PLANT LIFE MANAGEMENT MODELS WITH SPECIAL EMPHASIS TO THE INTEGRATION OF SAFETY WITH NON-SAFETY RELATED PROGRAMS

P.Contri†
European Commission, JRC-IE

E-mail address of main author: paolo.contri@jrc.nl

Abstract
Due to current social and economical framework, in last years many nuclear power plant owners started a program for the Long Term Operation (LTO)/PLIM (Plant Life Management) of their older nuclear facilities. A PLIM framework requires both a detailed review of the features of the main safety programs (Maintenance, ISI, Surveillance) and a complete integration of these safety programs into the general management system of the plant. New external factors, such as: large use of subcontractors, need for efficient management of spare parts, request for heavy plant refurbishment programs demand for updated techniques in the overall management of the plant. Therefore also new organisational models have to be developed to appropriately support the PLIM framework. Last year a network of European Research Organisations carried out many R&D tasks aiming at capturing the aspects of the maintenance programs where research is mostly needed and at developing suitable optimised maintenance models. Using the outcome of these initiatives, this paper aims at identifying the technical attributes of the maintenance program more directly affecting the decision for a long-term safe operation of a nuclear facility, and the issues related to its optimal implementation.

1. Introduction

Due to current social and economical framework, in last years many nuclear power plant owners started a program for the Long Term Operation (LTO)/PLIM (Plant Life Management) of their older nuclear facilities [1,2]. This process has many nuclear safety implications, other than strategic and political ones. The need for tailoring the available safety assessment tools to such applications has become urgent in recent years and triggered many research actions. In particular, a PLIM framework requires both a detailed review of the features of the main safety programs (Maintenance, ISI, Surveillance) and a complete integration of these programs into the general management system of the plant.
New external factors, such as: large use of subcontractors, need for efficient management of spare parts, request for heavy plant refurbishment programs demand for updated techniques in the overall management of the plant. Therefore also new organisational models have to be developed to appropriately support the PLIM framework, integrating both safety related and non safety related issues.

In 2003, the JRC-IE (Joint Research Center, Institute for Energy) launched a network of European Organisations operating Nuclear Power Plants, SENUF (Safety of European

† Scientific Officer at Nuclear Operation Safety Unit

Nuclear Facilities). The SENUF Working Group on "Safety of Nuclear Facilities in Eastern Europe dedicated to Nuclear Power Plant Maintenance", hereinafter referred to as SENUF-WG-NPPM, was founded with the following objectives:

1) Review and identification of the remaining open (generic/specific) maintenance related issues,
2) Promotion of well designed and prepared maintenance plans for systems, structures and components,
3) Support for the implementation of advanced maintenance approaches, including implementation of preventive (condition based) maintenance as well as preventive mitigation measures,
4) Evaluation of the advanced risk based maintenance approach and provision of assistance in its implementation.

A background report was developed by the network in 2004 on Maintenance optimisation issues in the EU, supported by a detailed questionnaire in the EU countries [3]. The report collected and evaluated the available and applied maintenance methods at NPPs of acceding and candidate countries to the European Union (ACCs) as well as of the wider Europe (covering Russian Federation and Ukraine), and based on this evaluation, preliminary identified areas for further collaboration with them.

A very successful workshop was organised in Madrid on June 19-21, 2006 on "Maintenance rules: improving maintenance effectiveness", by the JRC-IE (SENUF network), UNESA, EPRI, Iberdrola, Soluziona and Tecnatom [4]. The workshop confirmed that improving the maintenance program is one of the best tools to improving the overall plant performance and the cost control, even improving the overall plant safety.
A second Workshop was organised by the JRC-IE (SENUF network) and by the International Atomic Energy Agency (IAEA), in Petten on October 2-5, 2006, on "Advanced Methods for Safety Assessment and Optimization of NPP Maintenance" [5]. The workshop addressed the application of advanced probabilistic methods to the optimisation of the maintenance programmes at the European NPPs.

