NUCLEAR POWER PLANT LIFE MANAGEMENT IN SOME EUROPEAN COUNTRIES

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TABLE OF CONTENTS

FOREWARD AND ACKNOWLEDGEMENTS

LIST of TABLES

LIST of FIGURES

FOREWORD and ACKNOWLEDGEMENTS

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This paper draws heavily on previously published work by the authors and also from various IAEA published and unpublished work. The IAEA is thanked particularly for permission to quote from unpublished IAEA reports that, in turn, represents the work of several contributors. In this context some of the more recent contributions from J Berthe, J-P Hutin, T Stokoe, L Fredlund, S Bougaenko, T Otsuka and R H Versaci are especially mentioned. Messrs B Gueorguiev and V Lyssakov of the IAEA are thanked for their support over the years. Mrs R Spiegelsberger is thanked for her continuing provision of data on Nuclear Power in the world.

1 INTRODUCTION

This paper is a survey on Nuclear Power and Nuclear Plant Life Management (PLIM) in European and some adjacent countries.

The countries chosen for this paper have Nuclear Power Plants (NPP) and are essentially 'European' nuclear countries but there are five exceptions, three of the exceptions are the Czech Republic, the Slovak Republic and Hungary-but it will be realised that these are now classified as PECO countries. Austria and Italy have been included because their nuclear powered plants are still incurring costs. Italy was also a nuclear country, became non-nuclear and now relies heavily on fossil fuel burning for electricity-'a producer of greenhouse gases'. Non-nuclear counties are not included other than to factually describe their electricity system but it will be noted that, generally, with the exception of Italy, these particular countries including Austria generate a total amount of less than about 60TWh of electricity per annum.

This paper includes contributions from national experts, papers from international meetings, referenced source documents or unpublished information. In most cases the responses from the national experts are quoted directly-having been edited in a minimal way, we consider it would have been presumptuous of us to tamper with these useful contributions.

2 ELECTRICITY AND FUEL BACKGROUND

Electricity statistics for European countries are given below in Table 1, for 2001-but these were published in January 2002 [Ref. 1].

	AUSTRIA	BELGIUM	FINLAND	FRANCE	GERMANY	G BRITAIN
Electricity supply (TWh)	60.18	80.17	67.19	519.12	519.38	359.64
Nuclear	0.00	45.75	21.57	394.67	158.87	78.33
Other	60.18	34.42	45.62	124.45	360.51	281.31
Imports	13.81	11.64	12.21	3.44	45.03	14.31
Exports	13.50	7.32	0.33	72.93	41.88	0.14
Consumption p. c. (kWh)	6286	7383	14427	6752	5935	5527
GDP p.c. ($)	25740	24380	25090	23560	25750	24390

DENMARK	GREECE	IRELAND	ITALY	LUXEMBOURG	NETHERLANDS	PORTUGAL
34.23	49.49	20.36	262.37	1.12	86.08	35.08
0.00	0.00	0.00	0.00	0.00	3.7	0.00
49.49	49.49	21.99	262.37	1.12	82.38	35.08
8.32	1.73	0.17	44.83	6.45	22.93	4.70
7.68	1.74	0.07	0.48	0.74	4.03	3.78
6162	3988	4976	4632	13750	6136	3673
32780	11870	25060	20310	42930	24910	11380

continued:

SPAIN	SWEDEN
202.86	141.90
59.54	54.76
142.72	87.14
12.27	18.31
7.83	13.63
4599	14461
15120	26950

Table 1: Summary view of electricity generated
Nuclear share Imports and Exports of electricity and electricity consumption per capita in the countries of Europe, GDP pc values from [Ref. 2**]**

The amount of electricity supplied (produced) in the different countries in Europe in 1999 varied from 0.99 TWh in Luxembourg to 511.42 TWh in Germany and the individual values for the other countries are shown in Fig.1 below. It will be noted that, with the exception of Italy, which generates no nuclear power, each of the non-nuclear supply a total of less than about 60 TWh.

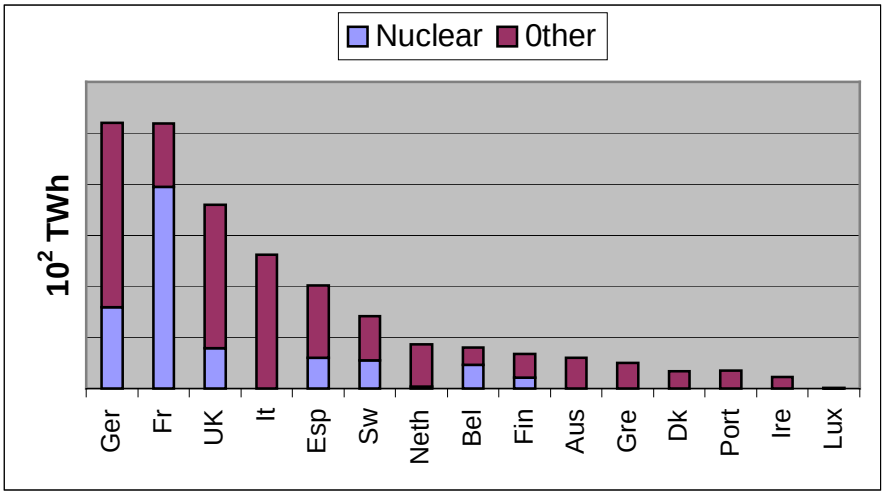


Figure 1: Electricity supplied in European countries showing 'nuclear capacity'
[Ref. 1]

There are differences in population between European countries but it will be seen that when electricity supply is converted to per capita values, which takes population differences into account, there is also quite a large variation in the consumption per capita between these countries- the per capita value is sometimes a 'rough' reflection of national wealth and one has to look at the detailed differences in the use of electricity in the various countries for an explanation.

In the developed world there is an approximate 'straight line' correlation between electricity consumption per capita and the individual wealth in a particular country (GDP per capita)], however, electricity consumption per capita for the various consuming sectors would also need to be compared to fully evaluate the underlying reasons for national differences. The GDP per capita is plotted against electricity supplied in Figure 2, where a 'straight line' has been drawn through the majority of the European countries. Countries which are exceptions to this straight line are Sweden and Finland-but we do not provide an explanation here for these variations here-one would need to examine the use of electricity in those countries and the components of GDP-which is beyond the remit of this paper.

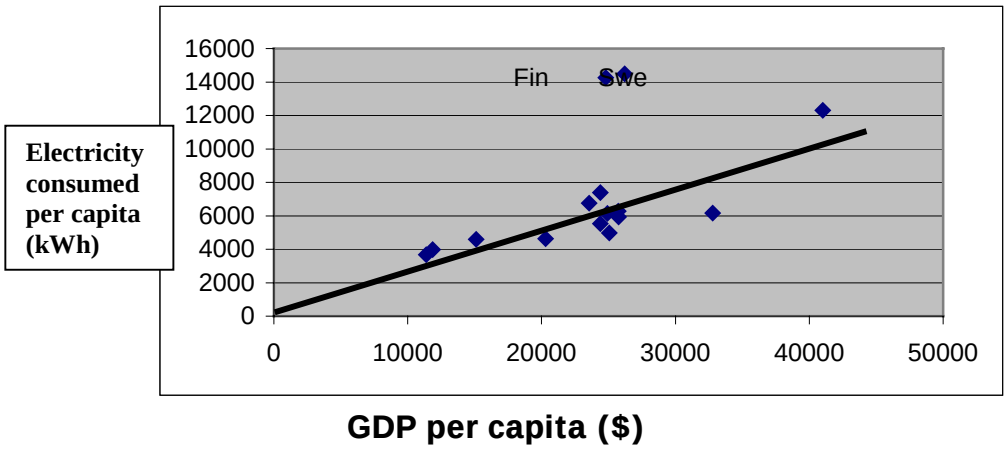


Figure 2: GDP per capita plotted against electricity consumer per capita (kWh)

(see Table 1). A straight line has been drawn to show the 'rough straight line relationship' between wealth and electricity used in a particular country. But, note the 'outlier positions' of both Sweden and Finland. The rule of thumb' is that in developed world countries the higher the electricity use per capita then the richer the people in that country

The margin between the installed capacity for electricity generation and the peak electricity requirement (usually the peak winter demand plus a margin for plant breakdown) is a key factor in establishing the need for new power plant. The prediction of estimated peak demand and the appropriate margin for future years compared with the current margins determines the future new plant introduction strategy.

Attention is again drawn to Table 1 where the higher levels of the net exports of electricity from France and Sweden signify the 'generation wealth' (excess electricity generating capacity) of those countries.

It is a fact that NPP construction in the world has been decreasing steadily since the peak number of 'starts' of operation of new plants in the mid 1980s to the current situation of a small number of new plant 'starts'. These are shown graphically in Figure 3 where it can be clearly seen that the number of NPP 'starts of operation' in the world has decreased dramatically from a peak of thirty five in 1985 to the present levels [Ref 3]. However the number of 'plant starts of operation' in recent years includes those in France, India and Brazil and shows that plants are continuing to come into operation in the world, but not at the previous high rates.

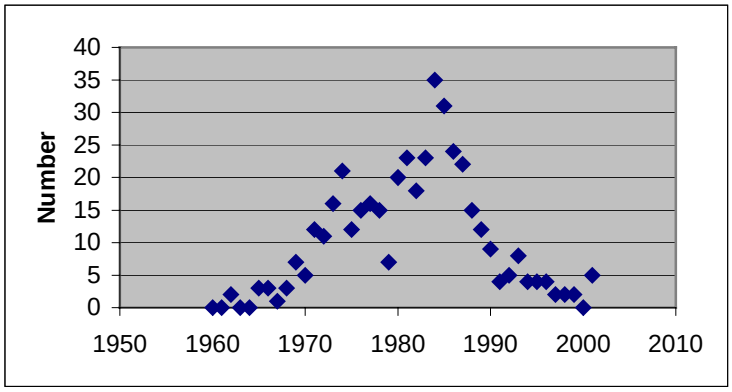


Figure 3: Number of nuclear power plant 'starts of operation' in the world

Note the peak in about 1985 and the subsequent decrease [Ref. 3**].**

There are probably many reasons for this downward trend, and it happens to be a fruitful area for the usual assertive reasons and explanations. However, what is not in question is that to enable the countries of the world to maintain progress in their social development i.e. increased use of electricity, we will need all the energy sources we can get for the future, and these sources will also now have to be environmentally 'clean'. The amount of electricity being used *in the world* is increasing both in total amount and per capita. The population of the world is increasing, so even to maintain existing living standards the amount of clean electricity generation will need to increase The decisions to be taken will of course be on the basis of national strategic requirements, bearing in mind that in many countries the existing generating capacity, the rate of expanding electricity needs of the future, the requirement for replacement of existing plant, the availability of indigenous fuels and the contradictory national demands on available capital for investment. The choice of plant employed will need to be cost effective on a nationalistic basis, require decisions to be taken on fuel use and availability, meet indigenous manufacturing needs, and will also need to use proven, established technology. This approach is sometimes contradicted by technologically unrealistic proposals. But a 'jam tomorrow' approach, using commercially unproved technologies needs to be robustly resisted on the basis of not being relevant to the schedule for electricity

requirements, a waste of resources or to be a sensible contribution to the needs of the environmental 'clean-up' expected from Europe.

The fuels used for generating electricity in European countries are diverse and range from an almost total reliance on conventional fossil fuels (as in Ireland) to a high percentage of nuclear power (as in France) as shown in Figure 4, which demonstrates that different countries in Europe at their current state of development are producing a variety of solutions to the fuel/electricity problem.

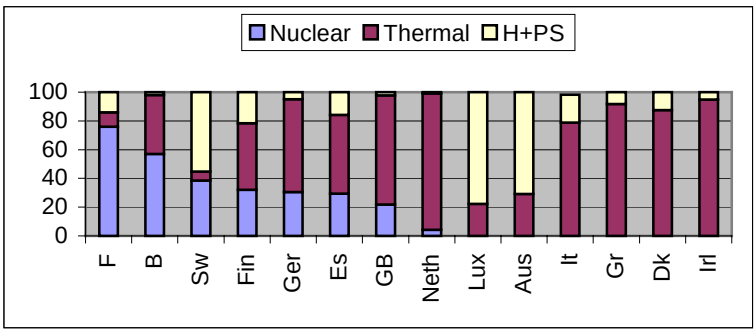


Figure 4: Fuels used for generating electricity in European countries on a % basis and showing the range of diversity of fuels and their amounts for generating electricity (Ref. 1).

3 BACKGROUND TO PLIM, PLEX AND THE PSR

3.1 DEFINITIONS

The terms Plant Life, Power Plant Life Management (PLIM) and Plant Life Extension (PLEX) are now defined and generally accepted but are still sometimes used in an ambiguous way. Current definitions of these terms have evolved nationalistically and have been founded on usage and development in that country. For this reason there has been confusion in the meaning of the terms used. Generally, PLIM is taken as an activity carried out during the period of commercial operation of the Nuclear Power Plant (NPP). However, this was found to be too restrictive in describing plant life when considering the whole plant life cycle and its effect on the price of electricity. It is now accepted that plant life is used in the wider context of that period when financial charges can be made against the NPP.

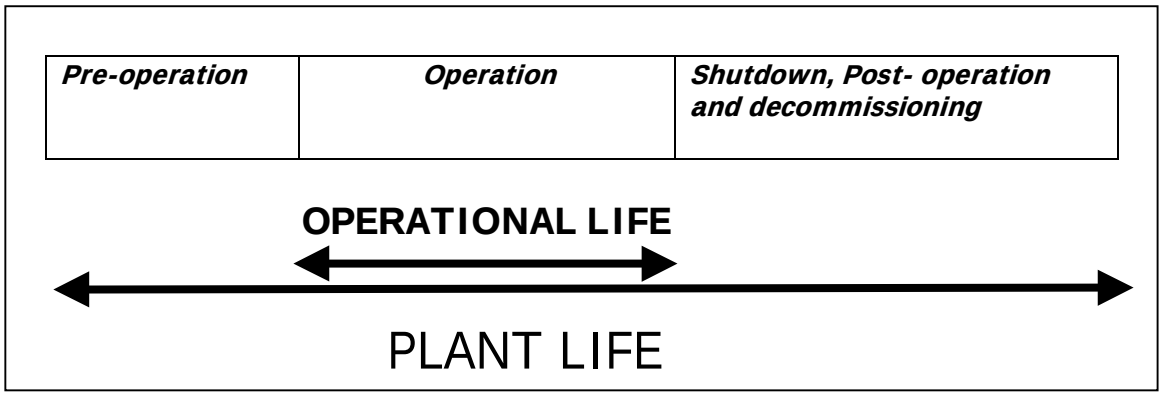


Figure 5: Plant life includes the period when changes can be made against the NPP

The scope of Plant Life includes the choice of design and it's eventual decommissioning to a 'green field site'. In the past 'Plant Life' was confused with 'Operational' or 'Service' Life. Life Extension refers to Operational or Service Life

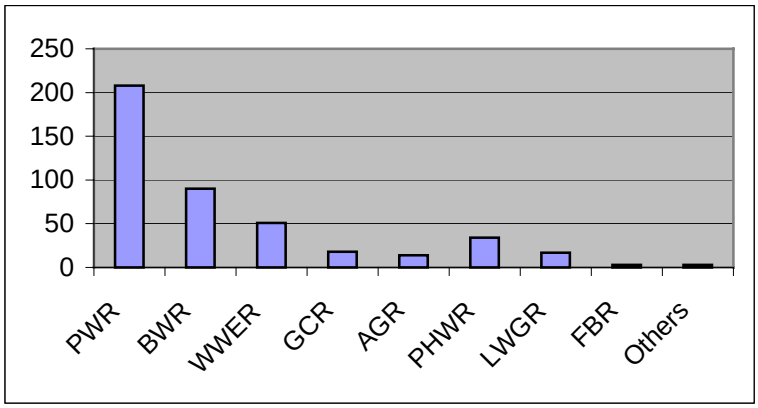
The term Plant Life thus includes the pre- and post- operational activities of choice of plant, funding, siting, design, construction, commissioning, operation, preparation for shut-down and decommissioning-that is, the Whole Life Cycle.

To show the interaction between the roles of Utilities and Regulators in a particular country it is useful to also link the definitions of PLIM and PLEX to the Periodic Safety Review (PSR)-which assumes a greater significance than PLIM in some countries. Definitions and descriptions will be given in this section while the process of Plant Life Management is given in Section 4.

An overview of nuclear power plant life management in European, and neighbouring countries is given in Section 5 below and which also describes the national inventory, age and genus of their NPP together with expert national views on NPPLIM. According to the IAEA there were 438

operating reactors at 31/12/2001 and 33 were under construction .The types of NPP is varied, the PWR being the commonest, and the global inventory is shown in Figure 6 below:

In some countries the period of actual operation is evaluated at some stage after plant start-up. [see e.g. Ref. 4]. It is a re-defined period when the Plant can be evaluated against the target design life and amortisation period in terms of the actual plant and its actual operation. However it Plant Life Management (PLIM) is now usually taken to mean those many activities which are to do with the normal operational management of a nuclear power plant to maintain its 'good condition' and to enable operators or Owner(s) to meet the plant's intended amortisation period, operational life or design operational life. That is, it is to do with existing planned Plant Operational or Service Life assurance and not necessarily to do with meeting an additional period or extended operation time in excess of that intended at the design or evaluation stage, which is usually known as Plant Life Extension (PLEX).



(IAEA publication Nuclear Power reactors in the world)

Figure 6: Number of different operating reactor types in the world on 31/12/2001

It will be remembered that many of the NPP now operating have only just reached 'middle age' as can be seen in Figure 7 below:

'Life' encompasses the pre- and post-operational activities on the NPP and, as suggested earlier, a pragmatic definition of 'life' could be the time when charges are accrued by the NPP. This time includes other activities such as, for example, design, acquisition and decommissioning and then the return of the site to a 'green field' after use.

'Plant Operational Life' is not usually a pre-defined period. The initial aim is to operate for a period (plus a margin of sometimes 5 years) that allows the full recovery of capital costs and charges (the amortisation period). The term PLEX is now falling out of favour because, if 'Plant Life' or 'Operational Life' is undefined, it is then illogical to talk about plant life extension. PLEX

tended to be used when referring to ‘Design Life’ or ‘Licensed Life’. A re-evaluation of this ‘life’

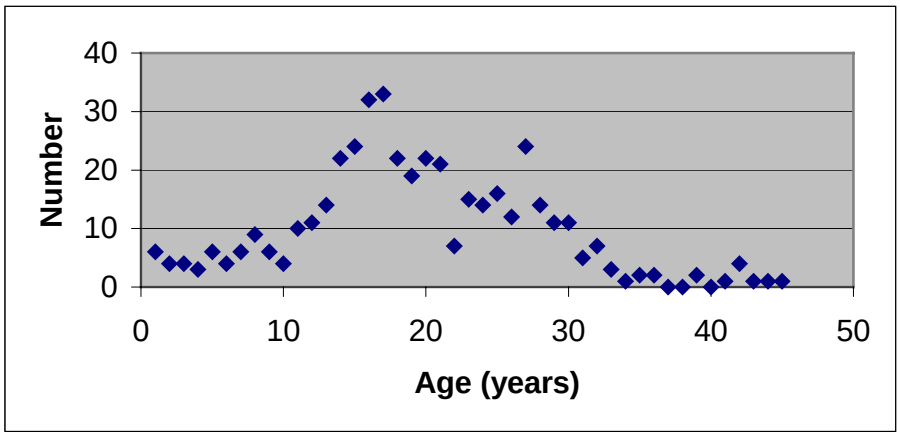


Figure 7: The number of NPP and their Age

(as at 31/12/2001 - source IAEA, Nuclear Power Reactors in the World)

when the Plant was ‘up and running’ gave rise to the term PLEX.

In order to ensure the safe operation of NPP, and as distinct from PLIM activities, which are generally seen as commercial activities, the NPP is subjected to a Periodic Safety Review (PSR)-a Regulator driven activity. The periodicity of this Review varies from country to country and can be up to usually ten years. The scope of the PSR is large in terms of effort and is a response by the Utility to the request of the safety authorities that are the Reviewing organisation. In basic terms the owners have to demonstrate that the NPP has to continue to meet the safety case and, as a result of the Safety Review, engineering work may have to be undertaken to allow the plant to continue operation. This PSR has to be distinguished from the Licensing approach stemming from the Atomic Laws of the country where the Regulator acts as a government Agent to permit plant start up and operation. There is a variation on the licensing process in the US where the initial license period of 40 years not only coincided with the Design Life Period but also arose from the ‘Anti-trust’ laws. However, since the early 1990s the licensee has to demonstrate to the USNRC, for a proposal to prolong operation beyond the 40-year license period, that the plant can operate safely. To avoid uncertainties there is a trend for licensees to re-apply 20 years after start up. The re-licensing of plants has now started and will have the added benefit of a decreased rate of return, which will improve the economics of electricity from nuclear power. Plant Life Management can directly affect the cost of electricity from NPP in an increasingly competitive environment. Of course the safety considerations of a NPP are paramount and safety requirements have to be met to maintain or obtain an operating licence.

Some countries have advanced PLIM Programmes others have none. In part this is because countries with a relatively large number of NPP have already established their PLIM programmes to optimise their operational requirements.

The IAEA and the OECD/NEA have published many reports on the topic. Nuclear Engineering International, the journal, organises an international meeting every two years on the topic of PLIM/PLEX. A strong convergence of views is emerging from these different international for a, particularly in the area of the commercial aspects of Nuclear Power Plant (NPP) operation and in the evolution in the scope of Nuclear Power Plant Life Management (PLIM). However, it is stressed that this is one area of nuclear engineering where Codes and Standards have not yet impinged significantly. It may be that as these studies, and also as the development of Codes and Standards on PLIM, progress they will move into areas where a common approach may be adopted by different countries because new plant is not currently being introduced and the existing population of NPP are getting older, and these require the development of common approaches in an economically efficient way.

3.2 PLIM AND THE REGULATORS

As an example of the PLIM approach, the Reactor Pressure Vessel has been identified as the highest priority key component in PLIM for PWRs and BWRs, and the probability of its failure is very low. However, the accumulated service life of existing (reactor pressure vessels including those in seagoing vessels) is not as low as the predicted failure rate. The RPV therefore requires special attention to maintain its structural integrity during its lifetime. It should be stressed that no single parameter can be invoked to establish a high level of structural integrity in an RPV, but it is the attention to the many interacting requirements that provides the assurance of RPV reliability. Not only is it dependent on the design and construction to a recognised and successful Code that anticipates the rigours of the different facets of operational requirements. It assumes the use of carefully specified and tested best quality materials, fabrication using well tried and tested procedures (such as proven welding practices), a comprehensive quality assurance programme, extensive but efficient inspection during fabrication and the effectiveness of the hydrostatic pressure test. Up to this stage the integrity is the responsibility of the designer and fabricator. During operation the integrity is dependent on the initial quality of the vessel as designed and fabricated, the degradation of mechanical properties with operation the compliance of operations within the constraints of the design intent. The degradation of <u>all</u> the NPP materials during operation has to be monitored and assessed, and the operating history recorded to ensure that the designs operational intent is met. In terms of the RPV the frequency and magnitude of any pressure vessel transients to which it has been subjected, knowledge of the appropriate crack growth rates and laws as a function of the environment, the material condition and the frequency of in service ultrasonic inspection.

Studies of the factors which degrade materials and equipment, investigations of ageing and degradation mechanisms as well as studies on the development of methods and means to reduce the

influence of ageing and to maintain equipment operation in a good state (performance, operation) led to the creation of the term “ageing management”.

In its turn, the methodology and measures for assurance, or even enhance, NPP safety level during its operation is described as “safety management”. Joint implementation of measures for ageing management and safety management to assure NPP safe operation then define the content of the term “life management”.

From a technical point of view, PLIM is a complex of activities to maintain/enhance NPP safety to provide operability and evaluate the durability of the main components and power unit, as a whole. Conditions provided for implementing PLIM must be considered at all the stages of the power unit life cycle.

We have already stated that the safety of a NPP is of paramount importance in order to protect the public from the health risks associated with the release of radioactivity. The safety concern leads to a continuous and interactive process between the Plant Operator/Owner, who is responsible and accountable for the safe operation of the NPP and the Safety Regulatory Body, which provides operating authorisation.

In addition to safety monitoring of operation for conformance with established and agreed procedures and inspections, the safety of NPP is usually periodically reviewed in order to confirm that the plant is not less safe than originally intended and to evaluate the current condition of structures, systems and components, with regard to ageing degradation and with the expected future requirements.

In fact, most countries have no specific regulations covering the absolute value for operating lifetimes of NPP and the plant owners can continue to operate as long as they are demonstrably safe. However, nearly all National Safety Regulatory Bodies have instructed Owners to perform comprehensive Periodic Safety Reviews (PSRs) to ensure continued safety.

The other approach adopted is to have a licensed period of operation. In the USA, the license is for forty years. We have seen that the initial consideration for this period was based on economic and “anti-trust” factors rather than safety, technical or environmental standards. Since the early 1990s the licensee, if the Owner wished to continue operating, has had to demonstrate to the USNRC that the NPP can operate for twenty years beyond the forty-year license period. The necessary amendments focus on matters to do with the effect of ageing on systems, structures and components for the period of extension (delaying the license application to a date just in advance of license expiry could leave the licensee with large uncertainties-so there is a trend for licensees to re-apply twenty years after the start of operation to give advance knowledge for planning purposes).

