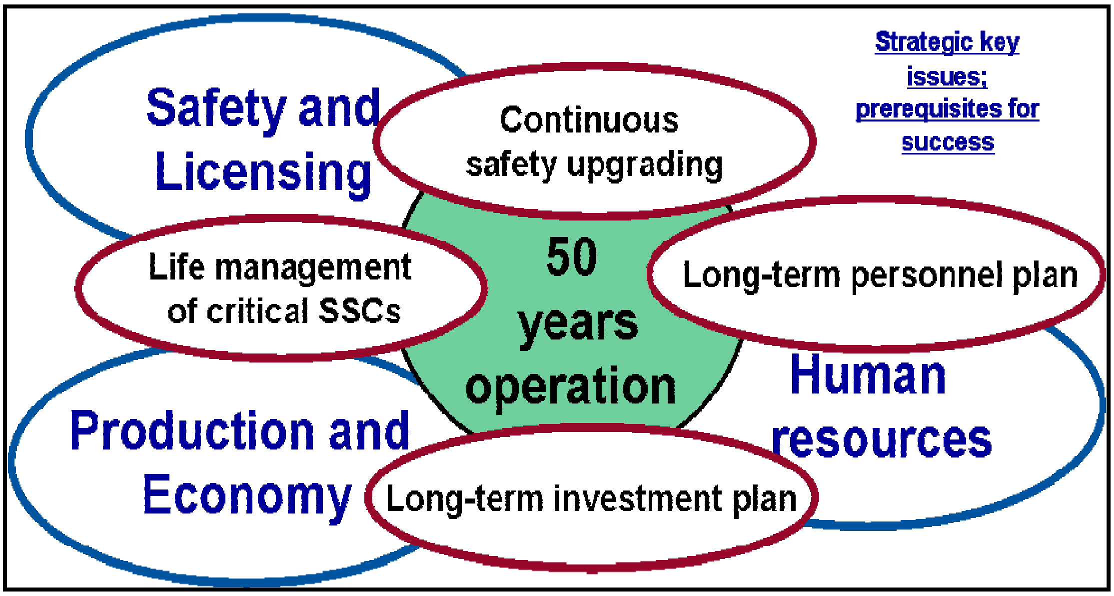

Figure 1 - Examples of approach to component life management [13].

In this example, the PLIM program aims at demonstrating that during the design and possibly the extended plant operational life [1,2]:

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 safety function(s) are adequately managed all along the envisaged lifetime;
3. There is a mechanism to deal with unexpected ageing mechanisms that can surface.
4. There is a pro-active process for decision making, also involving non-safety equipments significant to plant availability
5. There is a program to manage human resources and knowledge
6. Plant economic assets are properly managed

In this framework some 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 uprating, modernisation, etc.)

In particular, the AMP is a transversal program [1] 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 [15]. 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 is deeply covered in this report and why the PLIM model strongly relies on specific assumptions in the field of MS&I.

In conclusion, the implementation of an AMP and a predictive MS&I (maintenance, surveillance and inspection) program is definitely a condition for the operation within the limits of design or licensed lifetime and is a condition for a PLIM as well.

KM 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.

2.2 Countries' generic experience with PLIM

Thanks to the large survey on Countries' practice carried out through the organization of many international events, it was possible to summarize the most relevant aspects of some Countries' practice in the field of PLIM, with special emphasis to the relationship with other programs running at the EU Countries.

For example in Hungary [9], the PLIM context was triggered by the life extension of the nuclear units, though with some specific features, as shown in Fig.2.

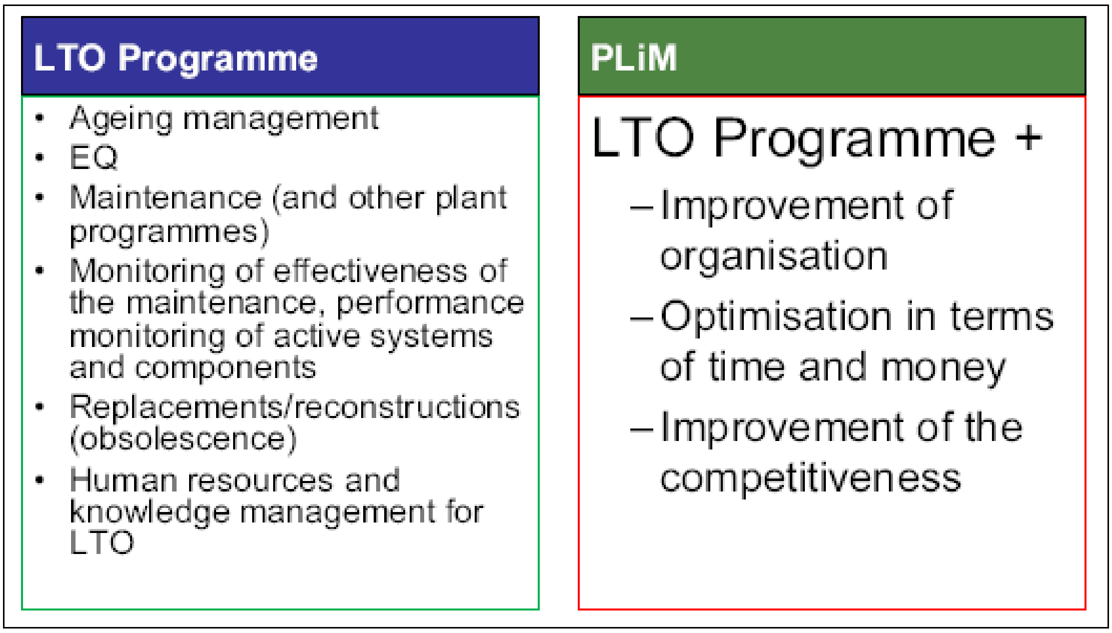

Figure 2 – Example of PLIM scoping for mechanical components

In Spain the PLIM context is even more focused to the LTO [8], as shown in Fig.3.

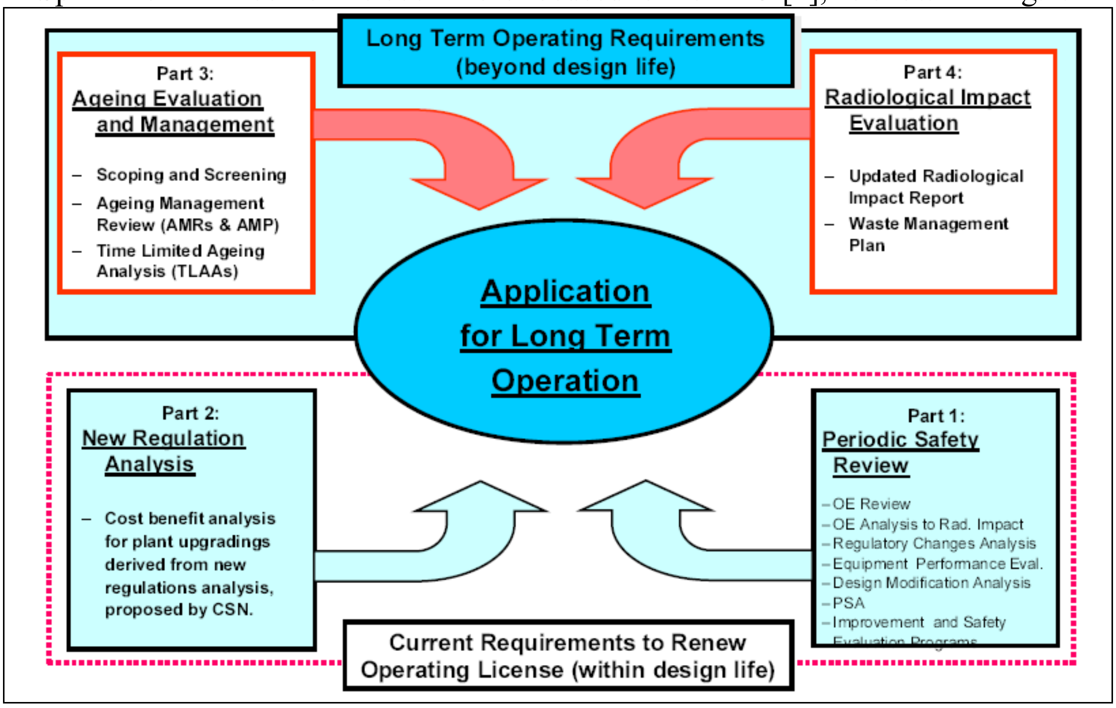

Figure 3 – Spanish practice in PLIM organization

In France PLIM is mostly transparent to the Regulator [9], and it really integrates the most relevant plant programs, as shown in Fig.4.

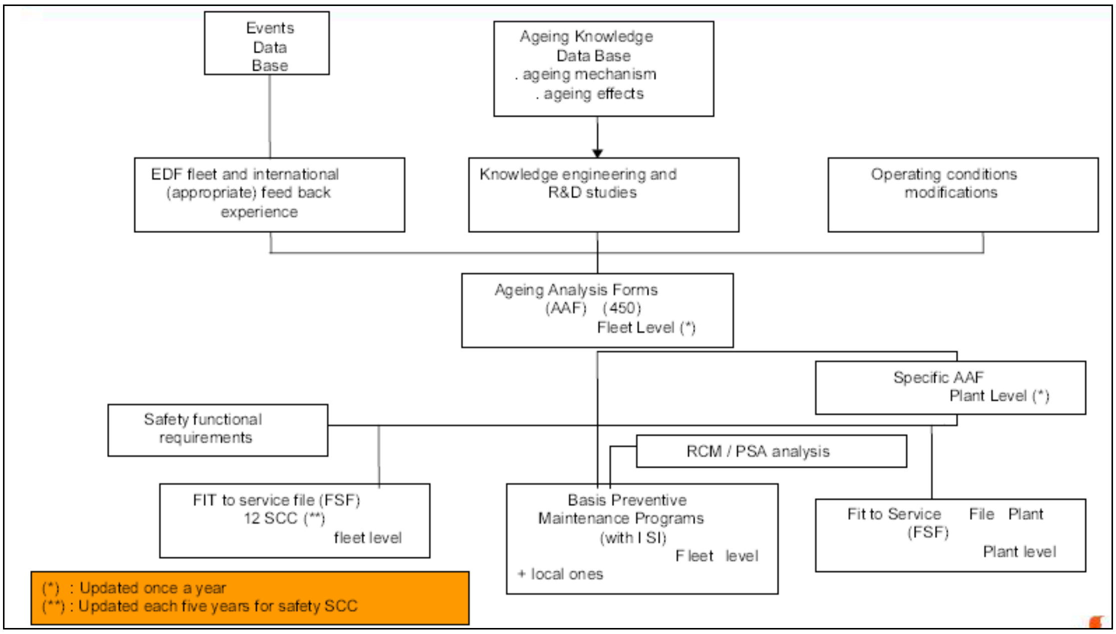

Figure 4 – Organization of the PLIM program at French NPPs

In Germany (EON) [9], a rigid hierarchy of programs clarifies also their objectives, as shown in Fig.5. The PLIM (here called Life Management (LM)) is summarized in Fig.6.

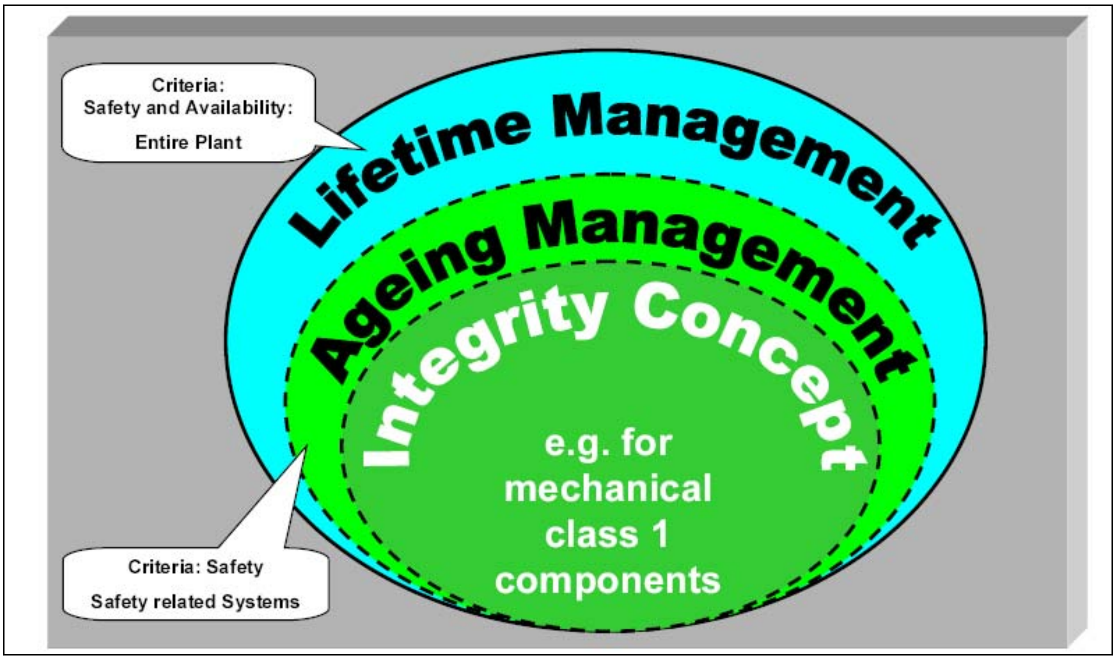

Figure 5 – PLIM approach at EON plants

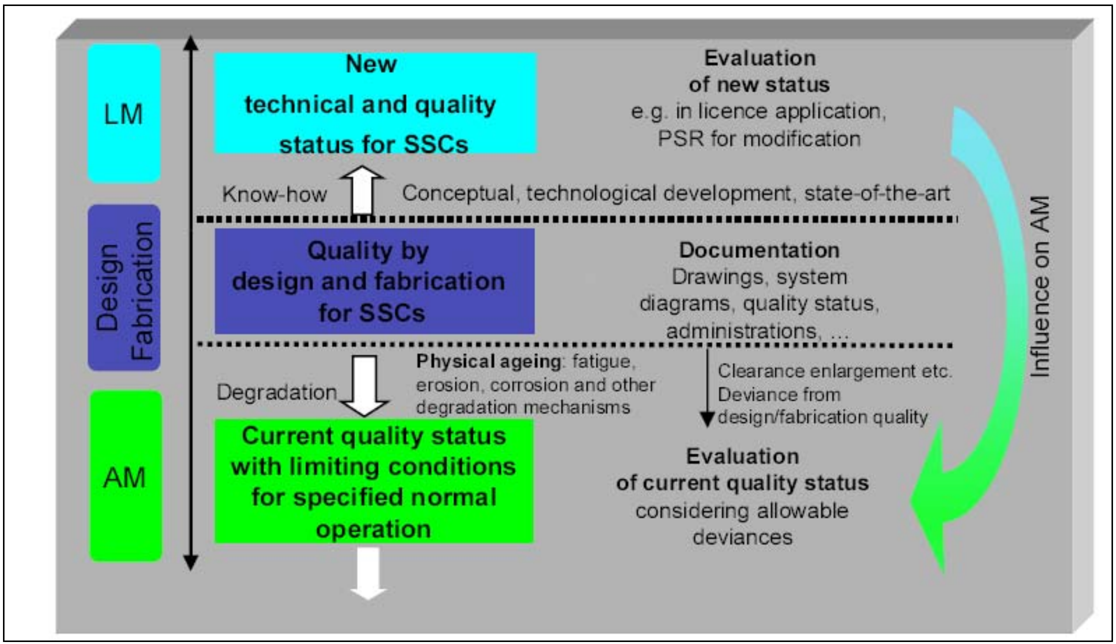

Figure 6 – PLIM organization at EON plants

In the USA the US INPO AP-913 provides a well established approach to component reliability, addressing component integrity, some economics and management issues.

