Unclassified **NEA/SEN/NDC(2000)6**

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

OLIS : 02-May-2000
Dist. : 03-May-2000

English text only

OECD OCDE PARIS

NEA/SEN/NDC(2000)6
Unclassified

NUCLEAR ENERGY AGENCY
COMMITTEE FOR TECHNICAL AND ECONOMIC STUDIES ON NUCLEAR ENERGY DEVELOPMENT AND FUEL CYCLE

STATUS REPORT ON NUCLEAR POWER PLANT LIFE MANAGEMENT

prepared by the Expert Group on Nuclear Power Plant Life Management

English text only

90566

Document complet disponible sur OLIS dans son format d'origine
Complete document available on OLIS in its original format

COMMITTEE FOR TECHNICAL AND ECONOMIC STUDIES ON NUCLEAR ENERGY DEVELOPMENT AND THE FUEL CYCLE (NDC)

The Committee for Technical and Economic Studies on Nuclear Energy and the Fuel Cycle, known as the Nuclear Development Committee (NDC), was established in 1977, initially with the aim of analysing the resources that would be needed for future exploitation of nuclear energy. The Mandate of the NDC currently defines the following areas of interest:

- Assessment of the potential future contribution of nuclear energy to overall energy demand.
- Assessment of demand and supply for the different phases of the nuclear fuel cycle.
- Review of the technical and economic characteristics of nuclear energy growth and of the nuclear fuel cycle.
- Evaluation of the technical and economic consequences of the various strategies for the nuclear fuel cycle.

Participation in the NDC is restricted to Members of the NEA. In recent years, however, the ad hoc groups that undertake most of the Programme of Work have included experts from Russia and other non-OECD countries of Central and Eastern Europe, Latin America, and Asia.

FOREWORD

Electric utilities may consider provisions to properly maintain and preserve the existing base of electricity generation to the extent practicable, taking into account growing demand, the limits of energy conservation, and difficulties to find new sites. Generally, nuclear power plant life extension is an attractive option for utilities to supply electricity, as the marginal cost of most existing nuclear power plants is lower than almost all other sources. Consequently, nuclear power plant life management (PLIM) has become an important issue in the context of the regulatory reform of the electricity market.

The NEA provides an opportunity for international exchange of information on strategic and economic handling of nuclear plant life management for governments and plant owners. The Expert Group on nuclear power plant life management held its first meeting in 1991. Members have discussed various types of information over many years.

The main objective of this report is to provide a summary of the current status of industry programmes and government policies for nuclear power plant life management in OECD Member countries. Such data will facilitate discussion on maintaining nuclear power viability in the immediate future through improved plant life management.

TABLE OF CONTENTS

I. INTRODUCTION

Background

At the end of 1998, there were 345 nuclear power plants connected to the grid within OECD Member countries, representing a total capacity of 292 GWe and generating some 24% of the electricity produced by these countries. One third of these nuclear power plants have been in operation for over 20 years. These operating nuclear power plants represent a significant energy source that utilities and governments cannot overlook in present and future decision-makings.

Most plant owners would like to keep existing nuclear power plants in operation as long as they can continue to function safely and economically. In the late 1980s, when competition in electricity supply was becoming harder and the capital cost of new nuclear plants so much higher than, for instance, combined cycle gas turbine plants, the life extension option seemed particularly desirable. The current difficulties in finding new sites for nuclear power plants, and in some countries for almost any type of new power plant, only add to its desirability. The preservation of nuclear capacity derives added attraction in the light of the wish to avoid disturbing economic growth that can be generated by over-reliance on outside energy suppliers, as was the case in the 1970s, and of newer concerns to avoid increased dependence on power sources emitting carbon dioxide and other atmospheric pollutants.

All these considerations are fed back into governments' policies on medium and long-term energy supply. Consequently, governments are also concerned about the reality of the life extension option. There can be challenges to this reality owing to technical, regulatory and economic factors and, perhaps more importantly so, to the interplay of these factors.

A number of safety studies at company, national and international level contribute to the recognition and control of degradation mechanisms. The Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) provide a forum for exploring what, if any, are the technical factors that will limit component and plant life. They also provide fora for discussion of the procedures for licensing older plants in the context of updated regulations.

On the other hand, we have already, in reality, observed a number of early shutdowns of nuclear power plants and the attributed reasons were severer economic competition and the uncertain future expenditure.

In Member countries where nuclear power is a significant component of energy supply, governments may have an interest in helping to develop efficient procedures for plant life management. Exchange of experience, transfer of lessons between different countries could help to reduce uncertainties, point to the scale of effort needed and what types of efforts are most useful, and generally add to the solidity of understanding the future course of nuclear energy.

Past NEA activities

The NEA provides an opportunity for international exchange of information on strategic and economic handling of nuclear plant life management for governments and plant owners. The Expert Group on nuclear power plant life management held its first meeting in 1991. Members have discussed various types of information over many years. An international common ageing terminology for nuclear power plant life management (OECD 1999a) in five languages (English, French, German, Spanish and Russian), based on the work of EPRI (EPRI 1993), was completed in co-operation with the IAEA and the European

Commission (EC), to improve the common understanding of the terminology of ageing phenomena, facilitate the reporting of relevant plant failure data, and promote uniform interpretations of standards and regulations that address ageing. A study on Refurbishment Costs of Nuclear Power Plants presents refurbishment cost data derived from experience and plans to implement PLIM programmes in ten OECD countries (Belgium, Canada, Czech Republic, Finland, France, Hungary, Mexico, the Netherlands, Spain, and the United Kingdom) (NDC 1999).

Also, the NEA has activities relevant to life management, organised by specialised standing committees, the Committee on the Safety of Nuclear Installations (CSNI) and the Committee on Nuclear Regulatory Activities (CNRA). In general, the emphases of the OECD/NEA safety programme are related to safety research, and do not consider economic aspects.

Other relevant activities

The IAEA has established projects on Nuclear Plant Life Management and on Safety Aspects of Nuclear Power Plant Ageing. These projects have produced a wealth of information by organising specialist meeting, preparing technical publications on related topics and arranging co-ordinated research programmes. The IAEA has produced a series of guidance documents on ageing management, from a safety viewpoint.

There have been a series of PLIM/PLEX conferences organised by Nuclear Engineering International (NEI 1995, 1997, 1999). The proceedings of these conferences contain much information, but do not attempt to synthesise or summarise it.

Objectives and scope

The main objective of this report is to provide a summary of the current status of industry programmes and government policies for nuclear power plant life management in OECD Member countries. Such data will facilitate discussion on maintaining nuclear power viability in the immediate future through improved plant life management. Technical and safety issues have not been considered in detail.

Most of the information on which this report is based was obtained through a questionnaire circulated to OECD Member countries. The following countries have responded to the questionnaire and/or provided information to the Secretariat: Belgium, Canada, Czech Republic, Finland, France, Germany, Hungary, Japan, Korea, Netherlands, Spain, Sweden, United Kingdom, and the United States. These responses are contained in Annex 2. The main body of the report aims at synthesising this information, which includes technical, economic, safety, environmental, public and political, and organisational considerations.

II. CURRENT STATUS OF NUCLEAR POWER PLANT LIFE MANAGEMENT

A. Definition, objectives, scope, and strategy

Nuclear power plant life management (PLIM) has been defined as an integration of ageing management and economic planning to: (a) optimise the operation, maintenance, and service life of the system, structure, and components (SSCs); (b) maintain an acceptable level of performance and safety; and (c) maximise return on investment over the service life of the plant (EPRI, 1992, OECD 1999a).

Earlier, plant life management was referred to as plant life extension (PLEX). This was the revision of the original design life by reviewing actual service condition and ageing phenomena and improving maintenance. The economics of plant life management have become an important aspect in competitive electricity markets. Plant life management is now defined in a broader manner (see above) and also includes acting to reduce occupational exposure and amounts of waste and to increase capacity.

In most countries, electricity generating stations including nuclear are owned and operated in the private sector. The decision on when and whether or not to retire a generating unit is therefore usually the responsibility of the industry.

Most plant owners would like to keep existing nuclear power plants in operation as long as they can continue to function safely and economically. In the late 1980s, when competition in electricity supply was becoming harder and the capital cost of new nuclear plants became much higher than other options such as combined cycle gas turbine plants, the availability of the life extension option seemed particularly desirable.

A plant life management programme typically includes the following elements:

- Strategy and objectives.
- Economic analysis.
- Critical items.
- External influences evaluation.
- Schedule.
- Maintenance strategy.
- Research and development.
- Industry-wide initiatives and collaboration.

Strategy and objectives of a plant life management programme are provided to facilitate the design of the programme. Objectives to be considered include:

a) Economy
   - Maximising the profit
   - Reducing the costs including operation, maintenance, and waste management
   - Increasing the load factor

b) Safety
   - Maintaining/increasing safety and reliability level of a plant.
   - Protecting the environment and the public.
   - Reducing occupational exposure.
   - Managing risk and uncertainty (e.g. unexpected technical degradation or changes).

c) Others
- Modernising/upgrading a plant
- Enhancing public acceptance

Objectives differ from plant owner to plant owner. Table 1 shows some examples of objectives of plant life management.

Some plant owners adopt a two-step strategy:

First step: Maintaining the safety of a plant during original design life or license period.
Second step: Operating a plant for its optimum lifetime beyond original design life or license period.

B. Background for Plant Life Management (PLIM)

1. Growing electricity demand

The demand for electricity throughout OECD Member countries has continued to grow steadily and there are no signs of its diminishing in the foreseeable future as shown in Figure 1. Over the next decade, electricity capacity in Member countries is expected to grow at a rate of about 1.4% per year in order to keep up with demand (OECD 1999b). Electricity's share in final energy consumption throughout the world is also projected to increase. For example, in the OECD Member countries, electricity is expected to increase its share of the final energy consumption from 18.7% in 1995 to 23.5% by 2020 (OECD 1998a). Although the projected rate of growth in electricity demand varies from nation to nation and region to region, it is clear to all countries that efficient, safe, and economical electricity production, distribution, and consumption is vital to continued economic growth, competition in world markets, and to rising standard of living and quality of life.

Figure 1. **Estimates of total electricity generation and capacity in OECD** (OECD 1999b)

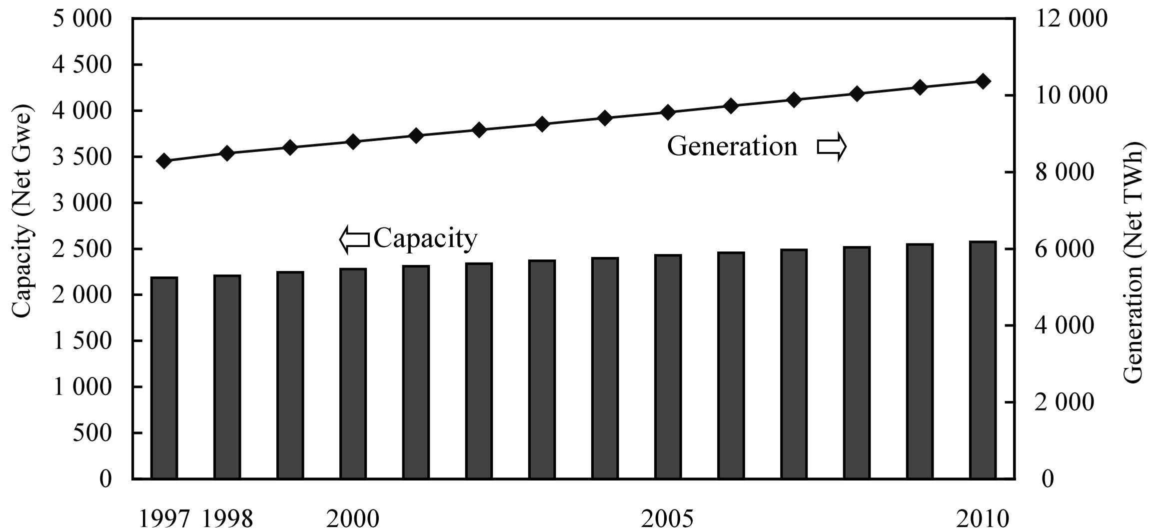


Table 1. **Examples of objectives of plant life management.**

	Economy	Safety	Others
Belgium	Capability of plants. Increasing the load factor and decreasing the total operational cost.	Safe operation. Protection of the environment and the people including the management of liquid and solid wastes and the workers dosimetry.	Reduction of the degradation rate of the equipment. The acceptance by the public.
Canada (Shalaby, NEI, 1997)	To maintain the long-term reliability and safety of CANDU NPPs during design life (life assurance). To maintain the long-term availability and capacity factors of these plants with controlled and reasonable generating costs during the normal design life (life assurance). To "avoid surprise" through identification of potential ageing issues, ahead of its occurrence and provide means for monitoring and mitigation to ensure reliable component performance. To preserve option of extending the life of current CANDU 6 plants with good safety and availability at reasonable costs, beyond the nominal design life of 30 years, up to 50 years or more (life extension).		
Czech Republic	To protect the capital investment by maximising the availability and extension of the design lifetime.	To maintain the safety level required by the IAEA mission and audits.	Modernisation programme.
Finland	Maintain the present availability of NPPs with reasonable operation costs.	Continuous safety improvement programme according to the PSA-results, operation experiences and research results including the international cooperation.	Olkiluoto NPP targets to a permanent lifetime during operation years and Loviisa NPP has stated a planned lifetime over 45 years.
Germany	Reduction of maintenance cost. Reduction of operating cost. Reduction of cost for waste management.	Man-rem-reduction. Increase of safety and reliability.	Optimised operation. Plant life extension. Reduction of amount of waste.

Table 1. **Examples of objectives of plant life management (continued).**

	Economy	Safety	Others
Hungary	To provide the long-term operation of the high-value or critical components of the plant with an economically optimal standard and in compliance with the safety requirements. To avoid unexpected malfunctions and operation failures with severe consequences. To allow the plant to operate beyond 30 years, even if main component replacement is necessary.		
Japan (ICON-7, 1997)		To develop measures against ageing degradation and establish the methods of evaluating the integrity of long-term operation.	
Korea	Basic objectives: Economic operation of nuclear power plants by enhancing plant safety, integrity, and performance. The first goal: Safe plant operation to the original design life. The second goal: Safe plant operation to the optimum life beyond the design life.		
Spain	Strategic objective To extend the life cycle of nuclear power plants maintaining their levels of safety and efficiency. Current objectives To monitor and control the ageing of important components to guarantee a life cycle of 40 years. To keep the possibility of extending beyond 40 years technically prepared and open.		
Sweden	Improved operation and maintenance. Energy production capability.	Design reconstitute. Additional safety improvement. Primary system integrity. Reduction of effluents. Dose reduction.	
United States	To ensure that current nuclear plants can continue to deliver adequate and affordable energy supplies up to and beyond their initial 40 year license period by developing technology to manage the long-term effects of plant ageing, and to improve overall plant reliability and productivity.		

2. Limitations of conservation and site availability

Both energy conservation measures and the construction of new power production capacity can help to ease the tightness on demand and supply. However, both also have limitations on the amount of "capacity" which they can supply and the speed with which the infrastructure and new capacity can be established. Few new nuclear power plants are expected except in Japan, Korea, and Turkey. New sites for all types of electricity generation are becoming increasingly difficult to locate and acquire. This is due not only to a diminishing availability of sites which can support the technical requirements of a power plant (e.g. cooling water, transmission line access, environmental impact acceptability, etc.) but also simply to increased public resistance to new industrial facilities as a whole, the so called NIMBY syndrome (Not IN My BackYard).

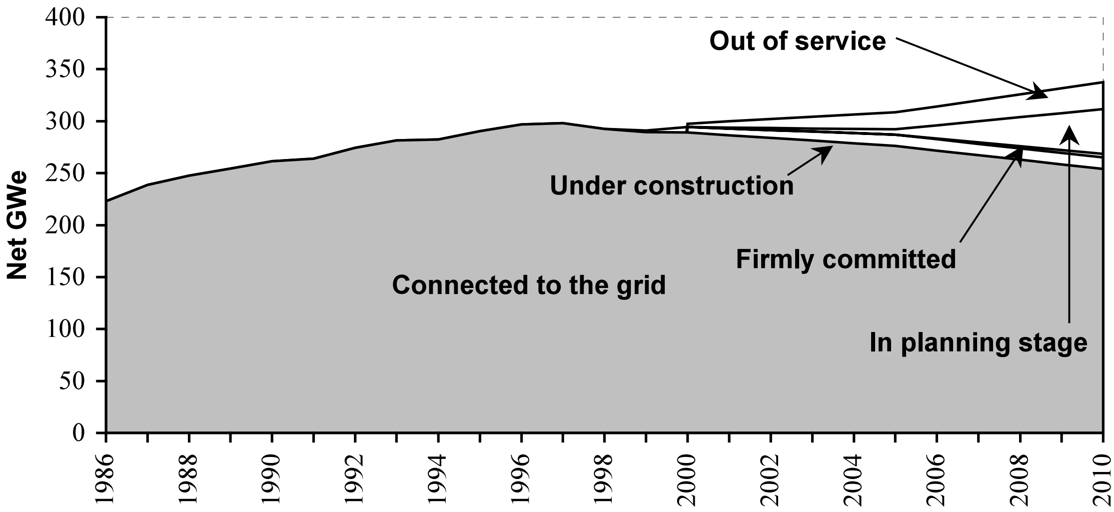
3. Nuclear power plant retirements

At the end of 1998, there were 345 nuclear power plants connected to the grid within OECD Member countries, representing a total capacity of 292 GWe and generating some 24% of the electricity produced by these countries. One third of these nuclear power plants have been in operation for over 20 years. Up to the year 2015, 85 nuclear power plants with total net capacity of 48 GWe representing 16% of the present total net nuclear capacity, are scheduled to be taken out of service in OECD Member countries. Most of those are planned to retire before each lifetime reaches 40 years.

To extend the lifetime of these nuclear power plants is equivalent to constructing new plants. If the lifetime of these nuclear power plants is not extended the security and diversity of energy supply will be reduced. Also, life time extension affects economy and the environment. Nuclear programmes offset the equivalent of about 10 million barrels of oil per day, which is equivalent to the output from Saudi Arabia and Kuwait, and avoid the emission of 1200 million tonnes of carbon dioxide equivalent to 11% of total emissions in OECD Member countries. The generating costs of depreciated nuclear power plants are generally lower than almost other sources. (see Sections D and F)

Figure 2 shows the projected installed capacity in OECD, taking into account construction and retirement.