On the basis of the outcome from the SENUF activities in the last years, the objectives of this paper are the following:

- To analyze and summarize the existing strategies on nuclear power plant (NPP) maintenance optimization, i.e. predictive maintenance based on monitoring component condition, reliability centred maintenance, and risk-informed maintenance in the NPPs of the collaborating parties
- To identify the technical attributes of the maintenance programs more directly affecting the decision for a long-term safe operation of a nuclear facility, their implementation issues and safety review.
- To identify differences and commonalities in the Western and Eastern European practice, and based on this evaluation, to identify areas for further research and development (R&D).

2. The maintenance program in the Long Term Operation perspective

There is a generic convincement in the nuclear community, also confirmed by the SENUF questionnaire carried out in 2004 [3], that the maintenance program should have specific attributes in order to support a long term operation (LTO/PLEX) program for the plant. In this sense, the International Standards (e.g. the IAEA) can be seen, but also the national experience of USA, Spain, Hungary, etc. More specifically, the maintenance programs based

on standard preventive maintenance (time based), not oriented to the monitoring of its effectiveness and to the prediction/prevention/control of the damage, are not considered suitable to support the LTO/PLEX programs. Crucial attributes for maintenance programs in order to support LTO/PLEX 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 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 [6,7], 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 LTO/PLEX of their plants.
The SENUF WG carried out a detailed analysis on the experience of some of the above mentioned countries on the interfaces between LTO/PLEX and maintenance programs, as a background for the development of a state-of-art approach to modern maintenance programs [4,5]. The most relevant conclusions are summarised in the following chapters.

3. The RCM programs in the experience of the European Countries

The objectives of the Reliability Centred Maintenance (RCM) and Maintenance Rule [8,9,10] programs as they are usually defined, are listed as in the following (with some differences according to the country framework):

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
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.

In relation to the operating cost reduction as a consequence of RCM application, the SENUF WG recorded the following reductions [5]:

- 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.

In relation to the Scoping process applied in the RCM, the WG noted that the approaches are quite different in the Countries:

- In SWE 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 HUN RCM is applied to 70% of the safety related SSCs and to 30% of other systems
- In SKR RCM is applied to 44 systems (100-500 components) selected on the basis of different criteria, including safety significance.

The quality of the maintenance documentation was recognized as crucial to feed a proper feedback mechanism. The culture of communication (including the “no blame”) may play a major role in ensuring all failure mechanisms have been properly identified and all actual equipment failures have been recorded.

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. 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 optimised maintenance systems in different EU Countries:

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)

In general, the Ukrainian, Slovenian, Czech, Russian representatives expressed 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, [11]). Many of them already created some training centers which are developing procedures in this direction.

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.

4. Tools for measuring maintenance performance

Recent statistics carried out in the USA (INPO) [4] show that 40% of the failures are related to human factors: among them, 30% are related to engineering deficiencies an 30% to work performance. Most of the significant events in the latter category have been triggered by the supplemental workers. Therefore the contractor performance becomes 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.
Performance Indicators for maintenance effectiveness are considered very useful. However 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 WG developed a special set of indicators [14] under testing at many European NPPs.

A special group of indicators are now made available [4] 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 AP-930)

The techniques for the risk monitor during maintenance are also crucial, mainly in relation to the NUMARC 93-01 [12,13] 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.

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.

The WG recognized that no tools are available yet to manage the maintenance process in a comprehensive manner, even if the EPRI proposals are excellent in some fields. The user groups (EPRI/NMAC, EPRI/MRUG, etc.) are providing an invaluable contribution to this concern to their subscribers.

5. Use of PSA for maintenance optimization

In case the maintenance optimization is supported by the application of PSA results and models [5], the quality of the PSA becomes an important issue for the success of the maintenance optimization. As any PSA application, the maintenance optimization has crucial requirements for the PSA quality. The scope, completeness, modelling 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 [15]. 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 monitors are useful tools to support maintenance planning off-line and on-line restoration strategies in case of equipment failures during the plant operation.