In general, in the OECD countries (whose practice is summarized for example in [9]), PLIM is recognized as a tool with specific and immediate advantages in the planning of the plant life extension (LTO/PLEX), as summarized in the following:

Economic aspects

- LTO/PLEX avoids the need for investment in new generating capacity
- The capital cost of LTO/PLEX is much smaller than any other type of replacement capacity
- LTO/PLEX implies a reduction in specific costs (per KWh) for waste management and decommissioning
- LTO/PLEX provides electricity at a lower cost than other available option

Safety

- LTO/PLEX helps justifying investments in safety upgrades
- Helps to raise safety level (when possible)

Public acceptance

- LTO/PLEX makes the investment in alternative sources possible
- It minimizes the public acceptance issues for the opening of new sites

This short survey may be completed with the following summary:

- The USA, Canada, Spain and some other Countries accumulated a valuable experience in recent years in PLIM issues and related programs. The interest of the international community of plant operators on reliability based approaches to PLIM and maintenance optimisation in particular is definitely growing. The US approach is codified in the INPO AP-913 [32], closely followed by some Europeans.

- Other European Countries are more in favour of integrated approaches to Plant Life, such as Finland, with a more explicit control of the component degradation and a clear day-to-day basis for the decision makers on replacement, maintenance and operation.

- 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.

- Some pre-conditions for PLIM in many countries include maintenance optimisation, RI-ISI, fuel management, outage optimisation, knowledge management, public acceptance, seismic upgrading, etc. making sometimes the program very complex. In all cases they are assisted by complex software tools and databases, also for the management of the daily work.

- 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.

2.3 The PLIM objectives in the Countries' experience

As a summary of the above mentioned survey of the EU practice, reasonable objectives for a PLIM program could be stated 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.

2.4 The scope of the PLIM program in the Countries' experience - Affected items and their classification

There seems to be quite an agreement among the Countries' practice in relation to the scope of the PLIM program. In many cases a grading of MS&I tasks is codified through a formal component classification in relation to PLIM. This classification shows some differences according to the Country experience and in relation to the nature of the components (civil, mechanical, electrical, etc.).
Moreover, the different types of component classification in use at European plants (e.g. for safety, for maintenance, for PLIM, for ageing, etc.) sometimes do not match each other, making their review somehow difficult.
One example of classification for PLIM for mechanical components is shown in Fig.7, taken from the Hungarian experience [9]: it is probably representative of a widely used approach, at least in Europe.

1. Separately managed components:

- Reactor pressure vessel
- Reactor cover
- Reactor inner components
- Pressurizer
- Steam generator
- Main circulation pump
- Main gate valve
- Primary piping

Scoping: Safety Class 1- 3+
~ 250,000 items

Screening: Long lived, passive
~ 160,000 items

2. Commodity groups (mechanical components):

Safety class	Component type	Medium	Material
Safety Class 1 Safety Class 2 Safety Class 3 Non safety class 4 which may inhibit safety functions	Housing of valves Housing of pumps Piping Vessels Heat exchangers Tanks	Borated water Dematerialized water River water Steam, gas-steam mixture Oil, Etc..	Stainless steel Cast stainless steel Carbon steel

Figure 7 – Example of PLIM scoping for mechanical components

A proposal for a unified approach is developed at Chapter 4.

2.5 PLIM precondition: why PLIM needs an optimized MS&I model?

In 2003 the JRC-IE carried out a preliminary investigation of the priorities in the European Countries in relation to the PLIM programs [1]. The conclusion was that there is a generic convincement in the nuclear community that the maintenance, surveillance and in-service inspection (MS&I) program should have specific attributes

in order to support a long term operation (LTO/PLEX) program for the plant and a PLIM program in general.
In this sense, the International Standards (e.g. the IAEA), but also the national experience of USA, Spain, Hungary, etc. proved a confirmation of this statement. More specifically, the maintenance programs based on standard preventive maintenance (time based), not oriented to the monitoring of its effectiveness and to the prediction of the damage, are not considered suitable to support a PLIM program. Crucial attributes for maintenance programs in order to support PLIM are considered: the verification of the performance goals, the root cause analysis of failures, the feedback from maintenance to the ISI program, and the feedback on the OLC (operational limits and conditions).
All Countries implementing an PLIM/LTO program applied extensive modifications to their requirements on maintenance at first step, setting up mechanisms to monitor the effectiveness of the maintenance activities. In particular, the following features are believed to be indispensable for a maintenance program in a PLIM framework:

1) Monitor the performance of the SSCs (structures, systems and components) 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.

In order to implement these requirements, some issues have to be addressed by an optimized MS&I program, namely:

1) The identification of the **scope** of the condition based maintenance rules: typically the Countries choose the safety related SSCs, SSCs which mitigates accidents or transients, SSCs interacting with safety related SSCs, and SSCs that could cause scram or actuation of safety related systems. Therefore, many non-safety related SSCs may see the application of such maintenance rules, with augmented efforts in monitoring their performance and planning their reparation.
2) The setting of the performance **goals** for every component in the scope of the maintenance rules, ranking them according to their risk significance for the plant safety. This task may end up very challenging as, when industry experience is not available, either dedicated PSA tasks have to be developed (with special requirements on PSA quality) or special qualification programs for the evaluation of the component reliability.
3) The performance **monitoring** techniques for the very broad categories of structures systems and components in the scope of the rules.
4) The assessment of the safety **during implementation** of maintenance actions.
5) The **feedback** from the result of the monitoring of the component reliability back into the inspection, surveillance and maintenance procedures. Root cause analysis, equipment performance trend analysis and corrective actions have to be developed on a case by case basis.

In this sense for example the experience of the USA and Spain (where a LTO/PLEX program is well established), Hungary, and Finland (where a PLIM model is in place at the Loviisa NPP) are a confirmation of this generic statement: all these countries modified their regulatory requirements or practice on maintenance, in the direction mentioned above, as one of the preconditions for the PLIM/LTO of their plants.

2.6 Support tools

As stated above, the implementation of a PLM program implies a heavy effort of coordination, automation, and homogenization among a large number of programs at the plant. Such an effort requires a valid support by dedicated tools in order to be effective. Many Countries and plants developed tailored tools for the PLIM, at different level of details: some covered only the asset management of the plant, some others include many processes, such as those maintenance related and ISI.

The experience of selected Countries is shortly presented below.

In the Czeck Republic (at the Dukovany NPP), a special tool was developed to support the integrated analysis of technical and economical (TE) databases [10]. The application has three main modules:

1. Evaluation of described cost drivers (according to the IAEA [33])
2. Planning of the implementation of modernisation measures
3. Data exports for presentations and other evaluations

Cost parameters were determined using economical model developed from the following inputs:

- Necessary measures costs from the Technical part of the study.
- Transformation of these costs to a required format through the use of the accounting system developed by the IAEA [33].
- Normal plant operating costs, such as fuel, labour, materials, insurance and decommissioning
- Other necessary estimations of market developments as predictions of electricity prices.
- Prices of CO2 certificates and different methods of their trading.
- Discount rate.

More comprehensive tools are in use in many Countries, with some local adaptations (customization) of commercial software, such as Maximo [34] or Indus [35]. They show a full integration (see Fig.8) of many basic processes at the plant, including both technical and economical issues. Fig.9 shows some of these processes.

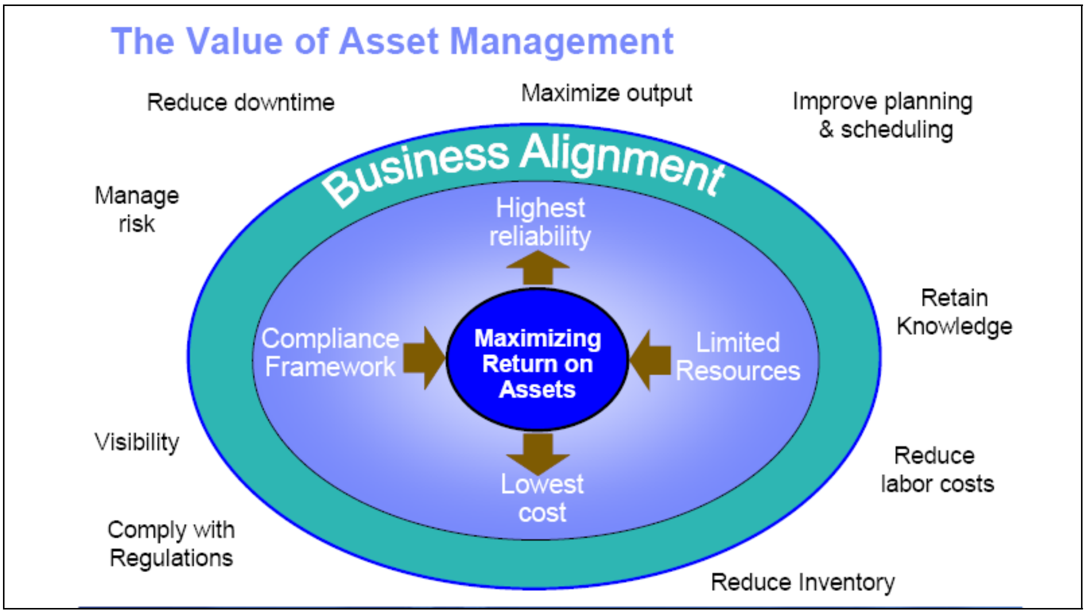

Figure 8 – Maximo integration of modules

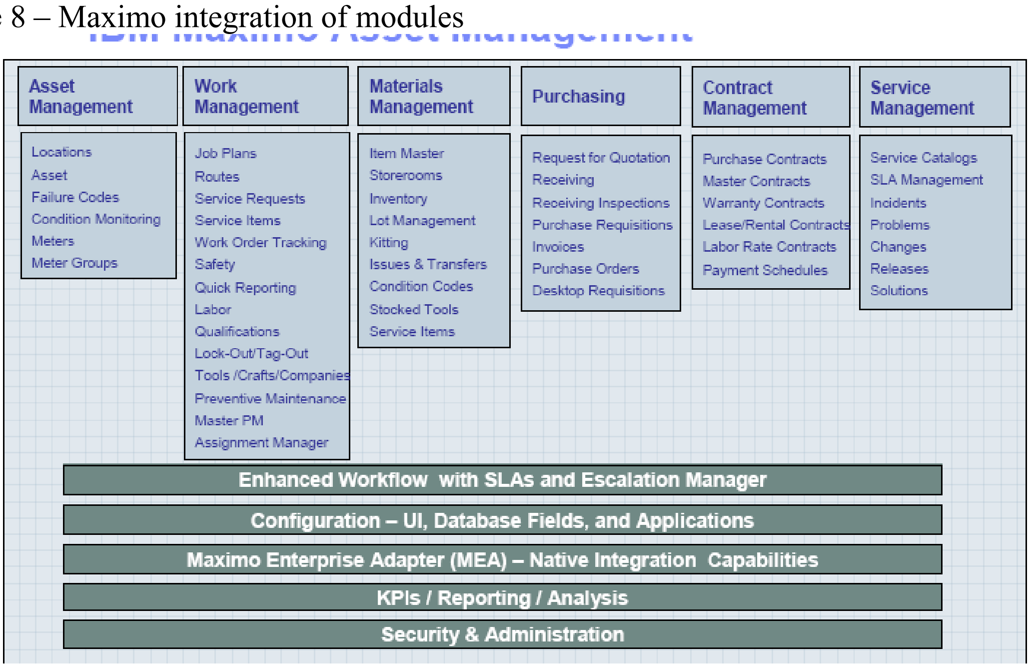

Figure 9 – Maximo main processes

An other sample list of the functions managed by one of those systems is shown in Fig.10.

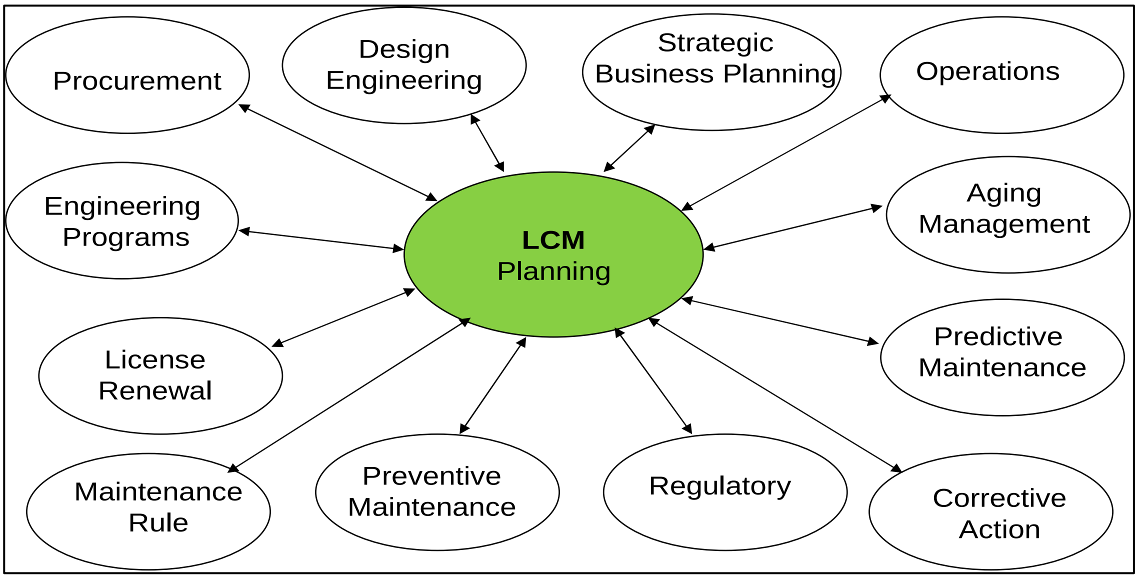

Figure 10 - Ventyx basic modules and functions

More in detail, the data processed by those systems are listed in the following:

Asset data:

- Functional structure (tag), description, specification, aging parameters, failure codes, compatible, material, vendor, spares, documents, drawings, procedures…
- Nuclear specifics: Tech Specs, LCO, Plant mode, Unit condition, Regulation requirements, RWP, ALARA…

Work activity data

- Maintenance / inspection plans, work procedures, outage plan, compliance, roles and activities, Personal Qualification (PQD)…

The sub programs typically addressed by these systems are listed in the following:

- Preventive Maintenance
  Manage the preventive maintenance tasks providing tracking, reminding and escalation for tasks key to equipment reliability and safe operation Optimizing the grouping of different PM tasks

- Inventory management and order processing
  Automatic re-ordering of parts and tracking of the order approval processes and notifications when delivery time is exceeded Historical data on parts usage and suppliers performance

- Management of subcontractors and service providers
  Definition, ordering and tracking of tasks assigned to third parties

- Commitment tracking
  Assure traceability of actions decided or committed
  Captures review comments applicable to the commitments

- Surveillance testing
  assure that key regular checks are done on components
  Optimized scheduling within allowable schedule windows

- Calibration
  Storage of calibration data

- Vendor qualification
  Only parts coming from certified vendors can be purchased
  Provide tracking of supplier certification and audit

- Equipment reliability
  Capture data supporting equipment reliability management and analysis
  Supports decision making based on equipment reliability

- Ageing management
  Ageing Evaluation criteria programs,
  Monitoring solutions for critical components,
  Analysis and decision tools like analytical programs that assess material degradation and fatigue due to thermal cycling, reactor trips, finite elements analysis tool…

- Human resources
  Checks the qualification of workers for every assigned tasks

- Configuration control
  Provides management accountability for preparation, review, approval application, modification and restoration
  Automatic grouping of working orders within common clearance boundary
  Support independent verification of component positioning

- Impact plans
  Checking the impact of maintenance tasks on tech. specs for planning of post maintenance tests and checking violations of LCO

- Equipment corrective action program
  Identification, tracking, analysis and correction of equipment defects
  Analysis of recurrent defects

- Integration
  Integration with external systems such as chemical analysis and radiation protection
  Support of mobile devices
  Management of pre-defined approval processes
  Reduce administrative costs

Most of the systems rely on such models like the standard Nuclear Performance Model (SNPM) developed by NEI/EPRI [36], sketched in Fig.11.