Figure 2. **Installed nuclear capacity projections in the OECD area (OECD 1999b)**



C. Technology

1. Critical items

Generally, “critical” and “non-critical” items are determined using a screening methodology normally specific to the technical and regulatory requirements of the plant (see Figure 3).

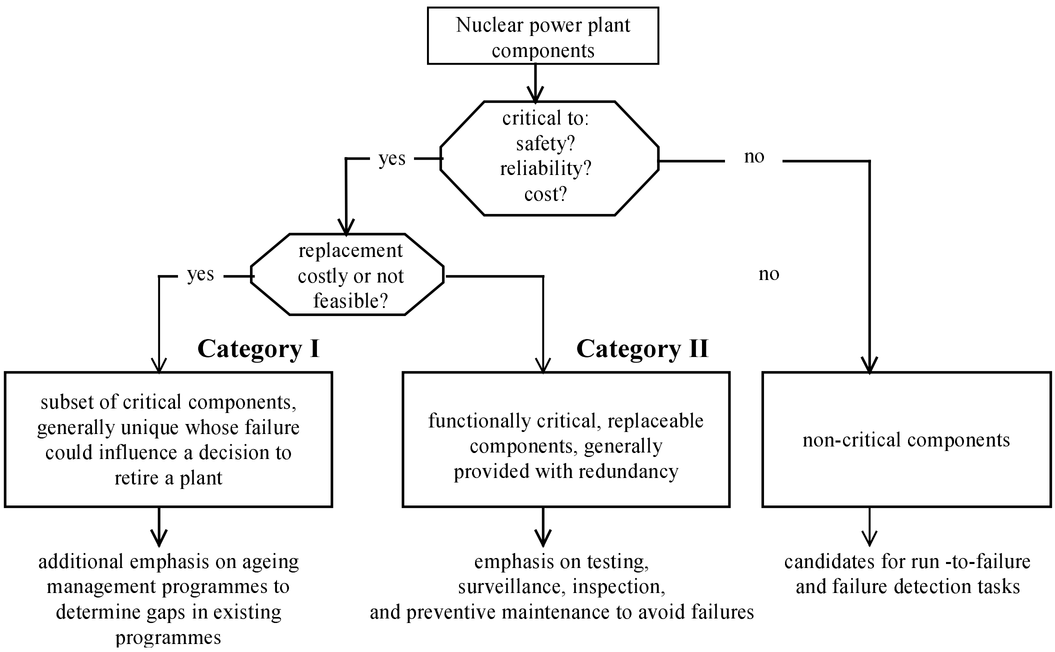
The critical items to safety, reliability, or cost of plant operation are classified into: “Category I”, that is not replaceable technically or costly; and “Category II”, that is replaceable economically. Category I is a subset of critical systems, generally unique, whose failure could influence a decision to retire a plant. Plant owners put additional emphasis on ageing management programmes to determine gaps in existing programmes. Category II is a subset of functionally critical, replaceable systems, generally provided with redundancy. Plant owners put emphasis on testing, surveillance, inspection, and preventive maintenance to avoid failure.

For most PWRs, the parts classified under Category I are: reactor pressure vessel, vessel internals, pressuriser, steam generators, main primary pipes, main primary pump, containment, cable, and concrete structures.

For most BWRs, the parts classified under Category I are: reactor pressure vessel, vessel internals, main primary pipes, recirculation pump, containment, cable, and concrete structures.

In Canada, the criteria as critical are (1) non-replaceable and (2) replaceable but costly in terms of capital expenditures (> 50 M$) and outage time requirements (> 6 months).

Figure 3. **Component categories for plant life management**



Certain systems are not critical to safety, reliability, or cost of plant operation. These “non-critical systems” are not given priority over “critical systems” and candidates for run-to-failure and failure detection tasks when the plant life management programme is established. The maintenance of “non-critical systems” is optimised taking into account ageing management practice for critical systems.

Thanks to research and development, and experience feedback, maintenance and replacement can now technically manage ageing of these critical SSCs. Even ageing of the reactor pressure vessel could, in principle, be managed by annealing.

In France, although 18 components were considered as critical earlier because they were irreplaceable or require large-scale repair or replacement, nowadays only the reactor vessel and reactor building containment are considered as critical. All other have been considered as replaceable or possibly replaceable.

In the United States, some operating plants may exceed the pressurised thermal shock screening criteria of NRC’s requirement for assessing RPV embrittlement during a 20-year license renewal term. An indirect gas-fired furnace heating technology was demonstrated to establish a viable annealing option by the Department of Energy.

One critical system consists of many components, such as pipes and tubes, supports, valves, pumps, motors, nuts and bolts, and welding point. Plant owners identify components within critical systems by carefully reviewing maintenance rules, final safety analysis reports, and accident, incident, and trouble database.

It is inefficient to establish programmes for all components individually. Based on a review of the structure, material, and operation environment, components can be categorised into different groups. It is efficient to establish maintenance programmes for representative components selected for each group and taking into account operational conditions and capacity.

Representative components in Category I are those which should be the subject of research or specific studies in the case of a plant lifetime management programme. For each of them, the necessary action is taken to ensure safety and availability up to the end of the life of the unit.

2. Maintenance strategy

The primary role of maintenance is to allow nuclear operators to use all functions necessary for a safe and economic production, by ensuring that they are available and reliable. A second, but almost as important goal, is to achieve this at the lowest possible cost. The maintenance choices have to be balanced to optimise equipment reliability and maintenance workload in nuclear plants.

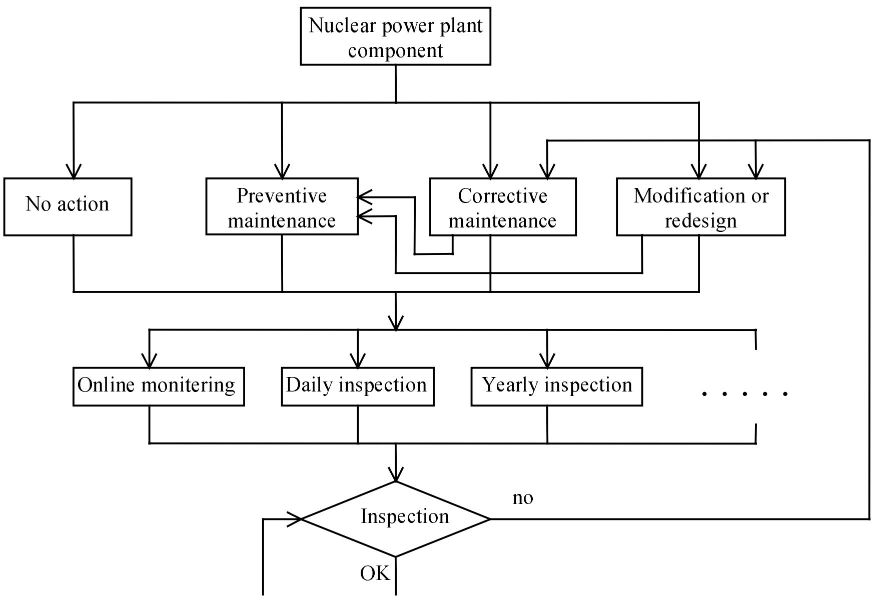
Although existing maintenance is sufficient from a technical viewpoint, modification may be better from an economic viewpoint, especially if performance is improved in the process. The maintenance strategy for each equipment in the plant consists (NEI, 1997) of a combination of:

a) no action;
b) preventive maintenance;
c) corrective maintenance;
d) modification of systems and plant; and
e) inspection.

The expected net present value of each possible maintenance strategy (see Figure 4) can be calculated from revenue and cost including operation, maintenance and fuel.

Reliability centred maintenance is quite a new technique to optimise maintenance with increased use of operating experience and probabilistic/risk considerations. Reliability data are easiest to obtain in those countries with standardised nuclear programmes. In these countries standardisation could become a weakness if problems are not anticipated early enough.

Figure 4. **Possible maintenance strategies.**



3. Research and development

In order to know long-term equipment behaviour, develop new measures, and verify them, the nuclear industry has been carrying out extensive research and development related to plant ageing. It is the owner/operator who has prime responsibility for acquiring the information, and undertaking research and analyses needed to support decisions affecting his investment. In some cases, however, the pursuit of research may not be cost-effective on a single plant basis. In cases where the research is generically applicable to many plants in the country, governments may play a role in co-ordinating and supporting industry initiatives. A key element of national framework for plant life management is the development of suitable industry-government co-ordination mechanisms. Organisation of research and development activities is described in section H. International co-ordinated research work funded by EU, IAEA, etc. play an important role for guidance on complex questions.

Research and development activities cover management guidelines, safety regulation and industry standards, and technical aspects.

Management guidelines: Detailed and generic technical evaluations of ageing mechanisms and management strategies for systems, structures and components important to plant life management are useful for all plant owners. The United States Department of Energy co-ordinated and sponsored the ageing management guidelines in co-operation with the industry and national laboratories for some equipment groups. It has published nine ageing management guidelines on various components of nuclear power plants.

Safety regulation and industrial standards: Safety regulation and industrial standards necessarily include margins and conservatisms, reflecting uncertainties and an allowance for unknown factors. Although these conservatisms may be reduced in the light of increased operating experience and new research results, sufficient resources must be available to do this. In addition there is a move away from the traditionally deterministically based safety cases to a so-called “risk informed” approach. This change is partly driven by the increased economic pressure on the industry. In this context, there is a possible difference of interest between the regulator who wishes to use such a change to increase safety at constant resources, and the operator, who wishes to decreases the resources applied, at constant safety.

Technical research and developments: While the integrity of aged nuclear power plants can be maintained by the present technology, it is important to continue efforts of technology development in order to conduct more reliable management. The development themes are roughly classified into the following four areas:

- Preventive and corrective maintenance, such as water chemistry control, reactor pressure vessel annealing, and core internal replacement.
- Ageing and degradation mechanisms and evaluation, such as irradiation embrittlement, wear, corrosion/erosion, fatigue, and stress corrosion.
- Monitoring, surveillance, and inspection, such as fatigue monitoring and non-destructive testing.
- Optimisation of maintenance, for example using risk based analysis.

4. Technical support and suppliers

One business factor is technical support by manufacturers, fuel companies, and construction companies. Nuclear power plant owners have a significant but limited influence on these companies. Plant owners may have difficulties to keep a technical base and skilled workers. It is a matter for debate whether plant life management can keep nuclear technology alive in the era of few or no new plants constructed.

The acquisition of equipment, components, and spare parts is a constant activity throughout the life of a nuclear power plant. However, the declining nuclear market in the world has made this activity more difficult. Some suppliers abandoned the component replacing. For example, in Spain, spare parts have been standardised as much as possible. Commercial-grade components in the replacement process of safety-related components can be used after the technical evaluation.

There are concerns also from a regulatory point of view about the maintenance of knowledge and knowledgeable personnel, with the closure of research facilities, the reduction in staff numbers under increasing economic pressure and the lack of new construction. These issues have been considered, for example, by the NEA Committee on Nuclear Regulatory Activities (CNRA 1999c).

5. Waste management and decommissioning

As mentioned in Section A, nuclear power plant life management includes reducing amounts of waste. Nuclear power plant owners endeavour to reduce costs of waste management. Life extension reduces the amount of decommissioning waste per kilowatt-hour. Moreover, plant life extension can delay decommissioning thus giving time to develop better technology and reducing the net present value of decommissioning costs.

D. Economics

1. Cost analysis

Nuclear power plant lifetimes are, for the most part, driven by cost and revenue consideration. In most cases, the decision to continue operating an existing plant is based upon its marginal generation cost, i.e., operation, maintenance and fuel cycle cost, and amortisation of the investment required for lifetime extension if applicable, as compared with the marginal generation costs of other options. The marginal cost is lower for existing nuclear power plants than for most alternatives. Therefore, lifetime extension generally is an attractive option from an economic viewpoint.

Deregulation of electricity market is increasing competition and eliminating monopolies and guaranteed sales at fixed rates. Therefore, nuclear power plant owners endeavour to reduce the cost of plant life management.

The choice between plant life management and building a new power plant, fossil-fuelled or nuclear, is influenced also by the size of the investment which is smaller for refurbishment than for a new construction. The refurbishment cost of major components (steam generators, etc.) are in the order of tens to a few hundred million US dollars per net GWe capacity (NDC, 1999) but these costs are relatively small compared to new plant investment.

Nuclear power plant life management brings additional benefits in term of electricity cost, and price, stability since fuel cycle costs represent only a small share (typically around 20%) of total generation costs, and are not as volatile as gas prices for example.

Figure 5 illustrates generating costs of nuclear and coal power built in 1976 and gas power built in 2006, based on the assumptions given in Table 2. The assumptions were made taking into account cost data provided by OECD Member countries. After amortisation, generating costs consists of operation, maintenance, and fuel costs. The marginal generating cost of an existing power plant, that is equal to the generating cost of a depreciated power plant, is lower for nuclear units, which have very low fuel cost (0.004 USD/kWh), than for gas or coal units (for gas-fired power plants, fuel cost is 0.025 USD/kWh). Generating costs of gas-fired power plants heavily depend on the fuel cost. The cost of a large refurbishment, 300 million USD/GWe, of a nuclear power plant increases its generating costs during the amortisation period but these costs remain lower than those of gas and coal fired plants. Figure 5 also shows the fuel and operation and maintenance cost range in 1994-96 in the United States, for reference.

An economic analysis for decision-making on plant life management, providing minimal maintenance or retiring, requires developing a set of competing scenarios and then testing them against such impacts as higher than foreseen operation and maintenance costs through the use of sensitivity studies. The options are illustrated in Figure 6. The net present value (NPV) of different scenarios and operating lifetimes is used to compare scenarios and also to optimise lifetime (Shalaby, in NEI 1997). Scenarios include various costs, including future operation and maintenance, fuel, capital cost, and assumptions such as capacity factors and major equipment failures. These involve some degree of uncertainty. Each scenario is compared with the base case and tested by a sensitivity analysis. A long-term business plan is desired, but short-term cash flow is also important for management in some cases, as a small electric company cannot afford the short-term cost of raising funds for a long-term business plan. The choice is determined by the best scenario for both the long and short term. Some examples of the scenario approach are given below.

Figure 5. **Generating costs of nuclear and coal power built in 1976 and gas power in 2006.**

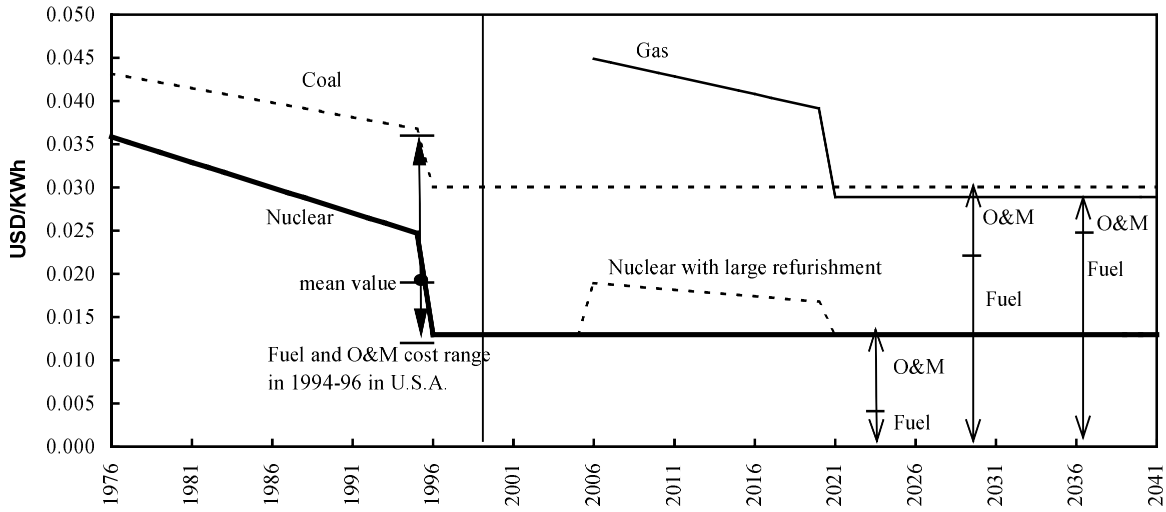


Table 2. **Assumptions adopted in the generating cost calculations.**

	Nuclear	**Coal**	**Gas**
Investment at 1976 (a)	1 540 USD/kWe	880 USD/kWe	
Investment at 2006 (b)			880 USD/kWe
Amortisation period	20 years	20 years	15 years
Refurbishment at 2006 (c)	300 USD/kWe		
Interest rate	5%	5%	5%
Load Factor	75%	75%	75%
Thermal Efficiency	34%	34%	52%
O & M cost (b, d)	58.6 USD/kWe/year	52.5 USD/kWe/year	27.0 USD/kWe/year
Coal & Gas cost (b)		2.09 USD/Gjoule	3.58 USD/Gjoule
Uranium cost (b)	50.2 USD/kg		
Enrichment cost (b)	103.8 USD/SWU		
Fabrication cost (b)	310.5 USD/kg		

(a) Average in OECD countries in 1981(OECD 1983); it is assumed that the investment was the same in 1976.
(b) Average in OECD countries (OECD 1998b).
(c) Assumed large refurbishment costs 300 USD/kWe (NDC 1999) and amortisation period is 15 years.
(d) The data of power plants expected to be commercially available by 2005-2010 (OECD 1998b).

In Belgium, before deciding to replace the steam generators of Doel 3, several strategies were investigated: immediate replacement of the steam generators; no repairs (plugging of degraded tubes to delay the replacement while minimising the maintenance costs); repair of degraded tubes; and repair of degraded tubes combined with preventive actions to extend as far as possible the lifetime of the steam generators.