In all cases, safety concerns and regulations interact with the PLIM, mainly in two ways:

- Directly through operating authorisation: if the number of incidents is too high, if safety-related systems are not sufficiently reliable, then regulators will require shutting down of

the plant until satisfactory conditions are restored. This may take sufficiently long time to be an important burden for utility financial situation.

- Indirectly through expenses that are required to comply with regulations and which affect plant cost-effectiveness. It may happen even though regulation has not been changing because ageing modifies components and structures to such a point that they don't meet design characteristics any more. A conflict situation could arise when the safety regulation itself is changing. This can arise from lessons drawn from operating experience anywhere in the world or from evolving technology that offers new possibilities to improve reliability. In most cases, new regulation is not strictly applicable to older plants but generally, the regulatory body would ask the plant operator/owner to check whether or not the facility would more or less comply with the new rules. And if not, plant operator/owner is asked what could be done to reduce the gap associated with the rule change. And if some modifications appear to be feasible, it quickly becomes mandatory to do it. Such jobs are generally very costly and will definitely have a detrimental effect on plant cost-effectiveness.

A specific case related to regulatory change is the question of spare parts: do they have to be designed and built according to current rules when they have to fit in an old plant? Because we are dealing with single components, the applicable rules are generally not the general safety requirements given by regulatory texts but the codes and standards established by industry. However, the question remains the same: what rules have to be applied and what consistency demonstration must be made? INSAG (IAEA) recommendations give interesting insights into the best way to deal with such an issue.

It has been said that changing the "rules of the safety game" may introduce very costly modifications to a plant. Moreover, in some cases, it may be totally impossible to comply with the new rules. For example, changing the seismic analysis methodology may lead to a plant shutdown if the necessary modifications of civil work are just unthinkable. In that sense, the new safety characteristics of advanced nuclear power plant, although they have not been built, are a real threat for continuing operation of older plants.

From these considerations, it can be inferred that Safety Regulation has an impact on the profitability or competitiveness of a NPP. But, without an operating license there is no operating plant, and hence no revenue. Safety considerations and provisions are part of the plant capital and production costs. On the other hand, Economic Regulation may be part of electricity rate setting and will have an impact on revenue aspects. However, in many countries, safety regulation and economic regulation are not integrated, that is, they are not coupled. Because of this de-coupling then changes in costs without a change in revenue can have a direct impact on the profitability of the NPP. Any increase in safety requirements during the life of the NPP can lead to an increase in the cost of its electricity.

The main driver for the upsurge in interest in PLIM during the past decade has been essentially to meet the needs of lower electricity production costs and to maximise the returns on the NPP capital. This situation was likely to have arisen at this stage of nuclear developments anyway, because of the increasing age of NPP and the increased requirement to replace major components, but the

situation with regard to PLIM has been exaggerated by the low number of new NPP being built in the world, the increasing age of existing nuclear power plants and the increased competitiveness in the price of electricity when compared to other fuels for generating electricity.

Governments are becoming less directly involved in what are now commercial, privatised ventures. It is the ‘market place’ that, increasingly, determines the price of the electricity to the consumer. Nuclear is only one of the competitor fuels for generating electricity and therefore has to be competitively priced. Any operational decision or action which impacts on the generating cost of the electricity has a direct bearing on the profitability of the utility.

The assessment of the NPP financial and technical risks is a continuous process throughout the lifetime of the plant. But, from the earliest stage in evaluating the project until the return of the site to a 'green field', costs are being incurred by the project.

As the NPP project proceeds beyond the choice of plan, approval and its financing then specification preparation, planning, cost estimates, financial arrangements, procurement, manufacture construction and commissioning, staffing, training, setting up databases and inspection 'fingerprinting' are carried out as part of this pre-operational phase.

After commissioning, the plant generates electricity for sale. The revenue from this sale of electricity in the commercial world has to cover the operational costs, the pre- and post-operational costs and liabilities, the company internal costs, shareholders rewards and also provide for investments for the future development of the company. The impact of operating beyond the amortisation time decreases the annual cost, where the annual capital cost component is reduced to zero and the remaining charges are just for operation or ‘mothballing’ the plant. There would be a difference in the Annual Capital Charge and in the annual running costs between different NPP types (showing that choice of NPP is important).

Together with these factors the operational period and the annual operational generating time determines the annual cost of generating electricity for that year which, for a profit, has to be less than the returns from the sale of electricity.

Depending on the financial methodology employed then, as a minimum, the capital costs to do with NPP procurement should be recovered and construction time should be reduced during the amortisation period, which varies between (and within) countries. The closure of some NPP have also been spectacular in their financial losses with regard to their amortisation life, for example, Three Mile Island in the USA, Chernobyl in the Ukraine, Zwentendorf in Austria, the NPP in Italy and the impending closure of NPP in Germany.

Over the past thirty or so years some commercial nuclear power plants have been shut down prematurely for a variety of reasons but a small number have operated for a period greater than that envisaged at the start of their operation (Calder Hall, Oldbury, Sizewell A, etc.). The increase in operational life of a small number of NPP, has usually had the effect of producing cheaper

electricity because their generating period is greater than the amortisation period, consequently the capital cost component was eliminated from the current cost of electricity generation of that plant.

In many developed countries there is an excess of total generating capacity (not just nuclear alone) above that required to meet the existing and predicted peak electricity demand. This situation has arisen because the demand for electricity was met, or over-predicted, or power stations were constructed in order to provide continuity of orders in plant production during 'lean' years but that there has been a saturation of industrial demand and also in population growth in the developed world. The important observation is that this 'boom' period of growth in electricity generation came to an end and the overall situation was dominated by an increased competitiveness in the price of electricity from different fuel sources. Also with the development of efficient international electricity distribution systems exporting and importing electricity has reduced capacity need in some countries. It is important to note that the rate of construction of all, new, big generating plants has markedly slowed down. Undoubtedly, the fact that the cost of new power plants is large and money is expensive (high interest rates) to borrow seems to be a discouragement for building new plants. But the excess generating capacity available in some countries, or the continued use of cheaper existing power plants (because capital cost components are low or non-existent) are major factors inhibiting the construction of new power plant. 'Old plant' replacement does not seem to be providing many orders for new plants. But the overall generation situation seems to be changing. Global and national electricity demand is again increasing and because of environmental constraints the path is again being prepared for nuclear power.

However, in the modern competitive world the 'cost' and 'price' of electricity seem to be the current dominant factors in determining the course of new developments.

There is a large amount of capital money 'on deposit' in an ageing population of nuclear power plants-but they are not very old plants (but to replace this generating capacity would be very expensive). Very few existing plants have an operational life that is greater than thirty years. So the emphasis has shifted to that of increasing the cost effectiveness of existing plant. The current priorities are to do with Plant Life Management. As already mentioned, PLIM is the methodology and practice of optimising expenses to gain maximum profit while preserving competitiveness in the market place. The simple relationship:

REVENUE - COST = PROFIT

serves as the basic equation when calculating profitability and optimisation of NPP expenses. The cost is composed of many constituents, including expenses for: fuel costs, staff costs, infrastructure costs maintenance, safety, R&D works, future liabilities such as de-commissioning, etc.

Garry Young, from Entergy in the USA, recently reported at the 2001 Nuclear Engineering International PLIM/PLEX meeting in London that eight Units had received licence renewal from the USNRC, 14 plants had registered licence renewal applications and 25 Units have announced plans of intent. This means that 40% of the 103 operating plants are publicly committed to licence renewal. Moreover, it is predicted that 100 or more plants will eventually seek licence renewal over the next 10-20 years. Besides this large increase in operational lives of plants there is a corresponding potential for reducing the price of electricity and, importantly there is the added benefit of increased capacity-without renewal more than three dozen plants would reach the end of their operating lives by 2015. This contribution to the current need provides a bridge to the future by providing an interval to consider a 'new build' programme.

3.3 APPROACHES TO PLIM

The approaches to plant life management in different countries are not necessarily consistent but at the same time there seems to be a growing requirement for an international harmonised approach. But the actual current situation is complex. There are many different types of NPP in the different countries and each has its own variants**.** The conclusion has to be drawn that each nuclear power plant has its own characteristics and is therefore unique. In reality PLIM is a Plant specific exercise. There may be some generic common feature of a particular variant of a power plant type but this commonality, for many countries with a small number of power plants, is an exceptional feature. As a working principle for this paper each power plant is unique. The average age of all nuclear power plants in the world is still relatively low but there is a growing awareness for a need to address those ageing and degradation issues which could affect the plant lifetime and hence its profitability

In addition NPP were designed and built at different times using contemporary or other national Codes and Standards. Codes and Standards have changed continuously and modified as a function of time. Some countries as part of their own industrial development are also, in turn, developing their own Codes and Standards. Major components for many older plants can no longer be provided by the original suppliers because some manufacturers are no longer in that business or the manufacturing methods have been substantially changed and also current material choice and specifications can be significantly different to those in older components.

Unfortunately the resources to develop and improve initial databases to support PLIM are very often underestimated. Information is usually specific to a particular NPP but 'generic data' is useful for establishing trends in behaviour. Improving and updating databases is the main purpose of the generic constituent, where the following main trends can be separated: research, methodological, technological, hardware, software design, and regulations.

In particular the works are performed in the following fields:

- development/improvement and verification of computer codes;

- improvement of methods and instrumentation for research and analysis;
- development of methods and instrumentation for monitoring and diagnostics of condition;
- improvement of technology of integrity and safety assurance;
- development of complex of regulating and technical documentation;
- development and filling of knowledge bases and databases for information support of PLIM.

3.4 THE IMPORTANCE OF THE POWER SYSTEM (for a region, country)

The nuclear power plants may represent a technical and financial asset with strategic significance for both the utility/corporation and the country.

Many of the tasks associated with PLIM include input to the corporate strategy and interaction with many corporate elements not directly associated with plant operations. These activities include economic evaluations of alternatives for major refurbishment or replacement projects as well as strategic decisions regarding use and disposition of the plant.

To assess the economic benefits the following factors should be considered:

- PLIM economic dependence on a many 'system-level' characteristics, including alternatives
- options for replacement capacity, short-term replacement energy costs during nuclear
- plant outages, corporate financial situation, and accounting policies
- PLIM uncertainties: the long planning horizon determined by the licensing lead time, the lead time for possible replacement capacity and the period of actual operation. Furthermore the lack of industry experience with PLIM creates uncertainty about capital and operating costs, regulatory requirements and long-term plant performance.
- PLIM should present interest for both customers and investors. From the viewpoint of investors and Owners, the operating life of a nuclear unit will be determined primarily by its profitability rates relative to other available generation options. With respect to the customers, their major interest will be the minimisation of electricity rates.

The most comprehensive approach in assessing the economic viability of actual operational lifetime would be within a power system analysis. In practice, it means that in order to decide on economic viability of extended nuclear generation, one should compare the costs (or rather the present value) of this generation with the costs of replacement power. As replacement power alternatives, generation on conventional or innovative power sources, power purchases from neighbouring power pools, contracts with independent power producers or demand side measures should be considered. Based on the power system analysis conclusions, the decision making group of one Utility/Corporation selects the adequate grid development scenario for the next period (usually the time interval considered is 25-30 years) to meet the demand for electricity at the minimum cost, subject to a set of financial, resource, technical, environmental and political constraints.

3.5 PLIM, POLITICAL / PUBLIC ACCEPTANCE

A Nuclear Power Plant may be viewed by its Owners in the same way as any other asset, but there are two key differences with regard to nuclear power plants:

- any serious shortcomings in safety will be viewed adversely by society and that could affect continued operation of that plant in that country and have an impact on nuclear power world-wide;
- the amount and longevity of the liability remaining after production of electricity ceases are considerably larger than for most business assets.

The first of these points provides a focus for the clear moral position that safety of staff and the public must be of paramount concern in operating a nuclear power plant. From a life management point of view, this means simply that when the cost of demonstrably maintaining the required standard of safety cannot be justified by the commercial benefits, the correct business decision is to shut down.

The second is more complex. Continued operation of the plant will produce income, which will be partly offset by costs and any investment in upgrades required-but a positive cash flow may be expected. However, the effect on liabilities can influence this in two ways. Firstly, operating the plant is likely to give rise to further waste volumes thereby adding to the liability, but this effect will usually be small. Secondly, ongoing operation will defer the need for spend on decommissioning reducing the present day value of his liability.

Usually these activities have been associated with the pursuit of establishing a new NPP or in the areas of fuel reprocessing, disposal of radioactive waste. Undoubtedly, the industry has been responsible for much criticism by not being as 'open' as it should be in the explanations provided to its own workers and to the outside world. However much of the 'attack' is orchestrated but can only be countered by 'good' information that is readily communicated. The balancing argument is that such 'open' activities can be counter-productive in that the ‘opposition’ groups seem to have an unquenchable thirst for data on which to base their arguments. Providing such data costs money and professional effort. Perhaps consideration should be given to providing the information being sought- but at a price.

A paper on 'Policy issues for Nuclear Power Programmes' has been published on these aspects by the IAEA.

As a note of caution in this area of Political and Public Acceptance the Nuclear Industry has been less than successful in its endeavours to date. Unfortunately, a widely held perception is that the Industry asserts the problem area and then dissipates a lot of resources in providing answers to that particular issue.

4 THE METHODOLOGY OF PLANT LIFE MANAGEMENT

4.1 INTRODUCTION

Degradation processes have highlighted the need to develop the methodology to allow an improvement in the understanding and management of degradation and ageing in a timely and planned way so that adequate safety and operational margins can be maintained while the plants economic viability is protected

An outline of NNPLM processes is shown in Figure 12. The main stages are described here in a general way.

4.2 DEGRADATION AND AGEING

Degradation is a deterioration phenomenon that might lead to component failure or limit the life of a component or power plant. Ageing describes a continuous time or operational degradation of materials due to operating conditions, which include normal and operating conditions (but excludes 'design' and 'beyond design basis' accidents). As a result of ageing degradation the plant or component state could vary through the operating life.

Age-related component failures may occur by degradation processes, which are common to all industrial plant (with the exception of irradiation effects which are unique to NPP). Components include a large variety of materials. So, it should be remembered that in addition to the metallic components which will be discussed below -by way of examples of the approach, important components include cables and Instrumentation, civil structures made from concrete, non-metallic materials, etc.. However in the examples chosen we have tended to concentrate on the metallic materials, which are for Category 1 items. Degradation mechanisms for these metallic components include:

- general and local corrosion
- erosion/corrosion
- fatigue
- corrosion fatigue
- material changes due to irradiation and temperature
- creep
- wear

All components of NPP are subject to ageing. However the rates and significance of degradation, and therefore component lifetimes, vary considerably. Ageing may lead to the degradation of physical barriers and redundant components resulting in an increased probability of common cause failures. It is possible that degradation not revealed during normal operation and testing could lead to failures. Ageing in NPP must be managed effectively for the following reasons:

- to ensure that necessary safety margins and adequate reliability exist to ensure the operational viability of the NNP.

- to ensure that unforeseen and uncontrolled ageing of critical plant components do not shorten the NPP lifetime

Experience of severe degradation of major components has highlighted the need to develop methods for:

- improving our understanding of degradation and ageing
- processes, and,
- managing the influence and effects of ageing

The reasons for this are to assure continued safety, to prolong the life of major components and to establish the economic case for planned replacements. The aim is to maintain the current condition of the NPP in a state of high reliability by evaluating the current state of the plant and considering the impact possible ageing/degradation mechanisms. Plans are classified as follows:

- assessment of the life of components which cannot readily replaced
- operating life assessment or planned replacement of major
- components where economic considerations will largely condition whether
- replacement or decommissioning should be pursued
- planning for maintenance and replacements so that outages and delays (i.e., loss of revenue) can be minimised

As indicated previously many of these activities are considered to be plant specific, particularly where there are a small number of NPP. But for a larger number of plants there could be a sharing of equipment and skills on a utility-wide basis. Also safety and reliability activities on a NPP cannot usually be separated because the activity might be planned and actions discharged by the same resource. Similarly there can be a common international requirement for information. There is a growing need for the development of economic models for the assessment of the benefits of further operation, and also the identification of the key factors which will determine whether replacement of major components, maintenance, repair, refurbishment is of economic benefit.

4.3 DEGRADATION MECHANISMS

It has already been mentioned that all components 'age', but it is the rate of degradation and its significance that determines its importance with regard to failure. While the following is not an exhaustive exposition we have again taken metallic materials of key component materials as an example, where the main degradation mechanisms include metallurgical phenomena such as irradiation embrittlement, fatigue, corrosion, interaction of mechanisms and so on. Some of these are shown in Figure 5 below.

The detailed description of these mechanisms are not given here, but ageing degradation mechanisms are usually classified into categories, which can be subdivided into those which:

- affect the internal microstructure or chemical composition of the material and thereby change its intrinsic properties (thermal ageing, creep, irradiation etc.),
- impose physical damage on the component either by metal loss (corrosion, wear) or by cracking or deformation (stress-corrosion, deformation or cracking).

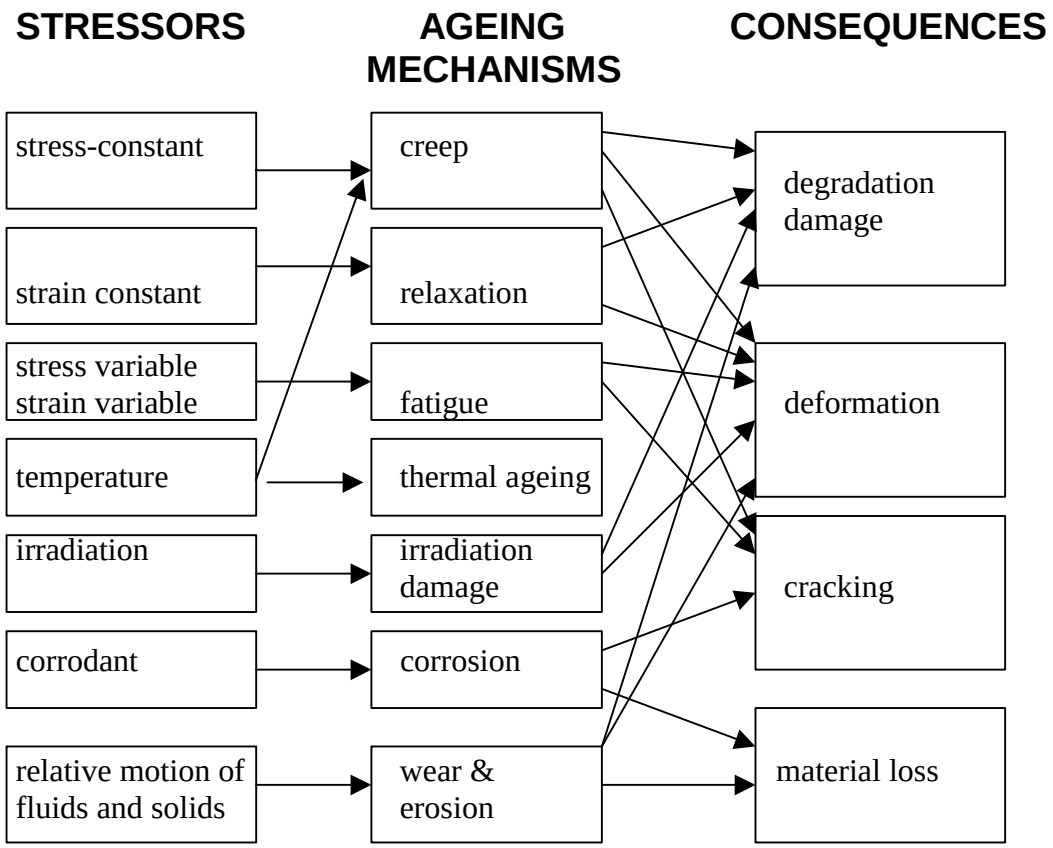


Figure 8: Ageing factors, basic ageing mechanisms and possible consequences

A major stressor in an ageing structure is time itself.
(For example, in the embrittlement of rubber and plastic materials in components)

There are a large number of degradation mechanisms operating in the major components of NPP. Potential ageing mechanisms and the resulting degradation effects on components are shown in Figure 9 while many degradation mechanisms for a variety of NPP types are listed in Figure 10:

	Irradiation	Thermal ageing	Creep	Fatigue	Corrosion Fatigue	Stress corr^n cracking	Strain induced corr^n cracking	Intergranular attack	Erosion corr^n	Local corr^n attack	General Corr^n	Wear
Change of Material properties	x	x	x	x								
Cracking	x		x	x	x	x	x	x				x
Dimensional changes	x		x									
Wall thickness									x		x	x
Denting											x	
Pitting										x		

Figure 9: Potential ageing mechanisms and resulting effects on components

	RPV and head Bolts	RPV Supports	RPV Internals	Control rod mechanisms	Reactor Coolant Pipe work	Pressuriser	Pressuriser Pipe work	Reactor coolant Pumps	Steam generator shell	Steam gen. tube bundle	Steam and Feed water lines	Containment (concrete)	Basemat (concrete)	Pressure tube	Calandria	AGR structures
THERMAL																
Strain ageing	x	x			x	x		x		x						x
475^0C embrittlement				x			x									
Temper embrittlement	x	x			x			x								x
Sigma embrittlement																x
Age hardening/softening				x											x	
Sensitisation			x	x					x							x
IRRADIATION																
Embrittlement	x		x											x	x	x
Helium embrittlement																x
Irradiation growth														x	x	
CORROSION																
General corrosion/oxidation	x		x	x	x	x	x	x		x	x	x	x	x	x	x
Galvanic																
Crevice										x						
Erosion							x	x		x	x					
Pitting	x	x														
Cavitation								x								
Intergranular					x					x						
Gas oxidation	x	x														x
HYDRIDING OF ZIRCONIUM														x	x	
WEAR																
Sliding				x				x		x	x					x
Fretting	x		x					x			x					x
Impact			x					x		x						x
Stiction/Friction				x												x
CRACKING	x		x			x	x	x		x	x	x	x	x	x	x
STRESS CORROSION			x		x						x					
DEFORMATION			x				x		x							

Figure 10: Degradation mechanisms for main components

4.4 MONITORING DEGRADATION

Evidence on ageing and degradation are very important for optimising PLIM processes. Moreover, this evidence is often plant/component specific. Monitoring of degradation is very important in Plant Life Management and it encompasses direct detection and evaluation of degradation and also the monitoring of the parameters that can influence degradation mechanisms. It includes continuous (or on-line) monitoring, in service inspection, intermittent testing of specimens made from plant materials that can be installed inside components or in autoclaves.

	Acoustic	Vibration	Stress wave emission	Dimensional measurements	X and gamma ray	Ultrasonics	Eddy currents	Dye and Magnetic particle	Visual	TV	Photography	Leak detection	Hardness	Electrochemical	Internal monitoring specimens	External monitoring specimens
THERMAL																
Strain ageing						?	?								x	x
475C embrittlement						?	?						x		x	x
Temper embrittlement														x	x	
Sigma embrittlement						?	?						?		x	x
Age hardening/softening						?	?						x		x	x
Sensitisation														x		
IRRADIATION																
Embrittlement													x		x	
Helium embrittlement															x	
Irradiation growth				x												
CORROSION																
Gen corr^n/oxid^n						x	x								x	x
Galvanic									x	x		x	x	x		
Crevice						x	x		x	x	x					
Erosion						x	x		x	x	x					
Pitting						x	x		x	x	x	x				
Cavitation						x	x		x	x	x					
Intergranular						x	x	x								
Gas Oxidation						x	x								x	x
HYDRIDING OF ZIRCONIUM																
WEAR																
Sliding	x	x				x	x		x	x	x					
Fretting	x	x				x	x		x	x	x	x				
Impact	x	x				x	x		x	x	x	x				
Stiction/friction																
CRACKING				x		x	x	x	x	x	x	x	x	x		
DEFORMATIONS	x	x			x					x	x	x				

Figure 11: Monitoring methods for a selected range of degradation mechanisms

While each method employed has its own objectives and has advantages and disadvantages, all contribute to give information on component ageing, allows the taking appropriate and timely actions, and yields relevant data for PLIM considerations. Many monitoring and inspection technologies are already used to satisfy regulation requirements or maintenance purpose (see Section 4). But, of course, the development of new technologies will offer greater capacity to evaluate component life expectancy. These developments reflect the increasing enthusiasm for

Condition-Based Maintenance, which relies on monitoring. Amongst the many techniques available for monitoring the various degradation phenomena are those listed in Figure 11.