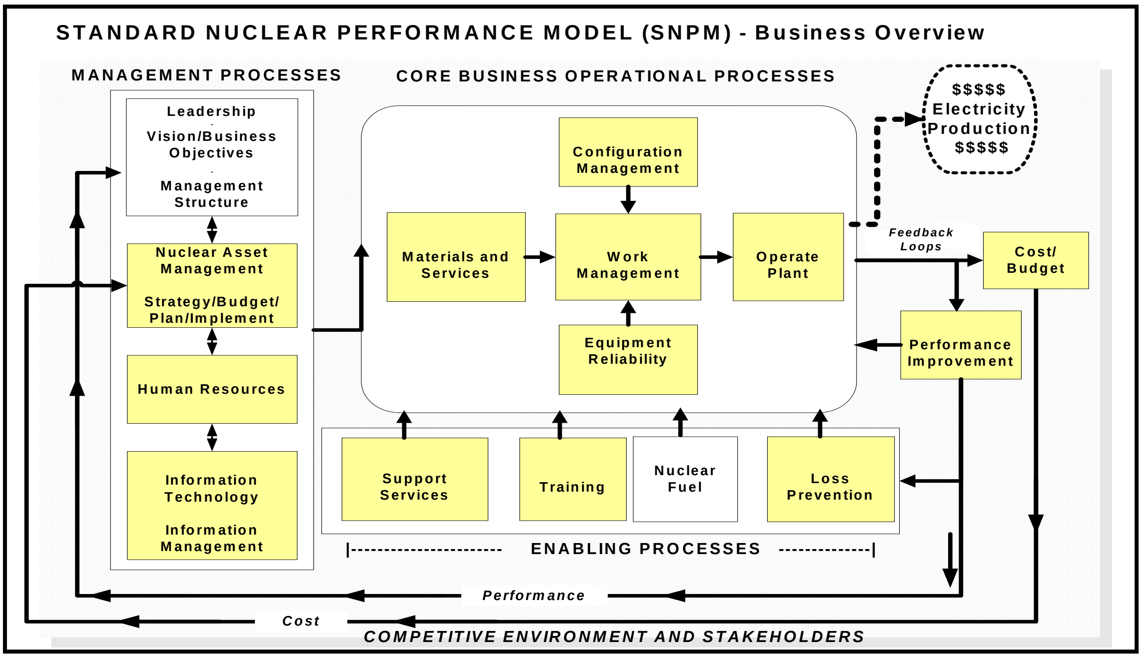

Figure 11 – EPRI/SNPM process model

2.7 The regulatory review of the PLIM programs

On the issue of the regulatory review of the PLIM programs, the widest differences among the Countries' practice was recorded. In fact, while in some Countries the PLIM issues are not transferred to the Regulator, in other Countries important regulatory decisions, such as the operating license renewal, are carefully reviewed and assessed by the Regulator. Often, the Regulatory review has different levels of detail for the different sub-programs involved, such as LTO/PLEX, AMP, TLAAs, etc.

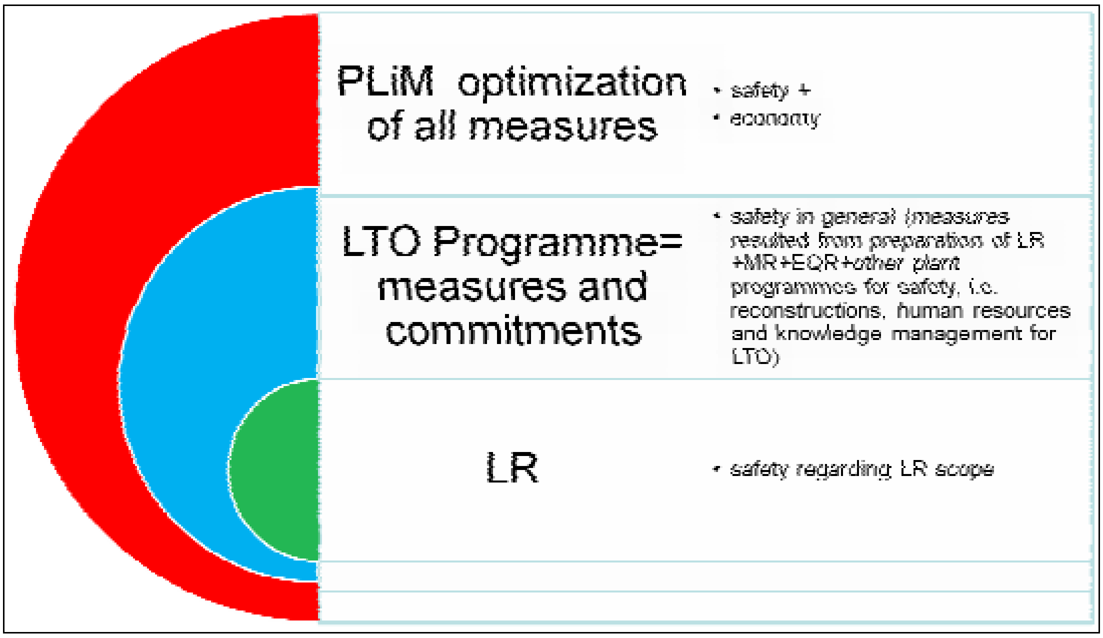

Figure 12 – Relationship between different review programs at the NPP in Hungary

Some examples in the following show the highlights taken from the Hungarian and Canadian practice.

In Hungary, the relationship between programs and sub-programs is shown in Fig.12 [9]. The scope of the regulatory review is highlighted in Fig.13, where all steps of the LTO/PLIM are carefully reviewed.

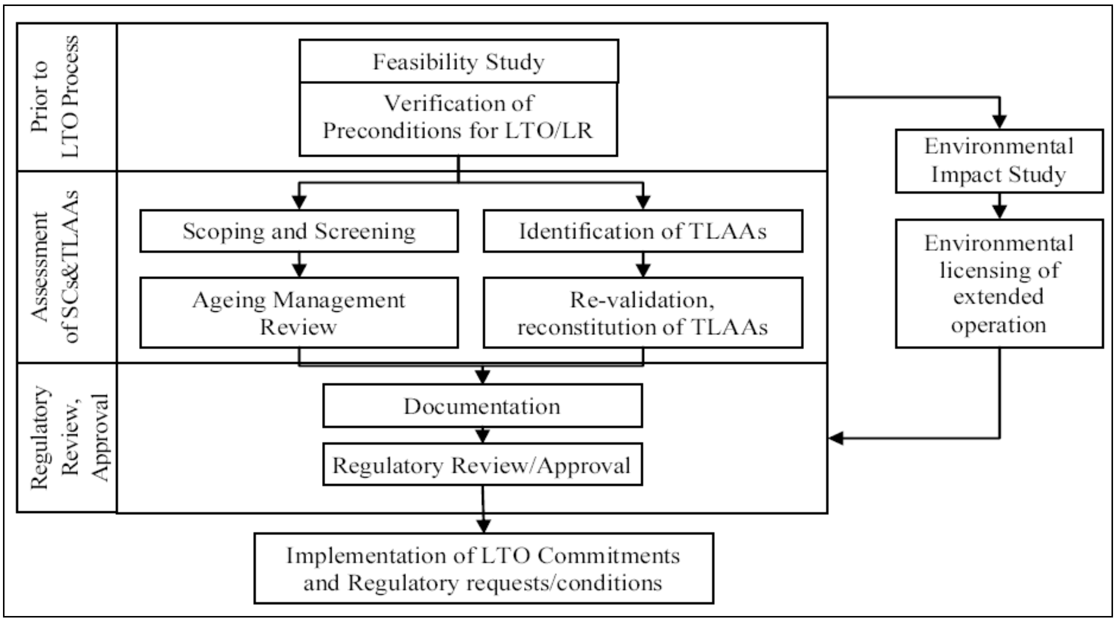

Figure 13 – Detailed scheme of the PLIM regulatory review steps in Hungary

In Canada the regulatory review of the AMP is the result of an integrated safety review (ISR) of plant conditions, aiming at assessing the following:

- The actual physical conditions of the SSCs
- The understanding of the ageing mechanisms and their effects
- The consistency between ageing trend and predictions
- The identification of the life limiting issues
- The existence of adequate margins to ensure safe operation also for extended plant life
- The effectiveness of the supporting programs such as chemistry control, MS&I, etc.

2.8 PLIM at the design stage for the new reactors: AP1000 and EPR

The comparison of the approach to PLIM among other technology areas suggests some interesting considerations. For example, in the aerospace industry the maintenance program (considered one of the most crucial component in PLIM) is optimized at the design phase, due to the large number of identical aircrafts; in the nuclear practice, time is needed to accumulate statistics and to develop confidence in the optimization procedures.

However, it is common judgment that PLIM should be applied since the design phase of the NPPs, possibly based on the lesson learnt from the operating fleets. In this sense, practice could be assimilated to that in other industrial technologies, as mentioned above.

Up to today, the development of standards and design rules for the new generation reactors is lagging behind. This delay also makes the certification of the new reactors quite difficult. At the same time, also the safety assessment methods and the QA rules for construction and operation need to be revised. The role of both licensee and regulators is still to be defined in many countries.

This generic statement is applicable also to the PLIM relevant aspects which do deserve an early understanding at the design phase. In particular, ageing considerations should be addressed since the design stage, for example providing inspectability, replaceability, and access to the most sensitive components and a solid basis for the control of their degradation.

Ageing should also be addressed since the beginning of operation in order to make available a broad range of data for trending and optimisation.

In particular, the following PLIM/ageing relevant issues should be addressed in the pre-design or pre-licensing phase of new reactors:

- Choice of materials
- Major drawings
- Operating conditions
- Collection of relevant data
- Monitoring, surveillance
- ISI : inspectability / access
- Radiation protection of workers

For example, in the Areva/EPR, the following design actions were taken in order to improve the PLIM performance [37]:

- Accessibility of the reactor building during normal operation to perform maintenance tasks and inspections, but also to start refuelling seven days before reactor shutdown and to continue demobilisation three days after reactor restart
- Improved main coolant loop cool down, depressurisation and vessel head opening after shutdown bringing the standard outage time to 16 days.
- Very low radiation level to workers
- Some modifications in SG or Pressurizer or RVI
- Improvements of nozzles and tees for thermal fatigue reduction
- In general FU factors have to be less than 0.5 for limited ISI in Operation

In the Westinghouse AP1000 [38] the following design actions intends to address the PLIM issues:

- Large use of passive features, also to reduce MS&I tasks
- Variable speed in the reactor coolant pump, to shorten startup and shutdown
- Special design of the digital I&C which reduces the I&C surveillance testing
- Large use of component standardization to reduce parts inventory and training

- Built-in testing capabilities is provided for many critical components
- Easy access for MS&I tasks and lifting devices
- Few nuclear grade equipment
- Very low radiation level to workers

2.9 R&D needs identified by the engineering community in relation to PLIM

As a spin-off of the survey, all the international events mentioned above highlighted that maintenance optimization, ISI, engineering programs (e.g. plant upgrading) and human factors are indeed the crucial issues needed to be addressed in a PLIM context. In fact basic research in component integrity, such as RPV degradation, I&C obsolescence, cable ageing etc. is still important, but a more urgent effort is now needed in the scientific community in the development of more general guidelines and requirements, able to keep both the overall safety and economics of the facility under daily control.

To this concern, huge effort is in place in many countries and international organizations starting from the collection of the operating experience and the analysis (and dissemination) of the relevant lesson learnt, to the identification of component reliabilities, control of the human factors, improvement of the safety assessment methods, quality of the inspections, etc.
However, in relation to the analysis of the operating experience, most of the relevant databases still show too small record number for the analysis of component reliabilities, though they are suitable for the analysis of the lesson learnt.
Moreover, the use of non-nuclear data still appear improper, as the design, construction and operating procedures for the non-nuclear industry are too far from the nuclear ones, making the comparison of the failure rates absolutely misleading.

As a consequence, it was pointed out in many recent occasions that a significant R&D effort is still needed at three levels:

1. The large uncertainties still affecting the ageing control on SSCs could be reduced with the help of innovative inspection and maintenance approaches integrated with adaptive ageing management program (i.e. open to new degradation mechanisms which may surface or be detected after the onset of the program). In this framework, also the sharing of experience, the analysis of operational feedback and the international connection may provide invaluable contribution). The improved knowledge in component degradation mechanisms should bring to an evaluation of the component reliabilities, for all components affecting the plant safety (mechanical, civil and electric).
2. In the field of MS&I, develop advanced techniques for integration of maintenance and in-service inspection (ISI) programs into broader approaches to plant asset and safety management. The research should address:

    - Maintenance related issues, built on the SENUF experience, in relation to operational performance indicators, reliability centred methods, and operational plant life management

- Effectiveness and efficiency of ISI programmes and strategies, specifically inspection qualification and Risk-informed ISI by investigations into all RI-ISI relevant aspects influencing the components probability of failure and consequence of failure; evaluation and estimation of NDT systems reliability through the qualification process, benchmarks and quantitative modelling; experimental studies and development of non-destructive testing (NDT) methods for selected safety significant components.

3. In the field of organizational issues, address new organizational models optimally integrating operating cost optimization, safety and asset management, safety culture issues, recovery of the operational experience feedback, safety performance indicators, knowledge management issues, effective control of external suppliers, control of organizational changes, and man-machine interface issues, to the extent needed in order to develop models and techniques for state-of-the-art safe plant management. This last group of issues is in strict connection with the precedent group and should aim at the development of appropriate organizational models which optimize operational costs and reduce the effects of human factors, still very significant in the operational records and feedback analysis.

3 The Maintenance optimization problem

3.1 Setting the problem

As stated in the previous chapters, the implementation of a Maintenance Optimization (MOPT) program is a sort of pre-condition for a successful PLIM. Maintenance program still represents a large portion of the operating budget of a NPP and therefore one of the areas where optimization is most beneficial. In detail, 75% of the maintenance hours are spent on preventive M and 25% in corrective: the former program is where optimization is more beneficial.

MOPT is very often connected to the outage planning and minimization: 2 days of business interruption represent in fact 10% of yearly MS&I costs (~1-3 Meuro/day) [8]. Moreover stretching the interval between refueling outages may have a high impact on PLIM in general and MOPT planning in particular: very long intervals (>24 months) may cost a lot on fuel, while too short intervals may cost in terms of plant availability factor.

The rationale for MOPT is stated in previous JRC-IE studies [1,5,6] and are not repeated here, where only the implications at the PLIM level are discussed.

In the PLIM framework, most of the Countries make reference to well consolidated M schemes, such as RCM, PM, etc., which answer to the following needs [5]:

1) Need to control the maintenance cost, particularly in liberalized energy markets, through reduction of unnecessary tasks and optimized maintenance periodicity
2) Improvement of plant safety through better scheduling of maintenance activities
3) Optimization of the management organization, more suitable to control

plant safety
4) Development of pre-conditions for the plant life extension [2]
5) Support the production through minimization of outages duration and optimized work control
6) Minimization of the radiation doses
7) Optimized integration among existing safety programs, such as: ISI, AMP, configuration management, design basis reconstruction, etc.

Thanks to the large survey on Countries' practice carried out through the organization of many international events, it was possible to summarize the most relevant aspects of some Countries' practice in the field of MOPT, as collected in the next chapters.

3.2 Countries' generic experience in maintenance optimization

Spanish model
In Spain, MOPT is based on the US practice and regulations. It represents the integration of the following different programs:

1. Reliability Centred Maintenance (RCM) as plan of the preventive M. Predictive M has the priority on preventive. Reduction of 30% on the man hours

2. Maintenance Rule (MR) (according to the US 10CFR 50.65): risk informed and performance based

3. Risk monitor: it supports the full implementation of the MR, for the on-line maintenance. For the off-line M the shutdown PSA is available

4. Risk-Informed In-Service-Inspections (RI ISI). It is applied to piping of Class 1 and 2, with 75% reduction of the inspection effort, keeping the same risk

5. RI ISTesting. Applied to valves and pumps, to reduce doses to personnel. No impact on cost reduction

6. Motor operated valves performance program

The equipment reliability program (INPO AP-913) is also in place in Spain, though not compulsory. It integrates the existing programs and optimizes costs and safety in a typical PLIM framework.
It applies full performance monitoring to few components (Cat1). Cat 2 includes only components which may induce operation transients. Cat 3 includes the passive components.
The equipment reliability (ER) program is the last step of a complicated history of methods and requirements, as shown in the following fig.14 [8].