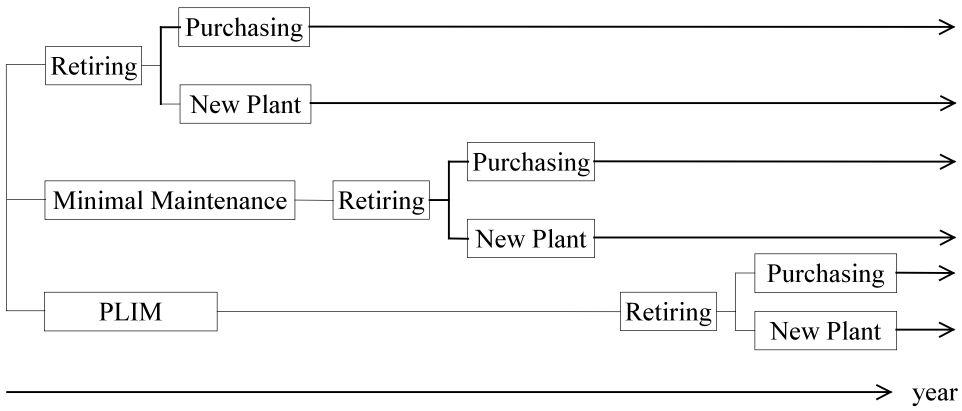
In the Czech Republic, life extension of two VVER 440/230 units was compared with the construction of new combined cycle gas units 3 x 300 MWe. The internal rate of return of the life extension of the VVERs was much higher.

In Japan, the Central Research Institute of Electric Power Industry (CRIEPI) developed an economic evaluation system for costs of counter measures of ageing degradation, for example increasing maintenance cost, capacity improved by large-scale refurbishment, and maintenance schedule. This system also has the following functions:

- optimising the refurbishment schedule of large components taking into account the estimated curve of degradation and the cost of counter measures; and
- comparing the costs of reconstruction and life extension, including capital, operational, and fuel costs (CRIEPI, 1995).

In the United States, the EPRI Nuclear Options Model calculates the value of a nuclear power plant in a deregulated electricity market and provides management guidance for license renewal or early shutdown.

Figure 6. **Set of scenarios**



2. Economic regulation

Nuclear plant revenues are heavily influenced by governmental economic regulation (rate setting or liberalisation of electricity market). Generally speaking, economic regulatory bodies are independent of both safety regulatory bodies and the organisation for promotion of plant life management. No economic regulatory policy specific to nuclear plant ageing, life management or life extension exists. However, economic regulation decides the life of nuclear power plants in some cases, as shown by the following examples.

In the Netherlands, eventual investments should have been bounded by the decision that for a fixed lifetime of 10 years the total kWh cost may not exceed 8 ct/kWh which is comparable with the generating cost of gas fired plants. In the meantime, the Dutch government decided to limit the operation license to 2004 and to compensate EPZ and SEP financially. In 1996, the Dutch Utility Board decided to take the demonstration BWR of 56 MWe out of service in 1997 on economical grounds.

In the United States, the Energy Policy Act of 1992 requires electric utilities to select the least-costly way to meet electricity demand. Some nuclear power plants were shut down, for example, because of the availability of cheap electricity from hydropower in Canada. The United States electric utility industry is undergoing a major restructuring due to deregulation of the industry. At present, some uncertainty remains associated with this restructuring because the regulations and the implementing processes in some States have not been finalised.

E. Safety

1. Term of licence

Governmental regulatory policies on nuclear plant safety exert a significant influence on operating and maintenance costs, as well as on the capital additions needed to comply with evolving safety standards. Safety regulation policy for PLIM differs from country to country, and may be roughly grouped into two categories according to whether or not a country has legislation dealing with the term and the renewal of the licence of the nuclear power plants (CEC 1990, OECD 1992, see Table 3).

Table 3. **Term of operating licence of nuclear power plant**

Limited term	Unlimited term with periodic safety review
Canada (0.5-3 years) Finland (10-20 (a) years) Hungary (12 years) Korea (b) Unites States (40 years)	Belgium (10 years) France (10 years) Germany (10 years) Japan (10 years) Sweden (8-10 years) United Kingdom (10 years)

(a) 20 years includes a periodic safety review after 10 years.
(b) Korea is in the process of establishing a rule.

i) Limited term of licence

In the United States, the term of license is limited. The Atomic Energy Act of 1954, as amended, limits the initial operating licenses of nuclear power plants to 40 years and allows their renewal. The initial 40-year license term was selected on the basis of economic and antitrust considerations. It is not based on safety, technical, or environmental limitations. In December 1991, the U.S. NRC issued the rule and associated documentation that describe the requirements a licensee must be able to demonstrate for the NRC to make a determination that the plant can continue to be operated for up to 20 additional years beyond the expiration of its 40-year license. The NRC issued an amendment to the license renewal rule that became effective June 7, 1995. The amendment to the rule is expected to provide a more stable and predictable regulatory process for license renewal by focusing the license renewal process on the management of long-term effects of ageing on passive systems, structures, and components during the period of extended operation. In a separate rulemaking, the NRC revised the scope of the agency’s environmental review process for reactor license renewal. The final revised rule became effective on September 5, 1996. The NRC has begun to develop regulatory guidance and standard review plans for license renewal. These plans are not expected to be finalised until after the first few applicants have gone through the process. The first license renewal application was submitted by Baltimore Gas and Electric Company in April 1998 for its two-unit Calvert Cliffs nuclear power plant, and was under review as of the end of 1999.

In Canada, the initial term of an operating licence issued by the Atomic Energy Control Board (AECB) is generally a year. There is no specific provision about the term or the renewal of the licence either in the Atomic Energy Control Act or in the Atomic Energy Control Regulations. They are at the discretion of the AECB. The term of the renewed operating licence is generally from six months to two or three years.

ii) Unlimited term of licence

Some countries have no specific regulations of the lifetime of nuclear power plant. Electric utilities can operate their nuclear power plants as long as they can continue to function safely. However in these cases electric utilities have to perform periodic safety reviews.

In Japan, the government accepted the technical evaluation that assumed 60-year operation and long-term maintenance programmes by electric utilities under the condition that the programmes ensure quality assurance including software compatibility, transferring technical base, and maintaining skilled workers.

2. Consistent policies

All policies and regulations should be consistent. Some countries have the generic method to ensure it. Leading plant approach and advance application are means unique to plant life management carried for long time.

i) Leading plant approach

Vintages of nuclear power plants differ. When the regulation and management is established for one of the oldest plants, the other plants can follow this regulation and management. This is known as the leading plant approach.

Japan is taking a leading plant approach. At first, three lead plants were selected. The technical evaluation of the major components/structures of these plants and the basic concept for dealing with the aged plants is considered to be phase one. In the second phase, the utilities conduct a detailed technical assessment of integrity on each component and structure including replaceable components, which is followed by government reviews. Upon completion of phase two, the identified important factors will be reflected in the long-term maintenance programme of the utilities and in the periodical inspections conducted by the government. The comprehensive long-term maintenance of the aged plants has been made in public on 8 February 1999. After that, the same programmes will be conducted at the other plants one by one.

In the United States, the Department of Energy in co-operation with industry completed Pilot Plant and Lead Plant License Renewal Demonstration programmes. The Pilot Plants were Monticello BWR and Surry PWR, while the Lead Plants were Monticello BWR and Yankee Rowe PWR. None of these demonstrations resulted in a license renewal application submittal to the Nuclear Regulatory Commission. However, much valuable experience was gained and transferred to Calvert Cliffs and Oconee license renewal applications submittals.

ii) Advance application

If the license renewal applications were to be reviewed just before the expiration date, electric utilities would have large uncertainties. In the United States, plant owners may apply to renew the license after the plant has completed 20 years of operation. This gives plant owners up to 20 years prior to expiration of the initial license to apply for license renewal.

iii) Standard review plan

Standard review plans are not unique to plant life management, but they are a generic method to ensure consistency of safety regulation. In the United States, the NRC has begun to develop regulatory guidance and standard review plans for license renewal. These plans are not expected to be finalised until after the first few applicants have gone through the process.

iv) Discussions between regulator and industry

Before regulations and guidelines are issued, discussions between regulator and industry are carried out in many countries in order to provide information on future regulation. These discussions are encouraged to be open. In some countries, the public and electric utilities have a chance to give comments to the government during a legal procedure.

F. Environment

1. Environmental regulation

Environmental regulatory policy is not unique to nuclear plant ageing, life management, or life extension. Competitive markets ignore some externalities, such as carbon dioxide emission from power plants. This prevents from economic competition for nuclear power that is more favourable than fossil fuel plants from the point of view of carbon dioxide.

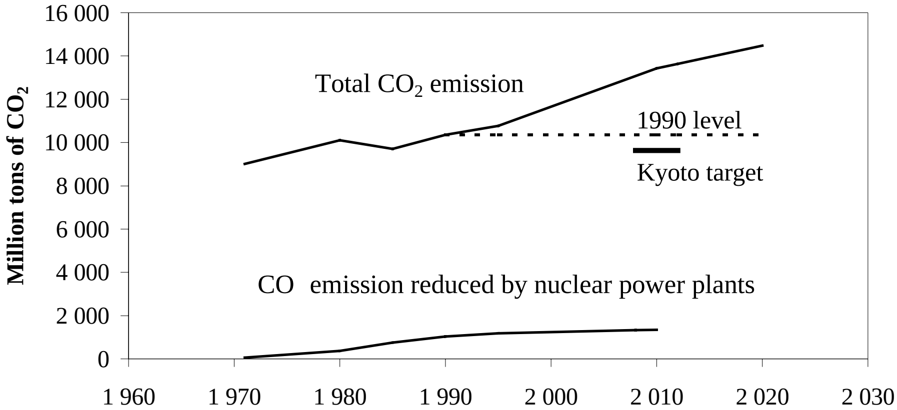
The preservation of nuclear capacity, in particular by plant life management, derives added attraction in the light of recent concerns to avoid increased dependence on power sources emitting carbon dioxide and other atmospheric pollutants. Emissions of sulphur dioxide, nitrogen oxides, and particulate matter from nuclear power plants are much less than those from fossil fuelled power plants. Nuclear power plants have been one of the factors that reduce the use of oil, gas, and coal for electrical generation and hence carbon dioxide emissions and environmental pollution (see Figure 7).

2. Future prospects – greenhouse gas considerations

Retirement of nuclear power plants without replacement by a carbon free generating source will increase the emission of carbon dioxide. In December 1997, in Kyoto, Japan, the Third Conference of the Parties to the United Nation Framework Convention on Climate Change established an international commitment to reduce greenhouse gas emissions. For example, European countries, Japan, and the United States shall reduce their emissions by 8%, 6%, and 7%, respectively, below 1990 levels, in the commitment period 2008 to 2012. Nuclear power plant life management could help these countries meeting their commitments.

Figure 7. **Total CO_2 emission and CO_2 emission reduction due to nuclear power plants in OECD**

(OECD 1998a, EC 1998)



G. Public acceptance and political decisions

1. Public acceptance

In most countries the public is not directly involved in decisions concerning the lifetime of nuclear plants. Nevertheless, public acceptance is indispensable to implement plant life management projects. Over the years, the public has taken an increasing part in the decision making process for nuclear electricity generation. A number of international experts feel that public attitudes toward ageing nuclear power plants will be key in terms of gaining acceptance for continued or extended operation. Where the constitution allows for referenda, there may be direct public involvement.

Public concerns include whether the safety levels of the plant are deteriorating with time or the level of uncertainty in safety is rising with time. The norms for acceptable levels of safety may also change with time as technology advances. The overall economics, the local economic impacts including employment and tax revenue of the local government, and the relative competitiveness of existing nuclear plants may also raise concerns in the local government, the public, and opinion leaders. Finally, the relative environmental impacts for continued operation versus replacement power options is important to public acceptance.

In general, there is an extensive record keeping, environmental monitoring, and performance tracking over the life of a nuclear power plant. Existing plants represent a well-known commodity as compared with new plants or alternative forms of energy production. Furthermore, the availability of existing nuclear capacity to be placed on line may be known with greater certainty than the availability of new projects.

Strategies for plant owners to get public acceptance include provisions for ensuring that the safety issues are transparent and that the solutions are readily understandable to the local community and opinion leaders, with an open dialogue; and pro-active public information feature, such as the provision by plant owners of visitor centres, information sheets, brochures, videos, and Internet homepages, to the media and the public.

No government has a specific programme to get public acceptance for plant life management. However, there are relevant examples of approaches taken by some countries.

In Finland, the public is not directly involved in the decisions concerning PLIM. However, 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.

In Japan, the Ministry of International Trade and Industry demonstrates the reliability of reactor internals replacement methods to get public acceptance. This project covers six replacement methods for in-core monitoring housing (BWR), core shroud (BWR), control rod drive housing and stub tube (BWR), jet pump riser brace (BWR), core internals (PWR) and bottom mounted instrumentation adapter (PWR).

In the United Kingdom, the Nuclear Installations Inspectorate has a commitment to answer all letters from members of the public.

In the United States, generally, all regulation changes are open to public comment prior to final issuance. Public participation can also occur through public hearings at the local, state or federal level. The License Renewal Rule also provides the opportunity for public hearing during the license renewal application regulatory review and approval process.

2. Phase-out decisions and referenda

In some countries, there have been government decisions to stop the continued operation of nuclear power plants or to curtail their lives. Political decision of phasing out an existing nuclear power plant threatens nuclear power plant owners even if their plants are safe and economical.

Examples are:

a) Austria (shutdown of Zwentendorf after referendum).

b) Switzerland (waste disposal facilities referenda).

c) Italy (moratorium after TMI as a result of referendum).

d) Sweden, the parliament decided in 1981 to phase out nuclear power by the year 2010. In February 1998, the government decided that Barsebäck Kraft AB was to close down Barsebäck 1 by 1 July 1998. This decision was based on the 1997 Act of the phasing-out of nuclear power. Following an appeal against this decision the Supreme Administrative Court ordered a postponement of the implementation of the decision until legal procedure has been completed. No final decision had been taken by the Court by the end of 1998. The plant was shut down by the end of 1999.

H. Organisation nationally

1. R&D organisation

It is the owner/operator who has prime responsibility for acquiring the information, research and analyses needed to support decisions affecting his investment. In certain cases, however, the pursuit of research may not be cost-effective on a single plant basis. In cases where the research is generically applicable to many plants in the nation, governments may play a role in co-ordinating and supporting industry initiatives. A key element of national framework for plant life management is the development of suitable industry-governmental co-ordination mechanisms.

Co-ordination mechanisms may be classified into the following four categories by sponsorship and topic selection system.

i) Full government initiative

Governments conduct research and developments on the topics that they have selected. Research and developments to establish and confirm safety regulation and standard generally belong to this category. Research and development on the main components critical to nuclear plant life, for example reactor pressure vessels, are conducted by some governments.

In Finland, 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 sub-task groups offer a good forum for national co-operation.

ii) Government sponsorship of industry

Governments conduct research and developments in compliance with the wishes of industry. Research and developments that are difficult technically and financially for industry to conduct are carried out by some governments.

In Japan, the government has carried out research and development to demonstrate the reliability of nuclear power technology, including reactor internal replacement method. It was selected by the government from the topics suggested by the industry (see section on public acceptance).

iii) Government-industry partnership

Research and development programmes are co-ordinated and co-sponsored by governments and industry. Topic selection is also co-ordinated by governments and industry. Duplication in research and development can be reduced in this way. Examples are:

a) The UK system for safety research.

b) The United States Department of Energy (DOE) Nuclear Energy Plant Optimisation (NEPO) is a co-operative with industry. The DOE has developed a joint strategic research and development plan with Electric Power Research Institute (EPRI) to address the issues which may prevent continued operation of current nuclear power plants. Industry will provide a minimum of 50 % cost share for research and development conducted under NEPO.

iv) Industry initiative

Owners groups, associations of electric utilities, and individual utilities have conducted research and developments for their own needs. Although the research and development information belonging to private companies is difficult to exchange for commercial reasons, such exchange is encouraged to avoid duplication.

2. Joint utilities organisations & owners groups

The industry has established and co-ordinated joint programmes to manage policy and regulatory issues, to develop new management tools, and to carry out research in order to resolve plant life issues. Most commonly, these take the form of owners groups although broader or narrower pacts can be made.

In the United States, the Nuclear Energy Institute (NEI) co-ordinates the efforts of all utilities licensed by the NRC to construct or operate nuclear power plants in all matters involving generic regulatory policy issues and the regulatory aspects of generic operational and technical issues. The Electric Power Research Institute is the main electric utility research co-ordination organisation which performs collaborative research for its member utilities on topics including plant life management. The Owners Groups, which are classified by reactor vendor, perform generic evaluations that can be shared by a number of utilities, submit the resulting Topical Report, generic License Renewal Application, etc., to the NRC, and work with the NRC to obtain its concurrence and/or approval.

Japan has similar organisations as the United States. The Federation of Electric Power Companies and the Central Research Institute of Electric Power Industry (CRIEPI) co-ordinate policy and regulatory issues and research activities, respectively.

At an international level, industry co-operation is arranged through WANO.

3. Governmental activities

As nuclear power plant life management may bring economic benefits, increase the diversity of energy supply, and reduce carbon dioxide emissions and other environmental impacts, some governments are taking initiatives to support the nuclear industry PLIM programmes. There can be challenges to PLIM owing to technical, regulatory and economic factors and, perhaps more importantly so, to the interplay of these factors. There have been a number of early shutdowns of nuclear power plants due to severer economic competition and the uncertainties on future expenditure. Some governments may have an interest in helping to develop efficient procedures for plant life management. These considerations may form part of government policies on medium and long-term energy supplies.

Nuclear power plant life management may help to lower costs and prices, and to stabilise electricity rates. In a competitive market, most existing nuclear power plants are expected to be a price leader because their marginal cost are lower than those of almost all other sources, as shown in Figure 5. In a regulated market, most depreciated nuclear power plants brings lower electricity rate because the generating cost of most depreciated nuclear power plants, that is equivalent to the marginal cost of an existing nuclear power plant, is lower than almost all other sources. Nuclear fuel price is robust against oil price disruption and the share of nuclear fuel cost in the total cost is lower than almost all other sources, so the generating cost of a nuclear power plant is stable, and this has a stabilising effect on overall electricity rate.

The preservation of nuclear capacity derives added attraction in the light of the wish to avoid disturbing economic growth that can be generated by over-reliance on outside suppliers, as was the case in the 1970s. Unaffected by oil supply disruptions, nuclear power fuel supply is a relatively more predictable resource. There is a current surplus of uranium on the world market and known uranium resources are expected to last well into the next century or even beyond with nuclear fuel recycling. Nuclear programmes offset the equivalent of about 10 million barrels of oil per day in OECD Member countries. This is equivalent to the output from Saudi Arabia and Kuwait.