4.5 THE PROCESS OF PLANT LIFE MANAGEMENT.

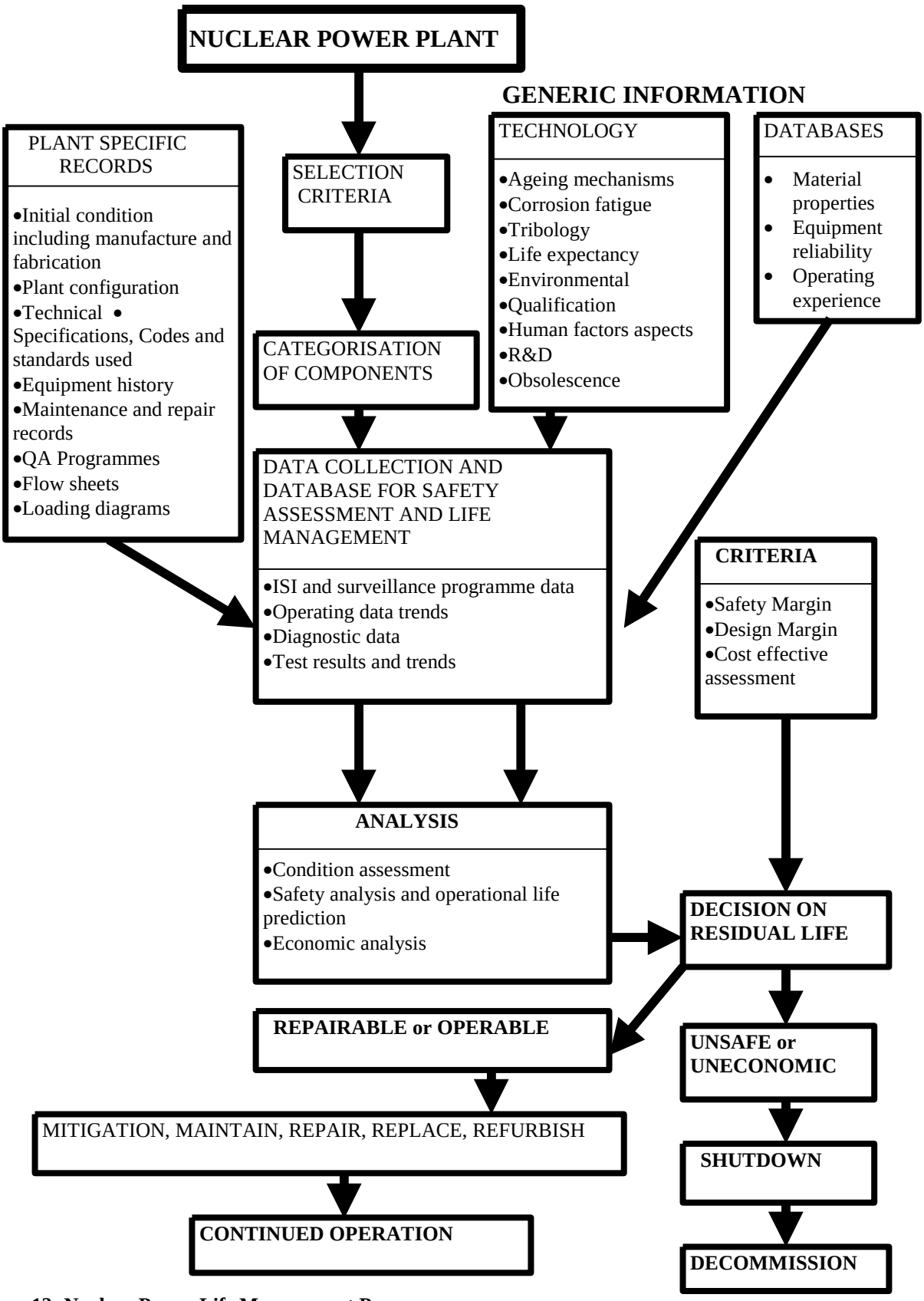


Figure 12: Nuclear Power Life Management Processes

It has been stressed previously in this report that each plant is unique and is a “prisoner” of its own history. But if a series of identical units are operated the same way (as in France), it allows the development of a broadly based interactive guide which is supported by plant specific items and which defines all the points to be monitored, the monitoring system and the periodicity and the acceptability criteria-leading to an overall improvement in PLIM efficiency.

4.6 SELECTION CRITERIA. IDENTIFICATION OF NPP KEY COMPONENTS AND CLASSIFICATION

Each NPP has thousands of components made from a variety of materials; ageing at different rates-and to evaluate each of these components in terms of its life would be a daunting task. Therefore it is desirable to categorise or 'rank' these components in terms of their importance in order to prioritise the work and to maximise the effective use of resources**.** The first step for safety or reliability is to identify those key components, which would be important if their failure would have a major impact on safety or Plant Operational life. In considering the economic assessment the key components are those whose repair or replacement would cause a major addition to the maintenance budget or an abnormally long shutdown such as to adversely affect the price of generating electricity from that plant. The second step is to classify the components into four categories as described in Figure 13. on the basis of the chosen criteria. Then a prioritisation of items is attempted to rationalise and optimise and identify resources.

The categorisation of components given in Figure 13 below is not unique and there can be a large number of factors such as those given in Figure 14:

- **CATEGORY 1 COMPONENTS** are those, which are generally considered to be irreplaceable. Examples of such components include the Reactor Pressure Vessel (RPV) and also the Containment Structure (with regard to replaceability it can be argued that even the RPV and the containment structure could be replaced-but at a great cost). Also with regard to irradiation embrittlement of RPVs in older NPP it is noted that more than fifteen WWER RPVs have been annealed.

- **CATEGORY 2 COMPONENTS** are those, which are replaceable, but are costly in terms of capital expenditure and outage time requirements. An example of this type of components would be steam generators, which have been replaced on many plants.

- **CATEGORY 3 COMPONENTS** are those, which are 'key' in terms of plant safety and reliability and are susceptible to ageing, but which are replaceable on a routine basis.

- **CATEGORY 4 COMPONENTS** are all other components not included in the earlier categories and are not related to 'life' considerations.

Figure 13: The four categories of Component for Plant Life Management

- Cost to replace/refurbish
- Impact on plant availability
- Loss of revenue (economic impact
- Radiation dose
- Regulatory importance
- Modifications required
- Leading plant influence
- Replacement precedent
- Generic applicability (User Group Influence)
- Mode of failure
- Consequences of modification on plant safety

Figure 14: Examples of categorisation factors

It follows from the approach adopted in this paper, that there may be special site/national features that can produce particular peculiarities in these lists. For example, the differences between 'dry' and 'wet' sites in the evaluation of concrete basemat life, the role of climatic and seismic factors may also be enhanced for specific sites. However a comparison of such listings may include commonalities, which could allow the development of common Utility National or Generic Plant strategies in the area of planned maintenance. National Lists would possibly reflect the Utility's experience operation and maintenance practices.

- Fuel channels
- Steam generators including their internals
- Calandria vessel
- Reactor headers
- PHT piping pressuriser
- General nuclear piping
- Calandria supports
- Secondary piping
- building
- Calandria vault and end shield .system
- Cables (power, control and instrumentation)
- Reactor building
- Turbines
- Generator
- CW intake structure
- Spent fuel bay/liner

Figure 15: Sixteen key components for CANDU

- Reactor Pressure Vessel and head
- Control and Safety Systems
- Primary piping (over 11 mm diameter
- Primary pumps, valves (PC of SGs)
- pressuriser
- Safety related electrical circuits
- RPV internals
- Secondary side of SGs
- ECCS
- Primary water preparation system
- Safety valves
- All main equipment in secondary circuit
- All main electric circuits

Figure 16: Thirteen key components for Russian WWERs

- Reactor pressure vessel
- Primary system large-diameter pipes
- Other primary system pipes
- Steam generators
- Primary pump casings
- Pressuriser
- Auxiliary pipes
- Control rod drive mechanisms
- Vessel internals
- Containment
- Reactor pit
- Anchorings
- Turbine
- Generator
- Instrumentation and Control
- Electrical cables
- Cooling tower
- Polar crane

Figure 17: Eighteen key components for French PWRs

- Reactor Pressure vessel
- RPV Internals
- Reactor coolant pressure boundary piping
- RPV safe ends
- CRD housings and guide tubes
- Drywell metal shell
- Suppression chamber and vent system
- Reactor vessel support
- Concrete structures; RPV pedestal, drywell foundation, biological shield, fuel pool slabs and walls, reactor building basemat sacrificial shield wall, reactor building floor slabs and walls and turbine pedestal
- Plant control centre
- Emergency diesel generator

Figure 18: Eleven key components for the US PWR

4.7 'LEAD PLANT' APPROACH

When a Utility Owns/Operates a large number of plants, a common practice is to apply life management concepts to one unit and draw lessons from the exercise. This allows an improvement in the methodology, to quickly identify missing items and unexpected difficulties, etc. Of course, such a 'prototype exercise' will yield more relevant conclusions if the 'lead' unit is an older one.

Attention must be paid to the fact that a single unit may be considered as 'lead' with respect to the implementation of PLIM process but probably not with respect to component ageing. Indeed, ageing mechanisms are not only related in time, but also to operating conditions and history which may be very different from one unit to another. The most 'aged' component does not necessarily belong to the 'aged' unit. As a consequence, the choice of a 'lead component' which would be supposed to cover a whole population, must be based on a consideration of operating times, actual operating conditions, (past and future), material and manufacturing specifications. It is likely that the choice of a 'lead component' will be relevant only with respect to one given type of degradation. Therefore it is important to select and evaluate each degradation phenomenon on a component-by-component basis.

4.8 DATA AND RECORD KEEPING ACTIVITIES

Data and accurate records are crucial for NPP life management evaluation and establish safety margins. The information required for these assessments needs to be established at the earliest stage. Not only is there a requirement for records but there is also a need for representative archive material for possible future testing. Utilities will store data on key components, but data organisations, in particular countries may not have identified what additional information could be

needed for operational life evaluation. Even if it is assumed that utilities have the ability to provide appropriate data on key component performance, they will also need to provide data on component repair and replacement, associated hardware and software, operational changes etc. In order to achieve a better understanding of ageing phenomena, exchange of information on the topic, organised under the framework of international organisations, Users Group of particular NPP, and Specialist Meetings such as the Bi-annual PLIM/PLEX meeting are particularly important.

'Proper' record keeping requires the identification of specific data. Only then can the impact of ageing on the availability and reliability of components be followed and evaluated. The data set represents a general approach to the assessment and evaluation of ageing in components and may vary with regard to the Categorisation of the specific component.

The data set could be based on information, which is necessary for detecting and following faults or degradation. This information will then provide a better picture of degradation development for lifetime evaluation. The data set in general terms should include the groups of data given in Figure 19.

1 Component specification data (baseline data)

- Material (manufacturing details, archive material)
- Initial properties
- Codes and Standards
- Design loading
- Anticipated ageing mechanisms
  (ageing sensitivity, methods of assessment)

2 Age or Failure tracking data

- Operational history
- In-service inspection
- In-service monitoring
- In-service loading (strain, stress)

3 Stressor and root cause data

4 Failure or degradation mechanism data

5 Test and maintenance data

Measures to improve material choice, design and operations (repair, updating, geometry, initial properties, Codes &Standards)

Figure 19: Scope of data set requirements

Provision or access of this data set would provide an opportunity to identify the ageing component behaviour. However, depending on a specific component category, together with the existing practice of record keeping, it might be difficult or economically unreasonable to obtain all the data that might be required. Therefore a 'proper' format for record keeping needs to be established at the outset of a NPP project.

In the component description the influence of the Codes, Standards and Regulations and rationale utilised for the choice of materials, design, fabrication, inspection and operational validation testing of the system will be recorded. In particular it will be important to indicate where these criteria differ significantly from those currently in use. Qualification data including materials tests, pre-operational testing, pre-service 'fingerprint' inspections, in-service inspection and repair information will form part of the data set. The design basis will provide the functional criteria, design assumptions about the operational requirements, structural integrity assessments and material condition. The operating conditions and the maintenance history will provide the basis to assess degradation. For this reason the Owners should collect and maintain records of all significant testing and plant transients to evaluate important transient events such as Pressurised Thermal Shock events and also fatigue processes.

4.9 SUMMARY OF THE PLIM METHODOLOGY

The operational life of a NPP determines, to a large extent, the cost of electricity generation. In some countries, nuclear power plants have a defined licence life-which can be extended. In others there is no prescribed limit on their operating life. However, in these countries, many of the components classified for basic NPP life assessment as Category 1 and 2 were designed for a life of typically forty years. Category 3 components may have a shorter life but are replaceable on a routine basis. Age related degradation mechanisms can cause a deterioration in component properties. It is therefore necessary to have an improved understanding of ageing to ensure that plant safety and reliability are maintained as components age. In order to meet NPP operational life assurance targets and a long operational life there is a need to develop the methodology for Operational Life Management of key components.

While the methodology can be applied to all categories of components. Usually the approach on Category 1 and 2 components is more rigorous.

Important features of the methodology are:

- the selection of key plant components is made using some prioritisation principles.
- the remaining life of each key component is determined using the available data from the original design documentation and the relevant Codes and Standards, relevant degradation mechanisms, degradation data, operational and maintenance history data and the present state derived from inspection, surveillance, condition monitoring data and relevant records, common experiences with similar plant similar of degradation.
- the estimated remaining life is compared with the target life of the plant.

As a result of this evaluation three possible courses of action are available:

- if the estimated remaining component life is considerably greater than target plant life no Utility action is necessary.
- if the estimated remaining life is close to the target NPP life then measures for mitigating the effects of ageing degradation would be required. New actions in the areas of preventative maintenance, improvements to operational procedures, record keeping and R & D might become necessary.
- if the predicted remaining component life is less than the target plant life, measures for slowing down ageing and for restoring reduced component performance would have to be initiated. These measures would include enhanced inspection and maintenance, repair or replacement. The schedule of the repair, or large-scale replacement initiatives must be based on an evaluation of safety, economics, reliability and other factors. For some plants such an evaluation could lead to the decision not to continue operation of the NPP.

Of course, these courses of action are not mutually exclusive. A mixture of possibilities exists; for example, some complex components may have sub-components to which different alternatives apply.

The methodology for NPP Operational Life Management will continue to require data in the areas of:

- materials data
- development of models for component residual life prediction
- component repair, and
- investigations in the field of feasibility of component
- replacement (e.g. by mock-up evaluation).

Amongst the documentation list for storage are:

- Plant design documents
- Safety analysis reports
- Licenses, permits, technical specifications
- Regulatory correspondence
- environmental reports
- Site description
- Emergency preparedness plans

Category 3 components generally include those components, which are part of the NPP Safety related systems. Programmes for their ageing management usually address the potential risk from failure from ageing degradation. Because these components can be replaced their economic impact on NPP operational life evaluation is, as expected, smaller than Category 1 or 2 components. The main question to be addressed is the timing of the replacement of these components in a timely way before a significant loss in functional capability. The potential impact of failure of Category 4 components is expected to be insignificant. The adequacy of existing programmes should be reviewed on a plant specific basis.

The full evaluation of components for operational lifetime assessment is a large task requiring the application of a large resource of manpower and data. However, the potential benefits in terms of plant life assurance and the extending the operational life of NPP is great. Upgrading of operational safety/reliability and reducing the cost of generating electricity from NPP are the targets.

4.10 MONITORING METHODS IN COMPONENT PERFORMANCE

4.10.1 MONITORING CHANGES IN MATERIAL CHARACTERISTICS

Generally, monitoring of changes in material characteristics is based on destructive techniques. Tests may be performed on specimens made from plant materials that can be installed inside components or in autoclaves. Such programmes exist for irradiation embrittlement of RPV steel, for stress corrosion of S.G. tubes or thermal ageing of cast austeno-ferritic steel. The main difficulty generally comes from the fact that specimens are not exactly in the same environment and conditions as in the part of the component to be monitored so that some kind of transposition must be assessed and quantified (because residual life assessment requires the estimate of the kinetics of the processes).

Some techniques have been developed to measure non-destructively a parameter, which, in turn, may be related to material characteristics. For example, change in thermo-electrical capacity can be related to hardening and then to embrittlement. Again, the difficulty is in assessing the relationship between various parameters.

Finally, destructive investigations may be necessary for unforeseen mechanisms for which no monitoring programmes have been implemented (embrittlement of martensitic steel valve rods, for example).

4.10.2 MONITORING COMPONENT DEGRADATION

This is mainly in the field of non-destructive examination techniques that are used for in-service inspection purposes. It includes visual, dye penetrant, ultra-sonic, radiography, eddy current techniques etc. In the framework of in-service inspection programmes, these techniques are generally implemented to assess the situation of a component manufactured to some acceptance criteria. However, life management processes will require additional data related to kinetics so that in-service inspection may have to be adopted to these requirements.

But there are cases where non-destructive examination techniques cannot provide all information necessary for component residual life assessment-so that some destructive investigations may be needed. An example is the steam generator tube bundles in PWR NPP. Assessing the residual life of that component requires knowledge of corrosion mechanisms and kinetics that can be obtained after 'pulling' tubes for destructive metallurgical examination.

4.10.3 MONITORING THE STRESSORS

For some ageing mechanisms, models exist, relevant parameters are identified, data on initial state and kinetics are available, so that monitoring stressors may yield a continuous assessment of component condition and residual ageing capacity.

A good example is the fatiguing of NSSS components. At the design stage, assumptions are made with regard to the number and nature of pressure and thermal cycles the components are likely to experience during their operational life. The ‘usage factor’ at the 'end-of-life' has been estimated using appropriate Design Codes. So that, carefully monitoring the actual primary pressure and temperature, and relating these to the design assumptions provides important information about the residual fatigue life of the components in question. If the actual stresses are less severe than assumed at the design stage, then there is no constraint on continued operation. However if the stressors are more severe than assumed in design then mitigation action may have to be taken to ameliorate the situation by 'smoothing out' operating transients and subject the new conditions to further fatigue analysis where the design input over-conservatisms might need to be adjusted. An ultimate action might involve consideration of the inspection/repair/replacement of the component.

Of course, monitoring stresses may miss some local unforeseen phenomena (unless specific investigations or inspections are carried out). But, in all cases, whether or not it is required by regulation, monitoring stresses when feasible always gives important input information for evaluating component residual life.

4.10.4 CONDITION BASED MAINTENANCE

Although the purpose of Condition Based Maintenance is different from Plant Life Management, the required technical background is similar so that implementing a programme to meet both sets of objectives are complementary.

Indeed, condition based maintenance requires knowledge of degradation mechanisms, parameters which are representative of degradation and criteria for acceptability. Moreover, although monitoring of representative parameters may be continuous, repair/replacement can generally be performed only during outages, so that capacity to predict 'when' the acceptability criteria will be met is necessary and that implies some knowledge of phenomenon kinetics. Then all information is gathered together to perform a competent residual life assessment, at least with respect to the considered type of ageing.

An example is the condition-based maintenance of valves by measuring the operating parameters and stress during the opening and closing of the valves. Another example is maintenance of piping, which have some risk of fatigue cracking and for which vibration monitoring is used to optimise inspection-and possibly repair schedules.

4.10.5 RELIABILITY

For active components, reliability data are generally collected on the basis of operating performance, failure and from the results of periodic tests. These reliability data are generally used

to optimise maintenance programmes and strategies. However, monitoring systems and component reliability using these data may help in alerting plant staff to an unexpected acceleration of some ageing phenomena or any unforeseen ageing phenomenon or any unforeseen degradation mechanisms.

4.11 ORGANISATION AND IMPLEMENTATION OF PLIM

The comprehensive nature of any plant life management programme requires the involvement and support of many people and organisations within the Utility. Moreover, lifetime concern is not as natural as availability concern or safety concern among plant staff. At least one person should be designated to promote, support and co-ordinate implementation of any plant life management programme.

This person will ensure that all involved with PLIM will have a good understanding of the overall process and how they contribute to it. Plant staff (maintenance and operation) who collect the data, engineering services who perform analyses, research and development organisations who bring information about degradation mechanisms and kinetics and again plant staff who will have to implement the outcomes of the process in their activity (changes in monitoring and surveillance activities, mitigation measures, repair/replacements etc.).

For smaller Utilities, engineering activities could, of course, buy in PLIM services or they could be performed by external organisations like Owners' Groups having similar plants.

Because the outcomes of a life management process are likely to change current practices of operating crews and maintenance personnel, it has to be supported by plant managers at a sufficiently high level. It follows that the person in charge of life management process reports directly to the plant manager.

Finally, the person in charge of the life management process should, as part of his remit, review the main Utility decisions in the light of life management concern to ensure that no decisions are taken (even on site activities) which could impinge on plant life activities without plant staff having a clear understanding of it. Fuel management, procurement policy, staff hiring are examples of fields where decisions could indirectly affect plant life expectancy.

For smaller Utilities, engineering activities could, of course, buy in PLIM services or they could be performed by external organisations like Owners' Groups, which have similar plants.

4.12 OTHER MATTERS TO DO WITH PLIM

PLIM activity includes a broad spectrum of works of which a few are described below.

4.12.1 AGEING OF RECORDS

This matter is described broadly in Section 4.8. “Data and Record keeping activities”. However, when considering the ageing of paperwork at a NPP, Configuration Management is one of the important items. Ageing factors include complications such as:

- Modifications not included in drawings
- Interactions not considered on design changes
- Analyses not updated
- Events reveal new safety issues
- New safety insights
- New analysis methods become available
- New measurements and techniques introduced

In a broad sense, Configuration Management is a programme ensuring that the design documentation accurately describes the actual physical plant in a timely way thus reflecting the modification of drawing, interactions in design changes and so on.

4.12.2 AGEING OF PEOPLE, LOSS OF EXPERTISE AND TRAINING

This is also one recent problem, which is growing in the nuclear industries because of the slowing-down in the number of new NPP being constructed. To meet this difficulty it is important to prepare programmes for personnel training/education/employment and to keep the number of experts at an optimum level while NPPs continue to operate. This may require trans-national training programmes.

4.12.3 REGULAR AND PREVENTIVE MAINTENANCE

It is important to distinguish between the PLIM activities and regular maintenance activities. The first is a long-term, systematic and strategic activity, but the second is a short or medium-term, periodic, conventional and well-understood activity.

Preventive maintenance is a keyword for both of the PLIM activities and the regular maintenance activities.

4.12.4 OWNERS GROUPS

Owners Groups having specific designs, and which may be trans-national, exchange information to plan PLIM programmes to promote common R&D for PLIM activities.

5 NUCLEAR POWER AND PLIM IN SELECTED COUNTRIES

5.1 AUSTRIA.

(Contribution from Mr G Weimann. [Ref. 5])

5.1.1 CURRENT POSITION ON NUCLEAR ENERGY USE IN AUSTRIA:

Austria entered the development of its Nuclear Energy use by establishing a dedicated research centre - the Österreichische Studiengesellschaft für Atomenergie Ges.m.b.H in Seibersdorf in 1955. An extended period of preparatory studies and evaluation work had been accomplished, when in 1972 the construction of the first of two planned Nuclear Power Plants was started and in 1975 the Energy Plan still envisaged 3 NPPs to be built. It took almost 7 years to get the first plant ready for startup after a number of safety related modifications had been implemented.

5.1.2 THE REFERENDUM AND THE SUBSEQUENT EVENTS:

It was the increasingly important environmental concerns and environmentalists protesting against the start-up that caused the federal government to conduct a public referendum to settle this matter. Following a series of demonstrations (attracting in some instances up to 10.000 people) during 1977. The government decided to hold a public referendum on November 5th, 1978. Almost two thirds of those registered voted (3.6 million voters at that time) and a majority of approx. 20.000 outweighed the supporters for nuclear energy use. With these 50.3% of the votes against Zwentendorf the parliament was compelled to pass a law- the "Atomsperrgesetz", on November 15th, 1978, which, in practice, stopped the imminent completion of the Zwentendorf Nuclear Power Plant. It has since become notoriously known as the only NPP commissioned and ready for service but never ever operated.

Some attempts to revise the decision, including a successful public petition were turned down in the political aftermath. Predominantly the now historical events at TMI and Chernobyl NPPs are considered to prove right the then articulated public opinion and the plain construction investment worth 1.4 billion US$ abandonment.

5.1.3 THE CONSEQUENCES OF THE 'NON-START' FOR THE AUSTRIAN POLICY MAKERS:

Ever since the Nuclear Issue was top ranking in the news and therefore in public perception. The media continued to act as the motor of the antinuclear campaign and raised issues like the Wackersdorf reprocessing plant until its cancellation, the final disposal issue etc..

The changes in countries Austria has common borders with, are the most important political development influencing Austrian Nuclear policy. The thread across borders, which was demonstrated in reality by the Chernobyl disaster, is still a recurrent issue and memento with plenty of publicity for all current developments. The concerned public represents a solid basis for opposing the operation of cross border Nuclear Power Plants. All groupings of Non-Governmental Organizations (NGOs) are sworn in advocates of political interventions aiming at the shut down of all NPPs. Since 1990 the government and further on all political parties have adopted this position.

In fall 1997 an initiative of a number of antinuclear groups initiated a petition "Atomfreies Österreich", which was supported by 250.000 people. Exceeding the margin of 100.000 the issues were discussed in the parliament:

- No nuclear weapons should come into or through Austria! No transit, no storage, no stationing.
- No final repository in Austria can dispose of foreign nuclear waste.
- No nuclear transit transports through Austria! Immediate halt to all transports of nuclear material through Austria (nuclear weapons, nuclear fuel, nuclear waste), exempt are medical use and medical research.
- No Nuclear Power Plants in Austria! Upgrading of the "Atomsperrgesetz" 1978 (Zwentendorf cancellation law) to a constitutional law.

In passing this Constitutional Law the parliament, namely all 5 parties represented there, have called upon the government to follow consequently a policy, which is supposed to pursue an "Atom Free Central Europe". As a consequence of this the parliament deemed it an appropriate confirming action to upgrade the above-mentioned law, the so-called "Atomsperrgesetz", to a constitutional law. This was accomplished by a unanimous vote, a rare exception in Austria's parliament records.

The Austrian foreign policy with respect to the European Union as well as those countries, which are applying or are already negotiating for membership with the European Union, is persistently along these lines.

Austria has pledged over the past years considerable amounts of money to facilitate the abandoning of the nuclear options in neighbouring countries, namely in Slovakia and the Czech Republic. It has intervened in Slovenia, Hungary, the Ukraine and Bulgaria in order to clarify its concerns about developments detrimental to Nuclear Safety. Austria has ratified bilateral treaties with Germany, the Czech Republic, Slovakia, Hungary and Slovenia concerning Periodic Information and Early Notification on Nuclear Events. It supported and supports all activities on international and supranational levels, which aim at the declared goals of this pronounced policy.