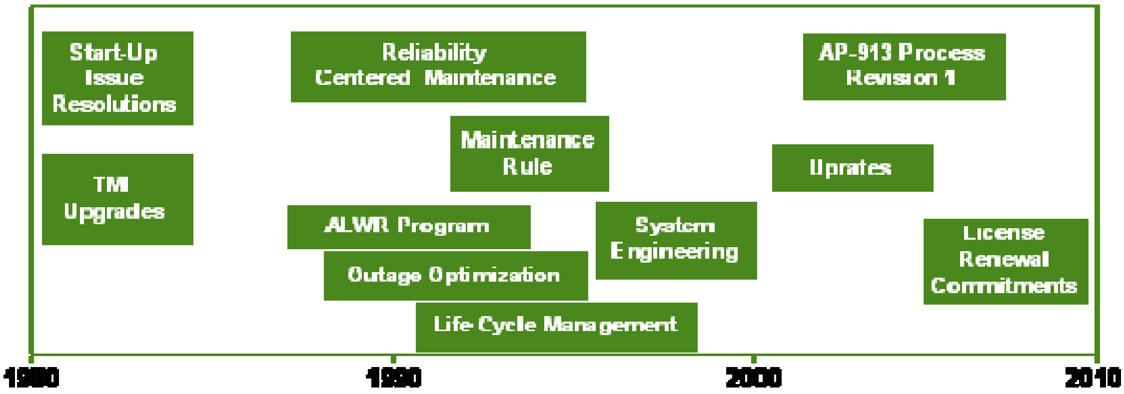

Figure 14 – Historical development of the US component reliability program

ER adds few tasks to MR: M effectiveness control, ER coordinators and committees, system engineers, etc.
In Spain the RCM/maintenance optimization led to the results shown in Table 1 [8].

Table 1 – Spanish experience in the application of MCR

GLOBAL RESULTS FROM PHASES I AND II IN A PWR								
	Analysed components	Critical components	Former tasks	Final tasks	Former hours	Final hours	%Tasks reduction	%Hours reduction
Phase I	5,226	1,017	2,798	1,889	8,140	6,306	32%	23%
Phase II	10,218	3,264	5,213	3,151	15,940	12,898	40%	19%
Mean	15,444	4,281	8,011	5,040	24,080	19,204	**37%**	**20%**

Slovakian model
Through the application of RCM, the saving was 10-40% of maintenance costs per system, per year.
The risk monitor was implemented for full power and shutdown, at PSA level 1 and 2. It is available in both control room (for safety control) and at the maintenance dept. (for maintenance planning).

German model
The main objectives of the MOPT are: improve plant conditions, quality and effectiveness of tools and resources, integration of maintenance history, diagnosis data and design data, reduction of preventive maintenance (based on engineering judgement only), condition monitoring (only as confirmation of the engineering assumptions on optimal maintenance intervals). The approach is mainly deterministic and experience based.
As a result for example at Neckarwestheim NPP, also the outage interval was reduced to 6 months, but with very short outage time (6 days). The refuelling outages were reduced from 34 days to 16 days.

The availability of qualified suppliers and appropriate spare parts are the most important constraints for the outage planning. Job control is the main issue in MS&I execution.
In relation to MS&I planning, the following issues are considered as the most relevant: dose minimization, industrial safety, fire protection, equipment damage, loose parts, system isolation procedures and post maintenance test. All aspects are reflected in the work permit.
The MOPT is assisted by computer controlled work flow: only the authorised person clears the order. This approach led to a drastic reduction of procedure violations.
Computers control also the tagging of the isolated system, including the relevant I&C items. The SFW systems becomes safety related, but it is worth.
Detailed analysis of the compatibility of the different work packages at the place of execution.

Bulgaria
The application of RI ISI is carried out on piping only. PSA level 1 and 2 are used to identify the most critical piping branches (in terms of potential consequences from failure) to assign the inspection areas.

Romania
Risk monitor is implemented in the control room for operator control and MS&I planning.
The SFW for work control manages the work-flow: issues work request and permit, manages performance indicators and the reporting to the regulator.

Czech Rep.
Large use of PSA for risk monitor, MS&I planning, support to short term exceptions to the plant technical specifications.

As summary of the Country practice in the field of MOPT, a quick questionnaire was run at one of the above mentioned events organized in 2007 on maintenance optimization issues. The result is summarized in the following table 2.

Table 2 – Summary of the experience in selected European Countries on specific PLIM related issues

Country	Type of non-time based M	Its scope (n.of systems)	M Optimisation process in place	Cost issues included?	Reduction in M cost after M optimisation	in CDF	in outage duration	SFW used for M planning/optimisation	Network of spare parts available	Indicators on M	Risk monitor available
RF – RBMK1000			plans					Desna / Primavera	Utility level	10	
Hungary	CBM	5%	CBM	yes	5%	no	40 - 28	Passport / ?	No	10	
Slovakia EMO	CBM	<10%	RCM - CBM	yes	10-15%	n.a.	45 - 26	Arsoz / Primavera	With Bohunice with big parts	30	Yes on living PSA
Ukraine			plans	plans				Primavera	no	no	
BG – VVER1000	diagnostic	Circ. Pumps, containment, etc.	plans	no			51 - 45	Primavera	With Temelin	Not sistematically	no
CR - Dukovany	CBM		Adaptive maintenance model,RCM, cost benefit, use of PSA etc.	yes	?		Overall decrease 48% in outages duration From 2 to 3 types	Passport / Primavera / MNT Graph, use of Safety monitor system		yes	Yes on living PSA
Cernavoda	CBM	50% (all safety related)	CBM analysis	No, plans			32 – 22, plans for 20 (every two years)	Passport	Few cases with Candu owners	10	Yes based on living PSA
Lithuania	CBM	<10%	CBM analysis	no	10%	no	10%	Fobos (IFS) / Primavera	no	~15	Yes, only for pipes (300 mm), main circulation circuits

In addition to that, Ukrainian, Slovenian, Czech, Russian representatives expressed in many occasions [5] their interest to adopt a MR-like approach in their Countries, even starting on a voluntary bases, most probably closer to the ”equipment reliability” model (INPO AP-913, [38]). Many of them already created some training centers which are developing procedures in this direction.

In conclusion, in relation to the operating cost reduction as a consequence of a kind of MOPT , the following reductions [5] in maintenance costs/tasks were recorded:

- In SWE, 10 - 20% of the effort, especially for I&C calibration intervals
- In SP, 20% in work, 30% in number of tasks
- In HUN, expected, not quantified
- In CZ, 30% on a restricted number of systems selected for a benchmark (according to the implemented Phare project in Dukovany NPP)
- In SKR, expected, not quantified.

It was noted that the “equipment reliability” program is not mandatory in most of the Countries (including the US). However, it is gaining growing interest for its systematic approach to the management of the plant safety. In particular, the correlation among the many existing safety related programs and the consistent classification of items (important, critical, run-to-failure) seems to be very attractive and practical.

3.3 The objectives of MOPT according to the Countries' experience

There is quite a large consensus among European Countries that the objectives of a MOPT program should be the following:

- Minimize overall operating costs; optimize cost spending in the tasks where it is more beneficial
- Maximize plan availability, reduce forced outages (i.e. improve plant reliability) and minimize outage duration
- Maximize safety and minimize plant induced risks to personnel (doses), public and environment
- Provide evidence on plant safety and control it in time, also in view of PLIM and PLEX
- Maximize public acceptance through plant availability and component reliability

3.4 The MOPT scope according to the Countries' experience - Affected items and their classification

In relation to the scoping process applied in the framework of MOPT, it was noted that the approaches are quite different in the European Countries. For example:

- In Sweden RCM is applied only to non-safety related SSCs. Safety SSCs are analyzed only to get a documented base for the preventive maintenance (PM) program. Analyses of safety system seldom result in any changes of the existing PM-program. The process to get a change of the Technical Specification requirement are very strict and in most cases not worth the effort.
- In Hungary RCM is applied to 70% of the safety related SSCs and to 30% of other systems
- In Slovak Rep. RCM is applied to 44 systems (100-500 components) selected on the basis of different criteria, including safety significance.

In general, it was noted that the MOPT scoping ends up with the items with high safety/availability/cost importance, evaluated according to PSA and analysis of the reparation cost. Therefore, not only safety relevance is the scoping criterion, but also availability and cost of repair/replacement.

3.5 Optimizing the maintenance strategy

The generic issue behind the MOPT program is a very basic dilemma: "Good maintenance with high costs and low probability of M-related events, or "bad" maintenance with low costs and high probability of M-related events?".

In general MOPT implies large investment in training, tools, risk analysis integrated with cost analysis and other tasks that may turn onto extra costs if not properly managed. It is general consensus that a proper MOPT program has two major components, namely:

- Accurate MS&I planning, execution, reporting, feedback, process monitoring and continuous adaptation. Optimization relies on reporting and feedback. Self-assessment is a key process.

- Finding the optimal mix among RCM, adaptive, preventive (PM) (time based) and condition based (CBM) (actually AMP based) approaches. In some countries, corrective M is on 70% of the components, the remaining part is on CBM and PM.

In particular the preventive, purely time based, maintenance and the corrective approach (typically run-to-failure) do not need explanation. Very common in the European practice are the following mixed strategies [8]:

- Reliability Centered Maintenance (RCM): it is a sort of predictive approach, based on extensive use of monitoring. Its main features are:
    - approach by component safety functions
    - Cost control
    - Staff involvement
    - High implementation costs: about 1000 hours per system
    - It concentrates on failures and not on degradation

  - It needs a lot of data on component failures for a good statistics and therefore it is valuable only for large utilities
  - Excellent for the document control

- Adaptive Maintenance: it is a sort of predictive approach, where failure and costs are analyzed. Its main features are:
  - Analysis of the cost of failures on safety and costs
  - It controls the consequences of failure in terms of production loss, repair cost, cascade effects & personnel safety
  - Probabilistic based and engineering based

- RI-Maintenance: it is a predictive maintenance based on the analysis of the consequences of potential failures. Its main features are:
  - The scope is very limited: only selected items, safety related.
  - It calculates change in plant risk (CDF), plant availability and cost savings when PM intervals are extended and postulated component failure rates changes as a result
  - No cost considerations.
  - It is difficult to define acceptability levels for Delta CDF

- Condition based, AMP based. It represents a predictive model with the following main features:
  - It focuses on degradation mechanisms and identifies the relevant diagnostics
  - It is based on engineering judgment and no component reliability data are needed
  - It does not include cost considerations and it addresses only safety related components and the potential consequences from their damage on safety
  - It may require complex monitoring and it may provide data which are difficult to correlate with the degradation
  - Only degradation mechanisms which can be monitored are really included
  - The maintenance planning sometimes is difficult as it has to wait for degradation effects.

A decision making flow chart was recently presented by some Finnish representatives [31]: it is shown in Fig.15.

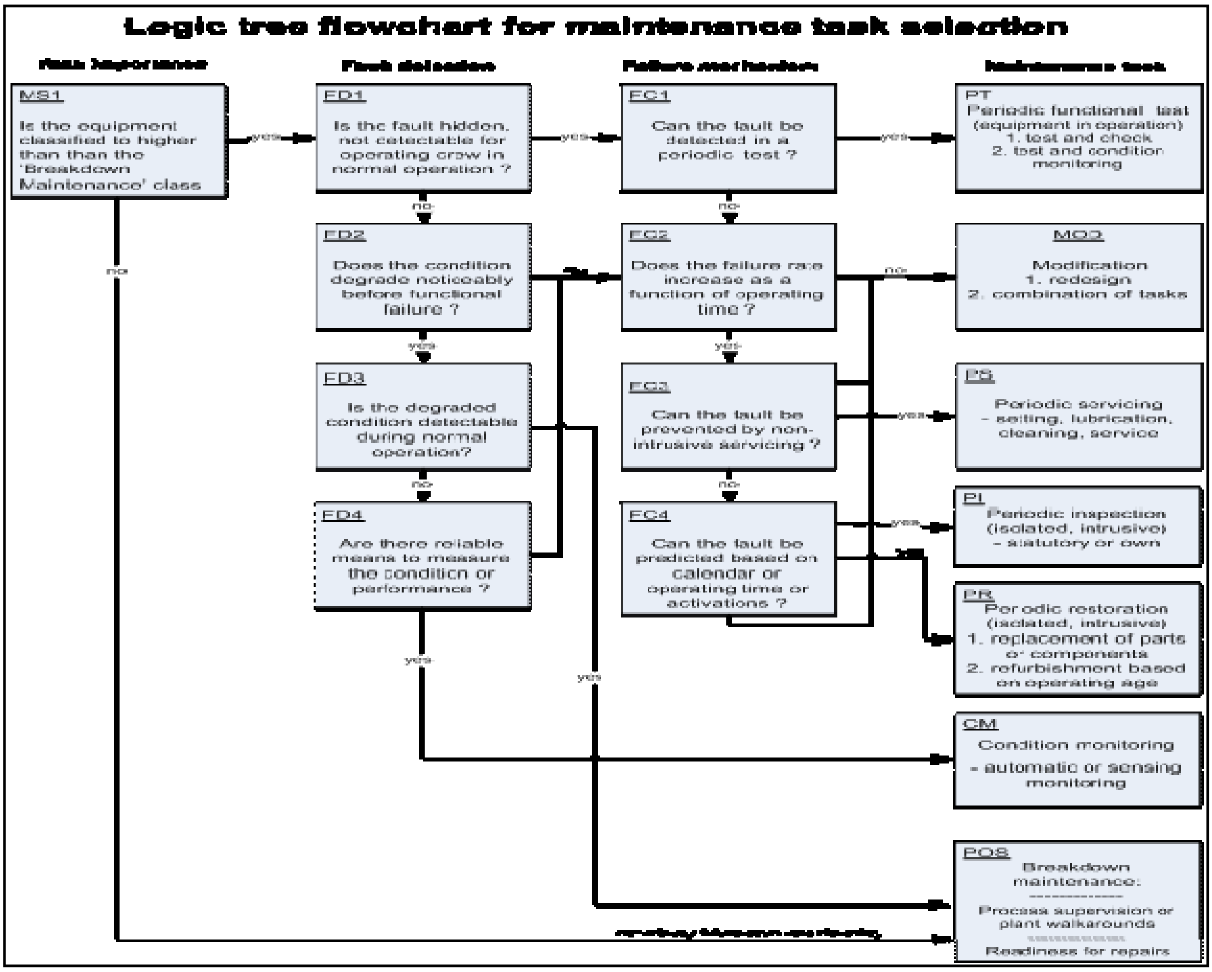

Figure 15 – Loviisa experience in maintenance optimization

3.6 On-line versus off-line maintenance

The experience of the European Countries in this field is quite heterogeneous: decision on on-line versus off-line maintenance is often taken on the basis of economic considerations only.
The example of the German practice is a typical lower bound of this range: on-line M usually accounts for 10% of the total M tasks, and for 50% of the mechanical components. It is believed that shifting tasks from off-line to on-line M does not reduce the overall outage time, as the items on the critical paths (I&C, electrical, heavy equipment) cannot be subjected to on-line M. A significant advantage of the on-line M is the optimization of the availability of "good" contractors and their more relaxed work schedule (typical for diesel engines and items outside the containment).
In addition to that, on line maintenance is allowed only 7 days/year per train [8]. For longer periods a PSA is needed. Post M test are different between on-line and off-line M. In case of M issues discovered during on-line M, often a shutdown is required to check the existence of common cause failures (CCF).
In conclusion, it seems that economic and design considerations are more relevant in this decision than purely safety considerations. The issue is covered in more details in the chapter on the maintenance oriented design for innovative reactors.

3.7 Human errors

Recent statistics carried out in the USA (INPO) [5] show that 40% of the failures at US NPPs are related to human factors: among them, 30% are related to engineering deficiencies and 30% to work performance during maintenance.
An other interesting conclusion is that most of the significant events in the latter category have been triggered by the supplemental workers. Therefore the human in general and the contractor performance in particular become a crucial issue where many utilities are investing large effort for their reduction.
Also supplier reliability is an issue: in many cases equipment were delivered with wrong or different specifications.