Nuclear power plants are more favourable than fossil fuel plants from the point of view of carbon dioxide and environmental pollution. Retirement of nuclear power plants without replacement by a carbon free generating source will increase the emission of carbon dioxide and make it difficult to achieve the commitment of Kyoto Protocol. In 1995, nuclear power plants reduced carbon dioxide emissions in OECD countries by 1200 million tonnes, i.e., by 11% of total emissions. Emissions of sulphur dioxide, nitrogen oxides, and particulate matter from nuclear power plants are insignificant in comparison with those from fossil fuelled power plants.

No country has an organisation that both regulates and promotes nuclear power plants since these two functions shall be independent. Some countries have promotional government organisations. Examples of organisations responsible for plant life management are:

a) In France, Electricité de France (EDF), a state-owned electric utility, is the single organisation that co-ordinates all activities of plant life management except safety regulation.

b) In Japan, the Ministry of International Trade and Industry that is responsible for safety regulation of nuclear power plants established the policy for plant life management in 1996, and has conducted research and development since 1983.

c) In Spain, life extension of nuclear power plants is considered an important alternative in the *Plan Energético Nacional 1991-2000* (National Energy Plan, NEP), the Spanish energy policy for the current decade defined by the Government.

d) In the United States, the Department of Energy (DOE) has a long-term strategy (Comprehensive National Energy Strategy, 1998) to improve the reliability and performance of the nuclear power plants (more than 100), in order to help meeting the Nation's future electrical needs more efficiently. DOE promotes plant life management by supporting R&D on age-related degradation of materials, and on developing technologies to improve and optimise the operation and output of the existing plants. National and private laboratories perform government and industry sponsored research tasks. The Nuclear Regulatory Commission is responsible for safety regulation.

I. Inter-governmental organisations

Exchange of experience and transfer of lessons learnt between different countries can help to reduce uncertainties, point to the scale of effort needed and what types of efforts are most useful, and generally add to the understanding of the future course of nuclear energy. Ageing experience has been accumulated world-wide since the beginning of commercial nuclear power in the 1950s. Although there are differences in the fine details from plant to plant and country to country, there are also some strong similarities in nuclear hardware and design. Major vendors such as Westinghouse, Framatome and Mitsubishi provide one such example due to similarities in their origins. Furthermore, the physical processes which determine ageing (erosion, corrosion, fatigue, embrittlement, etc.) are universal in nature. They affect valves, pumps, pipes, motors, alike and in all types of generating stations. Together, these facts suggest that many of the technical issues relating to safety, plant ageing and decommissioning are closely parallel, if not identical, across national borders. International comparisons may also be extremely useful in illustrating the institutional differences that affect nuclear power decision making and economics. Inter-governmental programmes in the area of plant ageing and life cycle management are arranged through the OECD Nuclear Energy Agency (NEA), CEC, and the International Atomic Energy Agency (IAEA). These co-operate with the industry organisation WANO as appropriate.

A number of safety studies at company, national and international level contribute to the recognition and control of degradation mechanisms. The NEA and the IAEA provide fora for exploring what, if any, are the technical factors that will limit component and plant life and for discussion of the procedures for licensing older plants in the context of updated regulations.

1. OECD Nuclear Energy Agency

The NEA provides an opportunity for international exchange of information on strategic and economic handling of nuclear plant life management for governments and plant owners. The Expert Group on nuclear power plant life management held its first meeting in 1991. Members have discussed various types of information. To date, seven meetings have been held. At the 6th meeting, the 1997 workshop on nuclear power plant life management, various papers on economic, technical and regulatory aspects of nuclear power plant life management were presented and discussed.

As the service life of operating nuclear power plants increases, potential misunderstanding of the terminology of ageing degradation of systems, structures, or components (SSCs) is receiving more attention. An international common ageing terminology for nuclear power plant life management (OECD 1999a) in five languages (English, French, German, Spanish and Russian), based on the work of EPRI (EPRI 1993), was completed in co-operation with the IAEA and the European Commission (EC), to improve the common understanding of the terminology of ageing phenomena, facilitate the reporting of relevant plant failure data, and promote uniform interpretations of standards and regulations that address ageing.

A study on Refurbishment Costs of Nuclear Power Plants was completed with the issuing of a working document early in 1999. This document presents refurbishment cost data derived from experience and plans to implement PLIM programmes in ten OECD countries (Belgium, Canada, Czech Republic, Finland, France, Hungary, Mexico, the Netherlands, Spain, and the United Kingdom). The cost data are presented in summarised form on a country-by-country basis and they are analysed on per a unit, per net capacity (MWe) and per component basis. Whenever possible, the cost data are separated into periodic and non-periodic costs. These two types of costs are considered to be the components of the overall reported cost.

The NEA also has activities relevant to life management, organised by specialised standing committees, the Committee on the Safety of Nuclear Installations (CSNI) and the Committee on Nuclear Regulatory Activities (CNRA). In general, the emphases of the OECD/NEA safety programme are related to safety research, and do not consider economic aspects. The CSNI is made up of senior scientists and engineers, with broad responsibilities for safety technology and research programmes. The relevant technical field of nuclear reactor safety interest for which the CSNI has designated a specific Principal Working Group (PWG3) is Integrity of Components and Structures. This has sub groups on the integrity of metal components and structures, the ageing of concrete structures (especially containment) and the seismic behaviour of structures. The mandate of the group was changed recently to give an overall emphasis on ageing. The groups work closely with other international organisations as appropriate, such as IAEA, EC, WANO, FIB and RILEM.

PWG3 has issued in recent years a number of reports relevant to life management or ageing (CSNI 95a,b, 97, 98a,b, OECD 96,97) and is currently preparing a technical position document for plant life management, providing a technical basis of long-term operation. Although seismic re-evaluation of old plant affects life management, it is not so clear that ageing is a technical problem for the seismic aspects, and the seismic sub group is currently discussing this topic.

The CNRA has also considered relevant topics from the regulatory point of view. These include periodic safety reviews, the safety case for ageing plants, and regulatory aspects of ageing reactors (CNRA 1999a,b).

Although not specifically addressed at life management problems, probabilistic methods are increasingly used for this purpose. PWG3 has considered probabilistic aspects of structural integrity (CSBI 1996), and CNRA has considered regulatory aspects of probabilistic safety assessment (PSA) (CNRA 1995, 1997).

2. International Atomic Energy Agency

The IAEA has established projects on Nuclear Plant Life Management in the Division of Nuclear Power (NENP) and on Safety Aspects of Nuclear Power Plant Ageing in the Division of Nuclear Installation Safety. In the Division of NENP the International Working Group on Life Management of Nuclear Power Plants carries out its activities within the IAEA Project A2.03 “Nuclear Power Plant Life Management”. Activities under this project have produced a wealth of information by organising specialists meeting, preparing technical publications on related topics and arranging co-ordinated research programmes with good results. The most recent development is the International Database on NPP Life Management. This is a multi-module Database, the first of which is called the International Database on Reactor Pressure Vessel (RPV) Materials which was completed last year. After the specification of the Database on RPV materials had been completed the IAEA developed a software and called for international participation. In 1998, the IAEA collected and analysed information on costs of safety upgrades necessary for continued operation of a nuclear unit, costs of lifetime extension measures and costs of decommissioning. The study which focuses on reactors of Soviet design was published in 1999 (IAEA 1999a).

In the Division of Nuclear Safety, activities on safety aspects of NPP ageing was initiated in 1985 to increase awareness of the emerging safety issue relating to physical ageing of plant systems, structures and components (SSCs). In 1989, a systematic project was launched to assist Member States in understanding ageing of SSCs important to safety and in effective ageing management of these SSCs aimed at ensuring the availability of required safety functions throughout plant service life. This project integrates information on the evaluation and management of safety aspects of NPP ageing generated by Member States into a common knowledge base, and derives guidance and assists Member States in the application of this guidance. Main results of the project are documented in References. They fall into three groups.

a) *Awareness.* Following up on the first International Conference on Safety Aspects of Ageing and Maintenance of Nuclear Power Plants (IAEA 1988), which was organised by the IAEA in 1987, increased awareness of physical ageing of SSCs and its potential safety impact was achieved by the development and wide dissemination in 1990 of an IAEA-TECDOC on Safety Aspect of Nuclear Power Plant Ageing (IAEA 1990). While in the 1980s most people believed that classical maintenance programmes were adequate for dealing with the ageing of nuclear plants, in the 1990s the need for ageing and life management of nuclear power plants became widely recognised.

b) *Programmatic Guidelines.* The following programmatic guidance reports have been developed using experience of Member States:

- Data Collection and Record Keeping for the Management of Nuclear Power Plant Ageing (IAEA 1991) provides information on the baseline, operating and maintenance data needed and a system for data collection and record keeping.

- Methodology for the Management of Ageing of Nuclear Power Plant Components Important to Safety (IAEA 1992) gives guidance on screening SSCs to make effective use of limited resources and on performing ageing management studies to identify or develop effective ageing management actions for the selected components.

- Implementation and Review of Nuclear Power Plant Ageing Management Programmes (IAEA 1999b) provides information on the systematic ageing management process and an organisational model for its implementation (see Figure 8).

- Guidelines for Ageing Management Assessment Teams (IAEA 1999c) is a reference document for the implementation of one of the Engineering Safety Review Services and for utility self-assessments; these reviews can be programmatic or problem oriented.

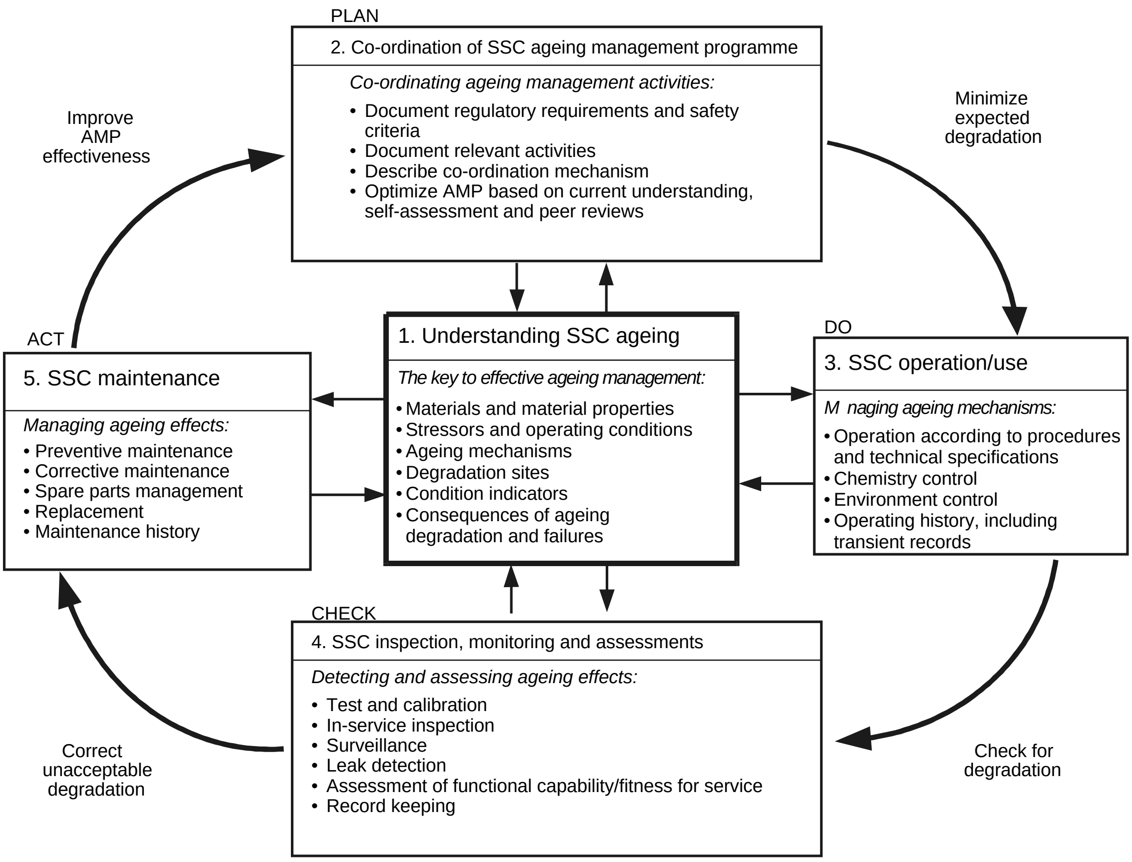
c) *Component specific guidelines.* The guidance of Methodology for the Management of Ageing of Nuclear Power Plant Components Important to Safety has been used to implement Co-ordinated Research Projects (CRPs) on management of ageing of concrete containment buildings and in-containment instrumentation and control cables, and to develop comprehensive technical documents on assessment and management of ageing of major nuclear power plant components important to safety. Comprehensive reports on steam generators (IAEA 1997), concrete containment buildings (IAEA 1998a) and CANDU pressure tubes (IAEA 1998b) have been issued and six are being prepared for additional major components.

The focus of the project has progressively shifted from developing awareness, to preparing first programmatic, and then component specific guidelines. In the future, the focus will be on providing services to assist Member States in the application of the guidelines. A reduced effort will be maintained to facilitate information exchange through the preparation of additional guidelines and the updating of existing guidelines.

3. European Commission (CEC)

The CEC in its 5th Framework Programme (1999-2002) for research has an increased emphasis on ageing aspects of nuclear power (CEC 1999).

Figure 8. **Deming's Plan-Act-Do-Check cycle, from IAEA Safety Report No. 15**



III. SUMMARY AND CONCLUSION

Electric utilities may consider provisions to properly maintain and preserve the existing base of electricity generation to the extent practicable, taking into account growing demand, the limits of energy conservation, and difficulties to find new sites. Generally, nuclear power plant life extension is an attractive option for utilities to supply electricity, as the marginal cost of most existing nuclear power plants is lower than almost all other sources. Consequently, nuclear power plant life management (PLIM) has become an important issue in the context of the regulatory reform of the electricity market.

The present report provides a summary of the current status of industry programmes and government policies for nuclear power plant life management in OECD Member countries. Such data will facilitate discussion on maintaining nuclear power viability in the immediate future through improved plant life management.

Nuclear power plant life management has been defined as an integration of ageing management and economic planning to:

(1) optimise the operation, maintenance, and service life of system, structure, and components;
(2) maintain an acceptable level of performance and safety; and
(3) maximise return on investment over the service life of the plant.

The following systems, structures, and components (SSCs) that are important to safety and irreplaceable or require large-scale repair or replacement are considered as critical to plant life management: reactor pressure vessel, vessel internals, main primary pipes and pump, containment, cables, concrete structures, pressuriser, steam generators (PWR), and primary loop recirculation pump (BWR). Plant life management considers all SSCs, not just the critical ones. As a result of past research, maintenance and replacement can now technically manage ageing of these critical SSCs. Technical support by manufacturers, fuel companies, and construction companies is a concern for PLIM.

The safety regulation approach to ageing varies between countries. Some countries have established safety regulations for ageing of nuclear power plants. There are generic methods to make regulation consistent and reduce regulatory risk for plant owners, such as the leading plant approach, advance application and standard review plans. One government accepted technical evaluation that assumed 60 years operation, another is considering to renew the licence another 20 years (total 60 years).

The marginal cost is lower for most existing nuclear power plants than for almost all other sources. Refurbishment costs are relatively small compared with new investments. The ongoing regulatory reform of the electricity market will bring increasing competition. There have already been a number of early shutdowns of nuclear power plants due to severe economic competition. Hydro power plants and combined cycle gas turbine plants are powerful competitors. Plant owners endeavour to minimise the total sum of future operation and maintenance costs and capital additions for all necessary future refurbishment. Economic optimisation of all SSCs and activities is ready.

Nuclear power plants are more favourable than fossil fuel plants from the point of view of carbon dioxide emissions and could help achieving the commitment of the Kyoto Protocol. Emissions of sulphur dioxide, nitrogen oxides, and particulate matter from nuclear power plants are insignificant in comparison with those from fossil fuelled power plants.

Although economic and environmental regulatory policy does not apply only to nuclear plant ageing, life management, or life extension, but to all forms of power generation, its effect on nuclear plants can be significant.

Public acceptance by the local community has become a key to continued and extended operation. Plant owners provide information to the local community. Legal and political factors also affect plant life management, and these vary between countries. In some countries, there have been government decisions to discontinue the operation of nuclear power plants or to curtail their lives. Experience shows that the cost of such a shut down may make the implementation difficult.

Industry has carried out research and development in order to resolve technical plant life issues. It has developed new management tools both independently and jointly, acting most commonly in the form of owners groups. Plant owners have established the technical management programmes and industry guidelines for preparing license procedures. Some of them have been approved by the regulatory authority, others are still under review.

Nuclear power plant life management brings the economic benefit not only to the plant owners in competitive markets, but also economic and environmental benefits to other stakeholders through a low and stable electricity price, and reduced carbon dioxide emissions and other environmental impacts. Some governments are taking initiatives to support the nuclear power plant life management industry programmes. These are policies and strategies for the promotion of plant life management. Some governments provide industry-government co-ordination mechanisms for research and development of plant life management. There are benefits of having standardised plant designs and of sharing the costs and the knowledge over a larger base of utilities.

International efforts in the area of plant ageing and life cycle management may be inter-governmentally organised (e.g., OECD/NEA, CEC, IAEA), industry-based (e.g., WANO), or a combination of the two. As the physical processes are universal in nature and there are some similarities in nuclear plant design, international comparisons and sharing the data are useful.

REFERENCES

CEC (1990), *PSRs in NPPs in EC Member States*, Finland and Sweden, EUR 13056EN.
CEC (1998), *Annual Energy Review*.
CEC (1999), *JRC-Euratom work programme (1999-2002)*, Commission decision of 16 April 1999, E/99/468 – C(99)881; C(99)881/2.

CNRA 1995, NEA/CNRA/R(95)2, *Regulatory Approaches to PSA – Survey of National Practices*.
CNRA 1997, NEA/CNRA/R(97)5, *Review Procedures & Criteria for Regulatory Applications of PSA*.
CNRA 1999a, NEA/CNRA/R(99)1, *Regulatory aspects of ageing reactors*.
CNRA 1999b, NEA/CNRA/R(99)2, *Regulatory inspection activities relating to older operating NPPs*.
CNRA 1999c, *Proceedings of CNRA Workshop on Assuring nuclear safety competence into the 21st century*, Budapest, October 1999, to be issued.