5.1.4 CURRENT STATUS OF ZWENTENDORF NPP

(Gemeinschaftskraftwerk Tullnerfeld (GKT)):

Zwentendorf NPP was 98% finished and ready for start-up when ‘finalization’ was halted. For some time after cancellation of the start-up the ownership of the NPP-a shared property-changed.

Various reasons for this were given, but all considerations respected to some extent the environmentalist's position. For the initial 7 years the plant was mothballed for later start-up if feasible. Then the 'mothballing' was changed to component preservation for later sell off. At the beginning of this procedure the steam-water circuit was preserved for the intensively studied and then intended plant conversion into a combined cycle (gas turbine – off heat boiler-steam turbine power plant), but later on after the sell off of the first core fuel and some components of the nuclear power supply system (re-circulation pumps, control rod drives, isolation valves etc, but also I+C equipment.) an agency was contracted to bulk sell the remaining equipment. It succeeded however in selling only the 860 MWe Generator, but the valve, piping, fuselage dismantling was not as successful as expected, given that all equipment was nuclear grade and certified where applicable.

In 1993 some of the buildings were turned over to uses not related to power generation. The remaining equipment is probably due to be given for compensation as scrap to a demolition firm in the closer future. Some of the larger components like the steel containment, the reactor pressure vessel, feed water tanks etc. will stay in place until a final decision about the civil structures will be executed.

The laws cited in the above read as follows:

Bundesgesetz über das Verbot der Nutzung der Kernspaltung für die Energieversorgung in Österreich	
Federal Law regarding Prohibition of Use of Nuclear Fission for Energy Supply in Austria	
Beschluß Law passed	Dezember 15, 1978,
StF:	BGBl. Nr. 676/1978
Kurztitel Short Title	Verbot der Nutzung der Kernspaltung für die Energieversorgung Prohibition of Use of Nuclear Fission for Energy Supply
Fundstelle Source	BGBl.Nr. 676/1978
Typ Type	BG Federal Law
Inkrafttretedatum Date effective	1978 12 30
Außerkrafttretedatum Date of withdrawal	---------
Gesetzesnummer Number of the Law	10006607
Dokumentnummer Document Number	NOR11006720
Alte DokNr Old Docet Number	N5197815865R
§ 1. Anlagen, mit denen zum Zwecke der Energieversorgung elektrische Energie durch Kernspaltung erzeugt werden soll, dürfen in Österreich nicht errichtet werden. Sofern jedoch derartige Anlagen bereits bestehen, dürfen sie nicht in Betrieb genommen werden. ***Installations, with which for the purpose of energy supplies electrical energy is supposed to be produced while using nuclear fission, are not to be erected in Austria. In case such installations do exist already, they must not go into operation.***	
§ 2 Die Vollziehung dieses Bundesgesetzes obliegt der Bundesregierung. ***The Federal Government is entrusted with the execution of this Federal Law.***	

Bundesverfassungsgesetz für ein atomfreies Österreich	
Federal Constitutional Law for an Atom-free Austria	
Dokument-nummer Document Number	BGBL/OS/19990813/1/0149
Typ Type	BVG Teil 1 Federal Constitutional Law
Datum Date passed	1999 08 13
Kundmachungsorgan Published as	BGBl. I Nr. 149/1999
Kurztitel Short Title	Bundesverfassungsgesetz: Atomfreies Österreich Federal Constitutional Law Atom-free Austria
	(NR: GP XX AB 2026 S. 179. BR: AB 6033 S. 657.)
Text Text	Bundesverfassungsgesetz für ein atomfreies Österreich Federal Constitutional Law for an Atom-free Austria

§ 1. In Österreich dürfen Atomwaffen nicht hergestellt, gelagert, transportiert, getestet oder verwendet werden. Einrichtungen für die Stationierung von Atomwaffen dürfen nicht geschaffen werden.
In Austria it is unlawful to produce, store, transport, test or use nuclear weapons. Installations for the stationing of nuclear weapons must not be created.

§ 2. Anlagen, die dem Zweck der Energiegewinnung durch Kernspaltung dienen, dürfen in Österreich nicht errichtet werden. Sofern derartige bereits bestehen, dürfen sie nicht in Betrieb genommen werden.
Installations, serving the purpose of energy production using nuclear fission, must not be erected in Austria. In case such (installations) do exist already, they must not be taken into operation.

§ 3. Die Beförderung von spaltbarem Material auf österreichischem Staatsgebiet ist untersagt, sofern dem völkerrechtliche Verpflichtungen nicht entgegenstehen. Von diesem Verbot ausgenommen ist der Transport für Zwecke der ausschließlich friedlichen Nutzung, nicht jedoch für Zwecke der Energiegewinnung durch Kernspaltung und deren Entsorgung. Darüber hinaus sind keine Ausnahmegenehmigungen zu erteilen.
Conveyance of fissile material on the state territory of Austria is forbidden, given that obligations relating to international law are not opposed. Exempted from this prohibition is the transport for scopes of exclusively peaceful uses, but not for purposes of energy production using nuclear fission and of their disposal. In excess of these no exemption permits can be granted.

§ 4. Durch Gesetz ist sicherzustellen, dass Schäden, die in Österreich auf Grund eines nuklearen Unfalles eintreten, angemessen ausgeglichen werden und dieser Schadenersatz möglichst auch gegenüber ausländischen Schädigern durchgesetzt werden kann.
By law it must be ascertained that damages caused within Austria as a result of a nuclear accident are adequately compensated and this compensation prevail as far as possible also against foreign liable.

§ 5. Die Vollziehung dieses Bundesverfassungsgesetzes obliegt der Bundesregierung.
The Federal Government is entrusted with the execution of this Federal Constitutional Law.

5.2 BELGIUM

Contribution from Mr Pierre Govaerts [Ref. 6]

5.2.1 NUCLEAR POWER STATIONS

STATION	START	Cumulative Generation (MWh)	Load Factor (%)	Type	MWe
Doel-1	*08/74*	*82638554*	*84.4*	*PWR*	*413*
Doel-2	*08/75*	*75150149*	*79.7*	*PWR*	*413*
Doel-3	*06/82*	*140875715*	*86.0*	*PWR*	*1056*
Doel-4	*04/85*	*123505213*	*80.8*	*PWR*	*1059*
Tihange-1	*03/75*	*175971428*	*80.4*	*PWR*	*1009*
Tihange-2	*10/82*	*134954580*	*84.7*	*PWR*	*1000*
Tihange-3	06/85	131534469	87.0	PWR	1070

Table 2: Performance of Belgian Nuclear power stations (Ref. 3**), Italicised data for plants > 20yrs old.**

In accordance with Belgian law, the Safety Regulatory body performs a continuous safety review during operation. Tests and inspections, modifications (hardware, procedures, organisation), feedback of national and foreign operational experience is dealt within this frame. Additionally, Periodic Safety Reports at ten-years intervals are required by the operating license.

The operating license of each NPP states:

> "10, 20, 30, ... years after the plant has reached its nominal power, the Utility and the Safety Authority jointly proceed to a comparative examination of the design, construction, operating rules and procedures of the existing plant with respect to the current rules and practices in use in the USA and in the European Community at the time of the review."

The joint report must cover:

- identification of the differences between the present state of the plant and the current safety rules and practices;
- evaluation of the acceptability of these differences;
- proposal for making appropriate improvements;
- schedule for the implementation of the modifications.

The report is sent for approval by the Belgian Safety Authorities. It is not a public document. There is/are no license/licenses for a fixed period). There are continuous safety reviews during operation and also periodic safety reviews at fixed intervals as described in the first paragraph of this section.

The *objectives* of the periodic safety reviews is to establish that the plant is as safe as originally designed, and:

- that there are no subtle degradations, e.g. due to accumulation of modifications.

- were all scenarios intended to be covered by the design, really considered for all circumstances?

Will the plant still be safe for the next 10 years after considering the effects of:

- ageing
- wear-out?

How does the plant compare with the requirements of the most recent safety standards:

- identification of improvements (reduction of risks at justifiable expense)
- balanced approach to safety

A listing of potential PSR-subjects include:

- all subjects discussed in the standard format and content of the FSAR according to the latest rules, i.e. R.G. 1.70 rev. 3 and related rules, SRP, etc.
- all rules, standards, norms, practices published since the original licensing or since the last PSR;
- all unresolved safety issues and generic issues;
- all subjects considered for the latest plants licensed in the country;
- the operational experience of the plant itself;
- the operational experience of other plants, nationally and internationally;
- the results from other periodic safety reviews;
- PSA studies and current research programmes topics;
- decommissioning, where appropriate.

Since Belgium did not develop (besides its basic law on the protection against radiation) its own rules and regulation and adopted the US rules for the design of its last four plants, the safety of the plants is evaluated by using foreign rules and regulations, i.e. mainly the rulemaking of the USNRC and to a lesser extent other rules applied in the European Community. As a consequence, the update of the applied rules and regulations stems to a large extent directly from the update of these foreign rulemaking systems.

The FSAR describes the applicable requirements and their implementation when applied to existing units. The license requires that the FSAR be kept up to date.

There are no specific criteria to evaluate and/or justify the current level of safety in comparison to modern safety standards. However, one should keep in mind that it is the goal of PSR's not only to justify but also to improve the current safety level to the extent practical (this may include cost-benefit considerations).

5.3 CZECH REPUBLIC

5.3.1 NUCLEAR POWER STATIONS

(Contribution by Ferenc Gillemot)

STATION	START	Cumulative Generation (MWh)	Load Factor	Type	MW(e)
Dukovany-1	02/85	51318891	80.0	PWR	442
Dukovany-2	01/86	49442604	80.7	PWR	460
Dukovany-3	11/86	47585751	79.3	PWR	460
Dukovany-4	06/87	46141782	80.7	PWR	456

Table 3: Performance of Czech Nuclear Power Stations

(Ref. 3)

In the Czech Republic two NPPs are operated. Dukovany has 4 WWER-440 units, very similar to those at NPP Paks, and one 1000 MW WWER unit is working at Temelin, while. Temelin 2 is under construction.

The units at the Dukovany plant are young; the oldest unit started electricity production in 1985. This plant belongs to the third generation of WWER-s, and the units were manufactured together with the Hungarian units at NPP Paks. The main equipment was produced at Skoda Works, to a high quality.

When Dukovany was built, Czechoslovakia already had experience in the operation of WWER-440 units at Bohunice because, at that time, Slovakia and the Czech Republic were still one country: Czechoslovakia. Since then Czechoslovakia became the producer of the main components of WWER-440 units and having a strong R&D background and national regulatory body has been developed. The activities of these organisations established the base of the life management programme.

5.3.2 BACKGROUND

During the nineties Czechoslovakia was an active and leading participant in the elaboration of the so-called Interatomenergo Normative Documents. These documents are based on the Russian Code and were supposed to become the design, safety, and later, life management rules for the WWER user countries. The outcome of this has been a high quality Czech national Regulatory Code system. The skilled staff and experience with Bohunice and Dukovany became the basis of the Czech Life Management Programme.

In 1992 Slovakia and the Czech Republic became two independent countries. Most of the Regulatory Body and Research capacity remained in the Czech Republic, as the nuclear production was in Plzen, which is in the present Czech Republic. After extended reorganisation and privatisation of the R&D, work on safety enhancement and life management was restarted. Czech R&D organisations still play an important role in the safety and life management of the Slovak NPP-s and helped other WWER users which partly lost the contact with and support of the Russian designer GIDROPRESS.

5.3.3 LIFE MANAGEMENT

Czech specialists started several Life Management activities in the middle of the nineties. First of all they started to elaborate a national code system.

The first step was the preparation of necessary Regulatory Requirements and Procedures for Lifetime assessment of WWER Components. These have practically been finished, providing a good basis for life management. The Czech Atomic law (No.18/1997) and the state office for Nuclear Safety (SONS) together with the Czech Associations of Nuclear Engineers elaborated the full set of rules and guides necessary for lifetime evaluation and Life Management.

Based on this expertise the Czech institutions successfully organised a consortium and prepared a proposal for the EU 5. Framework programme to harmonise the Finnish, Czech, Slovakian and Hungarian life management codes. This project is called VERLIFE and the following main documents are planned to be elaborated:

i. Structure of lifetime assessment report
ii. Procedure for determination of radiation field in reactor pressure vessels incl. monitoring
iii. Evaluation of material degradation during operation including monitoring
iv. Determination of the stress intensity factor K_I
v. Determination of a reference/design fracture toughness curve including the “Master Curve” approach
vi. Requirements for pressurised thermal shock calculations and evaluation
vii. Simplified elastic-plastic calculation for fatigue assessment (NTD IAE)
viii. Evaluation of fatigue damage during component operation based on operation measurements (incl. stratification etc.)
ix. Evaluation of corrosion-mechanical (erosion) damage in operating components
x. Schematisation of indications found during in-service inspection
xi. Tables of allowable sizes of indications found during in-service inspections
xii. Evaluation of defects allowance in components and piping (PV, austenitic, ferritic piping)
xiii. Evaluation of vibration damage

The second step of the Czech life management program has been to collect the required materials properties and to set up a database necessary for life management.

The third step was to collect the operation data.

The fourth step was to elaborate the standard PLIM programmes and procedures, trend curves for individual ageing mechanisms and components.

The Czech PLIM activity is highly supported by NPP Dukovany. The NPP introduced several measures to enhance the plant safety, reliability and maintenance, including an extended surveillance programme, which constitutes the basis of Life Management.

5.4 FINLAND

(provided by Jyrki Kohopaa on 4/9/01. Prepared by the Finnish Ministry of Trade and Industry)

5.4.1 NUCLEAR POWER STATIONS

STATION	START	Cumulative Generation (MWh)	Load Factor	Type	MWe
Loviisa-1	02/77	86285043	84.5	WWER	510
Loviisa-2	11/80	76072424	87.5	WWER	510
Olkiluoto-1	09/78	133847893	88.7	BWR	870
Olkiluoto-2	02/80	124572950	88.2	BWR	870

Table 4: Performance of Finnish Nuclear power stations

(Ref. 3)

In 1998, four nuclear power units with a total net capacity of 2.7 GWe supplied 31.3 per cent of all the electric power produced in Finland. Two ABB-type BWR units, Olkiluoto 1 and Olkiluoto 2 (start of operation in 1978 and 1980, respectively) are owned by Teollisuuden Voima Oy (TVO), and two VVER 440 units, Loviisa 1 and Loviisa 2 (start of operation in 1977 and 1981, respectively) are owned by Fortum Power and Heat Oy (formerly Imatran Voima Oy or IVO), which is a part of the Fortum Oyj. The Loviisa plants have been designed to meet the Finnish safety requirements.

The regulatory body in Finland is the Radiation and Nuclear Safety Authority, STUK, who has the responsibility to control nuclear and radiation safety of the nuclear facilities in Finland. The responsibilities of STUK also include regulatory control of radioactive wastes and nuclear materials as well as of physical protection and pressure vessels of nuclear facilities. In addition, STUK is an expert body on civil defence and rescue services in the case of a nuclear accident or radiological emergency, and it carries out research related to radiation and nuclear safety. STUK is under the administrative control of the Ministry of Social Affairs and Health. The duties and authorities of STUK are provided in the Finnish legislation. According to the Nuclear Energy Act it shall be the Licensee's obligation to look after the safety of the use of nuclear energy. The utility organisation Teollisuuden Voima Oy is the owner of the Olkiluoto units and Fortum Power and Heat Oy is the owner of the Loviisa units. Both utilities have created their own approach and strategy for plant

ageing and life management. Their approach has been expressed by a slogan “the plants must be kept in such a good condition that they have every day a remaining lifetime of 40 years”.

The research work on plant ageing phenomena and life management methods is mainly performed by the Technical research Centre of Finland (VTT). Research on material ageing has been carried out since the beginning of the 1970s. A multi-year (1999-2002) research programme on nuclear power plant safety, funded by the Ministry of Trade and Industry, VTT and STUK, is carried out at the VTT. The programme concentrates on three themes, which are ageing, accidents and risks. Besides the research programme, VTT has separate contracts and starting in 1999 a targeted research project on plant life management with the utilities. The co-operation/co-ordination of the national research programme is organised by nominating representatives from utilities and the regulatory body to the management board and advisory groups. In addition, a law-based Advisory Committee on Nuclear Energy and Advisory Committee on Nuclear Safety and their subtask groups offer a good forum for national co-operation.

At the plants the person responsible for a system or a component mainly performs the ageing follow-up work and special working groups decide recommendations for actions. These working groups are normally comprised of representatives from technical, maintenance, quality control and operation sections of the power plant site organisations.

International co-ordination of plant life management activities is carried out by participation in several international networks and working groups (NEA, IAEA, AMES, NESC, etc.).

The regulatory body responsible for plant ageing and life management in Finland is STUK. There is no clear regulation with regard to plant upgrading but the Decision of the Council of State (395/1991) states; “for further safety enhancement, actions shall be taken which can be regarded as justified considering operating experience and the results of safety research as well as the advancement of science and technology. A nuclear power plant-operating license is issued in Finland for a limited time, and it can be renewed only after a thorough safety review, which also includes the assessment of ageing. The current operating licenses of Olkiluoto and Loviisa units will expire at the end of 2018 and 2007, respectively. In addition, STUK will carry out periodic safety reviews with about ten-year interval. STUK´s annual inspection programme contains inspections, which are focused on the utilities activities important to safety. Component ageing and plant life management is one key subject of these inspections.

The utilities operate in the recently opened free electricity markets under commercial conditions. They make their own investment decisions concerning plant improvements and life management, taking into account the safety requirements set by STUK.

According to the Nuclear Energy Act the utilities are obliged on annual basis to collect funding for final disposal of spent fuel and plant decommissioning. The main target of plant ageing and life management is to follow the so-called SAHARA-principle -Safety As High As Reasonably Achievable- taking also the economical aspects into account. A key element in achieving this objective is the identification of components sensitive to ageing and the application of preventive maintenance or replacement in due time.

The major concern at the Loviisa VVER plant has been the radiation embrittlement of the reactor pressure vessel (RPV). According to the designer the design lifetime of the RPV was 40 years. The utility and STUK were, in spite of the vendors opposite views, worried about the embrittlement of the core region weld material due to the high neutron flux on the RPV. The test results from an extensive surveillance programme at the Loviisa 1 plant indicated that the embrittlement rate of the weld steel was almost three times what was expected. To tackle the problem, some backfitting actions were taken in 1980. Totally 36 fuel elements at the perimeter of the core were replaced by dummy elements to reduce the neutron flux, and the temperature of emergency core cooling water was raised to reduce thermal stresses in a possible emergency core cooling situation. However, radiation embrittlement can also be recovered by thermal annealing. The thermal annealing of the Loviisa 1 RPV core region weld was performed in 1996.

Intergranular stress corrosion cracking (IGSCC) of austenitic stainless steel pipes has been one of the most life-limiting factors in the BWR plants. Intensified inspection, water chemistry adjustment (low electric conductivity), repair and material replacements constitute the remedial actions. The IGSCC can be most effectively inhibited through low electrochemical potential (e.g., low electric conductivity of the water), and by the use of austenitic stainless steel grade with low carbon content (less than 0.03 percent).

In operation, the plant management in Loviisa especially stresses the importance of gentle treatment of all equipment during normal operating states and tests, i.e. limiting, as much as possible, the number and magnitude of thermal and hydraulic transient loads and maintaining the water chemistry parameters in all cooling systems within their specified limits. The maintenance strategy in Loviisa is based on:

- Assessing the equipment condition from reliability records and from results of in-service inspections, tests, and condition monitoring
- Active bilateral exchange of information with other VVER-440 plants, and on incorporation of lessons learned from other plants into the test and maintenance programmes
- Redefining service and overhaul intervals as need arises from the condition assessment

- Repairing or replacing the equipment before they fail

Cost/benefit analyses are usually regarded as a matter that concerns utilities. Utilities have been capable of backfitting matters required by the regulator. Preventive maintenance is addressed so well, however, that repair maintenance has not played any major role in cost/benefit analysis. Fortum performs itself probabilistic safety analyses (PSA) for the Loviisa plants. The results are used to assess the priority of the safety improvements and in decision-making.

The national research programme “Structural Integrity of Nuclear Power Plants, RATU2” was under way in 1998 and the new programme “Finnish Research Programme on Nuclear Power Plant Safety, FINNUS" was prepared. These programmes contain subjects relevant to plant ageing and life management. In addition, an industry driven public research project on plant ageing and life management was prepared for launching in 1999.

At the TVO plant about 90 per cent of all inspection and maintenance work is composed of preventive maintenance, improvement of construction, and short or long-term conditions monitoring. According to TVO's policy, these activities belong to the topics of Plant Ageing, Life Management and Life Extension. The quality control and preventive maintenance programmes being carried out at the plant site are continuously re-evaluated.

Fortum Power and Heat Oy are developing a company-wide approach to plant life management. The first stage of plant life management comprises the management of operational and maintenance history, design and plant inspection data, using advanced computer systems. The life of the plant can then be controlled by inspection, refurbishment and maintenance programmes, and by controlling the plant operation. On-Line monitoring is needed, and cost control and training must be taken into account if the life of the plant is to be managed efficiently.

The plant has recently started a project with three goals:

- To re-evaluate the original strength calculations to eliminate extra safety margins. This can be done by making the assumptions more precise and, especially, by comparing the actual usage history with the calculation assumptions. Typically, the number of load cycles occurred is now, after about 20 years of operation, much less than what has been assumed in the strength calculations. Also, most of the transients are less severe than assumed.

- In the original design, thermal stratification and mixing phenomena were not taken into consideration. The systems are now under review, and the goal is to find and list the potential areas of thermal stratification and mixing. The stratification typically occurs in horizontal pipe sections with a closed or leaking valve. T-junctions with different flow temperatures are typical mixing areas.

- A system will be developed to assist life management. It will be organized systematically and include, for instance, drawings from the critical areas, thickness measurement results and references to corresponding fatigue analyses.

The national research programme RATU2 being carried out in 1998 at the Technical Research Centre of Finland (VTT) focuses on topics which assure structural safety during planned and extended lifetime. The following areas are especially studied:

Important areas of study include all the factors affecting the performance of reactor pressure boundary materials. Material degradation rates in radiation damage and recovery, together with methods for determining neutron fluence, are of top priority. Environment assisted ageing mechanisms (stress corrosion, corrosion fatigue and thermal ageing) and the monitoring of water chemistry during operation form another top priority area. In addition, various recommendations are being drawn up, for example, for the repair of cracked components and for the prevention of stress corrosion.

Technical issues considered are lifetime extension of nuclear power plants, replacement of structural components, and construction of new plants. The objectives are: to improve expertise in the field of nuclear safety analysis, to create a widely applicable and well-tested analysis system for fast and reliable structural analyses, and to develop methods for analysing structural behaviour in abnormal loading situations as well as the severity of possible flaws detected in structures. Approaches include extension of fracture assessment capabilities, collection of the computer programmes for fracture analyses to an expert system, and verification of the reliability of the analyses by test calculations and simulating experiments.

Research is also aimed at developing and applying NDE methods and procedures of higher precision and reliability for nuclear structures and components. Specifically, flaws formed during operation are studied for detection and precise sizing under nuclear conditions with different ultrasonic, and eddy current techniques. Reliability of the NDE method is assessed in the international NESC programme (European Network for Evaluating Steel Components).

Objectives are to verify methods and data developed in other projects for safe and reliable evaluation of reactor pressure vessel and piping integrity, to assess technical lifetimes of critical components on the basis of full-size component tests, load monitoring, water chemistry monitoring, ageing of materials, new diagnostics methods (e.g., use of the PRAISE programme), and to verify the transferability of laboratory data on full-size components.

Technical reliability assessments in the maintenance of nuclear power plants help in the evaluation of ageing equipment, motors and piping, as well as in the planning of preventive maintenance. The work includes the use of statistical reliability-centred methods for evaluation of ageing and preventive maintenance of nuclear components by developing analysis methods for failure and ageing data, statistical assessment for piping failures and their time-dependence and PSA

evaluations, as well as management tools for plant life evaluation/extension. Research and other action on structures and structural materials result in preventing accidents and unforeseen outages and in making sure that the concerns and risks arising from faults in equipment and structures are kept to a minimum. Research ensures the safe and reliable operation of equipment throughout its planned life. At the same time ways are being sought to extend the lifetime of components.

A very good example of the outcome of the overall activity in Finland are the high load factors of over or very close to 90 per cent for all four nuclear power plant units over several years.

The public is not directly involved in the decisions concerning PLIM. However, the public hearings are included in the licence renewal process. If the modernisation could have significant effects on the environment also the Environmental Impact Assessment should be included in the licensing process. For example latest reactor power upgrades both in Loviisa and Olkiluoto were considered to have a significant effect on the environment because of increased heat releases to the seawater.

Critical components and systems in plant life management are selected based on their significance on the operational availability and safety of the plant taking credit of the worldwide operational experience data.

In drawing up the list of the most critical **BWR** components the following degradation mechanisms are considered:

erosion, stress corrosion cracking, irradiation assisted cracking, thermal stratification, fatigue, etc

For **PWR** components the following mechanisms are considered:

- radiation embrittlement of the RPV and internals,
- erosion,
- thermal embrittlement,
- fatigue,
- thermal stratification, etc

The largest mechanical components like reactor pressure vessel and steam generators deserve special attention due to their difficult and expensive replacement. Most other components and systems can be replaced but the plant life management strategy is to be well developed to predict and plan future upgrading.