It was noted by many participants to the above mentioned International Events that human errors and their minimization still lacks good models, including contractor performance, training effectiveness, work control, etc.

In particular, among the effects on the equipment recorded by some researchers [8], the following was noted (errors of **omission**):

- Restoration errors of operability after work, such as omission of the realignment of process or instrument valves, disconnectors, breakers, fuses, limit settings or blockings. Omission of refilling of fluid or gas into lines, tanks or draining at the end of work,
- Disconnected cables or electronic components not reconnected, settings or adjustments omitted during work. Omission to install packing, adjusting device or protection pipe. Omission of a preventive maintenance or inspection task.
- Foreign objects or impurities left behind inside the object of the work. Examples are dirt, garbage, metal shives, tools, scaffolds or covering material.

Among the errors of **commission**, the following was recorded:

- Wrong order or direction,
  - Wrong order, such as cables or instrument pipelines crosswise connected,
  - Wrong direction, such as reversed or twisted installation of valve or another sub-component. Wrong positioning of valve.
- Wrong selection,
  - Wrong place or object, such as cabling fixed on wrong connection, setting of wrong tripping conditions, or draining of wrong pipeline. Item installed on wrong equipment place.
  - Wrong or mixed spare parts, parts, materials, tools, fluids, or chemicals selected for work. Spare part, equipment or material or function deviates from design.
- Wrong settings/adjustments/calibrations,
  - Wrong settings of trip limits, limit switches, reference, indication or time delay values, or of adjusting devices. Deficient alignment of shaft, stem/spindle or pipe. Wrong setting of pipe support or packing.
- Other maintenance quality problems,
  - Too little force, e.g. loose connections of bolts, nuts, cables, terminals or sensors,
  - Too much force, e.g. excessive tightening or greasing,

- Damaging other equipment e.g. cabling, cable trays or small diameter piping by falling material or slugging/contacting. Can be due to carelessness and narrow spaces for work or transport.
- Other carelessness: e.g. worn tools, falling material, deficient weld, solder joint or insulation. Unclear trips initiated during testing, installation or maintenance. Wrong subtitling or recording. Wrong timing.

However, it is recognized that this special topic, though well linked to MOPT, deserves a dedicated coverage, which therefore is provided in the companion JRC-IE report [39].

3.8 Safety assessment and probabilistic tools

Probabilistic safety assessment is carried out in relation to normal operation and shutdown node. Shut down state accounts for around 100-60% of the CDF calculated in full power mode: in shutdown mode the contribution to the CDF from maintenance related activities is dominant through mechanism such as:

- Human errors
- Loss of Core Cooling (System loss)
- Loss of Power Supply
- Radioactivity bypass to the environment
- Load drops
- Fire
- Flooding
- Component damage
- Foreign Material Intrusion
- Interference (Welding, Testing)

According to many European Countries experience [8], main root causes for these potential events are:

- Tagging Mistakes
- Wrong System/component addressed
- Load drops or other interference to running systems
- Testing Mistakes (e.g. post maintenance testing)
- Human errors in general

In case the maintenance optimization is supported by the application of PSA models [6], the quality of the PSA becomes an important issue for the success of the process. As any PSA application, the maintenance optimization has crucial requirements for the PSA quality. Scope, completeness, modeling details and used data should be such that allow the PSA to be used for adequate support of maintenance optimization. In order to ensure an appropriate PSA quality, as minimum the following actions should be implemented:

- Use appropriate guidelines during development of PSA and review of PSA
- Involve both PSA experts and NPP maintenance staff in the development of PSA models
- Keep in mind the intended applications at the time of scope definition and if possible take into account the available standards.

- Perform PSA regulatory review before maintenance optimization is implemented.

Basically two guidance for qualification of PSAs for specific applications are available, namely: the ASME RA-S-2002 Standard for Probabilistic Risk Assessment for Nuclear Power Plant Applications and the IAEA TECDOC 1511 [40]. These documents facilitate determining how suitable a given PSA is for a specific application and in particular for supporting maintenance optimizations.
In particular, maintenance related special PSA needs may include the following:

- Separation of the maintenance related basic events in the component unavailability models, like unavailability due to repair, planned maintenance, test, human errors etc.
- Modeling of maintenance activities in each of the safety system trains to correctly reflect actual maintenance activities
- Use of more detailed reliability models for modeling of PSA basic events, e.g. to identify failure modes of components affected by different type of maintenance
- Additional special models to support ISI, On-line maintenance, RI configuration control, etc...

In addition, it was noted that risk monitor is a useful tool to support maintenance planning off-line and on-line restoration strategies in case of equipment failures during the plant operation. In any case risk monitor is not an M opt task; it is a tool to control risk during maintenance. In operation the priority with the TS has to be made clear in order to solve potential conflicts.
The techniques for the risk monitor during maintenance typically follow the NUMARC 93-01 [41] proposal. The use of panel of experts and/or PSA for the construction of the risk matrix or of the risk monitor (real time) are apparently the only two available techniques.

At last, some data bases are available on component reliability in Europe: for example the experience of DACNE for PSA failure probabilities and for MR performance criteria (by Tecnatom), the EPIX (by INPO) and the PKMJ (by EPRI). However, most of them remain country specific and/or restricted to the contributing users [5].

3.9 Indicators

Indicators of maintenance effectiveness should have generic attributes: they should be easy to calculate and should have clear corrective actions pre-defined.
Indicators may have different nature: maintenance effectiveness, production, plant availability

1. Indicators of status of components/systems: this is the so called "component health report"

2. Indicators of the efficiency of the process

Performance Indicators for maintenance effectiveness are considered very useful. However in many recent symposia it was recognized that some research work is still needed in this field. It was felt important for the International organization to provide assistance in this field and set up some benchmarking studies.

Maintenance performance indicators are typically based upon: ownership, time from exceedance of the performance criteria and setting of new goals, use of MR to drive performance, etc. Many Countries use the availability and reliability concepts defined in the MR also to monitor the performance of the ageing management programs (AMP).
The SENUF network developed a special set of indicators [42] under testing at many European NPPs, which is suggested to consult.

A special group of indicators are now made available on the "supplemental workers" and the "supplier reliability" in general, by INPO. They are recognized as very useful to monitor one of the main causes of deficiencies in the maintenance systems (they are included for example in the INPO AP-930 [43])

However, it is recognized that also this special topic, though well linked to MOPT, deserves a dedicated coverage, which therefore is provided in the companion JRC-IE report [44].

3.10 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 [8]:

1. Technical mission: anticipate and control the technical risks, capitalising 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 M optimisation, 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.

3.11 Support tools

As anticipated above, MOPT processes strongly require adequate support tools for an effective implementation. In particular these tools can support M operators in the collection of maintenance history, of data from diagnostics, of design data, propose a maintenance strategy, manage the event history, develop statistics, and issue updated drawings.

According to the European experience in some leading plants, the following figures may well show the effect of the adoption of such software tools [12]:

- Outage reduction from 36 to25-28 days (Seabrook NPP - USA)
- Backlog reduction from 350 to 50 work orders
- Workforce reduction from 800 to 650
- Reduction of forced shutdown events (Daya Bay NPP - China)

As an example, Fig.16 shows the main structure of a well known tool in use in Europe [8], where maintenance strategy, planning, work order management and documentation are inserted in a closed loop, heavily supported by IT advanced solutions (wireless, portable devices, etc.).

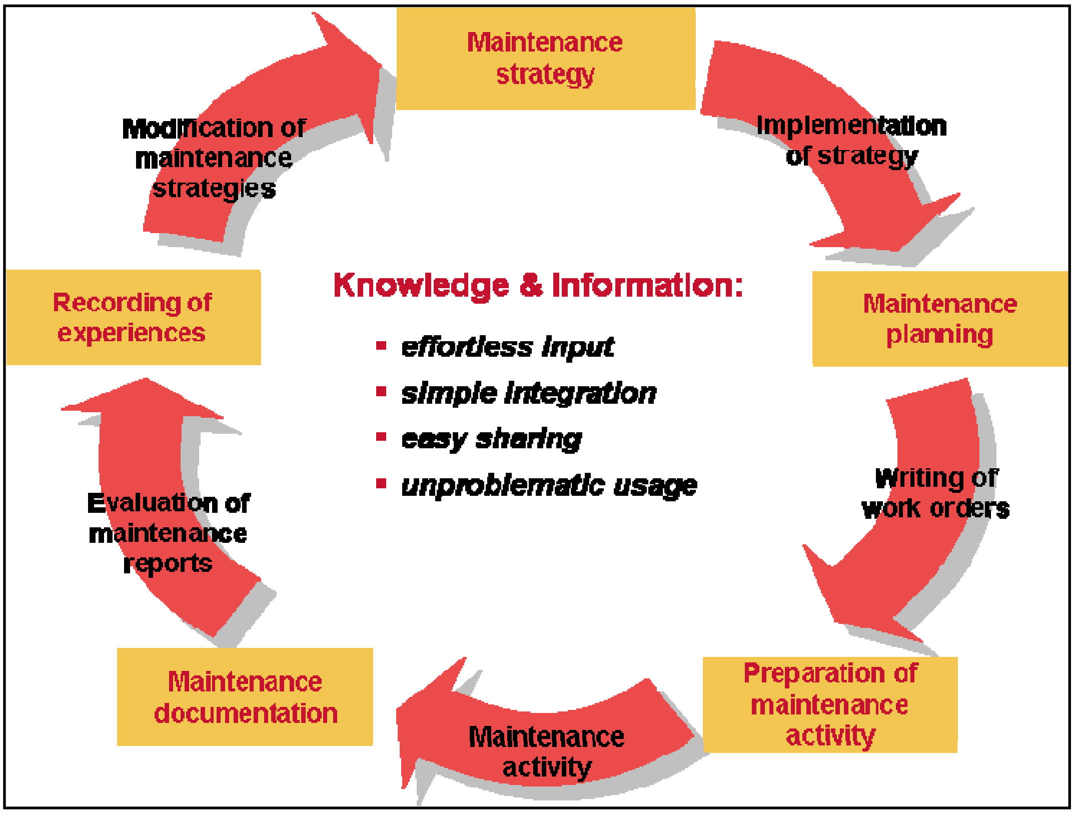

Figure 16 – Generic workflow of the Areva tool for maintenance (WIS)

3.12 R&D needs identified by the engineering community

The quality of the maintenance documentation was always recognized as crucial to feed a proper feedback mechanism, which represents the core of the MOPT process. The culture of communication (including the “no blame” culture) may also play a major role in ensuring all failure mechanisms have been properly identified and all actual equipment failures have been recorded. New methodologies to improve the quality of M would be welcome.

It was noted that in the current dynamic industry an optimized maintenance system should be adaptive. In particular mechanisms should be put in place to deal with configuration changes, changes of suppliers, emerging results from the aging management programmes (AMP), etc. At last, the need for implementation of a living RCM program under the responsibility of the system engineer was highlighted.

More in detail, the following difficulties and challenges were identified during the implementation of optimized maintenance systems in different EU Countries, identifying potential areas of R&D in the field of MOPT:

1) The implementation of the MR poses major challenges to the organization: in some cases the interfaces among existing departments were so many that new structures had to be developed. In other cases (Spain) the organization did not change at all and only the coordination was improved. Also in the US, the objective of the action was the re-definition of the interfaces. It was pointed out how the interfaces are very sensitive to the changes in plant configuration and should be promptly updated in such cases.
2) The development of suitable performance criteria is a crucial task. In Spain three years of historical data fed the statistical analysis, complemented by the PSA. In the USA the process was also reviewed by the regulator. The digital I&C cannot be monitored easily in time. Therefore the failure rate usually is provided by the supplier who can derive it on the basis of the whole population of the installed equipment.
3) There is no shared data base on maintenance among European NPPs. Only INPO and WANO provide a worldwide service to their members, though limited to some issues. There are confidentiality issues attached to it, national factors and plant dependent issues that still prevent such communication. Neither non-nuclear plants are involved in this exchange of experience. Some maintenance forum (such as EPRI/NMAC) provides a certain level of experience exchange, however again restricted to members.
4) The interfaces between ISI databases and MR databases are still poor, due to their history: ISI data bases are mainly related to passive components, MR to the active ones.
5) There are objective difficulties in the implementation of the RCM due to the required change in mentality of the personnel and amount of extra work in some cases (particularly when the RCM is not fully computer assisted)

As a consequence, the R&D tasks able to make the MOPT more broadly applied could be identified as in the following:

- Clarification of the reliability target for the different groups of components and reliability parameters calculation
- Integrated management of the data bases available at the plants: many sources of data are available at the plants (ISI, maintenance, AMP, PSA, operation, etc.) but often they are not integrated and they do not support an integrated approach to component reliability.
- Development of criteria for “good” performance of SSCs (acceptance criteria)
- Identification of representative maintenance effectiveness indicators
- Understanding of the impact of the RCM on the workforce: in relation to

different competencies needed and overall reduction of the workforce at the sites

- Comparison of the available methodologies for RCM: the available proposals are very much affected by the national frameworks where they have been developed. Benchmarking on selected systems and commodity groups would be very useful to this concern
- Derive failure rates for commodity groups (with some assumptions on anchoring, environment, etc.)
- Develop guidelines for training of personnel and use of training centres in the field of optimized maintenance programs oriented to PLIM.

4 A proposal for a PLIM model including maintenance optimization

4.1 Introduction

Previous chapters 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.
As a consequence, the JRC-IE researchers developed a preliminary version of a new PLIM model that they believe could 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.
The validation discussed in the following represents only the first step of a more ambitious program of validation/improvement that will be implemented in the course of 2008.
Some concepts are not copied from previous chapters into this chapter: therefore for application criteria and generic issues the reader is invited to read the previous chapters on the Countries' experience.

4.2 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.
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.

PLIM is not necessarily aimed at plant life extension, plant modernization (including power uprating), investment planning, licence renewal, periodic safety review or other specific programs (as it was the historic origin); it represents a framework where those programs may find data and results, but its main goal is the absolute integration and coordination of plant safety and economic issues for an optimised daily management of the plant assets.

4.3 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 (see Fig.17):

1. Nuclear safety and licensing
2. Production and economy (including fuel and waste management)
3. 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 uprating, fuel management may also be part of PLIM, but they are not necessarily implemented at all plants.
This concept is described in Fig.17, 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.

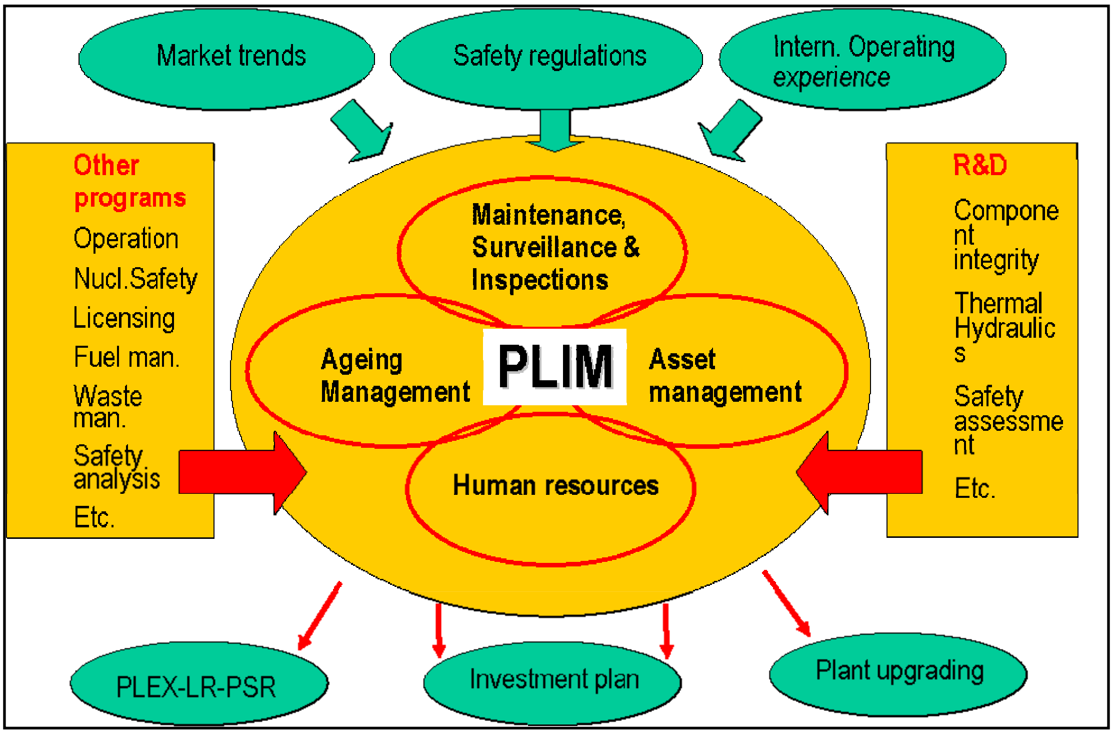

Figure 17 – Approach to PLIM and interfaces with related programs

These programs should also meet specific pre-conditions on their main features, as discussed at Chapter 2 and summarised in Fig.18.