CRIEPI (1995), Takeshi Takao, *Development of a Comprehensive Evaluation and Support System for Life Extension of Nuclear Power Plants* (No. 11): Developing a System to Plan Component Repair and Replacement Schedules, CRIEPI Report No. T94063, Tokyo, Japan, 1995.

CSNI 1995a, NEA/CSNI/R(95)17, *International Workshop on Aged and Decommissioned Material Collection and Testing for Structural Integrity Purpose*, Mol, Belgium, 1995.
CSNI 1995b, NEA/CSNI/ R(95)19, *Report of the Task Group reviewing national and international activities in the area of ageing of nuclear power plant concrete structures.*

CSNI 1996, NEA/CSNI/R(96)4, *Workshop on Probabilistic structure integrity analysis and its relationship to deterministic analysis*, Stockholm, Sweden, 1996.
CSNI 1997, NEA/CSNI/R(97)9, *Joint WANO/OECD-NEA Workshop: Prestress loss in NPP containments 1997*, Poitiers, France, 1997.
CSNI 1998a, NEA/CSNI/R(98)5, *Status report on seismic re-evaluation*.
CSNI 1998b, NEA/CSNI/R(98)7, *Survey on organic components in Nuclear Power Plants* (NPPs).

EPRI 1992, *Nuclear Power Plant Common Ageing Terminology*, California, United States.

IAEA (1988), Proceedings of 1987 International Symposium on *Safety Aspects of the Ageing and Maintenance of Nuclear Power Plants*, STI/PUB/759.
IAEA (1990), *Safety Aspects of Nuclear Power Plant Ageing*, IAEA-TECDOC-540.
IAEA (1991), *Data Collection and Record Keeping for the Management of Nuclear Power Plant Ageing*, Safety Series No. 50-P-3.
IAEA (1992), *Methodology for Ageing Management of Nuclear Power Plant Component Important to Safety*, Technical Reports Series No. 338.
IAEA (1997), *Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: Steam Generators*, IAEA-TECDOC-981.
IAEA (1998a), *Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety: Concrete Containment Buildings*, IAEA-TECDOC-1025.
IAEA (1998b), *Assessment and Management of Ageing of Major Nuclear Power Plant Components Important to Safety*: CANDU Pressure Tubes, IAEA-TECDOC-1037.
IAEA (1999a), TECDOC-1084 *Review of selected cost drivers for decisions on continued operation of older nuclear reactors*, Vienna, Austria.
IAEA (1999b), *Implementation and Review of Nuclear Power Plant Ageing Management Programme*, Safety Report Series No. 15.
IAEA (1999c), *Guidelines for Ageing Management Assessment Teams*, IAEA Services Series No. 4.

ICONE-7, 1999, Shin-ichi Kosugiyama, Kimihito Takeuchi, *Plant Life Management Activities of LWR Plants in Japan*, Tokyo, Japan.

NDC 1997, PLIM Workshop of OECD/NEA, Paris, France.
NDC 1999, NEA/NDC/DOC(99)1, *Refurbishment Costs of Nuclear Power Plants* (restricted report).

NEI 1995, PLIM+PLEX 95 Nice, France.
NEI 1997, PLIM+PLEX 97, Prague, Czech Republic.
NEI 1999, PLIM+PLEX 99, Madrid, Spain.

OECD/NEA (1983), *The Cost of Electricity Generation in Nuclear and Coal fired Power Stations*, Paris, France.
OECD/NEA (1992), *The Periodic Safety Review of NPPs*, Paris, France.
OECD/NEA (1996), *Nuclear Safety Research in OECD Countries – Areas of Agreement, Areas for Further Action, Increasing Need for Collaboration*, Paris, France.
OECD/NEA (1997), *Nuclear Safety Research in OECD Countries – Capabilities and Facilities*, Paris, France.
OECD/IEA (1998a), *World Energy Outlook*, Paris, France.
OECD/NEA (1998b), *Projected Costs of Generating Electricity*, Update 1998, Paris, France.
OECD/NEA (1999a), *Glossary of Nuclear Power Plant Ageing*, Paris, France.
OECD/NEA (1999b), *Nuclear Energy Data*, Paris, France.

ACRONYMS

AECB	Atomic Energy Control Board
BWR	Boiling Water Reactor
CANDU	Canadian Deuterium Uranium Reactor
CNRA	Committee on Nuclear Regulatory Activities, OECD/NEA
CRIEPI	Central Research Institute of Electric Power Industry
CSNI	Committee on the Safety of Nuclear Installations, OECD/NEA
EC	European Commission
EDF	Electricité de France
EPRI	Electric Power Research Institute
FIB	Fédération Internationale du Béton
IAEA	International Atomic Energy Agency
NDC	Committee for Technical and Economic Studies on Nuclear Energy Development and Fuel Cycle, OECD/NEA
NEA	Nuclear Energy Agency
NEI	Nuclear Energy Institute
NIMBY	Not IN My Back Yard
NPV	Net Present Value
NRC	Nuclear Regulatory Commission
PLEX	Plant Life Extension
PLIM	Plant Life Management
PWR	Pressurised Water Reactor
RILEM	International Union of Testing and Research Laboratories for Materials and Structures
RPV	Reactor Pressure Vessel
SEP	Samenwerkende Elektriciteits Productiebedrijven (Dutch Utility Board)
SSC	Systems, Structures, or Component
USDOE	United States Department of Energy
WANO	World Association of Nuclear Operators

Annex 1

LIST OF MEMBERS OF THE EXPERT GROUP

BELGIUM	
Mr. Paul HAVARD	ELECTRABEL
Mr. Jean-Claude HENNART	TRACTEBEL
Prof. Philippe MATHIEU (***Chairman***)	Université de Liège
Mr. Pierre STALLAERT	Ministète de l'Emploi et du Travail
Prof. Ir. F. VANMASSENHOVE	Universiteit Gent
Mr. Théo VAN RENTERGEM	Ministère des Affaires économiques
CANADA	
Mr. Tim ANDREEFF	Ontario Hydro
Mrs. Pauline WATSON	Ontario Hydro
CZECH REPUBLIC	
Dr. Jiri ZDÁREK	Nuclear Research Institute, REZ
FINLAND	
Mr. Timo HAAPALEHTO	Ministry of Trade and Industry
Mr. Yrjö HYTÖNEN	Fortum Engineering Ltd
Dr. Rauno RINTAMAA	Valtion Teknillinen Tutkimuskeskus
FRANCE	
Mr. Bruno BARTHELET	Electricité de France
Mr. Dominique LAGARDE	Direction Sûreté Installations Nucléaires
Mr. Robert PLOYART	Centre d'Études Nucléaires de Cadarache
Mr. Pierre SAURIN	FRAMATOME
GERMANY	
Dr. Dieter BROSCHE	BAYERNWERK AG
Mr. Manfred ERVE	Siemens AG
Mr. Christian HILLRICHS	Siemens AG
HUNGARY	
Mr. Sándor RATKAI	PAKS Nuclear Power Plant
JAPAN	
Mr. Masakuni KOYAMA	Japan Engineering & Inspection Corp.
Mr. Tsuyoshi OGAWA	Japanese Delegation to the OECD
Dr. Masahide SUZUKI	Japan Atomic Energy Research Institute
KOREA (REPUBLIC OF)	
Dr. Ill-Seok JEONG	Korea Electric Power Research Institute
NETHERLANDS	
Mr. Rudolf KOOPMAN	NV Electriciteits-Produktiemaatschaapij Zuid-Neder

SPAIN

Mrs. M. Dolores GOMEZ BRICEÑO	Centro de Investigaciones Energéticas Medioambiente
Mr. Martin REGAÑO	NUCLENOR
Mr. Vicente VERDÚ	C.N. ALMARAZ

SWEDEN

Mr. Kjell ELISSON	ABB Atom AB

SWITZERLAND

Dr. J. Peter HOSEMANN	Paul Scherrer Institute

UNITED KINGDOM

Dr. L. Myrddin DAVIES	
Dr. David P. G. LIDBURY	AEA Technology
Dr. Ray D. NICHOLSON	Health & Safety Executive
Dr. Tom Y. STOKOE	BNFL Magnox Generation
Mr. B. TOMKINS	AEA Technology

UNITED STATES OF AMERICA

Mr. Ralph BEEDLE	Nuclear Engineering Institute
Dr. John J. CAREY	Electric Power Research Institute
Dr. John M. CLAUSS	Sandia National Laboratories
Mr. Dennis HARRISON	United States Department of Energy
Dr. John KERRY	United States Department of Energy
Mr. David MUSOLF	Northern States Power Co.
Mr. Charles A. THOMPSON	United States Department of Energy

INTERNATIONAL ORGANISATIONS

INTERNATIONAL ATOMIC ENERGY AGENCY

Mr. Viatcheslav LYSSAKOV	Department of Nuclear Power

COMMISSION OF THE EUROPEAN COMMUNITIES

Mr. Odissefs PANOPOULOS, Brussels	DG XVII – C3 Energy

ORGANISATION DES PRODUCTEURS D'ÉNERGIE NUCLÉAIRE

Mr. Maxime KLEINPETER	

WORLD ASSOCIATION OF NUCLEAR OPERATORS

Mr. René VELLA	Paris Centre

OECD NUCLEAR ENERGY AGENCY

Dr. Hiroshi YAMAGATA (***Secretary***)	Nuclear Development Division
Dr. Alexander Miller	Nuclear Safety Division

Annex 2

COUNTRY REPORTS

The country report section gives an overview, background, and detailed information of nuclear power plant life management in each country. The following indicates the contents of a country report.

Overview

Current situation of nuclear power plants.
Recent changes and progresses in Plant Life Management (PLIM).

Organisation and their responsibility

The main government, industry, and research organisations involved in PLIM.
Their responsibilities.
How to co-ordinate their activities with one another.

Regulatory processes

a) Safety regulation

The current local, state, and federal safety regulators involved in PLIM.
Safety regulation related to PLIM, e.g. licence renewal and periodic safety review.

b) Economic regulation

The current local, state, and federal economic regulators involved in PLIM.
Economic regulation related to and affecting PLIM.

Objectives and strategy

Background, objectives, and strategy of PLIM.

Decision and economic analysis

Economic analysis methodologies developed and/or applied in PLIM.
Decisions made on whether or not to upgrade, backfit, PLIM, and retire.

Programmes

The history and the current status of the various programmes, e.g. PLIM of an individual plant, research and development.

Public acceptance

The nature by which the public participates, determines, or influences PLIM.

Critical components

The methodologies and the criteria developed for selecting critical components.
List of critical components.

BELGIUM

Overview

In 1998, seven nuclear power plants located at two sites, Tihange and Doe1, with a total net capacity of 5.7 GWe, supplied over 55% of all the electric power produced in Belgium. All existing units are equipped with pressurised water reactors (PWRs). Three units were commissioned in the mid-70s and four in the mid-80s. Belgian producers (Electrabel and SPE) have a share (capacity reservation) of 25% of the B1 and B2 units of the French CHOOZ NPP.

The objective of the PLIM project includes the safety, technical and economical aspects of safe operation, the protection of the environment and of the public, the optimum performance of the plant (high availability, high load factors, reduction of operating costs), the reduction of the degradation rate of the equipment and the acceptance by the public.

Organisations and their responsibilities

Plant life management is handled by various organisations and by the Licensing Authorities for nuclear power plants.

The authorisation of operation requests that nuclear power plants must be re-evaluated after each 10-year operation period, in compliance with the safety regulations currently in force. The aim of this *decennial revision* is to perform the following actions:

- comply with the regulatory requirements;
- perform maintenance operations requiring a lengthy shutdown;
- perform important repair or replacement operations, systems and equipment modifications;
- implement modifications resulting from safety re-evaluation since the beginning of industrial operation.

Plant life management is thus integrated in a permanent review process. However, particular concerns are addressed on a specific basis (e.g. potential for cracks in the reactor vessel head). The main organisations involved in this process are listed below.

The Belgian government

The Federal Nuclear Inspection Agency (AFCN) reporting to the Ministry of Interior Affairs

The industry

ELECTRABEL (ELB), a member of the TRACTEBEL Group, is an electric utility that is responsible for operating the plants.

TRACTEBEL Engineering (TBL), a member of the TRACTEBEL Group, is the engineering organisation that is responsible for the design, construction and engineering support to the operation (including periodic safety evaluation) and is in charge of co-ordination within the TRACTEBEL Group and at the national and international levels.

Research organisations responsible for testing

SCK-CEN, Nuclear Research Centre (Mol) and LABORELEC, Research Laboratory of the utilities.

Regulatory processes

Safety regulation

Most of the regulations concerning nuclear installations in Belgium is contained in the Act and Royal Orders of February 1963 for the Protection of the Population and of Workers and its subsequent updates (last update: October 1997).

Two Government departments - one, answerable called the Radiation Protection Service [“Service de Protection contre les Radiations Ionisantes” (SPRI)], and another called the Technical Safety Service for Nuclear Installations [“Service de la Sécurité Technique des Installations Nucléaires” (SSTIN)] – are responsible for the implementation and control of the regulations as well as the operating licences. The Federal Nuclear Inspection Agency (AFCN) has been created, according to the new law of 15 April 1994. AFCN has general responsibility for the inspection and surveillance of nuclear activities in Belgium. SPRI and SSTIN have been incorporated within the AFCN organisation.

Operating licences for nuclear installations are granted by Royal Order, countersigned by the Ministers of Interior Affairs, on the advice of the Special National Committee for Nuclear Safety.

Controls are carried out by private companies which must be non-profit-making, licensed for this purpose by the Government; they are responsible for making safety analyses and they report their conclusions to the Nuclear Safety Committee before operating licences are granted. These companies are also responsible for carrying out all permanent control tasks and for monitoring the activities of operators.

Classified and licensed installations are therefore subject to supervision by licensed control bodies and by the competent authorities.

Operating licenses are granted for an indefinite period, but under the 1963 legislation, Class 1 nuclear installations such as power plants are subject to permanent monitoring in order to ensure the continued safety of such installations and their compliance with any new regulations and standards, and to compare their safety practices with the most advanced techniques. The first units to be built – Doel 1 and 2 and Tihange 1, in 1974 and 1975 – were therefore already reviewed in 1984, and modernisation work were carried out. They have completed their second ten-year operation and it is expected that they will complete the third one a few years after 2000 without any significant problem.

Belgium was the first country to introduce a general legal obligation to carry out such ten-yearly reviews. In addition, the safety of each installation has been comprehensively verified on the occasion of special checks to apply the lessons learned from incidents in Belgian or foreign plants. The reassessments must be on a level comparable to the most recent plant rules and practices in use in the United States and in the European Community.

Such verifications have a threefold purpose: (1) to ensure that the plant is still as safe as it was when its operating licence was granted; (2) to take account of any possible future deterioration of equipment (ageing, wear and tear, etc.) in order to ensure safety for the ten years to come; and (3) to improve general safety by making any changes thought reasonable or necessary in the light of the most recent safety standards and practices.

In conclusion, the safety of nuclear power plants is based on compliance with fundamental safety principles which must be applied in everyday operation, following lessons learned from nuclear incidents, and on a regular and comprehensive review of safety in order to ensure that any necessary improvements are made.

In 1998 the total dosimetry of the Doel and Tihange plants were 1961 H*mSv and 3020 H*mSv respectively.

Economic regulation

The deregulation process of the electricity market has recently begun in Belgium, but it is still too early to measure the impact it may have. It seems however evident that this process will have a predominant impact, because of the needs to keep economical efficiency as well as safe operation. Moreover, it is feared that, due to increased competition between electricity producers, the sharing of experience and feedback information between them will no more occur.

Objectives and strategy

Due to the high quality standard applied to the design, operation and maintenance of NPPs, many aspects of plant life management have been incorporated in the everyday management of the plants since the beginning of their life. These aspects include: the design, quality assurance, in-service inspection, monitoring, testing, preventive and predictive maintenance, requalification, replacement, periodic safety reassessments, etc. A few of these aspects are hereafter further developed.

Design

There is no predetermined design life for the entire NPP, but a limited number of components have a predetermined design life; for example:

- Components subjected to fatigue due to low cycle thermal and pressure transients, such as primary components and piping. The number of occurrences considered in the original design for those components was evaluated on the basis of an anticipated conservative number of occurrences per year, multiplied by a number of years which was considered to be 40 years, except for the first three plants Doel 1&2 and Tihange 1, where 30 years was originally considered.
- Component subjected to irradiation embrittlement, such as the reactor pressure vessel.
- Primary containment tendons subjected to prestress relaxation.
- Electrical and mechanical equipment subjected to severe environment conditions and having a predefined “qualified life”. Those qualified lives have a duration which is component dependent.

In-service inspection

The irradiation surveillance programme of the reactor vessel is based on ASME E 185-73, Standard Recommended Practice for "Surveillance Test for Nuclear Reactor Vessels". The effect of fast neutron exposure on the fracture toughness of the ferritic reactor vessel materials surrounding the core region is determined by periodically removing and testing encapsulated specimens which were machined from actual reactor material used in the fabrication of the reactor vessel. The reactor vessel surveillance programme uses specimen capsules. Each capsule contains notched impact bar (Charpy V-Notch) specimens, tensile specimens and fracture mechanics (Compact Tension) specimens, all machined from actual material used in the fabrication of the reactor vessel. The Charpy-V-Notch specimens represent base material, associated weld material and weld heat-affected zone material. The tensile and compact tension specimen represent base material and weld material. Neutron dosimeters are included in the capsules for the purpose of evaluation of the fast neutron flux to which the specimens are exposed. In addition, thermal monitors of the low melting point alloys are included to determine the maximum temperature experienced by the specimens.

All classified pressure retaining components are inspected according to the requirements of the ASME Code Section XI. Moreover, complementary or voluntary inspections are decided by the operator on classified and non classified components according to variable aspects affecting the availability and the conventional security of the plant (e.g.: control of degradation due to erosion-corrosion), or depending on world feedback or experience.

Monitoring

Monitoring is used in several instances. A few examples are hereafter provided:

- Low cycle thermal and pressure transients are monitored in type and frequency to control components subject to fatigue and eventually to justify the extension of their fatigue life.
- Parameters such as ambient temperature cycle to which some electrical and I&C components are subjected, are monitored at a number of locations to control ageing of those components and eventually to justify the extension of their qualified life.
- Tests on surveillance capsules help monitoring the real ageing of the RP vessel material.
- Where transients are difficult to predict in amplitude and frequency, local monitoring is implemented (ex: to characterise thermal stratification transients).
- Vibration monitoring of main rotating components is used for predictive maintenance.