5.5 FRANCE

5.5.1 FRENCH NUCLEAR POWER STATIONS

(Note: Data for France was not included in Reference 3 so the previous year's data was used-see Reference Section)

STATION	START	Cumulative Generation (MWh)	Load Factor	Type	MWe
Phenix	***12/73***	***22428013***	***37.5***	***FBR***	***250***
Fessenheim 1	***04/77***	***126876824***	***64.9***	***PWR***	***930***
Fessenheim 2	10/77	127426570	66.6	PWR	930
Bugey 2	***05/78***	***118524703***	***61.3***	***PWR***	***964***
Bugey 3	***09/78***	***120791035***	***63.5***	***PWR***	***964***
Bugey 4	***03/79***	***117457481***	***63.5***	***PWR***	***957***
Bugey 5	***07/79***	***119857775***	***65.9***	***PWR***	***957***
Dampierre 1	***03/80***	***118282526***	***67.1***	***PWR***	***957***
Gravelines 1	***03/80***	***119009740***	***67.4***	***PWR***	***957***
Tricastin 1	05/80	123333106	70.6	PWR	957
Tricastin 2	08/80	121618193	70.2	PWR	957
Gravelines 2	08/80	123656552	71.6	PWR	957
Gravelines 3	***12/80***	***123843641***	***72.7***	***PWR***	***957***
Dampierre 2	***12/80***	***112594249***	***66.1***	***PWR***	***957***
Dampierre 3	01/81	116926641	69.1	PWR	957
St Laurent B1	*01/81*	*104408764*	*61.6*	*PWR*	*957*
Tricastin 3	*02/81*	*127058339*	*75.2*	*PWR*	*957*
Tricastin 4	*06/81*	*120439552*	*72.5*	*PWR*	*957*
St Laurent B2	*06/81*	*108451418*	*65.2*	*PWR*	*957*
Blayais 1	*06/81*	*113817644*	*69.0*	*PWR*	*951*
Gravelines 4	*06/81*	*119705842*	*72.1*	*PWR*	*957*
Dampierre 4	*08/81*	*112350206*	*68.3*	*PWR*	*957*
Blayais 2	07/82	116474718	74.7	PWR	951
Chinon B1	11/82	109757759	72.8	PWR	954
Blayais 4	05/83	110580756	74.2	PWR	951
Blayais 3	08/83	110335353	75.1	PWR	951
Chinon B2	11/83	102638989	72.3	PWR	954
Cruas 1	04/83	100474808	68.5	PWR	956
Paluel 1	06/84	133717640	66.3	PWR	1382
Cruas 2	09/84	97506017	70.8	PWR	956
Cruas 3	05/84	99428019	71.2	PWR	956
Gravelines 5	08/84	101476770	72.9	PWR	957
Paluel 2	09/84	129310392	65.0	PWR	1382
Cruas 4	10/84	96834441	71.6	PWR	956
St Alban 1	08/85	118727608	63.3	PWR	1381
Gravelines 6	08/85	96954135	73.8	PWR	957
Paluel 3	09/85	129814881	69.5	PWR	1382
Flamanville 1	12/85	120248414	65.2	PWR	1382
Paluel 4	04/86	126531429	70.1	PWR	1382
Flamanville 2	07/86	118896046	67.1	PWR	1382
St Alban 2	07/86	107946803	60.7	PWR	1381
Chinon B3	10/86	86384790	71.9	PWR	954
Cattenhom 1	11/86	109610855	64.1	PWR	1362
Cattenhom 2	09/87	112787970	70.0	PWR	1362
Belleville 1	10/87	104525562	65.1	PWR	1363
Nogent 1	10/87	105767673	66.0	PWR	1363
Chinon B4	11/87	81476623	73.1	PWR	954
Belleville 2	07/88	97847075	64.4	PWR	1363
Nogent 2	12/88	106046937	72.2	PWR	1363
Penly 1	05/90	94884289	71.8	PWR	1382
Cattenhom 3	07/90	91776883	71.6	PWR	1362
Golfech 1	06/90	92034920	71.2	PWR	1363
Cattenhom 4	05/91	87616623	74.5	PWR	1362
Penly 2	02/92	82231890	74.4	PWR	1382
Golfech 2	06/93	64059428	68.9	PWR	1363
Chooz B1	05/01	10258438	77.2	PWR	1516
Chooz B2	09/01	6327212	95.6	PWR	1516

Table 5: Performance of French Power stations

(Ref. 3 but see note above), Italicised print used to denote stations > 20 years old

5.5.2 PLANT LIFE MANAGEMENT IN FRENCH NPP

(communication from A Villemeur, EdF. and a publication in RGN International Edition dated December 1999 written by D Dubois, JP Hutin and A Villemeur).

The 900 and 1300MWe units in operation are relatively young with an average age of 17 years and 11 years respectively. They are a bout 50% amortised. It be noted that these nuclear plants provide about 80% of all electricity production.

Over the last twenty years the choice of the nuclear programme has formed the basis for a wide margin of competitiveness in electricity production, guaranteed energy independence and reduced releases of carbon dioxide into the atmosphere. Therefore control over existing nuclear power plants is of overriding importance and involves the following three objectives:

- Maintain current operating performances (safety, availability, costs, security, environment) in the long term, and possibly improve on some aspects
- wherever possible, operate the units throughout their design lifetimes, in other words 40 years, and even more if possible
- consolidate acceptance of nuclear energy, largely based on earning the public trust.

The financial stakes associated with maintaining the lifetime of nuclear power stations are very, high; thus if their lifetime is shortened by about ten years, dismantling and renewal would be brought forward which would increase their costs by several tens of billions of Francs. Furthermore, every extra year of operation of a 900 MWe unit should save about 50 million Francs per year on financial charges that would be necessary for new investment, provided that maintenance costs do not become excessive. The nuclear boiler was designed on the basis of an engineering lifetime of 40 years, as used in safety reports. However, from a regulatory point of view, French law does not specify any time limit on the operating lifetime of the installations within the construction authorisation decree. Therefore EDF should do everything in its power to

justify to Safety Authorities and to the public that this lifetime can be reached and if possible extended in order to make maximum use of investments already made.

The lifetime of a nuclear power plant may be affected by three main factors:

- normal wear of its components and systems (sometimes called ageing) that depends particularly on the age, operating conditions and maintenance conditions applied to them;
- the safety level, that must consistently comply with the safety requirements applicable to the power stations at al times, and which could change as a function of new regulations;
- competitiveness, which must remain satisfactory when compared with other production methods.

Within this context, obtaining a lifetime of 40 years depends firstly on control of the safety level which must comply with safety requirements at all times, and secondly of all technical and industrial aspects in order to operate units with a good level of competitiveness and safety.

Technically, the objective is to control understanding of ageing problems, and to define and then implement appropriate safeguards to maintain the performance level of units at their current level.

Industrially, the objective is to control changes to the industrial fabric, so that the skills, 'know how' and tools necessary are available when they are needed. In all cases, it is in EDF's interest to make sure that industrial expertise necessary for continued operation of its units is available in France or elsewhere in the world, even if there are no prospects for renewal.

Considering these elements, the general strategy is based firstly on a high quality routine operation, and on the following two points:

- the ten-year safety reassessment process,
- the implementation of two structured programmes in order to make sure that all technical and industrial actions necessary to achieve a lifetime of at least 40 years are actually committed:
    - the "Anticipation of Exceptional Maintenance Programme"
    - the "Lifetime" programme.

Obviously, there are ongoing discussions with the Safety Authorities about this process and these programmes.

French regulations require that the installation complies with the safety report at all times. In order to achieve this objective, it has been agreed with the Safety Authorities that every ten years:

- a check should be carried out to ensure that the units comply with safety requirements
- safety requirements should be re-evaluated, to take account of changes to safety rules and experience acquired, and the units shall then be made to comply with these new requirements

This process begins with the preparation for the second ten-year inspection (VD2), and within the VD2 project, involves the identification and production of a functional "modifications package".

The safety re-evaluation for the two Fessenheim units and the four Bugey units, which are now the oldest in France, was carried out starting in 1987; for example, significant improvements were made in protection against fire and internal floods. In general, the safety of these units after the modifications is equivalent to the safety of CP1-CP2 series.

The ongoing safety re-assessment of unit in the CP1-CP2 series is based on previous information, the revision of safety report accident studies and the results of probabilistic safety studies. Technical modifications approved by the Safety Authorities will be carried out consistently in VD2 inspections for the CP1-CP2 series, the first of which has just been completed at Tricastin 1. Furthermore, these VD2 inspections provide an opportunity to carry out a Complementary Actions Programme (PIC) in order to verify assumptions made about the lack of degradation in areas not inspected within the preventive maintenance programmes.

The cost of this project will be about 10 billion Francs for the thirty-four 900 MWe units. The first VD2 for the 1300MWe series will start in about 2005. Obviously, preparation of the third ten-year inspections (VD3) for 900MWe units will have an important influence on their lifetime. Therefore, good preparation of this VD3 project is essential and, considering the deadlines (first inspection to

be done in 2008, definition of the contents in about 2003), it will be necessary to start defining the corresponding organisation and the main objectives in 1999.

The fact that installations are highly standardised makes it necessary for us to have advance knowledge of major degradation that could affect the main components and to determine the most robust possible long-term renovation/replacement strategies.

"Exceptional Maintenance" means all maintenance operations programmed nationally on a large number of power stations, usually carried out once during the lifetime of units and which have a significant cost and/or impact on availability. Exceptional Maintenance actions (for example the replacement of steam generators, vessel heads, rod control mechanisms, rewinding of some alternator stators) represent an annual expenditure of about 1.5 to 2 billion Francs, compared with systematic costs of 9 billion Francs per year for routine maintenance.

The "Anticipation of Exceptional Maintenance" Programme consists firstly of identifying exceptional maintenance operations that could "probably" be carried out one day, and making sure that all the appropriate measures are taken so as to minimise the effect of their implementation on network performances. In particular, it is essential to avoid being obliged to carry out a large number of important operations in the same period of time. This programme periodically reviews design and manufacturing conditions and the operating experience with the forty most "sensitive" components, identifies major degradation that could occur on these components, evaluates the potential consequences and suggests the most appropriate strategies to deal with the consequences in order to achieve a lifetime of at least 40 years.

This is the context in which EDF has decided to initiate 'Components Replaceability' project, combined with a development programme with defined priorities in order to ensure that an industrial qualified assembly (techniques, operating methods, tools, personnel) is available for some components. Cases for which this effort is worthwhile will be identified, and the degree of anticipation (simple design, development, qualification or even procurement) that is reasonable for each of these cases will be analysed annually beginning in 1999. For example, note that replaceability of the pressuriser, and for the ability to repair the pressuriser bi-metallic link, have been selected for 1999.

In general, priorities selected for this project are such that replaceability of some equipment should be verified by about 2005.

Since 1987, EdF has been setting up a "Lifetime Programme" in order to understand and anticipate ageing problems. This programme functions as an active" observatory" assigned to do everything necessary to achieve the expected lifetime. It regularly reviews everything that can have an impact on the lifetime of installations, considering purely technical aspects related to equipment, and industrial, economic and regulatory aspects.

The "Lifetime" programme also identifies progress necessary to improve knowledge about ageing phenomena and to support Research and Development actions in order to make a better link between operating conditions and maintenance conditions for components and their lifetime.

This programme makes a distinction between:

- two non-replaceable components: the reactor vessel and confinement containments. A summary file related to the behaviour of 900 MWe PWR vessels in service for at least 40 years is currently being investigated by the Safety Authority. In particular, this file allows for reinforcement of irradiation resistance monitoring programme, taking account of specific characteristics of each vessel. For containments, the lifetime of at least 40 years has been globally accepted for the 900 MWe series. Containments for the 1300 MWe series must be monitored and solutions must be found for each individual case, considering that there are leaks on the internal wall of some containments (Belleville, Flamanville, Cattenom):
- fully or partially replaceable components, sometimes involving expensive but well controlled operations, for some components such as steam generators (already replaced on 7 units) or vessel heads (already replaced on 30 units). The corresponding actions are included in exceptional maintenance strategies with the objective of reaching a lifetime of at least 40 years in the maintenance policy.

Obviously, ambitious Research and Development programmes are being carried out in order to understand degradation mechanisms such as erosion, corrosion, fatigue, wear, thermal ageing and ageing under irradiation, and the dynamics of these mechanisms. These data are necessary to optimise strategies applicable throughout the network. Expertise programmes on real equipment have been carried out in order to confirm this work: thus an important expertise programme has been initiated on the Chooz A power plant (300 MWe) which was the first pressurised water reactor built in France and was decommissioned in 1991 after 24 years of operation. Furthermore, operating experience on nuclear power stations in other countries older than French units is monitored attentively and co-operation efforts have been organised with the operators concerned. In particular, there are about a hundred PWR nuclear units in the United States with an average age of 10 years more than the average of EDF's units, providing a major source of operating experience on the technical life of equipment: the performances of most of these power stations are continuing to improve, which confirms the concept that there are large operating margins in the life of these units.

The "Lifetime" programme includes studies about the long-term future of the nuclear industry, monitoring the situation of industrial facilities that will be both "sensitive" due to the essential nature of their capabilities for EDF, and "fragile" due to the lack of any new construction for a number of years.

Based on current knowledge, 900 and 1300 MWe units should apparently be able to achieve their 40-year lifetime objectives, provided that appropriate operating, monitoring and maintenance conditions are adopted.

In this respect, it's worth noting that this objective (at least) has now been announced by other countries such as the United States, Japan, United Kingdom and Spain. In the United States, the operator is granted an operating licence for 40 years and the regulations allow for an extension to this operating licence for an additional 20 years: thus, the NRC is currently investigating licence renewals for two PWR nuclear power stations and many operators are preparing files for similar requests. In Japan, leading operators have recently concluded that the life of PWR nuclear power stations could reach 60 years, provided that appropriate maintenance actions are carried out.

Based on technical, economic and regulatory date available now, the main objective of operating existing nuclear power plants during the lifetime of at least 40 years is quite possible provided that the necessary actions continue to be implemented. This is confirmed by international operating experience.

The ten-year safety reassessment process, and the "Lifetime" and the "Anticipation of exceptional maintenance" programmes, will help to prepare decisions to be made to achieve this objective.

5.6 GERMANY

(This revised section was provided by Klaus Metzner, E ON Kernkraft, Hannover, Germany. received 6 Feb. 2002 & revised 13 Feb.2002)

5.6.1 GERMAN NUCLEAR POWER STATIONS

STATION	START	Cumulative (lifetime) generation (MWh)	Load Factor	Type	Power MWe
Obrigheim	*10/68*	*80917288*	*78.5*	*PWR*	*357*
Stade	*01/72*	*142629755*	*81.6*	*PWR*	*672*
BiblisA	*08/74*	*192343540*	*67.0*	*PWR*	*1225*
Biblis B	*04/76*	*193061745*	*66.6*	*PWR*	*1300*
Neckarwestheim 1	*07/76*	*148725375*	*78.6*	*PWR*	*855*
Brunsbuettel	*07/76*	*98024837*	*55.0*	*BWR*	*806*
Isar 1	*12/77*	*139392979*	*73.6*	*BWR*	*907*
Unterweser	*09/78*	*211460514*	*79.6*	*PWR*	*1350*
Phillipsburg 1	*05/79*	*131858691*	*74.1*	*BWR*	*926*
Grafenrheinfeld	*12/81*	*192798065*	*84.4*	*PWR*	*1345*
Kruemmel	*09/83*	*152811321*	*73.6*	*BWR*	*1316*
Gundremmingen B	*03/84*	*160574445*	*79.3*	*BWR*	*1344*
Gundremmingen C	*11/84*	*152130482*	*77.6*	*BWR*	*1344*
Grohnde	*09/84*	*188509046*	*90.1*	*PWR*	*1430*
Phillipsburg 2	*12/84*	*179666943*	*88.1*	*PWR*	*1424*
Brokdorf	*10/86*	*157843960*	*85.4*	*PWR*	*1440*
Isar 2	*01/88*	*146737976*	*86.2*	*PWR*	*1455*
Emsland	*04/88*	*148144875*	*92.7*	*PWR*	*1363*
Neckarwestheim 2	*01/89*	*137584601*	*91.0*	*PWR*	*1365*

Table 6: Performance of German Nuclear Power Plant

(Ref. 3), Italicised print indicates plant > 20 years old.

5.6.2 PLANT LIFE MANAGEMENT IN GERMANY

(References: Communication with Helmut Shulz, 21/1/2000; Paper in IAEA SM Proceedings, IWG-LMNPP-98/2, pp33-44 on 'Strategies and Policies for NPP Life Management' by Manfred Erve, presented by Miss Beate Kastner, September 1998; 'Environmental Policy-Nuclear Safety in Germany', first review meeting in April 1999, publication of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) Deutscher Bundestag Report 13/11350; 'The Significance of Ageing Phenomena at German NPPs', by H.Liemersdorf and F Michel, GRS Cologne, presentation at the GRS/IPSN Annual meeting, Berlin, November 1998.)

The objective of the present Federal German Government is to limit the operating lifetime of NPPs in Germany. Discussions between the Government and the Utilities have finally led to an agreement about plant specific remaining operation periods and the amount of nuclear electricity to be produced by each plant.

While PLEX was not pursued on German NPP in the previous programmes it is certainly not being developed now. Because the licensing of German NPP includes no time limit the main part of the current political discussion has led to a limit on the operational lifetime.

Nevertheless, as a consequence of international developments, ageing management aspects were also introduced in Germany. Due to the different conceptual background compared to ageing management objectives in other countries, as a first step definitions had to be established for 'ageing', 'plant life management' and 'ageing management' considering the international wording and the liability for the related actions. Ageing phenomenon means degradation over time, with respect to NPP. Essentially the following categories of NPP items have to be considered:

- Equipment (mechanical components, structures, electrical and Instrumentation & Control systems)
- Computer Systems (hardware and software) required for plant operation
- Plant specifications and documents

The basic approach in Germany is to distinguish between 'Plant Life Management and 'Ageing Management'.

'Plant Life Management' includes all technical and organisational measures on ageing phenomena which are identified and managed by the plant operator and which guarantees achievement of the prospected service life-or identify when appropriate actions needs to be taken. 'Plant Life Management' is set up to ensure reliable and safe plant operation. It aims towards long-term integrity of a component/system or actions/measures comprising safety and availability issues.

Life Management is therefore an activity basically carried out by the utilities for each NPP. There is no special separate body to deal with life management of NPP.

‘Ageing’ of safety significant components/systems and all issues related to plant safety are already covered by regulatory supervision together with independent advisory organisations. The situation in Germany is determined by law and code regulations containing requirements for continuous precaution measures according to the current “state-of-the-art”, starting already with the plant commissioning. Those regulations include demands for redundant safety and surveillance measures. A continuous adjustment to the respective “state-of-the-art” is provided by the German utilities and submitted to the responsible safety authority. This procedure stems from the fundamental approach of eliminating weak aspects of the established design during the later plant operation time frame. The respective activities are being performed under different names. For components with high safety concerns (RPV, piping systems with ‘lbb’) specific high-level long-term integrity surveillance measures have been installed.

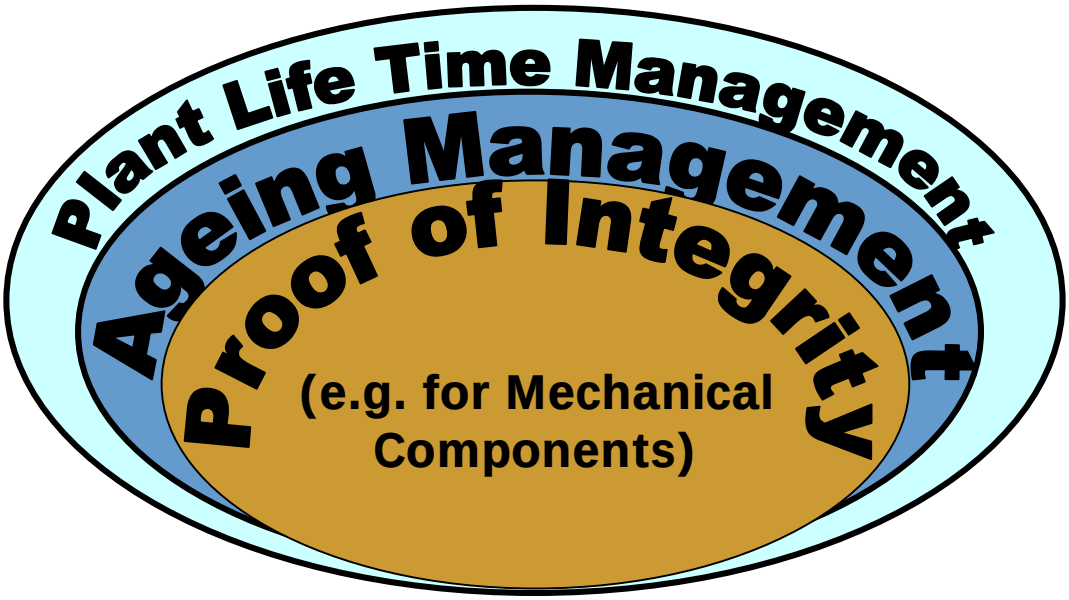


Figure 20: Ranking of 'ageing' related activities

Because of this particular attention the German NPP are now free from major constraints from age-related degradation.

The most important utility objective is the concern about safety issues (‘ageing management’). Additionally, economical reasons have to be considered. Those are:

- Plant availability

- Reduction of maintenance costs
- Optimisation of shut down periods
- Cost reduction in general

This leads to an intensified ‘plant life management’ towards the higher level ‘ageing management’ activities.

Although no specific ageing management programme exists, the German utilities understood that the subject ‘Ageing Management’ is comprehensively covered by the entirety of the different precaution and maintenance measures and regulations already established. A generic report was provided in 1997 containing a comprehensive listing of potential ageing phenomena and showing the technical and administrative handling of these ageing effects.

Comprehensive Safety Reviews have been carried out. The results show that even the older NPP built to earlier standards meet the present safety requirements and that sufficient precaution against damage to the environment has been taken. Thus, the safety related work that has been carried out already to bring NPP to the current ‘state-of-the-art’, has ensured that safety related obsolescence is not significant.

However, as a consequence of the international ‘ageing management’ activities, divergent interpretations as to how to handle technical contents and executing administrative issues led to the conclusion that harmonised understanding and handling is required for German ageing management activities, considering international practice. In the BMU 1998 report are goals for improvements and the respective measures already presented.

Therefore, intensive ageing management activities have been initiated in Germany driven by different motivations in spite of the specific German situation with limited remaining plant lifetimes. The Reactor Safety Commission (RSK) submitted recommendations containing basic principles. Further activities in RSK Subgroups are expected. In parallel, the German utilities have installed a Working Group to clarify the German utility ageing management approach in order to demonstrate that an ageing management concept already exists and its application by the German utilities is sound.

As a first step for the ageing management concept application the evaluation scope has to be defined.

Basically, the handling of ageing phenomena can be divided into:

- The technical and administrative ageing management of safety relevant systems/components and of safety relevant actions (e.g. PSA-Probabilistic Safety Analysis) and its supervision by the responsible safety authority (PLEX activities, but due to the current political situation in Germany, no lifetime extension approval is expected).
- The technical and administrative lifetime management of the remaining system/components and quality assurance actions and maintenance activities to be performed mainly on the utilities responsibility (PLIM-activities).

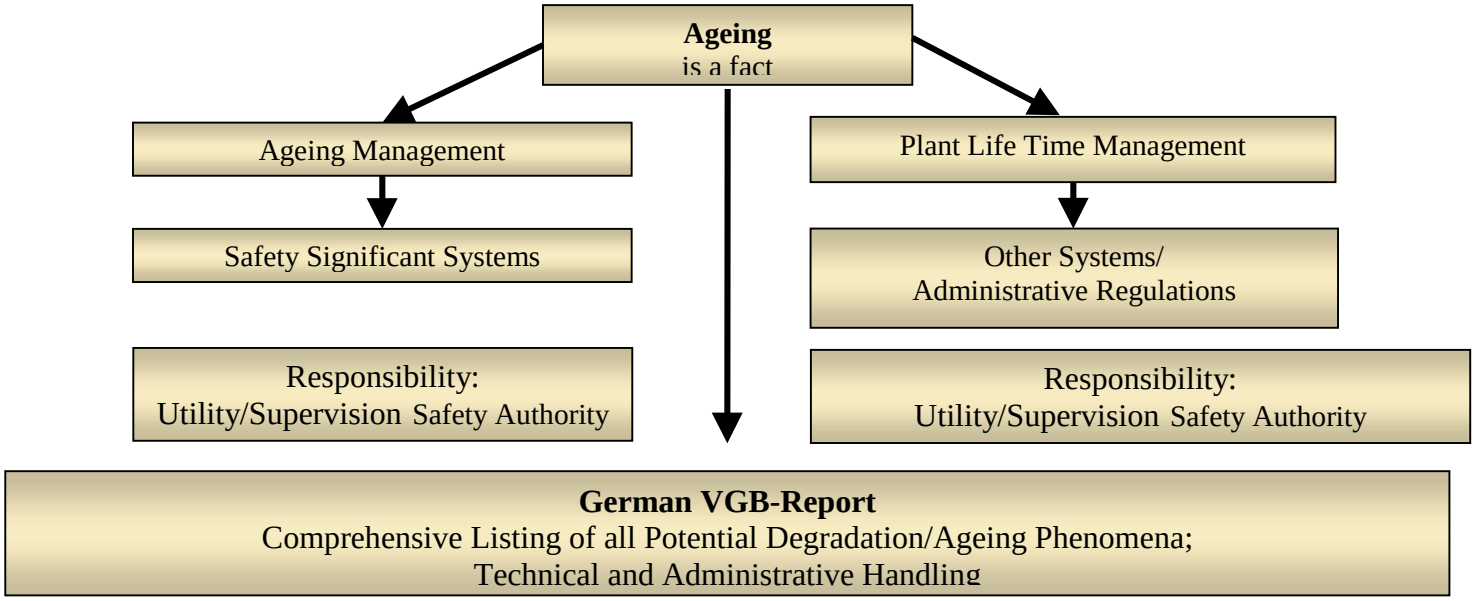


Figure 21: Distinction between availability and safety related ageing issues

The following paragraphs deal preferably with 'ageing management' concerning safety relevance, but consider availability aspects also, if appropriate. Adjusted to the specific purpose, they can be applied for all ageing related topics (mechanical components, electrical and I&C components, building structures as well as for non-technical ageing issues).