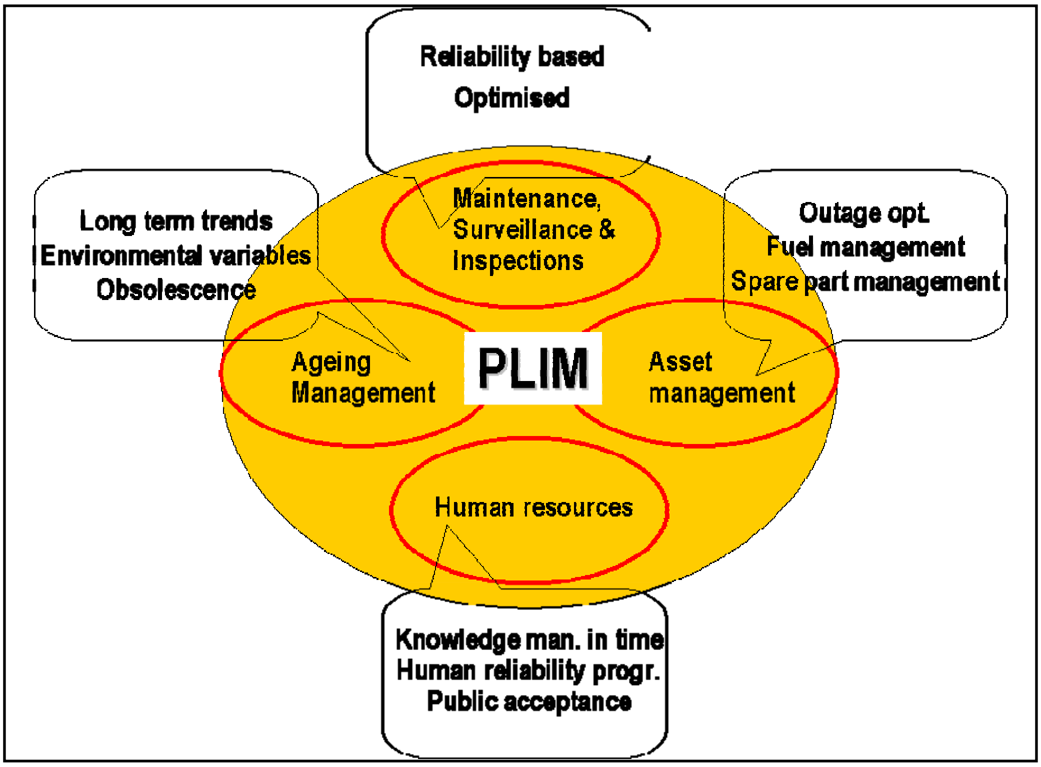

Figure 18 – Preconditions for the key programs to be part of PLIM

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

The close control on the component and structure degradation is summarised in Fig.19 [13], where the safety margin is highlighted between the growing stressors (due to degradation) and the lowering material capacity.

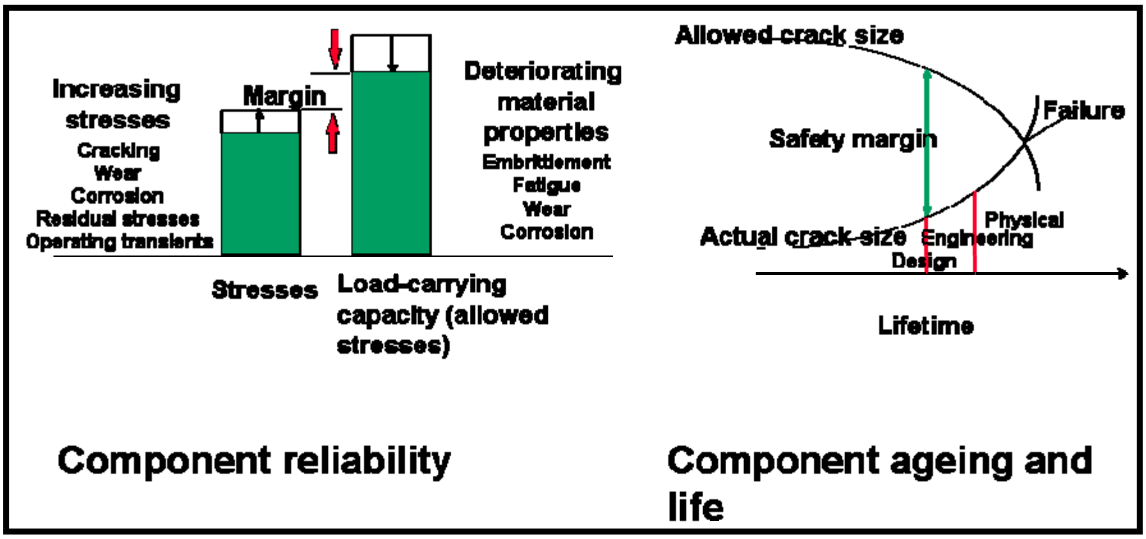

Figure 19 – Management of the component reliability

4.4 PLIM implementation issues

Suitable QA manual should define requirements for resources, procedures and actions needed to assure the optimal implementation of PLIM. A typical set of procedures regulating the PLIM tasks at the plant comprises the following:

- Classification of the equipment and systems (focusing of resource, research, investments etc.)
- Information and history data compilation, condition assessment, and investment proposals

- Development of procedures
- Meetings
- Documentations and reports
- Archiving.

PLIM should be based on an integrated archiving system for all the information of different nature (economical and technical), to be managed. Typically a large integrator system has interfaces with ageing management data, maintenance and surveillance data and economic data.

Typical yearly reporting includes the following:
- System specific reports on mechanical engineering
- Ageing reports on electricity and automation equipments
- Two load follow-up reports (operational events and temperature transients)

In relation to the assessment of the PLIM program, the following tasks represent standard practice:
- Follow-up meeting (twice a year)
- Review meeting by top management (once a year)

4.5 PLIM Scope - Component classification

A consistent application of PLIM suggests the use of a dedicated component classification, where safety, availability and cost issues contribute to form the criteria. All structures, systems and components at the plant, regardless of their safety relevance, should be covered by such classification.

According to the classification, a suitable grading of measures may be applied and therefore different levels of MS&I and AMP, economic analysis etc. may be assigned.

A proposal (see also Fig.20 from [13]) may group 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, feedwater 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.

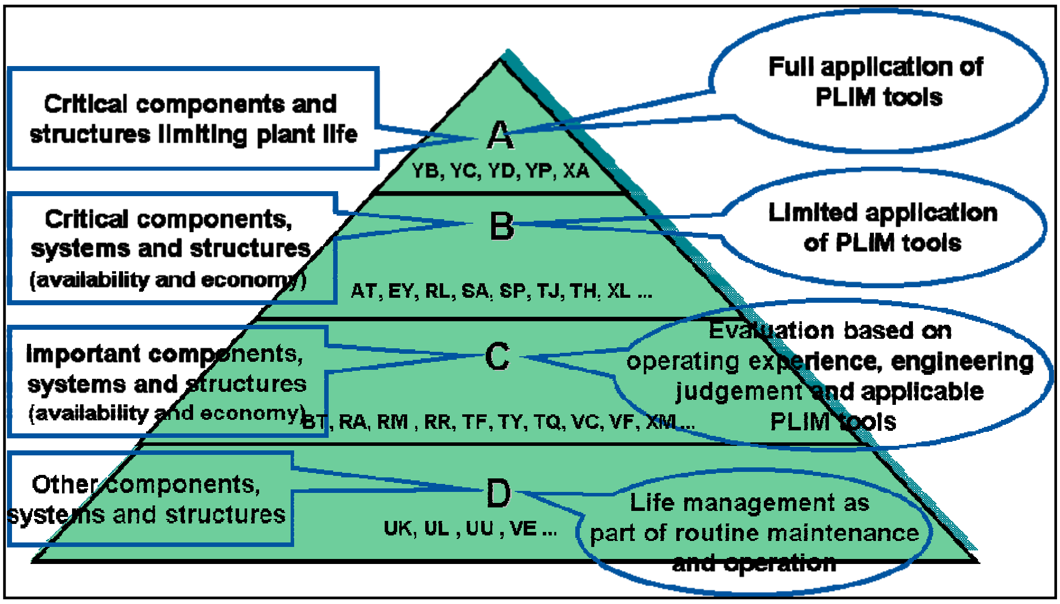

Figure 20 – proposal for PLIM oriented component classification

4.6 The organizational structure that supports the PLIM – The system engineers

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
- 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 generic organisational structure at a plant is shown in Fig.21 [13].

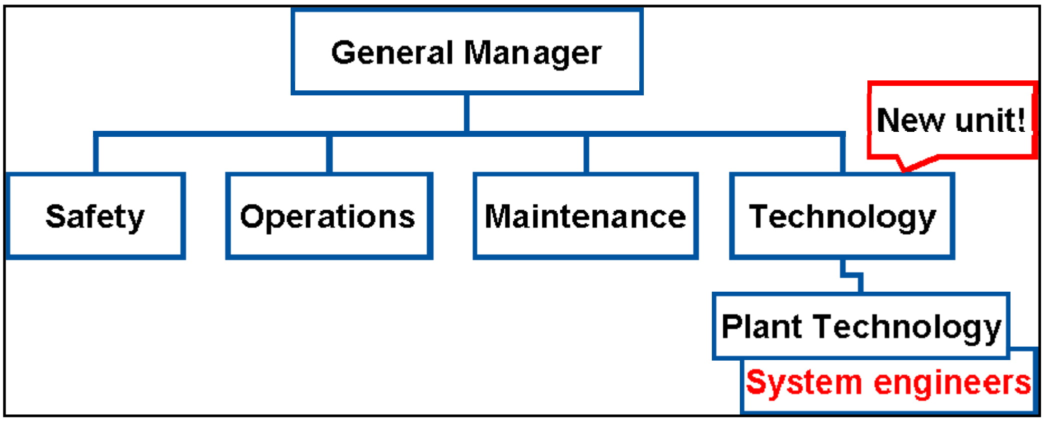

Figure 21 – Organisational structure, PLIM oriented

The traditional structure of most of the existing departments in a typical power plant can be maintained, namely:

- Maintenance (Mechanical, Automation, Planning, Service)
- Operation (Operation teams, Information technology, Operation technology, Chemistry)
- Safety (Quality and environment, Nuclear Safety, Inspection Body)
- Logistics, personnel and Administration are staff of the General Manager. In relation to PLIM, logistics is responsible for responsible for spare parts management, purchasing, warehouse management and transportation

In particular in the Technology department the following units may be identified [13]:

- Planning (for electrical and automation, mechanical, process and ventilation)
- Quality control
- Plant technology and special projects (Outages, projects, Investment and project management, Plant systems, Material and Process technology)

The functions of the Technology dept. may be as follows:

- Planning of plant equipment, structures and processes
- Outage planning and control
- Project and investment management
- Quality control of the design, manufacturing and procurement
- In-service inspection
- Plant life management

System engineers of the technology unit (typically 10-15 people for two power units) 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.

A summary of the interfaces of the system engineers is shown in Fig.22 [13] for the sample case of Loviisa NPP.

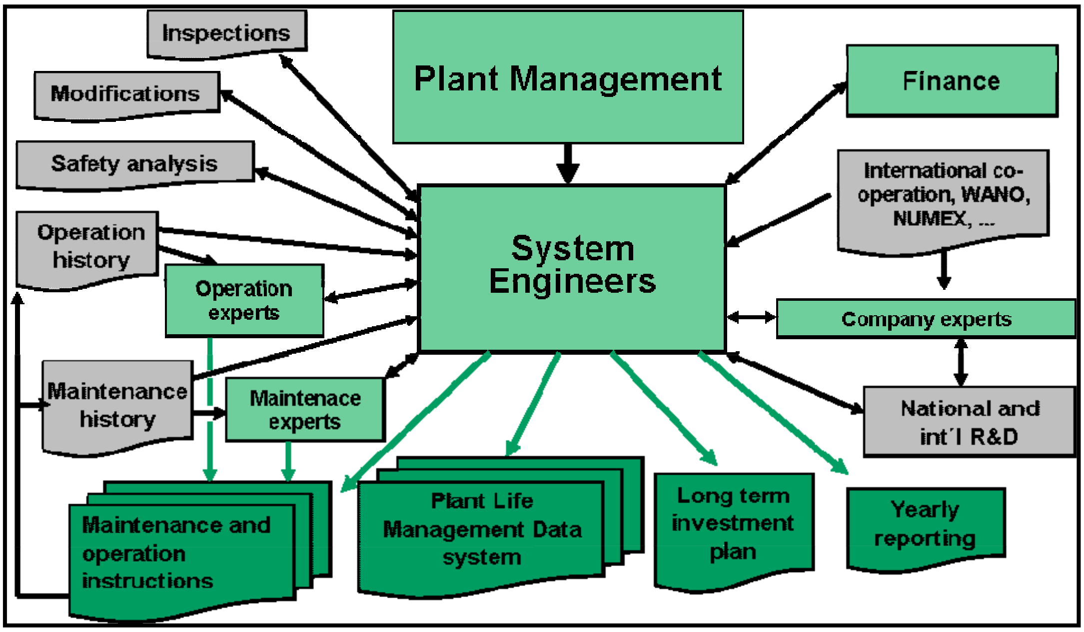

Figure 22 – Program interfaces inside PLIM

4.7 The management of the assets - The overall economic model

The long term investment plan should be developed with interfaces from all the above mentioned programs in order to represent a realistic tool for simulation and planning.

Its content may be organized as in the following (mainly according to the Loviisa experience):

- Content of the projects which are planned for 3 - 4 years onwards and, with less detail, even until the end of the plant lifetime
- The database should include component identification data, classification and component status information
- The economic data base should include the annual costs of each project
- Summary reports should give the big picture of the investment portfolio, including all planned projects (typically 150 - 200 different-sized projects may be in the database at the same time)

The main stages of the development of the investment plan may be organised as in the following:

1. Investment proposal inserted in the system
2. Proposal evaluation (weekly evaluation committee for modifications): background, nuclear safety, operating technology, maintenance, economy, timing, options, synergies etc.
3. Pre-planning: preparation, evaluation of alternatives, optimising the scope and timing etc.
4. Approval: different thresholds according to the budget entity of the project:
    a. Plant Management Team
    b. Site Management Team
    c. Corporate Management Team
5. Detailed planning
6. Implementation
7. Finalisation,
8. Follow-up

For the long range investment plan (typically 10 years and longer), the planning may be organised as in the following:

- The main guideline in planning and approving investments
- The yearly investment level may be identified as a certain proportion of the of the business unit (BU) depreciation (typically 80 - 90 %)
- Because of the finite ability to fund and implement new investments, the potential investment opportunities have to be prioritized based on
    – their significance for strategic objectives
    – their conformance with the company policies
    – the use of resources (human or capital) relative to the value creation potential and risks

Longer investment planning are also developed, with less detail, but with a more important contribution from the foreseen effect from the energy market and labour cost trends.
Special investment evaluation criteria should be developed for consistency. They may include the following:

1. Value creation potential
   - discounted cash flow calculations (net present value)
   - marginal return index (value created relative to the amount of capital to be invested)
2. Strategic fit
   - significance for strategic objectives
   - conformance to company policies
   - effective use of human and capital resources

All the above mentioned information should be inserted into a PLIM management tool, which is able to integrate:

- Normal work orders supplemented by the investment proposal data (costs, classification, requirements)
- All data in the same database: easier to update and trace single investment projects
- Separately developed reporting tools: varied summaries and graphics of the investment volume, selections

One of the most important contributions to the investment planning is the group of data related to the conversion of business interruption, component failures, component degradation into plant costs. Such models should be developed on scientific basis and continuously monitored on the basis of the experience.