Maintenance

Presently, there are preventive maintenance programmes based on manufacturer recommendations and operating experience. These programmes are changed progressively into combined predictive and preventive maintenance programmes based on continuous monitoring, periodic inspections and engineering assessments.

Requalification

Qualified components have a fixed qualified lifetime. After this lifetime these components are replaced. However there are re-qualification programmes at different stages of advancement depending on the components concerned. A few examples are provided hereafter.

- For components subjected to low cycle fatigue, it is intended to use them up until their fatigue usage factor reaches one (CUF=1). This will most probably extend their fatigue design life beyond the duration originally planned. This may entail fatigue reassessment:
- taking into account the real number of transient occurrences;
- using less conservative methods of fatigue analysis; etc.

The real environment conditions (temperature, exposure duration, etc.) have already been considered to extend the qualified life of some electrical and I&C components originally designed for harsh environment, such as transmitters, temperature probes, actuators.

Periodic safety reassessments

This topic is already covered in the paragraph entitled “Safety regulation”.

A specific Project has recently started; its main objective is to centralise all safety and economic aspects of plant life management. The two main output of the project will be:

- the determination, for each NPP unit, of the most probable cost required to maintain safely the unit in operation;
- the identification of the actions to be taken (e.g.: predictive maintenance, monitoring, etc.) to achieve that at the minimum cost.

Decision and economic analysis

Cost/benefit analyses are used to help making strategic decisions. The cost/benefit study is performed by the utility and the engineering organisation. Together, they analyse the economic impact of potential new requirements by the regulatory body, of component repair and replacement, of modifications for performance improvement, etc. In the last decade, this methodology was used in variety of situations, among which:

- Ten-year safety reassessments;
- Steam generator replacements;
- Reactor pressure vessel cover head replacements;
- Plant seismic reassessment;
- Redesign of heat sink.

The economic analysis involved in component repair/replacement decision making is hereafter illustrated for the Doel 3 steam generator replacement.

Replacement of steam generators at Doel 3

A thorough comparison was drawn between repair and replacement strategies before deciding to replace the steam generators of Doel 3. The possibility or upgrading the plant power output when rep1acing the steam generators appeared to be a major contributor to this cost/benefit analysis. The various steps of the techno-economic study are described be1ow.

The first step was the analysis of the present steam generator degradation phenomena and the analysis of other potential future problems.

In parallel, several technical and financial assumptions had to be made before proceeding with the cost analysis. The most significant were:

- the *time* available each year to perform inspection and repair operations without extending the refuelling outage;
- the *frequency* of unscheduled outages which is different if the steam generators are replaced or if the plant operates with degraded steam generators;
- the *availability* and effectiveness of repair techniques (installation rate, percentage of defective repairs and, most important of all, lifetime of the repairs);
- the *possibility* or increasing the power output of the plant with new steam generators.

As far as financial assumptions are concerned, various parameters have to be evaluated so as to select the most appropriate value for each one. These are mainly the interest rate for actualisation calculations; the replacement power costs per day of scheduled or unscheduled outage; the inspection costs; and the maintenance and repair costs.

Each scenario was based on a strategy regarding the management of the steam generator problems and on a degradation rate for each corrosion mechanism. Several strategies were adopted:

- immediate replacement of the steam generators;
- plugging of degraded tubes to delay the replacement while minimising the maintenance costs (no repairs);
- repair of degraded tubes;
- repair of degraded tubes combined with preventive actions (like A VB replacement for instance) to extend as far as possible the lifetime of the steam generators.

The objective of the repair strategy was to extend the lifetime of the steam generators while minimising the impact of the repair work on the duration of the refuelling outages and minimising global costs. The selection of the best strategy was based on the following considerations:

- plugging growth rate evaluation to make sure that the plugging rate will not exceed the available plugging margin;
- risk analysis. A long-term strategy based on repairs that need to be effective for 15 or 20 years is obviously more risky than one re1ying on new steam generators for the same duration;
- Overall costs.

Cost comparison showed that the repair strategy was marginally cost-effective only if applied to delaying the replacement by a few years and, even so, provided that all assumptions were taken in its favour.

So with more risks for the repair strategy and no benefit expected regardless of the assumptions used in the analysis, replacement of steam generators was selected for Doel 3. This was performed in 1993, under budget, together with the decennial revision and within the planned time schedule, allowing Doe13 to operate with a 10% power uprating.

It is interesting to note that with a low plugging rate and no major repair work necessary in the next few years, the obvious choice would have been to go on with the existing steam generators. Only a detailed long-term study could identify that immediate replacement was the most cost-effective strategy.

Consequently it appears so far that implementation of the selected strategy confirms the assumptions used and that this strategy was indeed the best choice.

Programmes

Programmes related to design, in-service inspection, maintenance, monitoring, requalifications and periodic safety reassessment have already been covered under paragraph *Objectives and strategies*. Therefore only the repair/replacement programmes will be addressed in this section of the report.

Steam generator replacements

The status of the SG replacements in all Belgian NPP units is summarised in the following table:

	Doel 3	Tihange 1	Doel 4	Tihange 3	Tihange 2	Doel 12
Commissioning	1983	1975	1985	1985	1984	1974/75
Year replacement	1993	1995	1996	1998	2001	Unknown
Outage duration (days)	96	93	92	77		
Duration on primary circuit (days)	> 40	31	27	20		
SGR dosimetry (mSv)	1955	1637	633	625		
Total dosimetry (mSv)	3169	3089	1231	1086		
Budget (MBEF)	4500	4700	4200	3720		
Power uprating (%)	8	8	-	-		

Baffle bolts replacements

Thus far cracked bolts have been found only at Tihange 1. This reactor belongs to the French CP0 type, similar to the Bugey 2 and Fessenheim 2 reactors. The cracks are attributed to irradiation assisted stress corrosion cracking. The status of the Reactor vessel internals baffle bolts inspections and replacements in all Belgian NPP units is summarised in the following table:

UNITS	DESCRIPTION
Ti 1	1991 – outage: US inspection: 21 bolts with defect; 32 bolts non interpretable --> justification by calculation; 1992 – outage: Programme to replace 43 bolts; only 5 bolts were replaced--> calculation to justify functioning to 1995 (SGR); mechanical and micro structural investigations was performed on 4 of the replaced bolts; **1995 – SGR: Replacement of 91 bolts during SGR outage by FRA / EBL; all 960 bolts inspected.**
	1998: One bolt withdrawn in 1995 was sent to Battalle Pacific Northwest Laboratory for detailed microstructural investigations. These investigations are financed by the co-operative IASCC Research Program, to which we participate. Results expected in 1999.

UNITS	DESCRIPTION
Ti 2	1993: internal inspection has not revealed any cracks.
Ti 3	No inspection.
Doel 1	Inspections performed--> No cracks found. This is attributed to the ACEC unique design (longer bolt shaft,...).
Doel 2	See Doel 1.
Doel 3	No inspection.
Doel 4	No inspection.

Reactor pressure vessel cover head replacement

All reactor cover heads have been inspected for cracks in penetrations due to stress corrosion cracking. The status of the cover head inspections and replacements in all Belgian NPP units is summarised in the following table:

UNITS	DESCRIPTION
Ti 1	- Inspected in 10/1992; 1 indication (length = 5 mm/depth = 1 mm).
	- Inspected in 03/1998 - 4 penetrations with cracks.
	- Head will be replaced in September 1999
Ti 2	- Inspected in 10/1993: no crack.
Ti 3	- Inspected in 03/1993, 12/1996 and 06/1998, no crack evolution; 1 crack.
Doel 1	- Inspected in 09/1993: no crack - (1 indication).
	- Reinspected in 09/1998: several indications – small cracks < 3 mm
Doel 2	- Inspected in 05/1994: no crack – indications of original defects in the weld due to lack of fusion.
Doel 3	- Inspected in 06/1993: no crack.
Doel 4	- Inspected in 04/1994: no crack.

Guide tube split pin replacements

Guide tube split pins have been inspected for cracks due to alloy 750 stress corrosion cracking. The status of their inspections and replacements in all Belgian NPP units is summarised in the following table:

UNITS	DESCRIPTION
Ti 1	Replacement material by Framatome 4th generation.
Ti 2	No indications at the last inspection (96).
Ti 3	Several indications on support pins leading to replacement of the pins. Replacement material by Framatome - generation BR 89.
Doel 1	Replacement material by Westinghouse advanced Design
Doel 2	Replacement material by Westinghouse advanced Design
Doel 3	Replacement material by Westinghouse advanced Design No inspections at the last outage (97).
Doel 4	No indications at the last inspection (96).

Canopy seal welds repairs

Canopy seal welds on control rod drive mechanisms have been inspected for leakage due to stress corrosion cracking. Repair involves either weld grinding and weld overlay or the placement of a canopy seal weld assembly (CSWA). The status of all repairs performed are given in the following table.

UNITS	DESCRIPTION
Ti 1	1 weld repair (local); 3 CSCA installed.
Ti 2	2 weld repairs.
Ti 3	1 total weld repair (new canopy joint).
Doel 1	No defect.
Doel 2	15 overlay welds (corrective and preventive action), see Attachment 2.
Doel 3	2 weld repairs (upper canopy joint).
Doel 4	3 CSCA installed in 1997 after rewelding on 5 positions. + 7 CSCA installed in 1998

Public acceptance

The public is not directly informed of the process concerning plant life management. However, at each replacement of large components, such as steam generators or reactor vessel cover head, information sheets are issued to the media and special videos are made for the public and for visitors of the plants. Brochures dedicated to these specific operations are also issued.

Critical components

Components important to safety

The following table provides the list of components the failure of which may entail significant safety problems.

Components	AGEING DESCRIPTION
R.P. Vessel	Irradiation Embrittlement.
	SCC in Cover Head Penetrations.
	SCC in Bottom Mounted Instrumentation Penetrations.
	Canopy Welds Seal Cracking.
Vessel Internals	IASCC in Baffle Bolts.
	Cracking in Guide Tube Split Pins.
	Wear.
Control Rods	Wear.
Steam Generators	SCC in Tubes.
R.C. Pumps	Cast Stainless Steel Pump Casing.
	Thermal Fatigue for Type 93D Pumps.

Components	AGEING DESCRIPTION
Pressuriser	SCC of Heating Rods.
	Cracks in Surge Line Nozzle.
R.C. Pipes	Cast Stainless Steel Elbows.
All	Fatigue - Transient Reconciliation.
Piping	Fatigue - Regulatory Reconciliation.
	Fatigue - Unexpected Transients.
	Flow Accelerated Corrosion.
	Microbiologically induced corrosion
Primary Containment	Relaxation in Prestressed Cables.
Seismic Cat. I concrete Structures	Leak Tightness.
Other concrete structures	Degradations due to Carbonation.
Diesel generators	
1E Equipment	Qualification programmes.
1E Equipment	Cable Ageing.

Components important to economy

As part of the Project mentioned here above under point 29, components important to economy will be identified and their follow-up will be included in the project. These are the components which do not necessarily fill a safety function, but the failure of which may entail costs and outages having a significant impact on the availability of the unit and on the cost of its production.

CANADA

In 1998, 21 nuclear power plants with a total net capacity of 15.5 GWe supplied 12.3% of all the electric power produced in Canada. Twenty plants, including 19 operating units and one mothballed unit, are owned by Ontario Hydro (OH) which is a fully integrated electrical utility entirely owned by the province of Ontario. It provides about 90% of the electrical power in the province with an installed capacity of 31 000 MW. The oldest site at Pickering NGS A has 4 units that have been operating for at least 26 years.

Currently the province of Ontario is embarking on a restructuring of the electricity industry. The new structure will have an increased emphasis on competition which will place considerable pressure on Ontario Hydro to reduce its costs, a pressure that is being transmitted to all business units.

Recent nuclear performance and safety problems have made it necessary to re-assess the Ontario Hydro nuclear plant fleet. The OH Board has raised questions about the short-term financial impacts of declining performance and increasing costs, and the long-term economic viability of the nuclear assets. OH are approaching the time in the station life cycle where major expenditures for retubing are required. The Nuclear Strategic Plan For Excellence and the Nuclear Recovery Plan need to demonstrate affordability and economic viability. The supporting nuclear Station Life Cycle Assessments (SLCAs) address both technical and financial issues related to the continued operation of the stations to the end of life.

Organisation and their responsibilities

The Atomic Energy Control Board (AECB), an agency of the Ministry of Energy, is a federal regulator. The Board is responsible for all aspects of reactor and public safety and for employee radiation safety. The AECB is concerned about ageing issues and has issued a generic letter to Ontario Hydro asking about the ageing management programmes.

The provincial regulators are the Ministry of Corporate and Consumer Affairs (MCCR) and the Ministry of Labour. The MCCR has a pressure vessels branch which is responsible for licensing of pressure vessels and for regulation of the ASME code. Responsibility for these areas has been delegated by the AECB to the MCCR. The Ministry of Labour is responsible for conventional safety.

The Ontario Hydro Nuclear business unit (OHN), the largest nuclear business in North America and one of the largest in the world, has the responsibility for developing an overall strategy related to life cycle management of their nuclear power plants.

Table 1. Age of Ontario Hydro’s nuclear generating stations

Station	*Units in-service date*			
Pickering A	1971	1971	1972	1973
Bruce A	1977	1976	1977	1978
Bruce B	1984	1984	1986	1987
Pickering B	1983	1984	1985	1986
Darlington	1992	1992	1992	1993

Atomic Energy of Canada Limited (AECL) is the original architect engineer for the CANDU reactor. They support the managing of ageing through research programmes at their two research facilities, Chalk River Nuclear Laboratories (CRNL), and Sheridan Park Engineering Laboratories (SPEL). These research activities are co-ordinated through the CANDU Owners Group (described below). In addition, AECL provides engineering services through their engineering company, AECL-Candu.

The Candu Owners Group (COG) co-ordinates some activities in this area for the three Canadian provincial utilities which operate nuclear power plants: Ontario Hydro, Hydro Quebec, and New Brunswick Power. For example, COG funds research programmes. COG administers working parties consisting of technical experts from Ontario Hydro, Hydro Quebec, and New Brunswick Power. Some of these working parties are concerned with ageing of nuclear power plant components, for example:

- WP 1 Process Systems and Equipment,
- WP 16 Instrumentation & Control,
- WP 19 Steam Generators.

Regulatory processes

Safety regulation

A three step procedure is used in the licensing of nuclear reactor projects in Canada. The first is site approval, followed by two formal licenses, the construction license and the operating license stating, respectively, the terms under which construction or operation is authorised [1]. The initial term of an operating licence issued by the AECB is generally a year. The comprehensive staff evaluation of facility performance and positive recommendation are necessary before the Board's approval to renew a licence is granted. There is no specific provision about the term or the renewal of the licence either in the Atomic Energy Control Act or in the Atomic Energy Control Regulations. They are at the discretion of the AECB.

For example, the AECB approved the renewal of the operating licences for Ontario Hydro's Pickering A and B nuclear power stations, for one-year terms to March 31, 1999. Pickering A licence requires that all four plants remain in an approved shutdown state. Approval of the AECB will be required prior to any future start-up of the units [2].

Economic regulation

The reliability and availability of nuclear power plants, reflected in capacity factors and operation and maintenance costs, must be controlled as the plants age in order to convince the utility's Board of Directors that continued operation of nuclear power plants is economical.

Ontario Hydro is a publicly owned utility and as such its rates are not regulated, however, there is an annual hearing before the Ontario Energy Board (a provincial agency) which provides the public with an opportunity to participate in the rate setting process. The hearing is formal and there is wide participation by private members of the public, intervenor groups and user groups such as the Municipal Electric Association. The Ontario Energy Board then makes a non-binding recommendation on rate increase. In practice, Ontario Hydro tends to stay close to the OEB recommendations.

Since rates are not regulated, there is no problem in incorporating ageing failures or capital modifications into the rate structure except that the utility must of course be responsive to public and government pressure to keep rates down.

Brief history of life cycle management at Ontario Hydro

1980s and early 1990s – Technical Ageing Evaluations

Pickering A was retubed in the 1980s due to premature pressure tube failure caused by an unanticipated degradation mechanism. The Nuclear Plant Life Assurance (NPLA) programme was initiated to address the technical aspects of life cycle management and to ensure no more surprise failures related to high cost equipment [3],[4].

Early 1990s – Economic Evaluations

In 1993, the need to replace the Steam Generators (SGs) at Bruce NGS unit 2 became evident. The Inconel 600 tubes were corroding because of contamination from a lead blanket left in the SGs. Pressure tube replacement would also be necessary at Bruce NGS unit 2 in a few years. An economic evaluation of the unit was performed. At the time the performance of nuclear stations (particularly the A units) had begun to decline *(see Figure)*. There was also excess generating capacity, as the 4 units at Darlington NGS had just been placed in-service and the growth in electricity demand had slowed. This combination of factors led to Bruce unit 2 being mothballed.

Economic evaluations were also done for Pickering NGS A & B.

Figure 1 (a). **OHN capability**

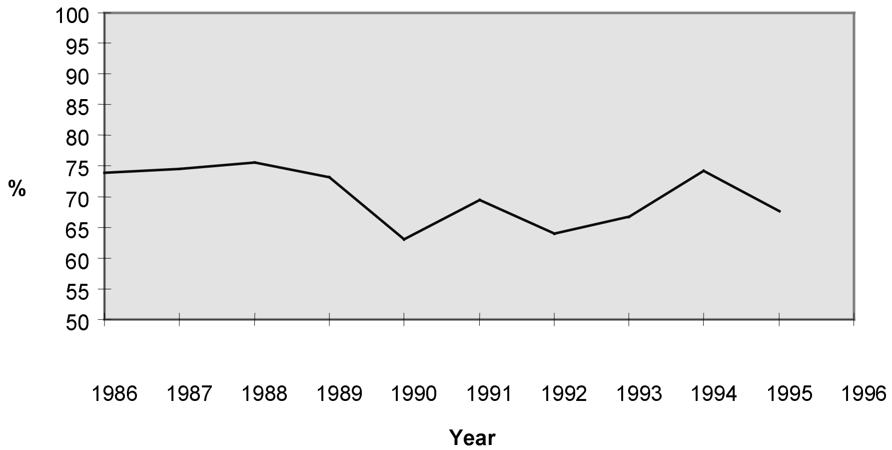
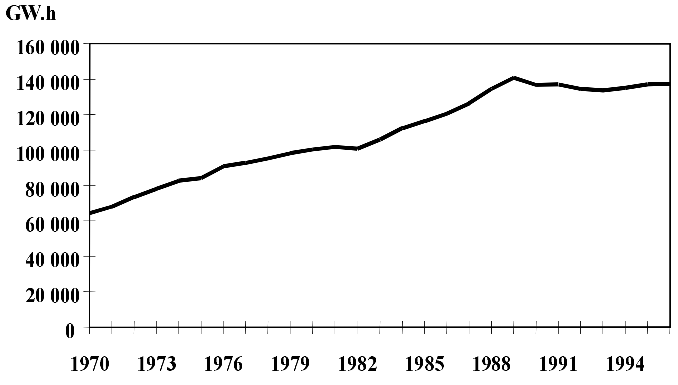


Figure 1 (b). **Ontario Hydro total system demand (1970-1996)**



Mid to late 1990s – life cycle assessment

In 1995 Station Life Plans were prepared to assist in Strategic Planning. Destiny Issues which could lead to premature unit shutdown, were determined for each site. Ensuring that programmes are in place to address these Destiny Issues is part of the strategic planning process.