For all general and specific ageing management approaches the basic criteria-determination of actual component quality and safeguarding of component quality during plant operation have to be evaluated covering the following topics:

- Defines safety/availability significant systems/components or non-technical issues (e.g. mechanical components, I&C components; building structure).
- Determine the current system/component quality status and safeguarding measures:

Quality initially provided by design and fabrication affected by relevant effects during operation so far?

- Are the root causes of operational degradation mechanisms known (from monitoring)?
- From them, have impacts on the (component) integrity been evaluated and conclusions been drawn?
- Are redundant ISI-/surveillance-measures of potential consequences of operational degradation mechanisms still appropriate?
- Have relevant changes of "the-state-of-the-art" been considered?

Safeguarding of quality requirements has to be ensured during plant operation by proactive and reactive measures. Proactive is the monitoring of root causes of potential operational degradation mechanisms in terms of operational loadings. The proactive approach tries to avoid/minimise premature degradation effects. The reactive surveillance of consequences of potential operational

degradation mechanisms deals with degradation effects after they have already occurred and been detected (e.g. by NDT-measures for mechanical components).

According to the international approaches, ageing management for safety relevant systems can be focussed on Class 1-systems and systems required for safe plant shutdown. Within these safety relevant systems, the following safety significant/component/part ranking can be introduced (cf. to the explanations in Section 4.6 of this report):

Group 1: Components of high safety requirements ("guarantee" required quality)

These are the RPV, systems with "lbb" requirements and other components classified in Group 1 due to specific safety or plant availability reasons.

Group2: Components with medium safety requirements ("preserve" required component quality)

These are mainly redundant components such as valves, pumps, electrical, I&C components, building structures and other components with specific safety or availability requirements.

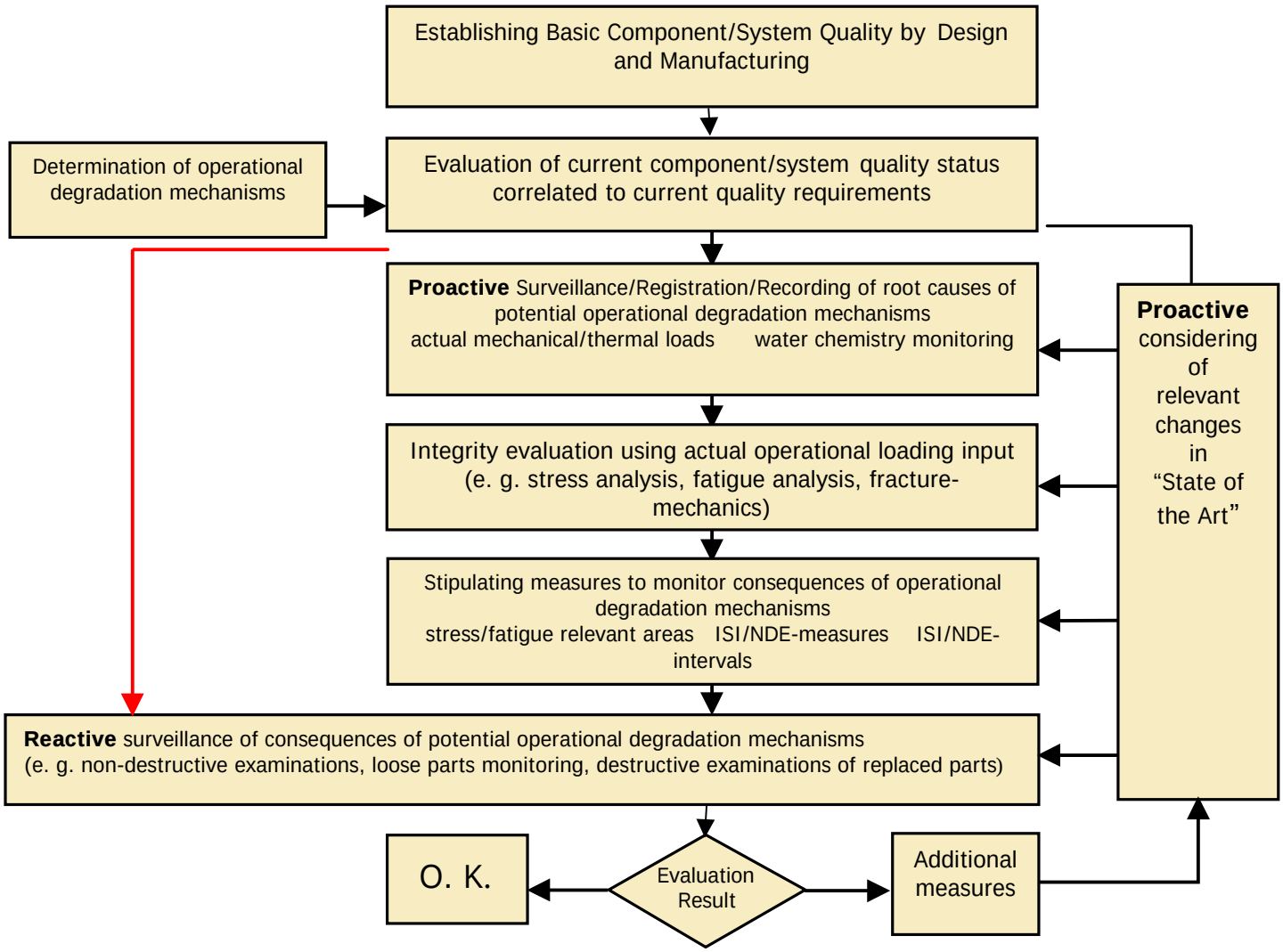


Figure 22: Proactive and reactive ageing management approach for group 1 components (high safety requirements)

For components existing redundantly, a single case failure is not a safety problem as long as no common cause failure occurs.

Group 3: Components with lower Safety requirements ("Component replacement after failure")
These are small components or redundant I&C Components. A single case failure is no safety problem as long as no common cause failure occurs.

The Ageing Management approach (proactive and/or reactive) varies according to the component safety significance ranking. Following system classification (safety relevant) and component ranking (high, medium, lower safety significance), ageing management starts with the evaluation of the current component/system quality status, because degradation mechanisms from operation may have had an impact on the original component quality so far. In addition relevant changes in the 'state-of-the-art' may have to be considered, too. Within the proactive approach the surveillance and monitoring of root causes of potential operational degradation mechanisms in terms of actual loads is required. Load monitoring results show whether the original design loads are still enveloping or not, or if new loadings have occurred. In case of new loadings, plant operation procedures may be changed to avoid premature degradation effects due to these new loadings. Based on actually occurring loads, integrity evaluations are performed in terms of stress and fatigue analyses to determine the actual integrity status of the component. Based on the evaluation results, subsequent surveillance measures have to be installed (determination of stress/fatigue relevant locations, implementing additional monitoring, optimising ISI/NDE measures).

For Group 1 components with high safety requirements in addition to redundant surveillance of consequences of potential operational degradation mechanisms are required.

For Group 2 components (example: mechanical components) with medium safety relevance the reactive approach is appropriate. As the first step the current component quality status has to be determined considering the original design and the impacts from plant operation so far and from potential changes in 'state-of-the-art'. For redundant components (e.g. valves) the failure of a single component is not a safety problem as long as no common root cause for the failure occurs. Safeguarding measures can then be limited to reactive surveillance of consequences of potential operation degradation mechanisms which have already occurred and which have been detected.

This approach is already covered by the common preventative maintenance measures performed in nuclear power plants (e.g. for valves). Maintenance is performed either as visual inspection, maintenance issues, repair or replacement (either time orientated or based on the actual component condition). Time orientated maintenance means that the components under consideration (e.g. valves) will be inspected in fixed time intervals (e.g. 4 or 8 years according to their safety classification). If the maintenance is based on the existing component condition the time period for

inspections will be chosen individually. It is known from experience that maintenance activities performed too frequently may lead to additional ageing effects.

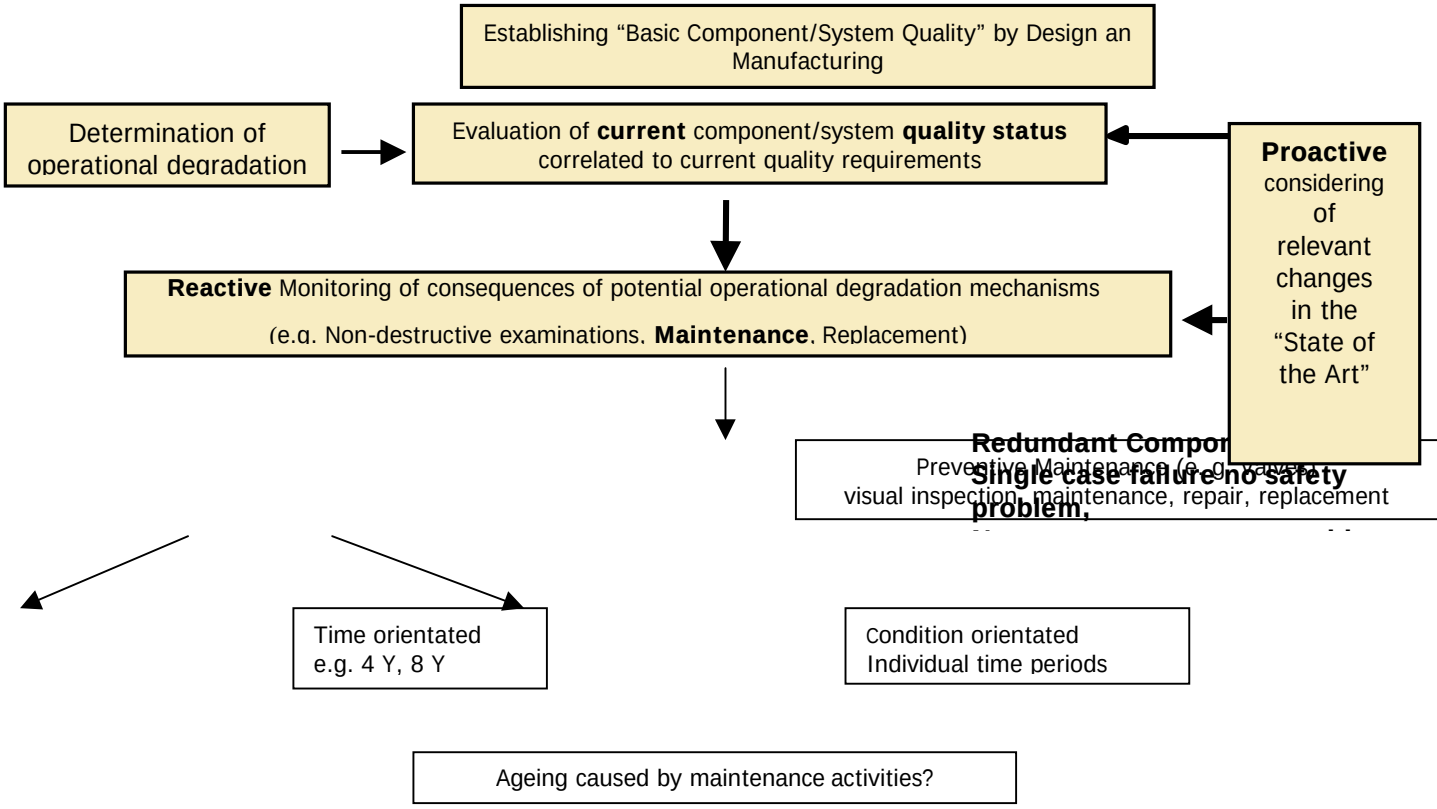


Figure 23: Reactive ageing management approach for group 2 components (medium safety requirements)

For Group 3 components (e.g. mechanical components) with lower safety relevance the reactive ageing management is sufficient. It is based on the original component/system quality established by design and manufacturing. Potential degradation effects of plant operation so far may be controlled by inspection measures. Impacts of relevant changes in the state-of-the-art may help to modify the inspection measures. Due to the fact that a Group 3 component failure is not safety relevant, the ageing management may be performed by replacement strategies. If for specific safety or for plant availability reasons a component failure may not be acceptable an upgrade from Group 3 into Group 2 with defined inspection measures is necessary.

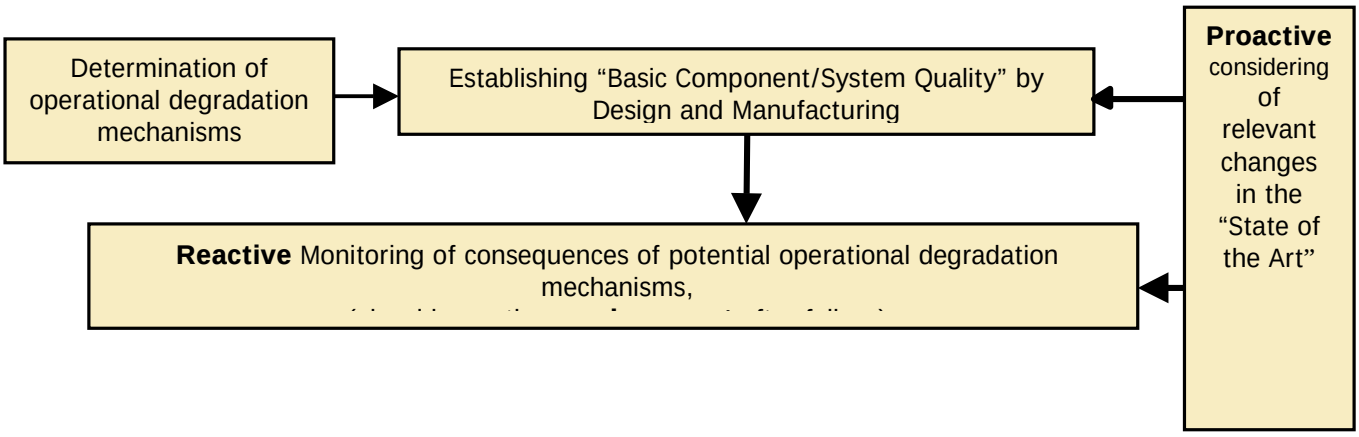


Figure 24: Reactive failure orientated ageing management for group 3 components (lower safety requirement)

All safety relevant long term integrity or ageing management activities are documented in reports etc. Although there is no specific ageing management documentation fixed in Germany, there are numerous reports being submitted to the safety authority demonstrating reliability of the ageing management actions even being performed under different names:

- Monthly plant operation report
- Annual plant operation report (including cycle counting for fatigue relevant components)
- Annual report about meeting 'state-of-the art' requirements
- Plant specific assessments concerning incidents from other plants
- Plant specific periodic safety analyses
- Etc

5.6.3 SUMMARY AND CONCLUSIONS

Due to German safety regulation requirements ageing management activities have been performed since the beginning of plant operation. Although no specific ageing management programme exists the German utilities understand that the relevant ageing mechanisms are technically and administratively covered by the entirety of the measures already taken.

Nevertheless, the German utilities intend to demonstrate how and where the AM actions have been carried out in terms of technical and administrative issues based on an overall ageing management concept. An utility working Group has been installed to clarify the overall ageing management concept criteria for the safety significant components (mechanical and I&C components, buildings) and to give a guideline for future plant specific applications. This work will be finished in the year 2002. It is intended to provide a plant specific documentation consisting of the following reports:

- **"Basic report"** containing all general criteria plant specific component classification and the present status concerning the ageing management issues
- **"Recurrent report"** (annual?) describing just the deviations ('Deltas') compared to the basic report.

5.7 HUNGARY

5.7.1 NUCLEAR POWER STATIONS

STATION	Cumulative START (MWh)	Load Generation	Factor	Type	MWe
Paks 1	12/82	62622536	84.5	WWER	460
Paks 2	09/84	57983288	85.0	WWER	460
Paks 3	09/86	52054364	85.9	WWER	463
Paks 4	08/87	49862396	87.2	WWER	460

Table 7: Performance of Hungarian Nuclear power plants

(Ref. 3)

The Hungarian nuclear electricity production is about 14 TWHh/year. NPP Paks where 4 WWER-440 type units are working with an efficiency of more than 80% for many years. About 40% of the total Hungarian electric energy production is generated at these plants, and their production costs are significantly lower than the average in the country.

With its high share of electricity production, the nuclear power plant nowadays is a potential tool for market control and for economic policy interventions.

The WWER-440 type is a pressurised light water reactor. OKG Gidropress, Russia was the designer. The Czech Skoda Works under Russian licence constructed the reactor and pressuriser. Other components of the primary circuits were manufactured in co-operation between Russian, Hungarian and Western European firms. During the installation period the Hungarian Central Electricity Board widely used the experience gained by the Finns during the construction of two similar units at Loviisa site and maintained a strict quality assurance testing and control system, independently from the quality checking carried out by the producers.

5.7.2 BACKGROUND

When the NPP was built (during the end of the seventies) life management was not a widely applied practice. As in most places, the basic idea was to build a power station, which could be operated safely for 30 years. Even though no life management plan was elaborated during the construction period, the investors, the Hungarian electricity board and the co-operating research institutions took several steps to form the basis of the Life Management of NPP Paks.

During the building period several important safety related measures were taken. These actions provided a solid base for the Life Management. The most important steps are summarised below.

In 1979 Hungary joined the IAEA IWG RRPC (International Atomic Energy Agency International Working Group on Reliability of Reactor Pressurised Components), which later became the IWG

LMNPP (International Working Group on Life Management of Nuclear Power Plants). Active participation in this and other working groups of the IAEA, together with the assistance and safety missions concluded by the Agency became important contributions to the Life Management programme.

Since Paks was the first nuclear power station in Hungary an obligatory NPP Safety Code (ABSZ) was issued in 1979 by the responsible authority, the State Energy and Safety Superintendence (AEEF). This was an extended version of the Soviet safety code.

The plant had been equipped with hot-cells, laboratories, testing devices. The staff was trained in parallel with the construction of the plant. Training and qualification (I., II, III. level) of non-destructive testing staff were in accordance with international standards. The plant staff, co-operating with other qualified laboratories in Hungary, managed continuous and strict quality testing during the installation, independently from the quality assurance of the producer, and required the proper quality documentation from manufacturers providing a proper basis for Life Management.

During the first decade of operation several steps were taken to increase the safety and lifetime of NPP Paks.

Periodic ISI tests are performed by the material testing specialists of the plant, under in-loco supervision of the responsible authority.

Obligatory inspection is complemented by tests proposed by the quality assurance department of the plant or by scientific institutes. The object of these tests is beside the acquisition of extra information in order to gain deeper insight into questions of safety to bridge discrepancies between the national codes and those used in international practice outside the country (ASME Code, KTA standards, IAEA recommendations), or in some cases newly accepted normative documents of the WWER users group.

In 1993 the Hungarian Government, on the recommendation of the IAEA, introduced the Periodic Safety Reviews -a system for periodic renewal of the operating permission. Scope of the Periodic Safety Reviews and simultaneously applicable requirements for systematic management of ageing processes of the safety equipment, is included in the Governmental Decree No. 108/1997 (VI. 25) and in the Nuclear Safety Codes. During review, as a condition of the operating licence, it shall be confirmed that equipment relevant for safety is operable in spite of ageing processes. According to this law after every 10 years of operation the NPP has to present a Periodic Safety Review and apply for further operational permission. The ageing of the plant and this new requirement forced the NPP management to commence systematic life management. NPP Paks ordered lifetime predictions for the main equipment in the middle of the nineties.

A comprehensive safety enhancement programme is to be finished in the Paks

Nuclear Power Plant in the near future. Due to the safety enhancement measures, between 1996-2002 the safety of the units will be the same as of similar age nuclear power plant units operated in develop countries

Low production costs are crucial in the operation of NPPs. Partial electricity market opening in Hungary is planned for 2003, which is a new but difficult challenge for NPP Paks.

Among the Hungarian electricity producers NPP Paks has the lowest production costs. On the basis of current prices, and taking into account that the Paks Nuclear Power Plant, differently from other electricity producers, already pays the external costs, too, it is expected that the Paks Nuclear Power Plant will maintain its competitiveness at the liberalised international market.

5.7.3 LIFE MANAGEMENT

Under such conditions the following strategic decisions have been made by the Paks Nuclear Power Plant, approved by the owner (Hungarian Electricity Generating Board) and accepted by the government:

1. The capacity of the units will be increased. Modernisation already performed in the secondary circuit, (condenser reconstruction and turbine retrofit), electrical output of the units currently is 470 MW. Furthermore the output is planned to be increased to 500-510 MW. A feasibility study for the power uprating supports this both from technical and safety aspects.
2. By means of an effective lifetime management, in accordance with technical, economical and safety requirements, the units shall be operated as long as possible. In 2000 the Paks Nuclear Power Plant investigated the nuclear power plant's lifetime extension possibilities and alternatives, as well as the technical and business feasibility. 50 years of operation is proved to be a realistic goal.

5.7.4 LIFE MANAGEMENT METHODS

The components, which are for life management, have been selected. The lifetime of the units at Paks depends on the reactor vessel, although vessel embrittlement can be decreased by heat treatment procedures. It is also hope that enhancement of the study of material properties and the PTS analysis method will also prove that the RPV-s can operate for 50 years.

Another irreplaceable life limiting structure is the containment. With proper maintenance it can probably be operated during the planned lifetime.

The WWER 440/V213 type plants have six steam generators/unit. These are built into the so-called box system. Even though several steam generators have already been replaced in the world, the replacement of the Paks ones is not realistic due to the high costs, thus their eventual failure is an

economic limit of lifetime. Maintenance, reconstruction, replacement of other components will ensure continued operation.

Research connected to lifetime management is being performed in several institutions.

Lifetime extension of the NPP is technically and scientifically feasible, possible restrictions are primarily based on economic, political, social and financial arguments, as it is shown by a feasibility study performed in 2000.

5.7.5 ECONOMIC ANALYSIS OF OPERATING LIFE EXTENSION

Compared to the establishment of combined cycle gas-turbine power plants, investments extending the lifetime of the Nuclear Power Plant Paks are more economical until the natural gas price valid in the period of extension is not reduced by 57% as compared to the present price level.

The summary of the plant life management of NPP Paks>

- There is no technical barrier limit to extending the operation of the Nuclear Power Plant Paks up to 50 years.
- The life limiting components are the reactor vessels and steam generators and containment.
- The plant life management is economic compared with other electricity sources available in Hungary
- Economy of the lifetime extension, as a project, has been studied in dual comparison:

5.8 ITALY

(Provided by F Sevini with an acknowledgement to Mr I Triputti from SoGin)

The four Italian nuclear power plants were shut down in the 1980s: Garigliano NPP in 1982 for technical and economic reasons, while Latina, Trino and Caorso NPPs were shut down after the Chernobyl accident and the results of the 1987 referendum stopping nuclear power in the Country. This decision also blocked the construction of Montalto di Castro (2x1000MWe BWR) and Trino (2x1000MWe PWR) NPPs, whose operation was planned to start in the 1990s.

In 1992 ENEL was transformed by law into a joint-stock company, property of the Treasury Ministry. As a consequence of the 1999 liberalisation of the electricity market, ENEL started to be privatised while the nuclear activities were separated to form a new Company called So.G.I.N. responsible for the decommissioning of Italian NPPs. So.G.I.N. remains the property of the Italian Treasury.

The decommissioning guidelines are issued by the Italian Ministry of Industry and foresee dismantling of the plants, release of the site without radiological restrictions, conditioning and final waste disposal into a repository.

Owing to the fact that Italy does not at present does not at present have a waste repository for the disposal of low and intermediate-level waste arising from plant dismantling, the Ministry of Industry initially chose a 'deferred decommissioning strategy divided into the following three phases:

Phase 1-*safe enclosure*

- de-fuelling and temporary storage and/or shipment of irradiated fuel
- plant operation termination and licence change
- decontamination of systems and structures. Safe Enclosure of some buildings (mainly the 'controlled area') and free release of the other buildings, by confinement and containment of the residual radioactivity in a limited number of buildings, with partial dismantling of contaminated systems and components.
- treatment and conditioning of radioactive waste.

Phase 2 - *Plant Safe Enclosure for 40 years*

Phase 3- *Release of the site after dismantling and/or decontamination of systems and components.*

With different schedules all the four NPPs should reach the start of Phase 2 in 2007.

Recently the decommissioning strategy has been accelerated, on consideration of local and national levels to adopt a 'prompt decommissioning strategy' and to build a national repository for nuclear waste.

5.9 NETHERLANDS

5.9.1 NUCLEAR POWER STATIONS

STATION	START	Cumulative Generation (MWh)	Load Factor	Type	MWe
Borssele	07/73	95498764	80.6	PWR	481

Table 8: Performance of Netherlands Nuclear Power plant

(Ref. 3)

In February 2000 the Dutch court blocked the attempt of the Government to force the early closure of the Borssele NPP, due to the fact that limiting the operating licence to 2003 was against the Dutch atomic law. EPZ, the plant owner plans to continue operations after 2003.