It is noted that in many plants the optimisation of the investment is carried out with fixed yearly budget, and assuming that the single programs (MS&I, AMP, etc) are already optimised by their own. Conversely, it is recommended to carry the cost optimisation out within a budget minimisation framework. Moreover, in this case, the economic model should be extended to the maintenance choices, evaluating, for example, the long term effects of the maintenance strategy selected for each critical SSC.
The same applies for the ISI program: expensive diagnostic techniques should be planned in a global framework of cost and safety optimisation. Local application of optimisation algorithms may lead to the wrong conclusion that moving for example components from CBM to corrective maintenance always provides a net cost saving, while a global approach may show heavy (and expensive) impact on spare parts availability, which may considered unacceptable.

4.8 Maintenance as part of PLIM - Objectives and scope

The main goals of the maintenance program in the framework of PLIM should be the following:

- Assure plant safety
- Maintain optimal plant availability
- Optimize operation and maintenance costs

- Assure and develop industrial safety
- Comply with codes, legislation and regulation
- Decrease failures of safety and availability critical components
- Find and implement performance improvements
- Increase the reliability and maintainability of the machinery and the performance of maintenance support
- Increase the economical service life of equipment and plant

A precondition for a MS&I program to be effectively inserted into a PLIM architecture is that the maintenance program is continuously optimised on the basis of the risk importance of any structure, system an component (SSC), controlling the overall reliability of operation and preventing functional failures.

One way of achieving this goal is the implementation of a rigorous SSC classification and the selection of the most appropriate maintenance tasks (and periodicity) for each type of equipment. The classification should be based on the importance to safety and operation, requirements of nuclear regulations, replacement costs, environmental risks and maintenance experience. Classification can be changed based on operation and maintenance experience.

The maintenance unit should be responsible for executing and planning normal maintenance work, carrying out the work in refurbishment and investment projects, carrying out inspections and periodical tests, managing spare parts, organizing personnel training and enforcing an appropriate QA system.

The selection of the most suitable strategy for the maintenance of any SSC should be done in the PLIM framework, therefore merging technical, economical and long term planning issues. A possible result is shown in Fig.23 [13].

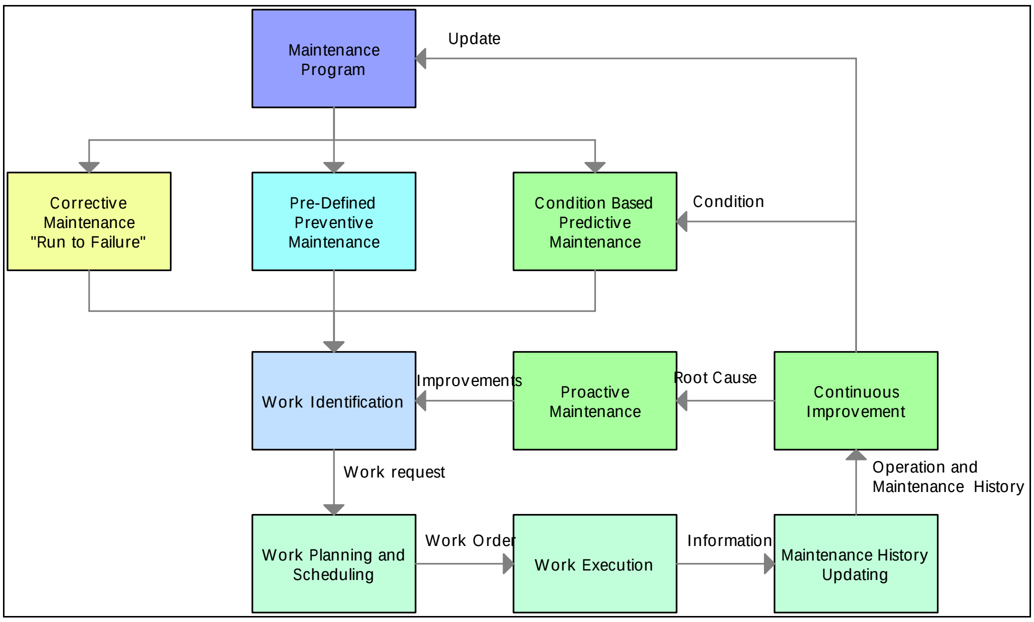

Figure 23 – Decision process for MOPT

One way of doing the component classification in relation to MS&I is shortly described in the following.

1. Maintenance Class 1
   - Critical equipment. The functional failure of the equipment (defined as the "termination of the ability of an item to perform a required function") causes remarkable production losses. The plant must be shut down or power must be reduced for significant period.

1. Maintenance Class 2
   - Important equipment. The funtional failure of the equipment causes problems to plant operation and moderate production losses.
   - The allowed unavailability of equipment is short according to Techinical specifications or Fussel-Vessely (FV) importance value is greater than 10-3

2. Maintenance Class 3
   - Significant equipment. The functional failure of the equipment causes low production losses
   - Equipment expensive to replace or predictive or preventive maintenance is economically justified or safety related equipment or Fussel-Vessely (FV) importance value1 is less than 10-3 and greater than 10-6

1. Maintenance Class 4
   - Other equipment.

Concerning the availability requirements, the following grid may be applied.

Class 1
- No functional failure is allowed during the operational period. The maintenance program of the equipment is most comprehensive.

Class 2
- No functional failure is allowed during the high season. The availability must be over 99 % during the other season.

Class 3
- The availability must be over 97.5 %.

Class 4
- No availability requirements. The condition of the equipment is monitored by visual inspection performed by operating and maintenance staff

A proposal for a classification flow chart is shown in Fig.24 [13].

[1] Fussell-Vesely Importance of a modeled plant component or system is defined as the fractional decrease in total risk level when the plant component or system is assumed perfectly reliable (failure rate = 0.0). If all the sequences comprising the total risk level are minimal, the F-V also equals the fractional contribution to the total risk level of all sequences containing the (failed) feature of interest.

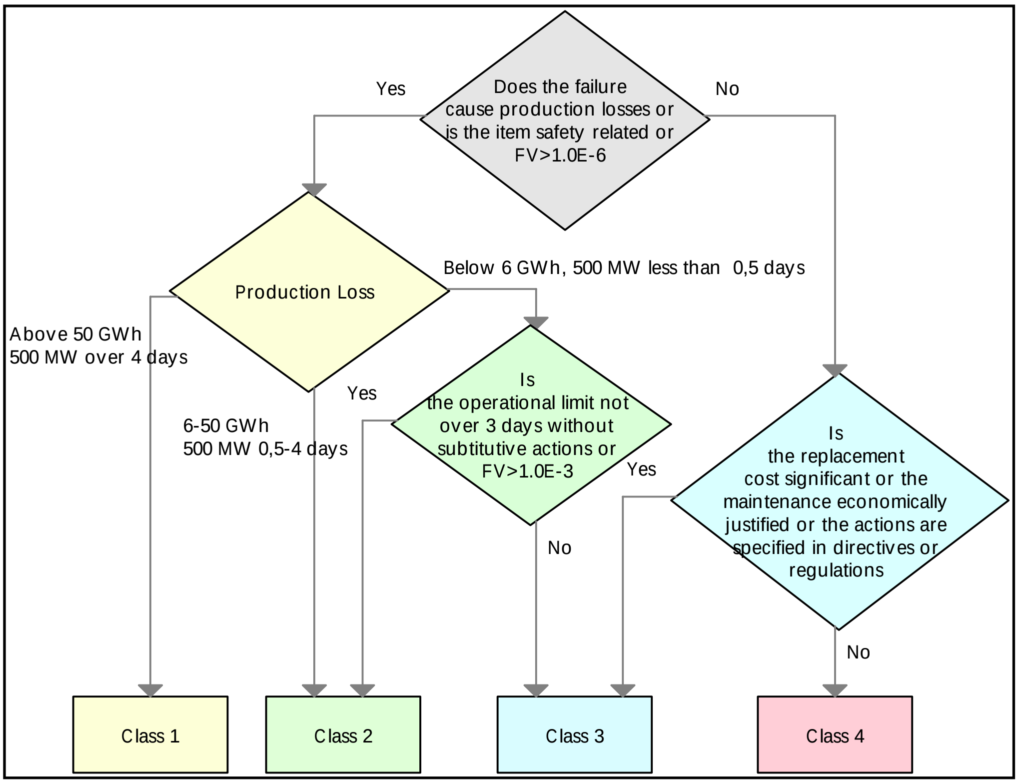

Figure 24 – Component classification for maintenance

It is clear that in a PLIM logic all these classification systems (i.e. PLIM, maintenance, spare parts, etc.) should be correlated and consistent.
Moreover, the ownership of the components should be clearly assigned to the system engineers: therefore any change n MS&I policy on any SSC should be agreed and planned wit the technological dept.

4.9 Maintenance strategy

The selection of the Maintenance strategy should allocate the SSCs in one of the following categories of maintenance.

Predictive Maintenance (Condition Based) - Maintenance based on performance and/or condition monitoring and subsequent actions. Performance and condition monitoring may be scheduled, on request or continuous. It includes:

- Condition monitoring
- Process monitoring
- On-line inspection (visual inspection during normal operation)
- Periodic testing

Preventive Maintenance (Predetermined, Scheduled) - Maintenance carried out at predetermined intervals or according to prescribed criteria and intended to reduce the probability of failure or the degradation of the functioning of an item. It includes:

- Periodic maintenance
- Periodic inspection

Corrective Maintenance (Run to Failure) - Maintenance performed to an item which is outside the scope of predictive or preventive maintenance program. Maintenance is carried out after fault recognation and intended to put an item into a state in which it can perform a required function. It includes:

- Repair of Impending Failure. Restore the operating state of a wear out item. The condition or performance of an item is degraded but it can perform a required function.
- Repair of functional failure. Restore the operating state of a item unable to perform its intended function satisfactorily or its performance is outside required limits

In some cases, **Proactive work** is performed, based on the analysis of history and feedback data. Proactive maintenance tasks includes:

- Analysis of feedback data
- Collection and analysis of performance data
- Find out improvements
- Assess improvements (life cycle costs, PSA)
- Carry out improvements

A selection scheme is shown in Fig.25 [13].

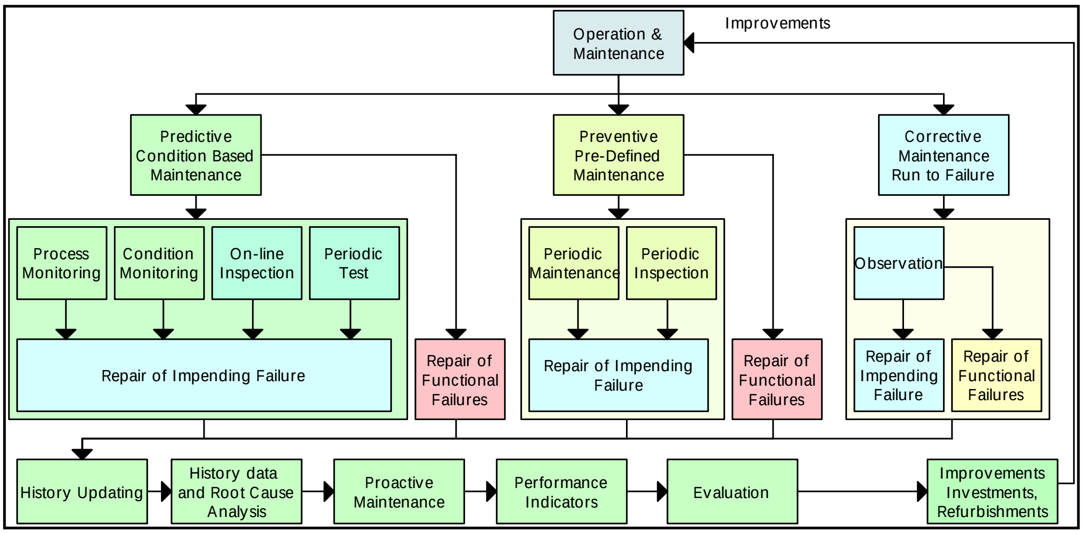

Figure 25 – Maintenance selection chart

The most relevant strategy in the PLIM framework, being applied to the highest PLIM class, is the predictive maintenance, which is then analyzed in more detail in the following.

It is accomplished by using all available information to make decisions about the maintenance requirements and carrying out corrective actions. Maintenance action is based on performance or parameter monitoring. Performance and parameter monitoring may be scheduled, on request or continuous. The corrective action is condition based work. Predictive maintenance tasks are as follows:

- Condition monitoring
- Analysis of history data
- Process monitoring
- On-line inspections
- Periodic tests
- Corrective actions
- Recording feedback data

The selection of the condition monitoring methods depends on the type of equipment and on the expected degradation mechanism. Examples are the following [13]:

- Vibration Monitoring (On-line and Off-line):
  - Rotating machinery (Spectral analysis and parameters, SPM)
  - Pipes and TC-heat exchanger (Low frequency analysis and acoustic emission)
  - Loose part monitoring of reactor vessel and primary circuit
  - Condition monitoring of control rods
- Condition Monitoring of Electrical Machinery (Current signature, resistance, PD, tanδ, bearing current, etc)
- Fatigue Monitoring (Primary circuit pipes)
- Oil Analysis (chemical, wear depris)
- Thermography (electrical and mechanical equipment, insulation)
- Corrosion Monitoring and Protection (condensers, sea water chambers)
- Performance Monitoring (pumps, turbines)
- Fatigue monitoring of primary circuit
- Process Monitoring, Water chemistry, Radiation Monitoring, Radiochemistry
- Monitoring the embrittlement of reactor vessel using sample pieces
- Process Monitoring, water chemistry
- Radiation Monitoring

A generic summary of the MS&I process based on CBM is shown in Fig.26 [13].

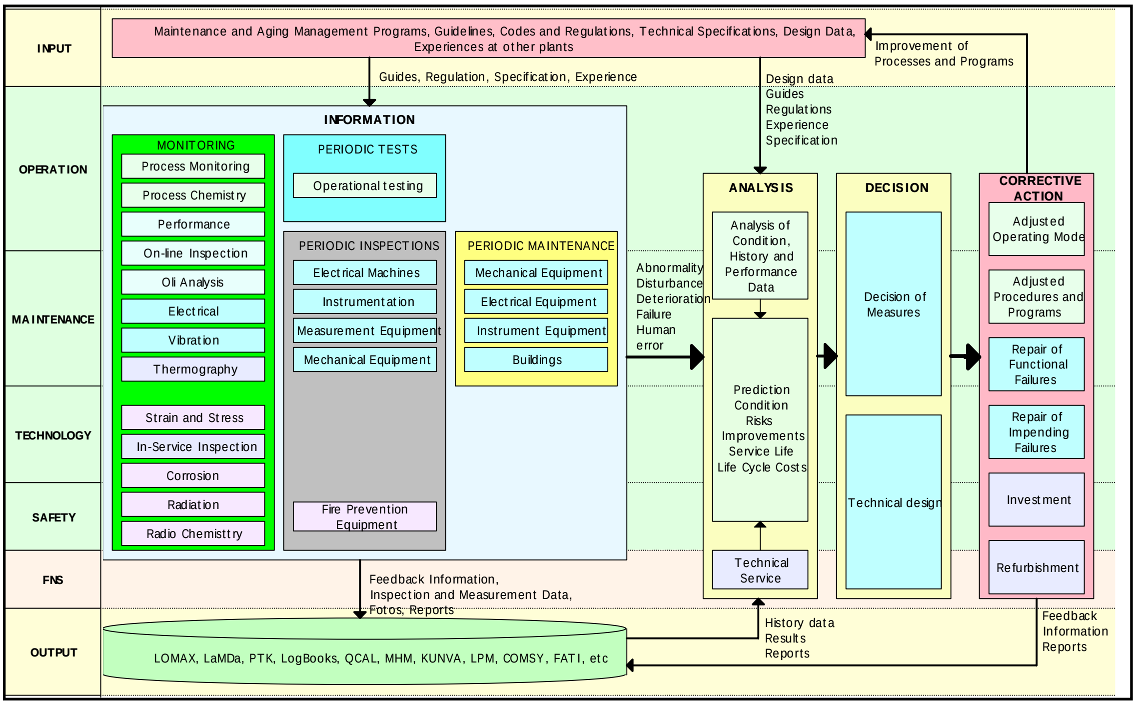

Figure 26 – Example of MS&I processes

Some comments may drive a proper implementation of the approaches described above:

- It has to be noted that the CBM approach, as well as the other approaches, do not calculate any residual life of the component: they just monitor the critical areas defined by the AMP, with reference to degradation mechanism defined in the AMP
- The reference degradation mechanisms considered in the AMP and therefore providing the basis for the CBM are usually selected on the basis of the experience and international standards. However, plant-specific lists of such mechanisms should be kept updated by the system engineers on the basis of the plant operating and maintenance history, environmental conditions, information from the suppliers, research outcome, etc. to prevent the surfacing of new mechanisms. It is suggested to review the AMP and the relevant degradation mechanisms at least on a yearly basis.