In 1996 performance of OH's nuclear units was still declining: Pickering NGS was in an extended outage after a failure of an elastomeric diaphragm on a relief valve and Bruce NGS was derated due to the Power Pulse problem. A request for a release of capital from the OH Board for Pickering NGS led to the requirement for additional life cycle evaluations all stations (SLCAs). These were completed in late 1996. The SLCAs contain a summary of destiny issues, preliminary condition assessment, estimated cost of regulatory upgrades and equipment programmes, and a financial (LUEC) assessment by station. The short time frame limited these evaluations to documenting existing programmes, and identifying gaps to be addressed by future work.

The SLCAs were reviewed by an independent consultant for consistency of assumptions between stations and with external best practice. This was to provide confidence in OH's assessments and suggestions for future enhancements.

The current Nuclear Recovery Plan contains an initiative to develop a strategy for Life Cycle Management (LCM). LCM is broadly defined as the integration of those activities (economic, technical and regulatory) which maximise the benefits of existing plant investment and maximise the operating life of a nuclear unit, including the possibility of operating beyond 40 years [5]. Technical activities related to LCM are part of OH's overall Ageing Management programme. The station is managed/maintained in such a way as to realise its optimum life. A project charter for an LCM strategy has been prepared.

Today

OH are currently conducting an integrated plant assessment at all OH's nuclear sites, similar to an American SALP assessment. The results should better define the requirements, strategy, and actions for Life Cycle Management. Therefore, further LCM strategy development is on hold pending completion of the assessment.

Life cycle management strategy

Because Ontario Hydro's LCM programme involves many different programmes and organisational units, organisational responsibility needs to be clearly defined. Regulatory feedback has pointed out the need for effective integration and control of Ageing Management programmes, including a point of contact at each station.

Table 2 shows the organisations involved in Life Cycle Management and how they have been co-ordinated through the use of integrating teams. The diagram in Figure 2 shows data flows between processes in LCM. Major processes involved in LCM include the Ageing Management Programme (technical aspects), developing Equipment Strategies, Inspection and Maintenance programmes, Condition Assessments, and Life Cycle Assessments.

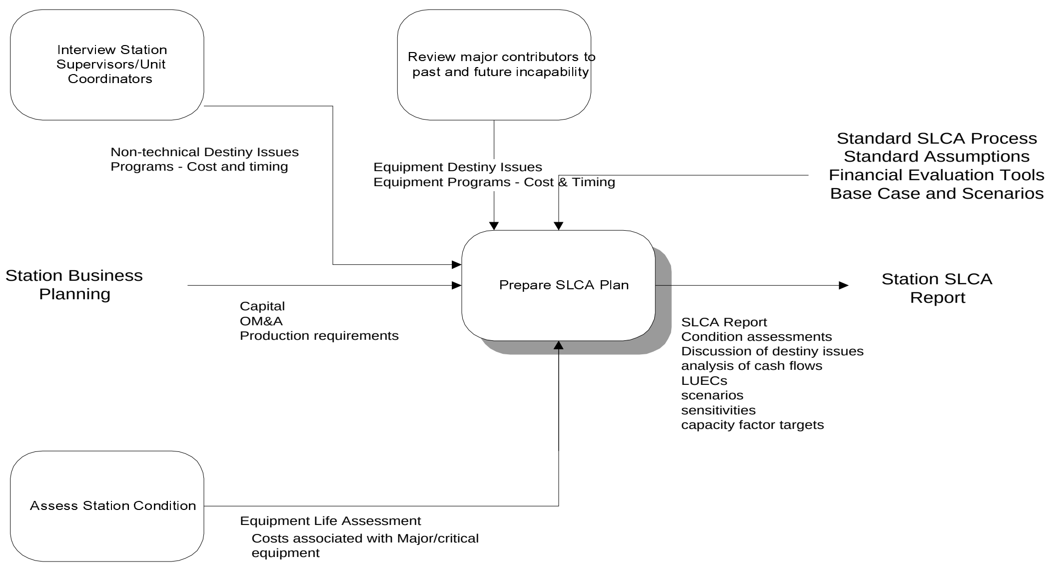
Table 2. **Integrating teams in life cycle management**

	Life Cycle Management	**Ageing Management**
Sponsor	Director OHN Finance and Business (F&BS)	OHN Support Director
Members	• HQ LCM Unit • Station F&BS	• HQ LCM Unit • Station Engineering Services • Nuclear Safety Division.
Functions	• Develop and Recommend to Sponsor methodology for LCM studies and reports • Review products from each station for uniform application of methodology	• Develop methodologies for ageing management studies • Agree on critical component lists • Agree on lead plants for studies/pilot programmes • Information exchange • Develop/recommend overall ageing management strategies

Life cycle assessment process

In 1996 a Station Life Cycle Assessment (SLCA) was done for each of OH's 4 nuclear sites. These assessments were necessary to ensure understanding of the financial risks, returns, and longer term viability of the nuclear line of business. The first SLCAs were also intended to provide early assessment of any gaps in the comprehensiveness of information and provide suggestions on new processes to accomplish the task. This new process presented in a standard format: destiny issues that might prematurely shorten a units life, cost data for major equipment programmes to end of life, a preliminary condition assessment of major equipment, and an economic assessment. Several gaps in knowledge were identified through this process.

Figure 3. **SLCA process**



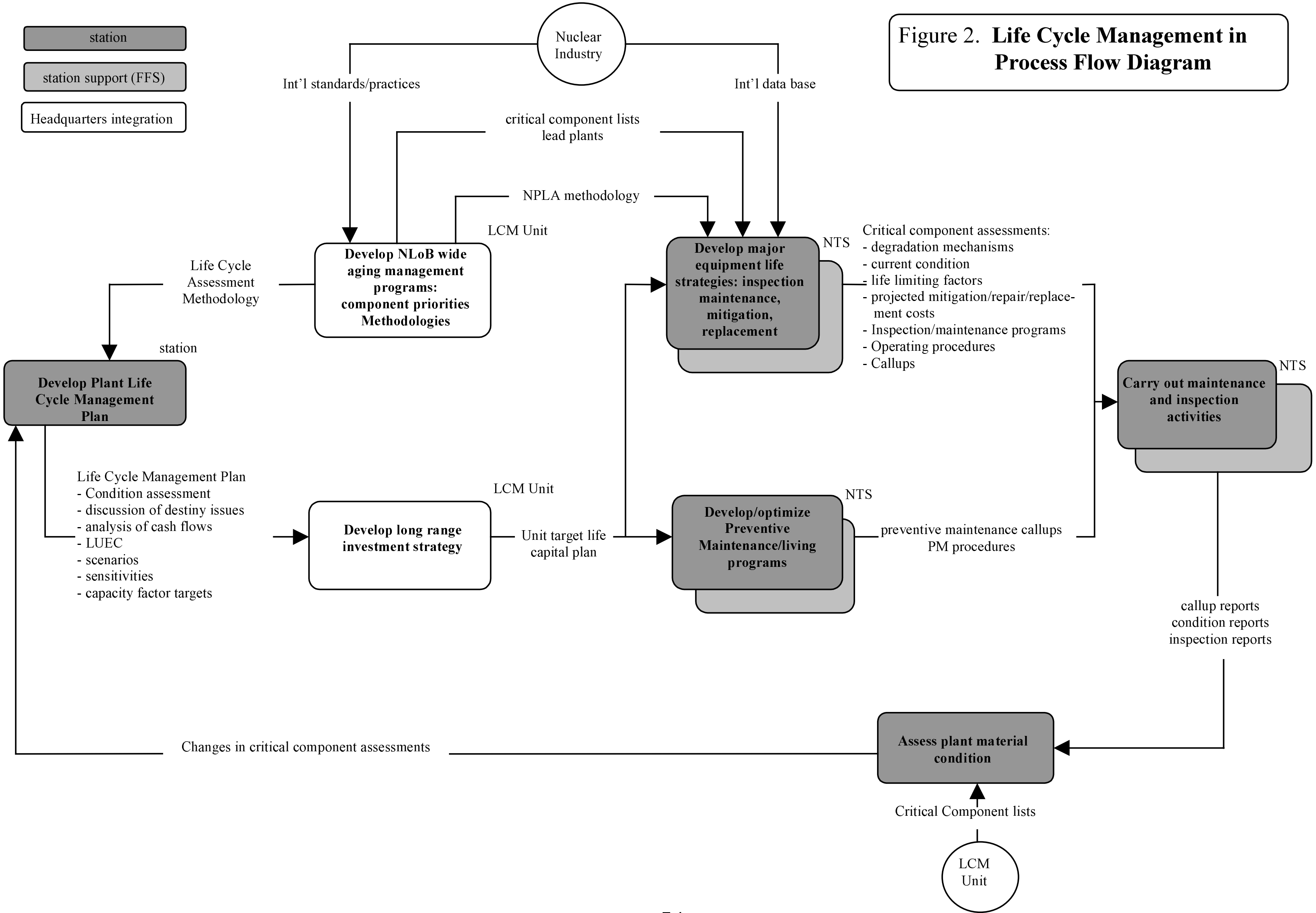


Figure 2. **Life Cycle Management in Process Flow Diagram**

A managed process should provide for a consistent life cycle assessment across OH's 19 nuclear units. The diagram below shows the inputs and outputs from the process "Prepare SLCA Plan", as followed in 1996. Standard assumptions and processes were provided by OHN headquarters to all 4 sites. Destiny issues were obtained at each station by reviewing contributors to incapability (historical and future) and by interviews with technical and non-technical supervisors. The condition of major plant equipment, and costs associated with its management to end-of-life, came from the "Condition Assessment Process". Business constraints, such as capital, OM&A, and production requirements came from the Station Business Planning process. The result of the SLCA process is the SLCA report, which addresses the economic viability for each station under various standard scenarios.

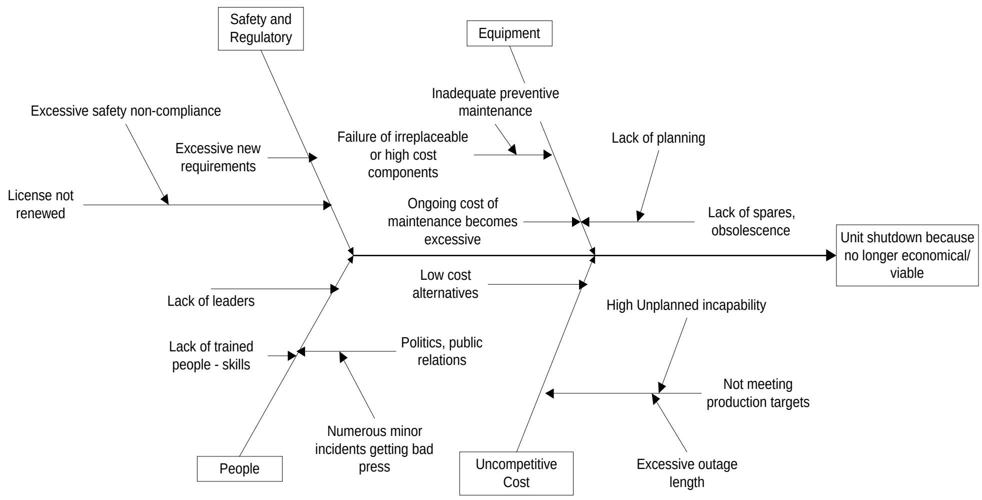
Destiny issues

As part of the SLCA process, each station prepared a list of Destiny Issues (DIs) under each of the Key Result Areas (KRAs): Strategic, Employees, Production of Electricity, Engineering, Public Safety, Sustainable Environment, and Public Support. Destiny issues were defined as issues both technical and non-technical that could lead to premature unit shutdown.

A Cause and Effect diagram (Fishbone diagram), such as in Figure 4, provides a pictorial representation of destiny issues. If the final effect is Premature Unit Shutdown, primary causes aligned with KRAs such as engineering issues, safety issues, electrical production or employees can be identified. Secondary and tertiary causes are also identified, to eventually arrive at root cause problems.

The lists of destiny issues from each station were compiled into a single matrix (Table 3). Each station must address each destiny issue in their SLCA report or explain why it is not an issue at that station. By doing this, it is hoped that the newer stations will benefit from the experience of the older stations in anticipating destiny issues.

Figure 4. **Sample fishbone (cause and effect) diagram**



A process to identify technical destiny issues was developed at Bruce NGS A: causes of past incapability and future incapability (due to ageing, operating condition changes, regulatory changes) were systematically reviewed. The criteria chosen for technical issues was exceeding 10 M$ Canadian or requiring a shutdown in excess of 3 months for repair, replacement or refurbishment.

Other destiny issues were obtained from interviews with station managers and supervisors in the appropriate area, such as Employee Services and Safety.

For each destiny issue, a template was completed (Figure 5), describing the issue and identifying programmes to address it. Responsibilities, milestones, and timing were to be identified. Future enhancements will be to include consequences of not addressing the issue as well as measures to determine whether the programmes were successful (closure).

Table 3. **Standard destiny issues**

Key Result Area	Destiny Issues
Strategic	• Nuclear Excellence – PEER Improvement Plan – COMPASS (including Configuration Management) • Meeting Performance Objectives & Criteria • Improving Overall Station Management
Employees	• Human Performance • Integrated Resource Plan
Production of Electricity	• Meeting Electrical Production Targets for Capacity/Reliability • Quality of Operations • Controlling Outage Duration • Maintenance Backlogs • Quality of Maintenance • Preventive Maintenance
Engineering	• Restoration of Full Reactor Power • Pressure Tube Programme • Equipment Ageing Programme • Steam Generator Programme • Material management -Critical Spare Parts • Calandria Vault Corrosion • Seismic Margin Assessment • Pressure Tube Blister Formation • Retube • Nuclear Plant Life Assurance & Preliminary Condition Assessment
Public Safety	• Reactor Safety (OP&Ps, SERs, Licensing) • Analytical discovery risk • Environmental Qualification
Sustainable Environment	• Used Fuel Management • Emissions • MOEE , Freon, PCB management, Chlorine • Low and Intermediate Waste
Public Support	• Public Support

Figure 5. **Sample destiny issue template**

SECTION 3.6 PUBLIC SAFETY DESTINY ISSUES
ISSUE 3.6.1 NUCLEAR SAFETY

KEY RESULT AREAS AFFECTED
PS-02 OP&P Non-Compliance Frequency
PS-03 Serious Process Failures
PS-04 Special Safety System Performance
PS-05 AECB Commitments Met

ISSUE DESCRIPTION
The over-riding management mandate to ensure that operation is sustained through the plant lifetime requires that the plant must continually meet corporate safety goals and the AECB's licensing requirements and that defence in depth must be demonstrably maintained.
There is evidence that BBND has failed to meet excellence targets in the areas of nuclear safety.

There is evidence that staffing and staff capability need to be increased.

Specifically, the areas that threaten long-term and short-term nuclear safety not including improvements cited in Peer Evaluations, are: *(Note: only 3 areas reproduced here for illustrative purposes).*
1. Training for Analysis and Integration staff.
2. Experience and succession planning for Analysis and Integration staff.
3. Risk assessment needs formalisation via the application of the Risk Assessment computer programme.

References: 1994 Audit of Nuclear Safety Support Function

PROGRAMME DEVELOPMENT
1996 *(Note: only 3 areas reproduced here for illustrative purposes).*

- Complete Phase 3 of Analysis and Integration Training Programme
- Ten to eleven experienced contract staff will be maintained in 1996 and part of 1997
- BBND risk assessment tool completed and applications increase

Condition assessment

Condition assessments have been done for some major cost equipment (> 50 M$ or 6 months outage) as part of the Nuclear Plant Life Assurance (NPLA) programme, References 1 and 2. Comprehensive condition assessments have not been done for all nuclear plant critical equipment. Criteria for including equipment in a plant condition assessment should go beyond that of requiring a destiny issue (cost or outage length) to include safety related equipment, or equipment with the potential to cause a multi-unit outage.

The following text describes condition assessment as used in NPLA:

"Steps in a Condition Assessment should include identifying scope (equipment to be included), plausible degradation mechanisms, inspection results, degradation rate, life assessment, and applicable programmes."

Plausible degradation mechanisms are identified systematically by assessing material, design and environment. Components are grouped according to type for efficiency, provided the environment is similar. Degradation assessment matrices (Table 4) have been used.

Table 4. **Sample degradation assessment matrix**

Component Type ____

Degradation mechanism	Potential H,M,L	Description/justification	Source
Fatigue			
Thermal Embrittlement			
Mechanical Wear			
Corrosion			
Erosion			
Neutron Embrittlement			
Creep			
SCC			

Inspection results are documented to allow assessment of degradation rate for each plausible degradation mechanism. Where inspection results are not available, they should be scheduled and focused to assess the degradation mechanism(s) of concern. Once degradation rates are known, a life assessment for the equipment can be made. If the life assessment reveals a life that is less than the target life, programmes are required to address the gap. Programme costs are identified, programme activities/milestones are scheduled and assigned to a responsible individual(s).