6. Conclusions

The research started at the JRC identified in its preliminary phases some areas where some R&D effort is needed to support the full implementation of RCM models in European Countries. These areas cover research tasks and call for an initiative at the International Organizations level.
In the field of regulatory practice, support would be needed in the licensing of advanced maintenance optimization applications and information on the regulation in the countries with good practices in the field. In particular, the following recommendations for future support from international organizations were identified:

- Develop detailed guidelines for regulatory review of specific maintenance optimization applications such as: RI TS, RI ISI, On-line maintenance, etc.
- Provide training and/or training material, tutorials for regulatory review of maintenance optimization applications.
- Promote benchmark exercises.

In relation to the PSA quality issues, need for support was identified in the following tasks:

- Disseminate the available PSA quality guidelines (for example the IAEA TECDOC-1511) and promote their development towards Level 2 PSA and at least internal floods and fires in order to facilitate the regulatory use of the PSAs

- Provide support for establishment of WWER specific component reliability database

In terms of research tasks able to make the RCM more broadly applied, the following was identified:

- 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
- Exchange of information at the EU level, despite of the national differences and plant issues, would be very useful in the following areas:
    - Methodologies for RCM
    - Organizational aspects
- 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 optimised maintenance programs oriented to PLIM.

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.

In fact the implementation of RCM 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 [1] would be most probably very welcome and will provide concrete support to the enhancement of the safety of the European Plants.

7. References

[1] WORK PROGRAMME 2007, EURATOM FOR NUCLEAR RESEARCH AND TRAINING ACTIVITIES, European Commission C(2007) 564 of 26.02.07
[2] IAEA, Principles and Guidelines on Plant Life Management for Long Term Operation of Light Water Reactors, IAEA Technical Reports Series- 448 (2006)
[3] EUR 21903 EN, P.Contri et al., "Optimization of Maintenance Programmes at NPPs - Benchmarking study on implemented organizational Schemes, Advanced Methods and Strategies for Maintenance Optimization - Summary Report"
[4] EUR 22603 EN, P.Contri, Summary report on the workshop "Maintenance rules: improving maintenance effectiveness", Petten, 2006
[5] 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
[6] P.Contri, T.Katona, "Safety aspects of long term operation of nuclear power plants", SmiRT 17, Prague, 18 August 2003
[7] Havel, R., Contri, P., Toth, C., Inagaki, T., Guerpinar, A., Misak, J., "Long term operation – Maintaining safety margins while extending plant lifetime", International conference on topical issues in nuclear installation safety, 18-22 October 2004, Beijing
[8] US CFR (1998): Code of Federal Regulations 10 CFR Part 50.65, "Requirements for Monitoring the Effectiveness of Maintenance at Nuclear Power Plants," Office of the Federal Register National Archives and Records Administration, U. S. Government Printing Office, Washington DC.
[9] US NRC (1997): Monitoring the Effectiveness of Maintenance at Nuclear Power Plants. Regulatory Guide 1.160, Revision 2
[10] US NRC (2000): Assessing and managing risk before maintenance activities at Nuclear Power Plants. Regulatory Guide 1.182, Revision 2
[11] INPO 97-013, "Guidelines for the conduct of maintenance at nuclear power stations", Dec 1997
[12] NUMARC 93-01, "Industry guideline for monitoring the effectiveness of maintenance at Nuclear Power Plants, Revision 2, 1996
[13] NUMARC 93-01, Section 11, "Assessment of risk resulting from the performance of maintenance activities"2000
[14] EUR 22602 EN, P.Vaisnys et al., "Monitoring maintenance effectiveness using the performance indicators"
[15] IAEA, TECDOC 1511 - Determining the Quality of Probabilistic Safety Assessment (PSA) for Applications in Nuclear Power Plants, 2006.