4.10 Maintenance organisation

The functions of maintenance unit should be as follows:

- Maintain and improve maintenance program (classification of equipment in relation to MS&I, predictive and preventive maintenance tasks, generate and analyze maintenance history data, generate and analyze performance indicators, root cause analysis, identify and carry out improvements)
- Maintain and develop plant information management system
- Maintain guidelines and procedures

- Maintenance and work planning and control
- Perform periodic maintenance and repair work
- Condition monitoring (vibration monitoring, oil analysis, thermograph, electrical machines)

It is more and more common to use external contractors for the maintenance activities. A typical ratio between staff and contractor is around 1-8 to 1-10. A good approach may envisage to use contractors only during outages, or only selected ones for the on-line maintenance.

4.11 Work process

Work planning and control should be defined in the relevant procedures. One example is shown in Fig.27 [13].

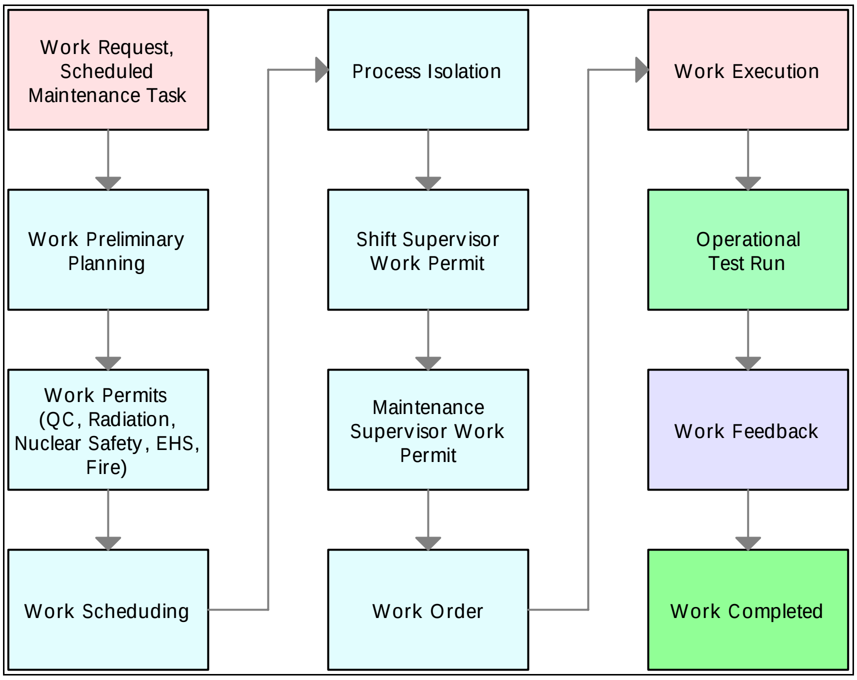

Figure 27 - Work planning and control procedures

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 [39].
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.

4.12 Maintenance effectiveness indicators

Maintenance effectiveness indicators should be set at plant, department and group levels, also linked to career and payment feedback. Examples of indicators in use could be the following (for a more comprehensive list, see the JRC-IE report [44]):

- Maintenance costs
- Investment costs
- Cost forecast monthly until the end of the year
- Delayed maintenance work
- Load factor (gross)
- Total production (net)
- Efficiency (gross)
- Production losses
- High season availability
- Availability outside high season
- Outage durations
- Unavailability caused by maintenance activities during operation
- Individual radiation doses
- Decreasing trend of collective radiation dose
- Internal contamination
- Number of industrial accidents of own personnel
- Number of industrial accidents of contractors
- Total recordable injuries
- Sick leaves
- Development discussions
- Number of nuclear incidents (INES)

- Processing speed of new work orders
- Duration and cost of outages
- Environmental incidents
- Working environment (work community index)
- Days of illness
- Share of successful improvement conversations.

Indicators should be carefully analysed by the system engineers for a detailed understanding of the root causes of the deviation from acceptable thresholds and of the contributions from the different classes of components.

4.13 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.

4.14 Maintenance optimisation

A maintenance optimisation system should be in place, also to feed the PLIM program. The Maintenance program should be optimised together with the other strictly related programs, such as surveillance an ISI, and optimised at the PLIM level in the long term. In many cases the MS&I program is optimised as a stand alone program without considering the feedback even on the investment planning.

Many optimisation approaches are available in the engineering practice, as described for example in [13]. However, the main tasks/steps should comply with the following list:

- Evaluation of maintenance strategies and equipment criticality classes
- Current maintenance program assessment
- Evaluation and selection of optimized maintenance tasks
    - Utilization of Reliability Centered Maintenance programs
- Maintenance program comparison (costs, risks)
- Optimized maintenance program implementation
- Evaluation of program effectiveness
- Continuous improvements
- Benefits of optimized maintenance
    - Improves availability of SSC's
    - Reduces maintenance costs
    - Improves maintainability of SSC's
    - Improves maintenance performance

– Improves safety

A special contributor to the optimisation of the MS&I programs is the outage planning.
The critical paths are covered by the plant cooldown, the inspections to the SGs and RPV, the pressure test, etc.
A significant optimisation can be achieved through detailed review of the work packages: if they are rigid, little room is left to the improvement of the MS&I planning.

4.15 Support tools

The main computer systems serving major parts of the organization are the following:

- process computer systems
- plant information system – PLIM manager
- laboratory information system
- personnel information system

Interfaces between these system and other software packages may be developed for example for:

- Graphical representation tools
- Plant diary
- Personal data management
- Payment application
- Instrumentation calibration
- Radiation control
- Outage planning and scheduling
- Document management
- Process data management system

The process computer system can be operated in the main control rooms (MCR) and auxiliary control rooms through several keyboards, displays, and printers. The information is also accessible to selected users outside the control room. The main functions of the process computer system are:

- Monitoring of process parameters and component status. The analog and binary measurements are displayed on process diagrams, trends, x-y plots etc.
- Alarm functions. Prioritized alarms are indicated by audible and visible signals
- Reactor performance calculations. These include 3D-calculations of reactor core power, marginals and burn-up
- Balance-of -plant calculations and component supervision.

The plant information system, PLIM manager supports all maintenance activities at the plant. The main functions are:

- plant component and location database

- maintenance work planning and execution
- scheduling of preventive maintenance and periodic testing
- spare parts management
- purchasing and invoicing activities
- logbook for the control room shifts

Access to the system is granted to each person according to his responsibilities.

The laboratory information system covers the main functions of the plant chemistry and radiochemistry. The main functions are:

- Collection, storing and reporting of the analysis results
- Calculations cumulative releases and radioactive waste

The personnel information system is used to store and handle the personnel data needed for plant access and rights.

5 Conclusions

The research started at the JRC identified in its preliminary phases 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.
Therefore the research developed a first proposal for a PLIM model which took the best practice of the European Countries and integrated 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 [3] would be most probably very welcome 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 2008 with a robust validation and improvement of the proposed model at real plants.

6 References

[1] EUR 21903 EN: “Optimization of Maintenance Programmes at NPPs - Benchmarking study on implemented organizational Schemes, Advanced Methods and Strategies for Maintenance Optimization - Summary Report”, January 2006.
[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Technical Report Series 448, Plant Life Management for Long Term Operation of Light Water Reactors, IAEA, Vienna (2006).
[3] WORK PROGRAMME 2007, EURATOM FOR NUCLEAR RESEARCH AND TRAINING ACTIVITIES, European Commission C(2007) 564 of 26.02.07
[4] JRC-IE, Safe Operation of Nuclear Installations (SONIS), Work program 2007 - PKS
[5] EUR 22603 EN, P.Contri, Summary report on the workshop “Maintenance rules: improving maintenance effectiveness”, Petten, 2006
[6] EUR 22604 EN, V.Ranguelova, P.Contri, I.Kouzmina, Summary report on the Workshop on “Advanced Methods for Safety Assessment and Optimization of NPP Maintenance” Petten, 2006
[7] Fourth Steering Committee Meeting (2007) of the “SENUF Network” – Technical and planning meeting with the stakeholders, 19-20/04/2007, Madrid, ENDESA
[8] JRC-IAEA-FTU Joint Workshop on Optimisation of Maintenance, Inspection and Testing with Insights of Risk, Reliability and Performance, FZK, Karlsruhe, Germany, July 9-13, 2007
[9] Second International Symposium on Nuclear Power Plant Life Management (PLiM), Shanghai International Convention Center, Shanghai, China 15-18 October 2007
[10] 19th International Conference on Structural Mechanics in Reactor Technology (SMiRT 19), Fairmont Royal York, Toronto, August 12-17, 2007
[11] 13th International Symposium on Applied Electromagnetics and Mechanics (ISEM) - Special Session on Maintenance Engineering, Kellogg Center, Michigan State University, East Lansing, MI USA, 9-12 September 2007
[12] JRC, Enlargement and Integration Workshop n. IE-W06, "Organisational Models and tools for optimised maintenance programs at Nuclear Power Plants (NPPs)", 6-7 December 2007, IE, Petten, The Netherlands
[13] Makela K., Technical documentation developed for the JRC-IE, 15/12/2007
[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Operation Requirements, Safety Standards Series No. NS-R-2, IAEA, Vienna (2000).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Maintenance, Surveillance and In-Service Inspection in Nuclear Power Plants; Safety Guide, Safety Standards Series No. NS-G-2.6, IAEA, Vienna (2002).
[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment and Verification for Nuclear Power Plants, Safety Guide, Safety Standards Series No. NS-G-1.2, IAEA, Vienna (2002).
[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of Life Cycle and Ageing at Nuclear Power Plants: Improved I&C Maintenance; IAEA-TECDOC-1402, IAEA, Vienna (2004).
[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for Optimizing Nuclear Power Plant Maintenance Programmes; IAEA-TECDOC-1383, IAEA, Vienna (2004).
[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Applications of Probabilistic Safety Assessment (PSA) for Nuclear Power Plants, IAEA-TECDOC-1200, IAEA, Vienna (2001).
[20] INTERNATIONAL ATOMIC ENERGY AGENCY, Technologies for Improving Current and Future Light Water Reactor Operation and Maintenance: Development on the Basis of Experience; IAEA-TECDOC-1175, IAEA, Vienna (2000).
[21] INTERNATIONAL ATOMIC ENERGY AGENCY, Advances in Safety Related Maintenance; IAEA-TECDOC-1138, IAEA, Vienna (2000).
[22] INTERNATIONAL ATOMIC ENERGY AGENCY, Regulatory Surveillance of Safety Related Maintenance at Nuclear Power Plants; IAEA-TECDOC-960, IAEA, Vienna (1997).
[23] INTERNATIONAL ATOMIC ENERGY AGENCY, Good Practices for Cost Effective Maintenance of Nuclear Power Plants; IAEA-TECDOC-928, IAEA, Vienna (1997).
[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Related Maintenance in the Framework of the Reliability Centred Maintenance Concept; IAEA-TECDOC-658, IAEA, Vienna (1992)
[25] P.Contri et al., "Optimisation of Maintenance Programs as pre-condition for the life extension of Nuclear Power Plants", SMiRT 19, Toronto, 13-16/08/2007
[26] M.Biéth et al., “Plant Life Management Models with special emphasis to the Integration of safety with non-safety related programs”, PLIM, Shanghai 15-18/10/2007
[27] P.Contri et al., "Needs in R&D Supporting Nuclear Power Plant Life Management”, PLIM, Shanghai 15-18/10/2007
[28] P.Contri et al., “Maintenance optimisation issues in the EC” - ISEM 2007, Lansing, 10/09/2007
[29] P.Contri, “Maintenance issues in long term operation of Nuclear Power Plants”, ENC2007, Bruxelles, 19/09/2007
[30] P.Vaisnys et al., "Monitoring the Effectiveness of maintenance programs through the use of peformance indicators", ENC 2007, 19/09/2007, Brussel
[31] P.Contri et al., Optimisation of Maintenance Programs in View of Long Term Operation of Nuclear Power Plants, 6th International Conference on Nuclear option in Countries with small and medium electricity grids, 21-25 May 2006, Dubrovnik, Croatia, published by ENS, Croatian Nuclear Society
[32] INSTITUTE OF NUCLEAR POWER OPERATIONS, Equipment Reliability Process Description, INPO AP-913, Atlanta, 2004
[33] INTERNATIONAL ATOMIC ENERGY AGENCY, Cost drivers for the

assessment of nuclear power plant life extension, IAEA-TECDOC-1309, IAEA, Vienna (2004).

[34] IBM Maximo Asset Management for energy and utilities

[35] Ventyx Asset Suite

[36] INPO, Epri, NEI, EUCG, Standard Nuclear Performance Model

[37] AREVA, EPR, 2007, www.areva-np.com

[38] Westinghouse, AP1000, www.AP1000.westinghousenuclear.com

[39] EUR 23226, G.Manna, Human and Organizational Factors in Nuclear Installations: Analysis of available models and identification of R&D issues, 2007, JRC-IE

[40] INTERNATIONAL ATOMIC ENERGY AGENCY, Determining the quality of probabilistic safety assessment (PSA) for applications in nuclear power plants, IAEA-TECDOC-1511, IAEA, Vienna (2005).

[41] NEI, NUMARC 93-01, Revision 2, “Industry Guideline for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants", (April, 1996)

[42] EUR 22602 EN, P.Vaisnys et al., “Monitoring maintenance effectiveness using performance indicators”, JRC-IE, 2007

[43] INSTITUTE OF NUCLEAR POWER OPERATIONS, Supplemental Personnel Process Description, INPO AP-930, Rev.0 (Preliminary), Atlanta, 2004

[44] EUR 23230, P.Vaisnys, P.Contri, Benchmarking study of maintenance performance monitoring practices, JRC-IE, 2007

7 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

EUR-23232 EN – JRC – Institute for Energy - SONIS Action n. 52103- A plant life management model including optimized MS&I program – Safety and economic issues - Technical Report

Luxembourg: Office for Official Publications of the European Communities
2007 – 16 pp. – 21 x 29.7 cm
Scientific and Technical Research Series
ISSN - 1018-5593

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Abstract
This report collects the experience of the European Countries in the field of Plant Life Management (PLIM) and maintenance optimisation, as a background for the development of a new PLIM models, suitable for the European framework.
The research highlights the the basic goal of PLiM in terms of support to a safe long-term supply of electricity in an economically competitive way.
A PLIM model is proposed, validated with the experience of the SENUF research network members and with the essential contribution of managers and staff of a selected nuclear plant.
The model addresses both technical and economic issues, as well as organizational and knowledge management issues and is now open for a broader validation by the research and engineering communities, to be carried out in the coming research steps.