No fuel has been shipped to COGEMA at La Hague since 1996, and a licence to start transporting fuel issued in July 2001 was challenged in the courts by Greenpeace.

The same type of problems affect the shut-down Dodewaard NPP, where decommissioning cannot begin until the plants'pool has been emptied and the fuel shipped to BNFL for reprocessing (from Nuclear Europe Worldscan No 7-8 July-August 2001. Ref. XX)

5.10 SLOVAK REPUBLIC

(Contribution from F.Gillemot)

5.10.1 NUCLEAR POWER STATIONS

STATION	START	Cumulative Generation (MWh)	Load Factor	Type	MWe
Bohunice 1	12/78	60935446	69.3	WWER	440
Bohunice 2	03/80	59949757	72.1	WWER	440
Bohunice 3	08/84	49597592	75.2	WWER	440
Bohunice 4	05/85	47815696	76.8	WWER	440

Table 9: Performance of Slovakian Nuclear Power Plants

(Ref. 3)

Slovakia has two nuclear power plants. There are 4 WWER-440 V230 units at Bohunice and two WWER-440 V213 units at Mohovce. The Bohunice plant belongs to the first generation of the WWER-s, Mohovce is brand new. Most of the safety upgrading and life management actions aim the survival of Bohunice. At Bohunice units one and two have already been annealed, and safety related equipment has partly been modernised, or replaced.

5.10.2 BACKGROUND

Slovakia, formerly part of Czechoslovakia became independent in 1992. After the separation the country set up the Slovakian Nuclear Regulatory body and improved the research institutes dealing with nuclear safety. The leading institute is the VUJE (research Institute for Nuclear Energy). The Welding Institute in Bratislava also plays an important role in nuclear research. Furthermore the Slovakian institutions have a traditionally good co-operation with their Czech counterparts and they mostly use similar codes and rules.

The Slovakian NPP-s are also part owners of the Czech NRI Institute. Activities are mainly centered on the monitoring of ageing in order to prove the safety and reliability of the operating units.

5.10.3 LIFE MANAGEMENT

At the Bohunice plant a very sophisticated and ambitious extended surveillance programme has been introduced.

Core has been reduced and dummy elements are used in most units to reduce the flux and extend the RPV-s lifetime.

In VUJE institute several pressurised components have been modelled by finite element method, and based on the results the most critical locations are selected for non-destructive testing.

The degradation mechanism has been defined for every component. Software for evaluation of different types of ageing has been developed and is widely used to calculate the lifetime of the components.

5.11 SPAIN

(Contribution from I. Marcelles and A.Ballesteros)

5.11.1 SPANISH NUCLEAR POWER STATIONS

STATION	START	Cumulative Generation (MWh)	Load Factor	Type	MWe
Almaraz-1	*05/81*	*129661427*	*77.1*	*PWR*	*974*
Almaraz-2	10/83	125501908	84.3	PWR	983
Asco 1	08/83	121026192	80.6	PWR	979
Asco 2	10/85	113643110	85.9	PWR	976
Cofrentes	10/84	126795424	85.9	BWR	1025
Zorita	07/68	30605770	62.9	PWR	160
Garona	*03/71*	*90449151*	*73.2*	*BWR*	*466*
Trillo 1	05/88	102963488	83.2	PWR	1066
Vandellos 2	12.87	102659339	84.1	PWR	1009

Table 10: Performance of Spanish Nuclear Power Stations (Ref. 3**), Italicised print denotes plants > 20 years old**

5.11.2 LWR POWER PLANTS LIFETIME MANAGEMENT STRATEGIES.

Recently, Spanish utilities that own nuclear power plants (NPP) have become increasingly concerned with optimising plant life management. As a result of this interest, Life Management Programmes have been set up with the strategic objective to operate the NPPs as long as they are considered safe. In parallel with this initiative, both utilities and the Spanish Regulatory body (CSN) are working together to identify specific aspects of the licensing process that could be necessary for long-term operation of NPP. This paper presents a summary of the present Spanish regulatory framework that could be applied to long-term operation of NPP and the methodology developed jointly by all the Spanish utilities for setting Life Management Programmes.

The current Spanish regulatory framework is based on periodical licence renewal by the NPP, without a specific time limit for operation. These renewals are done usually every ten years.

The status of the Spanish NPPs is as follows:

NPP	Type	Power (MWe)	Start Up Date	Date of the Last Authorization for Operation	Period of Validity of the Authorization (Years)
José Cabrera	PWR	160	1968	15 Oct 99	3
Garoña	BWR	466	1971	5 Jul 99	10
Almaraz I	PWR	973	1981	8 Jun 00	10
Almaraz II	PWR	982	1983	8 Jun 00	10
Ascó I	PWR	1.028	1983	2 Oct 01	10
Ascó II	PWR	1.027	1985	2 Oct 01	10
Cofrentes	BWR	1.025	1984	19 Mar 01	10
Vandellós II	PWR	1.087	1987	14 Jul 00	10
Trillo	PWR	1.066	1988	17 Nov 99	5

Table 11: Licensee data on Spanish NPP,.....* at the end of 2001

The current regulatory requirements are based on three main actions:

- Continuous safety evaluations of the NPP by the CSN through periodic inspections, etc
- Preparation and submittal to the CSN of an annual report, including the results of the plant Life Management Programme.
- Performance of Periodic Safety Reviews (PSR) by the NPP for the licence renewal.

The main objectives of the PSR are:

- Analyse internal and external operating experience.
- Guarantee the correct application of operating experience analysis process, including the modifications global revision.
- Analyse the plant behaviour during a long operating period, including the results of surveillance requirements and equipment maintenance, in order to verify the safety level has not decrease and to guarantee the safety operation during then next period.
- Plant Safety level evaluation, considering the new national and international codes and standards, in particular those applied in the project origin country to the similar NPPs.
- Update the safety evaluation and improvement programmes.

From the point of view of life management, the PSR have to include the analyse of the critical component behaviour, identifying the ageing or degradation mechanisms and the current corrective measures adopted by the plant to control and mitigate them, as well as updating the safety evaluation and improvement programmes.

PSR results have to be reported in a specific document produced by the NPP, including the analysis of all areas under the scope of the PSR, and identifying the safety improvement actions and its implementation schedule.

PSR requirements are stated in a specific guide (CSN Safety Guide Nº 1.10) published by the CSN in December 1995. This Safety Guide has been prepared following international practices and recommendations, including IAEA Safety Guide "Periodic Safety Review of Operational NPP".

In order to facilitate the application of CSN Safety Guide 1.10 "Periodic Safety Reviews of Nuclear Power Plants", the Spanish association of utilities UNESA has developed a specific guide, titled "Guideline for the development of Periodic Safety Review".

The areas considered within the UNESA guide are the following:

- Operating experience
- Experience related to the radiological impact
- Changes in the regulations and laws
- Equipment behaviour
- Installations modifications
- Probabilistic safety assessment
- Updating of safety evaluation and improvement programmes

The two areas related to ageing and life management are equipment behaviour and updating of safety evaluation and improvement programmes.

The approach to life management has also been standardised by UNESA by the development of a common methodology. This methodology has the following phases (see fig. 25):

1. System, structure and component prioritisation
2. Selection and identification of ageing mechanisms
3. Maintenance evaluation
4. Review of operation and maintenance programmes

5.11.2.1 SYSTEMS, STRUCTURES AND COMPONENTS PRIORITISATION

The first requirement for adequate plant life management is to avoid dispersion and to optimise the Programme resources. These limited resources should not cover the whole of plant systems, structures and components indiscriminately. Prioritisation is necessary and needs to be slightly adjusted periodically, to adapt to the margin of uncertainty of all predictions.

As basic criteria Life Management Programmes will centre on components having the greatest sensitivity to ageing and higher operating and maintenance (O&M) costs. These components are termed the **"critical components"** and will be the object of further investigations and research to identify the parameters that affected them.

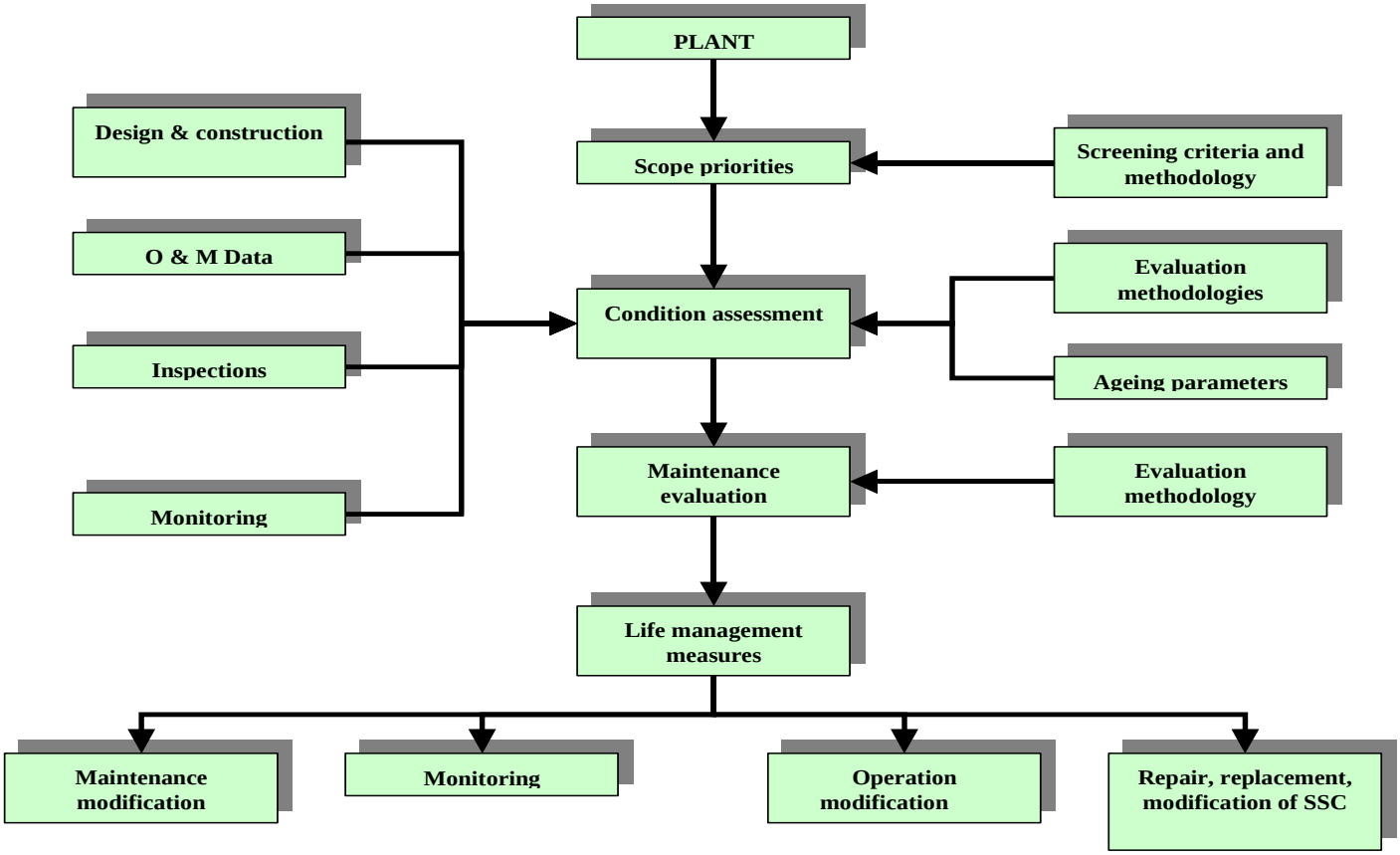


Figure 25: Spanish Plant Life Methodology

The steps for selection and prioritisation of critical components are the following (see figure 21):

- Selection of systems and components
- Prioritisation of components selected.
- Grouping of similar components.

The selection of systems is done considering safety, availability and cost criteria.

The selection of components within these systems is performed based on a wide range of criteria such as:

- High cost or long period needed for component replacement.
- Significant impact on safety level of component failure.
- Important component in licensing process
- More aggressive than design operating and environmental conditions.
- Component is safety-related or required for safe shut-down
- Component maintenance is not effective for ageing control and mitigation

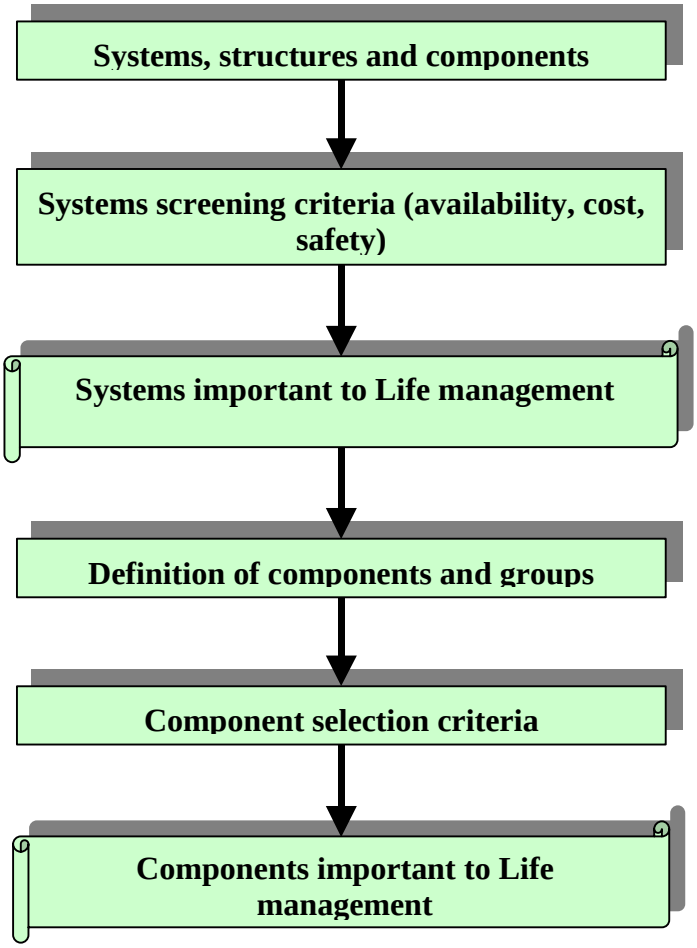


Figure 26: Component selection

The components selected are ordered following several criteria such as: service conditions and history, regulation factors, reliability considerations, programme effectiveness, etc. and a weight is given for each of the factors. Thus the association of total weights to each one prioritises the components.

Finally the establishment of grouping criteria allows inclusion in the same class of components with similar surveillance parameters and techniques. This allows for a more effective and efficient ageing surveillance and management of these grouped components, as they require similar parameters and techniques.

As an example, in the following table the list of the first 15 components for each kind of reactor, with their weightings, is shown.

Rank	Component/ Group/Structure	Weighting (*)
PWR		
1	Reactor Pressure Vessel	588
2	Steam Generators	561
3	Reactor Building	540
4	Reactor Vessel Pedestal	534
5	Metal Primary Containment	531
6	Auxiliary Building	520
7	Reactor Coolant Pumps Foundation	514
8	Pressurizer Pedestal	512
9	Steam Generator Pedestal	512
10	Essential Service Water Piping	496
11	Primary Containment Mechanical Penetration Assemblies	465
12	Pressurizer	463
13	Intake Structure	462
14	Primary System Equipment Supports	462
15	Electrical Building	461
BWR		
1	Reactor Pressure Vessel	637
2	Reactor Vessel Pedestal	550
3	Drywell Metal Shell Foundation	533
4	Reactor Building Basement	519
5	Suppression Chamber including support	519
6	Plant Control Centre	512
7	Biological Shield	506
8	Fuel Pool Slabs and Walls	503
9	Drywell Metal Shell	502
10	Snubbers	491
11	Sacrificial Shield Wall	489
12	Reactor Recirculation Piping	481
13	Control Rod Driver	470
14	Reactor Core Shroud	464
15	Reactor Vessel Nozzle Safe Ends	464

(*) Relative to 1000.

Table 12: List of the more significant components selected and their priorisation

5.11.2.2 *SELECTION/IDENTIFICATION OF AGEING MECHANISMS*

The Programme begins with an initial condition evaluation, which serves as the basis for establishing the main corrective and monitoring actions, and for preparing the first cost/benefit analyses for Life Management. The Programme continues to progress with periodic re-evaluation of condition to confirm the corrective measures are the right ones and to adopt new measures, if necessary, as a result of the monitoring established.

The initial conditional evaluation of each "critical component" is performed considering the following information:

- Component (or group of components) design, manufacturing and operational data, including process and service conditions, stress values, etc.

- Potential degradation mechanisms and of the level of harshness of selected components is determined based on previous collected data.
- The degradation mechanisms analysis is complemented by history of the operation and maintenance, and the results of diagnosis and monitoring, to detect incidents that might have affected the condition of the plant, or for evidence of degradations.
- Uncertainty about the severity of some of these ageing effects may require extra inspections or tests, to provide more precise data.

Condition evaluation requires collection and ordering of the documentation and records of manufacturer, operation and maintenance that contain information needed for the analysis. This collection requires application of procedures that establish the data and records, with the periodicity of their acquisition clearly identified for successive re-evaluations, and the screening requirements for easier collection and analysis.

The result of this analysis is an Evaluation Report (fig. 22) for each component or group of similar components. In addition, each evaluation report includes information about the following age related matters for the target component(s):

- Component detailed description, including design and service information, potential degradation mechanisms and main variables controlling ageing process.
- Techniques allowing to detect, survey and monitor the component ageing mechanisms, including inspection, surveillance and periodic testing.
- Lifetime prediction methodology, including life consumption assessment algorithms, degradation status determination and evolution calculations and acceptance criteria for ageing prediction.
- Recommendation for ageing mitigation: different theoretical approach to mitigate ageing effects are proposed in Evaluation reports, including new research and development activities to solve existing problems in mitigation techniques.

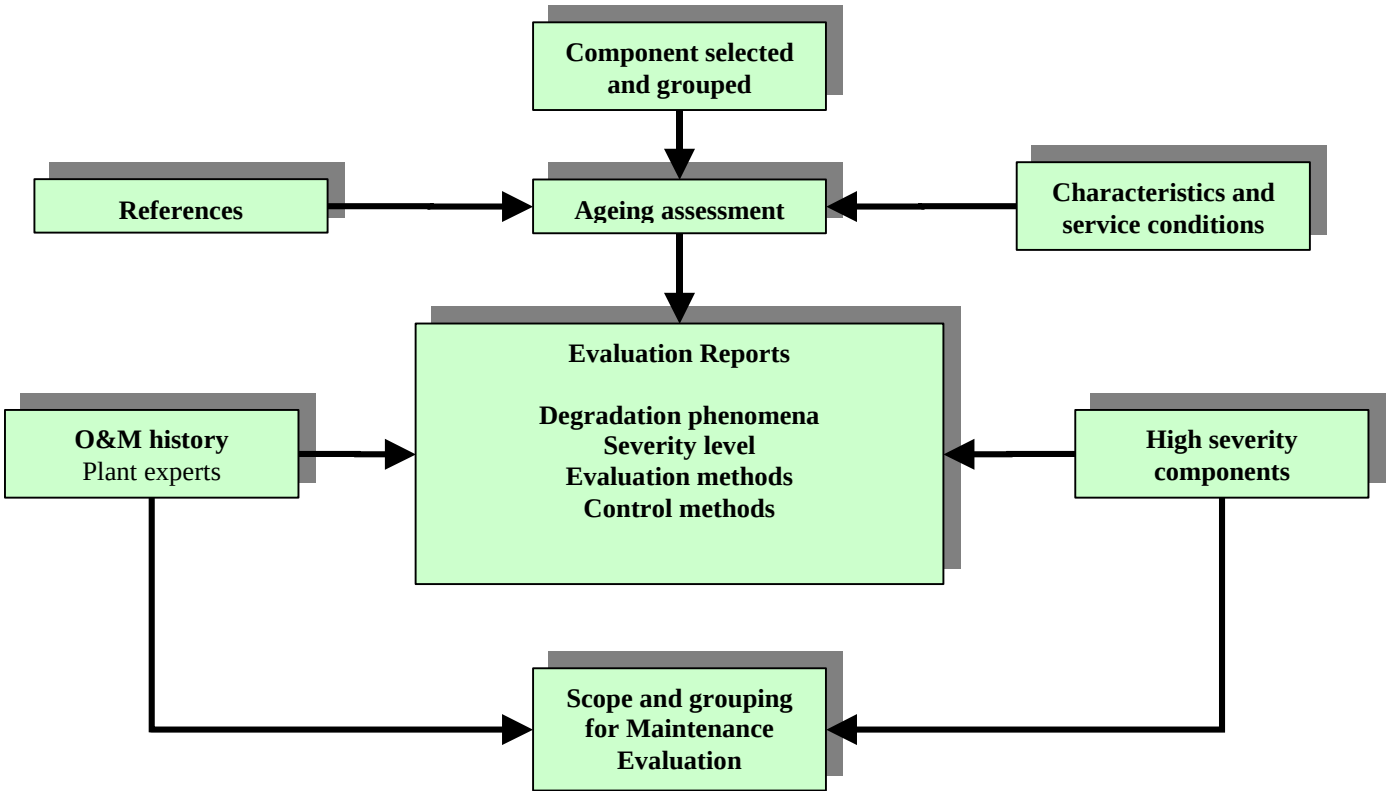


Figure 27: Ageing evaluation process

Examples of component–degradation mechanisms identified for Spanish Nuclear Power Plants are included in table 15.

5.11.2.2.1.1 PWR PLANT	
Component	**Degradation Mechanisms**
Reactor pressure vessel	Neutron embrittlement, fatigue, IGSCC, Wear
Steam generators	Fretting, SCC, Fatigue; Fouling
Pressurizer	Fatigue, IGSCC, Electrical ageing
RPV Internals	Wear, IGSCC, IASCC
Containment mechanical penetration assemblies	Galvanic corrosion
RPV support	Corrosion, Fatigue, SCC
Emergency diesel generator (engine)	Wear, Fatigue, Corrosion, Stress relaxation, Fouling, Erosion, MIC.

5.11.2.2.1.1.1 BWR PLANT	
Component	**Degradation Mechanisms**
Reactor Pressure Vessel	Neutron embrittlement, fatigue, IGSCC
RPV Internals	Wear, IGSCC, IASCC, Fatigue
Containment mechanical penetration assemblies	Galvanic corrosion
Metal containment	Corrosion, Galvanic corrosion
Drywell vent lines including bellows	Fatigue
Reactor building crane	Overload

Table 13: Examples of component - degradation mechanism pairs identified

5.11.2.3 MAINTENANCE EVALUATION

In addition to the improvements in operation and service conditions, a substantial part of the causes and effects of ageing mechanisms have to be mitigated by maintenance work. The nature of these long-term ageing mechanisms has meant that, in certain cases, current maintenance practices do not prevent them. This requires these practices to be evaluated and modified where necessary to improve their efficiency in conservation and the mitigation of degradation.

The maintenance evaluation methodology requires the following activities:

- Detection of the component-degradation mechanisms pairs to evaluate.
- Determination of the programmes, practices and procedures that affect each component/degradation mechanism pair
- Evaluation of the possible deficiencies in control of ageing of the maintenance of each components and propose, when necessary maintenance improvements.

These activities are materialised in the following procedure:

- Production of Component Degradation Data Sheets (CDDS): The data to be filled out on the CDDS are component description; functions; design parameters; operating experience; degradation mechanisms; and the part of the component affected by ageing.
- Generation of Maintenance Practices Data Sheets (MPDS): For each programme, practice and procedure that affect each component-degradation mechanism pair, a MPDS is prepared with: practice limitations; time when corrective action is taken; data needs; mitigation, detection and

monitoring actions; and criteria, as well as any other experience or comments from practices application experience.

- Creation of Maintenance Evaluation Checklist (MEC). Each component CDDS and all the MPDS that affect the component are compared to obtain the MEC of the component. MEC shows the possibly deficiencies in ageing control of each component maintenance. When required, maintenance improvements are proposed. The most extended actions are changes in service condition, fluid chemistry control and environmental conditions, as well as, improvement or recovery of material characteristics and modification in operation modes.

5.11.2.4 REVIEW OF OPERATION AND MAINTENANCE PROGRAMMES

Based on the conclusions of the previous activity, several actions can be taken in order to review the operation and maintenance programs. These actions could be the following:

- Repairs, replacement or modifications of the components most severely affected, if availability or performance improvement justify the investment.
- Modification of operating procedures and in service conditions to make them less harsh.
- Improve maintenance practices to achieve full efficiency for safe and economically viable life extension.
- Implement additional monitoring to improve condition evaluation and trends, especially for component–degradation mechanism combinations with more uncertainties. This will reduce the effort required for collection and analysis of information, and allow the use of realistic criteria for ageing parameters in the life management decision-making process.

Example of maintenance programs optimisation are the extensive effort in older plants to replace old cable and instrumentation, which were considered age-sensitive. An example of the mitigation activities is the core optimisation, which reduce reactor pressure vessel neutron embrittlement.

5.11.3 INTEGRATED AGEING MANAGEMENT SOFTWARE TOOL: SIGEVI.

In order to apply the methodology adopted in an easy and homogeneous way and to take advantage from previous developments performed within the sector, the Spanish utilities decides to develop jointly a computer system to facilitate condition evaluation as well as component life management of a NPP. This project was known as Integrated System for Life Management of NPPs (SIGEVI project) and took place from 1998 to 2001, with a budget of 2.4 million Euro. The project, in which all the Spanish NPP participated, was co-ordinated by UNESA. The Spanish engineering companies TECNATOM, Empresarios Agrupados INITEC, Soluziona Ingeniería and IIT developed the work. Vandellos II NPP was used as pilot plant for the development of the first prototype that included the following components: vessel, steam generator, pressurizer, vessel internals, diesel generator, turbine-generator set, transformer, relays and breakers, pumps, electrical machines, hydraulic valves, wiring, structures, and piping. Each of them constitutes a system module.

In each module several evaluation techniques are included. These have different complexity degrees, from just presenting parameters tendency to damage estimation or defect analysis, using fracture mechanics studies.

In figure 24 and 25 examples of computer screens of the SIGEVI are presented.

Currently the SIGEVI prototype is operating in Vandellos II NPP, and an ambitious programme is under study for its implementation in the rest of the Spanish NPP, including the necessary adaptations to each specific design. Both the methodology developed and the computer tool, as a whole or by specific system modules, is also available for its implementation in any other LWR NPP.

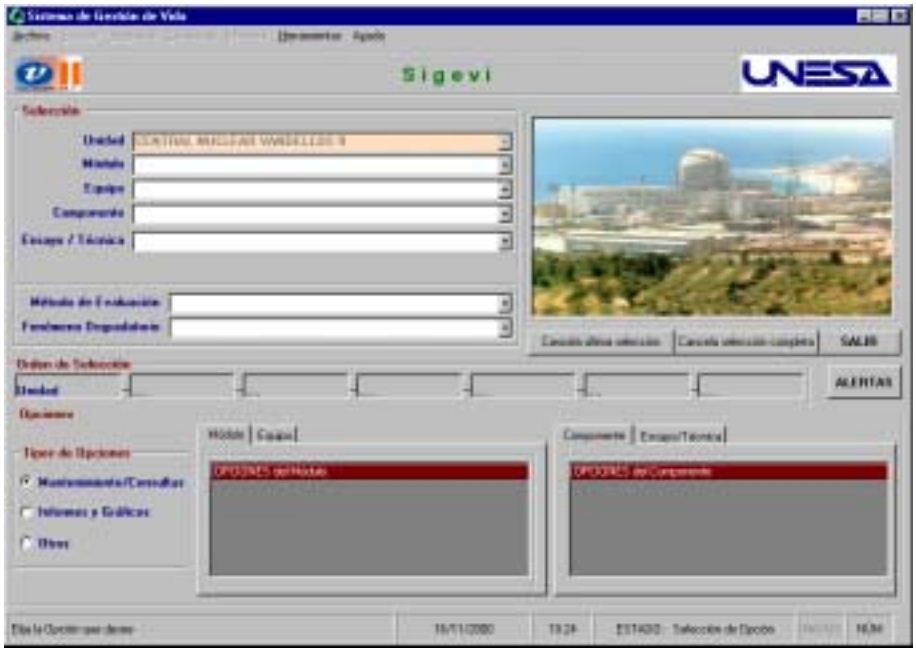


Figure 28: Integrated lifetime management application main screen

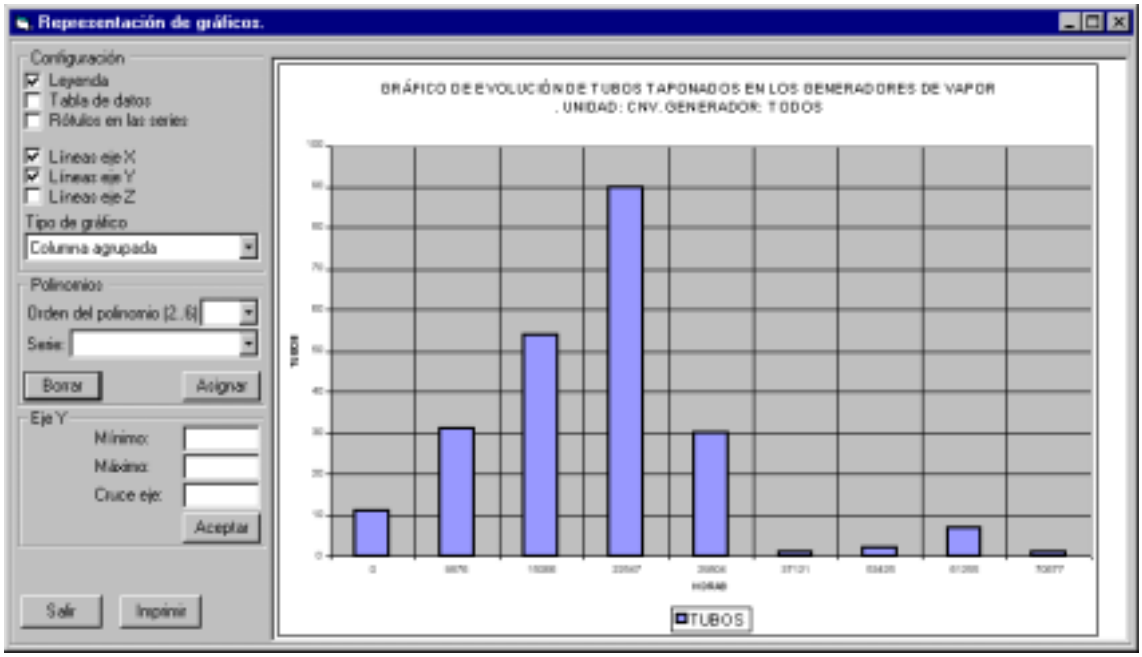


Figure 29: Mitigation measure efficiency surveillance: Steam generator plugged tubes vs. time

5.11.4 SUMMARY OF THE SPANISH 'STATE OF THE ART' ON PLIM

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Spanish utilities consider a strategic objective to operate their NPP on the long term, and so have set up a common plant life management methodology that is developed through specific Life Management Programmes.

The current Spanish regulatory framework is based on periodical licence renewal by the NPP, without a specific time limit for operation. These renewals are done usually every ten years, although this period can be shorter if the Regulatory Body considers the NPP does not fulfil all the requirements to operate safely through this period.

The Spanish Regulatory body and the utilities are working together to identify specific aspects of the licensing process that could be necessary for long-term operation of NPP. Although currently under discussion, the Spanish utilities do not foresee that the long-term operation of NPP will introduce significant changes in the regulatory requirements for licence renewal.

The common plant life management methodology adopted is divided into four main activities:

- Definition of the priorities and scope of the Life Management Programme. Plant systems, structures and components important for lifetime management are selected and prioritised using a methodology based on screening criteria.
- Evaluation of the initial condition as the basis for identifying ageing mechanisms and establishing the main corrective and monitoring actions. Periodic re-evaluation of condition confirm the corrective measures are the right ones or lead to adopt new measures, if necessary, as a result of the monitoring established.
- In addition to the improvements in operation and service conditions, effects of ageing mechanisms have to be mitigated by maintenance work. The nature of these long-term ageing mechanisms is such that, in certain cases, current maintenance practices do not prevent them. This requires these practices to be evaluated and modified when necessary.

- Based on results of previous activities, it is possible to propose measures to review the Operation and Maintenance programs to optimise lifetime management.

Finally, software tools to facilitate ageing assessment and condition evaluation for main important component for lifetime management have been developed and are available for NPPs.

5.12 SWEDEN

5.12.1 SWEDISH NUCLEAR POWER STATIONS

and communication with L Fredund. 30 January 2000.) (Ref. 3)

STATION	START	Cumulative Generation (MWh)	Load Factor	Type	MWe
Oskarshamn 1	***08/71***	***74336946***	***61.1***	***BWR***	***462***
Ringhals 2	***08/74***	***134042509***	***64.3***	***PWR***	***900***
Ringhals 1	***10/74***	***119922998***	***62.2***	***BWR***	***865***
Oskarshamn 2	***10/74***	***108816676***	***74.3***	***BWR***	***630***
Barseback 2	***03/77***	***97747762***	***74.9***	***BWR***	***615***
Forsmark 1	***06/80***	***145151375***	***78.9***	***BWR***	***1008***
Ringhals 3	*09/80*	*122498537*	*67.7*	*PWR*	*980*
Forsmark 2	*01/81*	*140290425*	*78.3*	*BWR*	*1010*
Ringhals 4	06/82	118627603	71.6	PWR	980
Oskarshamn 3	03/85	138904757	81.4	BWR	1205
Forsmark 3	03/85	139504637	82.2	BWR	1200

Table 14: Performance of Swedish Nuclear Power Stations

Italicised print denotes plant which is > 20 years old

5.12.2 PLIM AND PLEX IN SWEDEN

(communication with L Fredlund 27 January 2000. Also see 'An integrated approach to plant life management' by Fredlund, Proc. IAEA meeting on Strategies and Policies for NPP Life management, IAEA Paper IWG-LMNPP-98 P2)

There is no legally defined lifetime for NPP.

The nuclear power plants in Sweden were built and commissioned between 1972 and 1985. The design objective was for a load factor of around 70% with about 3-5 reactor trips a year. In financial terms the plant life was 25 years, but the technical lifetime was 40years (it should be noted that the former Swedish parliament decision to phase out nuclear power in 2010 was based on the 25 years of depreciation).

Nowadays capabilities of >90% are not uncommon. Plants have run for years without any unplanned trips. This means that 25 expected years of operation will happen in 20 years. Many plants only use a fraction of the design transients, thermal cycling of components hardly ever happens in many of the Units. The introduction of low-leakage fuel loading patterns have not only decreased the costs but also reduced the neutron dose rate at the Reactor Pressure Vessel wall.

Even if the plants are not utilised as originally designed one feature has become essential in defining plant life. Almost everything can be replaced! Steam Generators, primary piping, vessel internals, reactor vessel head, turbines, I&C equipment and many other components. Consideration is being given to the replacement of a PRZ, adding new and redundant electrical parts etc. **The major component that now determines plant life is the Reactor Pressure Vessel**.

Lifetime in Sweden is as long as the plant is economically viable-as long as the safety objectives are met. Operators talk of 25+ years and sometimes 40 years. Major plant replacements are usually considered as 'mid-life' replacements.

Plant life and plant life extension are very much linked to the licence and licence renewal activities. The system in Sweden is to have an operating permit that is usually (but not always) for a fixed period-normally up to 2010 (as this was decided as the 'phasing-out' date by the Parliament in the early 1980s. To renew this licence, there has been no links to any other activity-only on a case-by-case basis some specific safety issues have been addressed. So, PLEX is not an approach in Sweden, PLIM is.

The only connection between PLIM and the Periodic Safety Report is in the area of the number of transients that the plants are subject to. This design number is seldom reached. However, but within our constraints, this could of course be a limiting factor.

To manage plant life means to determine the essential maintenance activities and the needs for replacement. At the same time there is the need for 'software' activities to describe, evaluate (i.e. deterministic analyses of components and functions) and verify (i.e. probabilistically analyse) the design of the plant. All this supports the objective of meeting the reactor safety criteria and also financial and production objectives. A successful management of plant life will keep the plant running as long as possible and meet all the safety standards and principles.

In order to manage the plant life there must be a reliance on a good plant status, a high level of safety but also public acceptance. If the first two criteria are met then the last is probably easier to meet.

Public acceptance is essential. It is recognised that the public cannot easily understand the nuclear safety aspects and that their acceptance must be based on something else. One approach is to treat the plant very much like any other industrial enterprise and an environmental programme having a high profile is needed. If a plant, in addition to this, is also known to be safe essential for power production and aiming at the future then it should also be acceptable.

The technical status of the plant is essential for electricity production. It is probably managed today by existing maintenance systems-generally 95% of what is needed for the hardware part of plant life management is already covered by plant life maintenance.

Plant life management is part of normal activities, so our Regulator has stated in the nuclear codes that the plant should be maintained in such a way that (major) disturbances an accidents should be

avoided (SKIFS 1998:1 2kap1*). The Regulator states SKIFS 1998:1 5kap3* that safety related structures, systems and components shall continuously be monitored and maintained to make sure they are monitored as intended. There should be a preventive maintenance programme for every SSC of importance to safety.

There is also a statement a statement as to how the inspection of pressure retaining parts should be carried out (a separate Code, SKIFS 1994:1).

The approach followed for the RPV is the same as that of the US Standards. Other pressure retaining parts are inspected in accordance with their importance, that is the consequence of a leak/break in meeting applicable core cooling criteria. The approach is to all intents risk-informed and the general outline given in SKIFS 1994:1. For other SSCs it is up to the operators to decide programmes and to justify this when questioned.

Normal maintenance procedures are used for 'tracking' components. The only exception is the RPV.

There is no link between PLEX and the PSR because PLEX is not an issue.

Since early 1980 the Regulator has asked for a 10-year review of the safety of the plant. This review, called the 'As operated Safety Analysis Report' (ASAR), is mainly focused on operation and plant modifications.

All Swedish units have also a design re-constitution programme. The origin of this programme was to verify the safety level of these units, as defined by the 'Current Licensing Bases'. It also serves as a powerful tool to update and modernise the FSAR to a format that can better serve as a base for younger generation to understand the design of the unit, both 'why' and 'how' aspects. This programme is finished for a number of the BWRs in Sweden and in progress for the PWRs.

An integrated part of this programme is the deterministic analyses, both for components (i.e. structural analysis) and functions (i.e. transient and accident analyses). Also the probabilistic studies are performed, updated and expanded.

Modern Licensing Bases are under development in Sweden.

Both the Operators and Regulators have a common understanding that PLIM is a continuous process that started when the Units went 'on-line' for the first time. As the Units became older the PLIM Programme needed more attention and more funds.

A PLIM Programme should be based on:

- improvements identified from experience feed-backs
- improvements identified from different safety analyses
- End-of-Life issues and maintenance problems

5.13 UK

5.13.1 BRITISH NUCLEAR FUELS LIMITED

5.13.1.1 UK MAGNOX STATIONS

(information from T. Stokoe 30 January 2000 and 5 September 2001).

Station	Output (MWe)	Commissioned	Age (years)	Cumulative Generation (MWh)	LF%
Calder Hall	*240*	*1956*	*46*	*No data-ex BNFL*	
Chapelcross	*240*	*1959*	*43*	*No data-ex BNFL*	
Bradwell1 1	*348*	*1962*	*39*	*32929749*	*55.2*
Bradwell 2				*34897952*	*59.1*
Hinkley Point	*470*	*1965*	*36*	*119852953*	*70.7*
Dungeness A1	*470*	*1966*	*35*	*53299110*	*59.2*
Dungeness A2	*470*			*54660760*	*61.2*
Sizewell A1	*420*	*1966*	*35*	*59123450*	*57.9*
SizewellA2				*53716370*	*53.3*
Oldbury 1	*430*	*1968*	*33*	*54253400*	*58.3*
Oldbury 2				*55871234*	*61.0*
Wylfa 1	*950*	*1971*	*30*	*101396840*	*57.5*
Wylfa 2				*96255590*	*55.6*

Table 15: Performance of BNFL (UK) Nuclear Power Plants

(Ref. 3), All are > 20 years old

In the BNFL 2001 Annual report reference is made to the statement in May 2000 when the planning operational lifetimes of the Magnox Stations were announced. At that time the closure of Hinkley Point A, which had not generated since 1999 was announced. In December 1999 the closure of Bradwell on 31 March 2002 had been announced. The planning dates are given in the Table 18 below:

STATION	Licenced Operating Lifetime	Age at end of Generation	Projected latest date for end of generation
Calder Hall	50	50	2006-2008*
Chapelcross	50	50	2008-2010*
Bradwell	40	40	2002
Hinkley point A	40	35	2000
Dungeness A	40	40	2006
Sizewell A	40	40	2006
Oldbury	40	40	2008
Wylfa	33	38	2009

**the range of dates are due to the fact that each power station has four reactors that came into operation sequentially over two years.*

Table 16: Latest dates for the end of generation at BNFL plants

5.13.1.2 PLIM IN BNFL

(Communication with T. Stokoe, 30 January 2000).

BNFL is currently responsible for operating all the UK Magnox stations following a merger with Magnox Electric plc in 1998.The Magnox stations generate about 8% of the UK electricity production. Typically the output is about 22TWh per annum.

Data is often published on the Unit Capability Factor, which is defined as the electricity generated plus that which could have been generated but for factors outside the control of the station expressed as a percentage of the potential maximum generation. Typically the annual Unit Capability Factor for the stations is about 80%.

Lifetime is defined as the period from commissioning to the time when the last reactor on the site finally ceases generation. BNFL has announced that the closure of Bradwell Power station will take place in March 2002 when it achieves 40 years operation. No specific dates have yet been announced for any other operating station although all stations are expected to reach at least 40 years.

There is no direct linkage between the 'plant life' and the Periodic Safety Reviews (PSR). The PSR is a condition of the Nuclear Site Licence issued by the Regulator for each station and is a full review of the nuclear safety case completed at about 10 yearly intervals. The regulator must be satisfied with the PSR for the reactors to continue operating.

There is no specific definition of PLIM or PLEX. The Magnox stations had an originally defined life of 20 or 25 years for amortisation reasons; this was not intended to imply any specific technical or operational capability.

The regulations related to plant life are set down in the Nuclear Site Licences and concern the need for maintenance, PSRs, monitoring for ageing etc.

There is no specific end date referred to in the regulations.

In formal terms safety aspects of PLIM is implemented by meeting the requirements of the Nuclear Site Licence. This includes reference to maintenance, PSR and the need for a decommissioning safety case. Several reports have been published recently at International Conferences on the approach to PLIM for the Magnox Stations by BNFL/ Magnox Electric.

As regards the decision to close Bradwell the published statement states.

On 1 December (1999) it was announced that Bradwell is to cease generation in March 2002, the year of its 40th birthday'.

The decision follows a study, which concludes that a multi-million pound financial injection needed to keep the station operating to 2012 is not justified.

While it is technically feasible to operate Bradwell up to its 50th birthday, work has shown that a substantial investment would be required to make Bradwell economically viable for that further period of operation. This investment would give an acceptable business return only if the station operated for the full ten years, and if income from electricity sales could be maintained very close to current levels.

There will be no broader consequences for BNFL's Magnox Generation business. The two oldest power stations, Calder Hall and Chapelcross, have already satisfactorily conducted a Periodic Safety Review to cover operation for up to 50 years. Other stations will be reviewed as they approach 40 years old.

5.13.2 BRITISH ENERGY

5.13.2.1 BRITISH ENERGY NUCLEAR POWER PLANTS (communication with M E Johnson 25 January 2000)

STATION	START	ACCOUNTING LIFE	LF%	Cumulative Generation (MWh)
Hinkley Point B1	*1/4/76*	*35years (2011)*	*67.1*	*97005164*
Hinkley Point B2			64.0	95058391
Hunterson B1	*1/4/76*	*35years (2011)*	*65.7*	*97490246*
Hunterston B2			63.7	90215065
Dungeness B1	1/4/83	25years (2008)	31.6	33830079
Dungeness B2			35.1	32117329
Hartlepool 1	1/4/84	30years (2014)	54.4	57167829
Hartlepool 2			59.2	58161000
Heysham A1	1/4/84	30years (2014)	56.5	59655485
Heysham A2	1/4/88	35years (2023)	60.0	58999547
Heysham B1		35years (2023	71.2	56182583
Heysham B2			69.4	53445976
Torness 1	1/4/88	35years (2023)	70.5	56537974
Torness 2			71.7	54270955
Sizewell B	1/4/95	40years (2035)	81.1	59279794

Table 17: Performance of UK British Nuclear Power Plants

(Ref. 4) Italicised print indicates plants > 20 years old

5.13.2.2. PLANT LIFE MANAGEMENT IN BRITISH ENERGY

(Communication with ME Johnson January 2000 and Sept 2001)
Additional References: Proceedings of Nuclear Plant Life Management, 17-19 November 1998, Warrington:
i)"Experience Gained in Carrying out Periodic Safety Reviews of British Energy's Nuclear Power Stations", PJ Banks and AS Mills
ii)"Lifetime Management: The British Energy Model", SMB Wilmshurst

PLIM + PLEX 99, 3rd – 5th November 1999, Madrid:
I)*"The British Energy Approach to Lifetime Extension of its Nuclear Power Plants", PJ Banks*

Within British Energy Plant Life Extension is a commercially driven exercise. The term `lifetime' usually means the period over which the plant can reasonably be expected to continue to operate

safely and economically. This lifetime is reflected in the accounting life of the station. The accounting life determines the annual depreciation of the plant and the payments made to the segregated fund for decommissioning. By extending the accounting life both of these are reduced, a further benefit from Life Extension is the increase in net present value of the station arising from the extra generation expected during the extended period of operation.

In order to provide a justification for extending the accounting life of a station, all potentially life-limiting areas are assessed for their ability to achieve the target lifetime (which is normally set at 5 years beyond the existing accounting life); this is done within British Energy by conducting Lifetime Reviews. A component is potentially life limiting if the ageing of it could result in the inability to make a safety case, or for which the economic considerations necessary to enable continued operation become prohibitive. In general the commercial benefits of Lifetime Extension are such that it is the former that are of greatest concern; the main emphasis of the Lifetime Review is therefore on the nuclear plant for which rising dose rates, inaccessibility or engineering difficulties may make repair, replacement or refurbishment impracticable. Conventional plant is also reviewed, however, to ensure that replacements/refurbishments necessary to achieve an extended life are not too costly.

Since the process is a commercial one, Lifetime Reviews must determine whether the station can realistically achieve the target life. This means that assessments maybe performed on a best estimate basis, and that there is scope for applying expert judgement. It may be that a component will require a revision to its safety case in order for it to achieve extended life. It is not necessary that this be made at the time Life Extension is claimed, but rather that it can be achieved when required. It is therefore necessary that a credible strategy for revising the case be presented at the time of Lifetime Extension. Given the judgmental nature of many of the assessments, and the financial significance in gaining Life Extension, the Lifetime Review process is independently peer reviewed by senior staff from another company within the nuclear industry.

Once Life Extension is claimed, it is clear that all issues identified through the Lifetime Review as necessary to achieve the new accounting life must be addressed. This is achieved by establishing Lifetime Management Groups (LMGs) at the stations. The LMG members are staff concerned with each plant system, finance, outage management, and the central engineering division. Where possible, staff from sister stations attend to share practices and experiences on common issues. The management of lifetime issues is through the Lifetime Management Plan, which is reviewed periodically and enables work to be fed into station business plans when appropriate.

The Periodic Safety Review is a regulator (the Nuclear Installations Inspectorate) driven process. The requirement to undertake them is a condition of the nuclear site licence (Licence Condition 15). The role of PSR is to underwrite safe operation (i.e. the safety case) for a further period of 10 years. This demands that three key areas are considered: Review of operating history; comparison of the

safety case against current standards and; review of the effects of ageing and degradation. The PSR reviews all areas of the safety case, and in order to underwrite its validity for a further 10 years it necessarily applies a level of conservatism.

To satisfy the regulator that operation can continue to be safe, the PSR will define a programme of work that must be completed to an agreed timescale. This programme is managed by the central engineering division; tasks are then carried out by specific project groups. It should be emphasised, however, that PSR is a necessary but not sufficient condition to guarantee safe operation for a further 10 years; it will also be necessary to maintain safety cases for that period, and to justify re-starting the reactor after each three yearly statutory outage.

There are clear distinctions between the approaches of the two projects. Most notably that Life Extension considers the remaining life of the station and assesses the plant on a best estimate basis, whereas PSR considers a 10-year period and applies conservatisms.

Nonetheless, both exercises are concerned with the same plant and in practice the Lifetime Review will draw on work carried out for the PSR, and extend the conclusions on a best estimate basis to the end of life. It should be noted, however, that for the PSR it may be acceptable to show that if a component fails, the reactor can be shut down safely, whereas for the Lifetime Review we need to demonstrate that it will not result in station closure. Thus, for Lifetime Review, it may be necessary to develop contingency plans, such as repair or replacement techniques.

Plant Life Extension is a commercial exercise and, other than the normal financial rules affecting how Life Extensions can be claimed, there are no regulations defining the process. The Regulator is, however, kept fully informed with developments in this area.

However, PSR is a regulatory requirement. Further than this the position is less explicit; there is a requirement on the licensee to demonstrate a safety case, it is clearly prudent that ageing of the safety case is properly managed.

6 CONCLUDING COMMENTS

This is a survey of Plant Life Management in European 'nuclear' countries. It is obvious that there are large political constraints to nuclear power in Germany and in Sweden where the overriding concerns has been to do with the future NPP closure policies. In this context 'plant operational life' is constrained by political rather than technical, economic or safety factors. The current approach in Europe seems to be negatively based on prejudice rather than the utilisation of facilities to support the needs of a developing European society in terms of energy and care for the environment. Electricity consumption is increasing in Europe and some of the existing generating plant will need to be replaced in the relatively near term. In some countries consideration will have to be given to future fuels-other than fossil

In France it is evident that the construction programme has decreased markedly since the peak plant operational starts of 1981. The French PLIM programme is a highly co-ordinated extensive effort aimed at efficient utilisation of resources and experience having good communication with improvements in monitoring as central features.

The UK has the oldest plants and is decommissioning two and BNFL has announced the closure of a third. There is obviously much experience in plant life management and the UK contribution demonstrates an evolutionary approach of building on experience.

Nowadays in PLIM any additional costs for these activities will have to be weighed against the impact on the cost and price of electricity.

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Ref. 2: 'Pocket World in Figures', The Economist- 2002 Edition.

Ref. 3: Nuclear Engineering International, Feb.2002 and August 2001 for French Figures

Ref. 4: Tsujikura et al, 'Assuring a 60 year lifetime for Mihama 1' Nuc Eng Int. Dec.1999.

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