Economic and financial evaluation

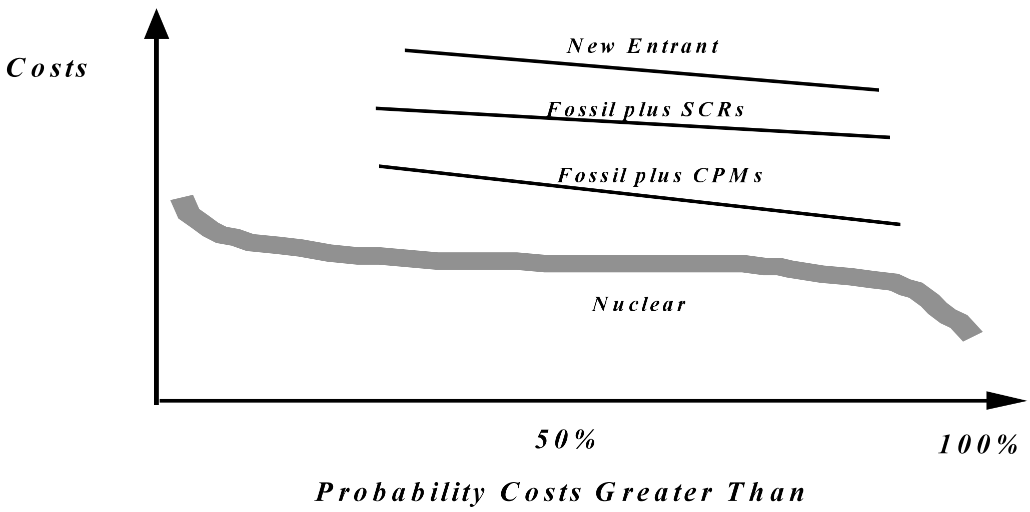
When investments are being considered in an existing facility they need to be made within the context of life cycle plans to provide assurance that continued investment in the facility is economically viable.

A life cycle plan must include an analysis of all the future cash flows associated with the facility, and an assessment of risks associated with those cash flows. The life cycle plan should represent a plan that maximises the expected value to the Corporation. Once the life cycle plan for a facility is approved, any project within the life cycle plan should not require a comprehensive evaluation. Life cycle plans need to be reviewed whenever there is a significant change in the underlying assumptions. Cash flows, performance and risk assumptions must be subjected to verification processes.

The SLCA process provides the costs and schedules of the programmes required to address the destiny issues, operate the facility and achieve the target life. Costs should be detailed for the first five years, then can be grouped according to five year intervals to the expected end of life. Significant thought needs to be given to analysing a range of reasonable technical, performance, business and environmental risks that face the facility. Various methodologies exist to address scenarios, sensitivities and full risk analysis to assess uncertainties, in fact, probably several should be used to provide more information to the decision makers.

The analysis which included the revenue and risks was undertaken by a separate programming function to the generating business unit. They incorporated the risks and impacts of external alternatives and competitors, market dynamics, environmental and political uncertainties that effect the business. The following graph illustrates the risk profile for a nuclear station compared to some fossil and new entrant costs. The incremental going forward costs of all OH's nuclear units is below the alternatives, such as fossil fuel powered plants.

Illustrative Cost Comparison



Critical components

Components which are subject to ageing but which are relatively easily **replaceable** are considered to be short-lived and are included in other programmes such as normal maintenance. The programme include long-lived components assessed as critical according to the following criteria:

- **Non-replaceable** components such as the calandria vessel, the vacuum building and the containment structure, which includes the calandria vault and the reactor building.

- Components which are **replaceable** but are **costly** in terms of capital expenditures (> 50 M$) and outage time requirements (> 6 months) such as steam generators, pressurisers, piping and turbine-generators.

For example, critical components for Bruce A and B are listed in Table 5.

Table 5. **Critical components – Bruce A & B**

REACTOR	Fuel Channels Calandria Vessel End Shields Shield Tank & Bearing
CIVIL STRUCTURES	Vacuum Building Reactor Buildings Calandria Vaults Cooling Water Intake Irradiated Fuel Bays Turbine Tables
PIPING	Nuclear Piping Secondary Piping Service Water System Piping Pressuriser
SECONDARY SIDE	Steam Generators & Steam Drums Turbines Generators Preheaters
OTHER	Electrical Cable Systems I & C and Computers Airlocks

REFERENCES

[1] OECD/NEA (1991), *Licensing Systems and Inspection of Nuclear Installations 1991*, Paris, France.

[2] AECB (1998), *Reporter Spring 1998*, Ottawa, Canada.

[3] Chadha, J., Andreeff, T., Rolfe, B., *Canadian Programs for Understanding and Managing Nuclear Power Plant Ageing Degradation*, Plex '91 Berlin, Germany, 1991.

[4] Watson, P., Maruska, C., and Andreeff, T., *Candu Nuclear Plant Life Assurance Program for Pickering A*, Plex '93, Zurich, Switzerland, 1993.

[5] *Benefits of Life Cycle Management Programs for Nuclear Power Plants*, draft EPRI report, March, 1993.

CZECH REPUBLIC

In 1998, four nuclear power plants of the VVER 440/213C type, located at Dukovany with a total net capacity of 1.6 GWe supplied 20.2% of all the electric power produced in the Czech Republic. These plants have reached over 100 000 hours of operation. At present there are several key projects under consideration: the modernisation of systems selected on the basis of systematic safety assessments; the increase of power output; and the introduction of equipment qualification programmes.

All of these projects require financial and human resources the extent of which has to be judged in relation to the returns on output and availability during the design lifetime and possible life extension.

Regulatory process

In January 1997 the new Atomic Act (No. 18/1997) was issued. It replaced the earlier act, No. 28/1984. Upgrading of the regulations and the decrees related to the new atomic act will complete the legal framework for the nuclear field in the Czech Republic.

The regulatory process is based on a periodic review of the unit before start-up and after refuelling by the regulatory body State Office for Nuclear Safety (SUJB). The relevant safety report is maintained and safety upgradings are planned and implemented to fulfil all requirements from these regulations.

One of the main aims of the Czech utility CEZ Inc., in its long-term investment programme, is the execution of retrofit activities in the nuclear units that ensures long-term operation while meeting international safety standards. To reach long and short-term economic objectives of the CEZ Inc., the head management of the nuclear power plant decided to perform a technical audit. The audit was designed to evaluate the present status of the nuclear equipment and the VVER/213 design.

The audit was divided into two parts. The first part consisted of an internal audit which was carried out with about 120 specialists from the Dukovany nuclear power plant. The plant experts collected data necessary for the evaluation of the design and operation of equipment. The second part consisted of an external audit conducted by the foreign company ENACT Consortium. The external audit relied on results and recommendations from the internal audit to evaluate the equipment according to international standards. The objective of the audit was to ensure that the nuclear power plant will be able to reach its designed life of 30 years and to determine whether it would be possible to extend its life another 10 years.

Based on the results and recommendations of the audit, a refurbishment plan will be designed during the 1998-2005 period.

Objectives and strategies

The design service life and current goal of the Dukovany nuclear power plant is 30 years of safe operation while preserving the option for life extension to 40 years. The technical lifetime of the reactor and reactor building is about 40 years.

The widely accepted methodology for life management consists of three basic steps:

- selecting plant components in which ageing should be evaluated from a safety perspective to assess effects of ageing degradation. The goal is to assess the ability of the SSCs to perform their design function and to ensure that existing programmes and activities allow the management of ageing effectively;

- performing ageing management studies for selected SSCs to determine appropriate ageing management actions; and
- using results of the ageing management studies to take appropriate management action.

The experience with main components is very positive and extension of service life to 40 years seems to be achievable. Life management programmes for selecting plant components have been elaborated in accordance with the IAEA methodology and evaluated by the safety authority.

Decision and economic analysis

In hitherto economic life practices, the simplest method for assessment of investments, the so-called "non-discounting" technique was practised. This method was governed by the central planning authority and other recommendations by the former Ministry of Fuel and Energy. The method is being reappraised today.

Economic evaluation of life extension efficiency practices includes:

- Dynamic methods for efficiency assessment suitable to any variant of solution (discount cash flow, internal rate of return, etc.).
- Unambiguous definition of necessary inputs for calculations.
- Economic effectiveness sensitivity testing of different parameters (cost of refurbishment, time of shutdown for refurbishment, life extension period, course of refurbishment financing, electricity cost development, loan conditions, etc.).

Two conclusions were compared for the year 2010 in 1992: lifetime extension of WWER 440/230 x two units; and new gas/steam units 3 x 300 MW (combined cycle, gas as fuel) construction.

A very broad spectrum of parameters to compare these possibilities was used for economic analysis. Conservative data was used for lifetime extension calculations (15 years of life extension, three years of shutdown for reconstruction, higher level of investment costs), though not due to any preference for the nuclear variant. The results of calculations with the most probable combination of parameters are considered in Table 1.

Table 1. **Economic analysis of lifetime extension and new units gas/steam**

	Lifetime extension	New unit gas/steam
	2 x 440 MW WWER-213	3 x 300 MW
Discounted cash flow (millions of CS crowns)	10 668	3 913
Internal rate of return (%)	38.8	11.4
Payback period (years)	5	14

Programmes

Dukovany nuclear power plant with four units of the WWER 440/213C type has reached over 100 000 hours of operation. At present there are several key projects under consideration: the modernisation of systems selected on the basis of systematic safety assessments; the increase in power output; and the introduction of equipment qualification programmes.

For the VVER type of reactors, the regulatory and utility policy for plant life management has not yet fully been defined. For several years the management of Dukovany NPP together with the Nuclear Research Institute have been preparing individual methods of assessment and more recently have been working on the overall concept of reliability oriented plant life management.

Most of the individual programmes are either already under way or the detailed work plan is being prepared. The database of individual tasks was prepared and matched with the other programmes specified earlier.

For each system or component, the structure is illustrated and described, and a flow chart is indicative of the evaluation scheme together with a statement on the status of the programme. Finally the conclusions and recommendations for work through to the year 2000 are given. For example, the principles of the concept are summarised for reactor pressure vessels as shown in Figure 1 and Tables 2 and 3.

Figure 1. **Pressurised thermal shock evaluation for RPV/Dukovany NPP**

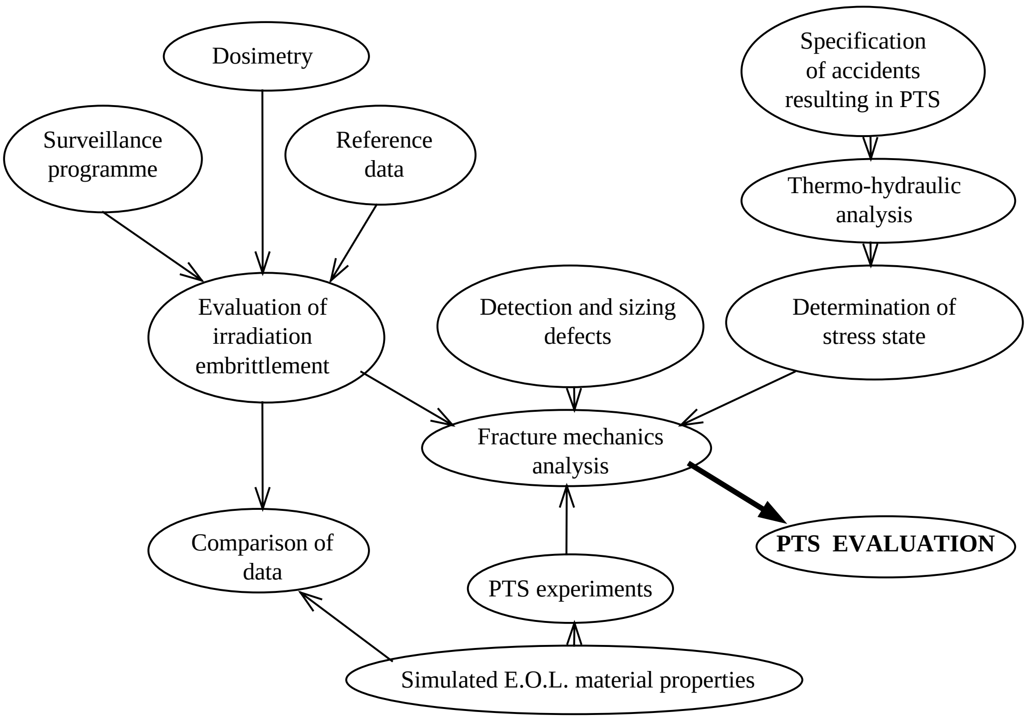


Table 2. **Present status of RPV/Dukovany NPP**

Surveillance programme (SP)	Evaluated and re-evaluated
Supplementary surveillance programme (SSP)	Prepared, 1st string set will be loaded in 1997
Dosimetry	Measurement inside and outside RPV, model experiments, recalculations
Reference data	Recommendation – join the IAEA databank
Detection and sizing of defects	ISI verification programme is in progress in the PHARE 4.1.2. frame
Thermo-hydraulic analyses	First calculations are performed very limited scope (RPV symmetrical cooling-down)
Determination of stress state	First calculations are of very limited scope
PTS experiments	To join and participate at the FALSIRE programme, to continue in experiments on the cruciform specimens
Simulation of the material properties at the end of life	Results of SP and DSP To start irradiation programme of the cladding during 97/98 years

Table 3. **Conclusions and recommendations for time period of 1997 to 2000 for RPV/Dukovany NPP**

To establish the supplementary surveillance programme
To continue in thermo-hydraulic and stress state calculations for *the selected* PTS modes
To perform and evaluate the cladding irradiation programme
To complete and maintain qualification of non-destructive inspections
To continue in experiments on cruciform specimens and in the measurement of instrumented hardness
To perform and evaluate temperature measurements of the HPI ECCS system including temperature measurements on the vessel
To define limiting factors in order to achieve extended RPV lifetime, including proposals for measures

Throughout each programme a significant feature is that of verification that the data, the analysis and any tests are of an acceptable standard. This is part of the quality assurance scheme applied to any programme of work in which NRI is involved. Some of the verification work, particularly that of NDT on piping, is being carried out within the framework of the PHARE programme.

The economic issues related to the plant life management have a significant influence on the decision-making process. The prime objective is to meet the safety requirements. In doing this it is also desirable to maximise availability and output of the plant. The possibility of lifetime extension must always be considered. Plant life management requires a full understanding for planned maintenance, repair and replacement. When the time arrives for consideration of plant life extension all the necessary data are to hand and the extension case can be readily made.

Dukovany NPP is only ten years into its operating life, unlike a large proportion of plants which are now approaching twenty years old or more. The opportunity therefore exists to apply reliability orientated plant life management and provide the utility with maximum economic return on their capital investment.

FINLAND

In 1998, four nuclear power units with a total net capacity of 2.7 GWe supplied 31.3% 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.

Organisations and their responsibilities

The regulatory body in Finland is the Radiation and Nuclear Safety Authority, STUK, whose responsibility it is 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 ensure the safe 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 the slogan “the plants must be kept in such a good condition that every day they have 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 ageing follow-up work is mainly performed by the person responsible for a system or a component and recommendations for actions are decided by special working groups. 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 participating in several international networks and working groups (NEA, IAEA, AMES, NESC, etc.).

Regulatory processes

Safety regulation

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.

Economic regulation

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.

Strategy

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. In total, 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%).

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.

Decision and economic analysis

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.

Programmes

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% 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 is 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:

a) 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.

b) 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.

c) 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:

Performance of structural materials

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.

Structural analyses for nuclear power plants

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.

Non-destructive methods and procedures for nuclear structures and components

Research is 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).

Technical service life and reliability assessment of nuclear components and structures

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% for all four nuclear power plant units over several years.

Public acceptance

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 sea water.

Critical components

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 world-wide 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.

FRANCE

In 1998, 58 nuclear power plants with a total net capacity of 61.7 GWe supplied 75.1% of all the electric power produced in France [1]. Electricité de France is a company whose priority is to supply its customers with the required kilowatt-hours (kWh) at a competitive nuclear kWh price. The decision to produce most of its electricity from nuclear energy results from this goal. Likewise, the lifetime management of the existing units and their possible extension, at the required safety levels, are primarily justified by economic reasons. EDF, for example, runs a generating capacity of more than 50 GWe standardised PWR units built in only a dozen years. If all units had a pre-defined lifetime (e.g. 40 years), a replacement effort on the same scale (about 5 000 MW per year) would be needed as of the year 2010 for the renewal of this generating capacity. If, on the other hand, lifetime management and extension of units was more individualised, the replacement operation could be performed over a much longer period and at a much more reasonable rate than recommended by industrial and financial standpoints.

On the strength of current knowledge, it is possible to assess that no equipment problem should prevent the 56 PWR nuclear power plants in operation from reaching the NSS's 40-year design mark. Due to their standardisation, French NPPs have a unique safety-related experience feedback and in 1996, they boasted 700 reactor years. This evaluation of the "Plant Life Programme", a systematic study programme set up at EDF as far back as 1985, is a reasonable target that fits in well with various international trends. This assessment is based on three main parameters: the reference frame of the safety requirements, the technical end of life of equipment items, and economical aspects. From a technical point of view, the French Safety Authority considers that the third ten yearly outages will mark a significant step in the life of NPPs and, thus, the French Safety Authority expects a significant technical insight in view of the further operation.

Organisations and their responsibilities

In France, a specific organisation known as the "Plant Life Programme" was set up within Electricité de France (EDF) to co-ordinate all problems relating to ageing and lifetime of nuclear plants. EDF periodically reports to the French safety authorities.

The role of the Plant Life Programme is twofold:

- to ensure consistency between positions taken by EDF on the above topics; and
- to ensure that the necessary actions are taken so that a technical and economic assessment is made for the French standardised PWR units.

This project was set up in 1986 and uses the know-how of three EDF branches:

- Production Transfer Branch (NPP utility).
- Equipment Branch (NPP designer, architect engineer and manufacturer).
- Research and Development Branch.

The project is directed by a Steering Committee, in which the three branches are represented.

Each area of work, sensitive component or major topic is placed under the responsibility of a co-ordinating committee or at least a duo of specialists (utility and designer), whose role is to integrate French or foreign experience feedback on the topic; to propose to the Steering Committee any additional work (studies for closer knowledge of ageing-related phenomena, etc.) it considers necessary; to have the work performed or direct it; and to generate status and summary reports and propose conclusions or guidelines. About 30 groups work in this manner under the supervision of the Project Steering Committee.

Of course, partners outside EDF are major contributors to this work, mainly through design study contracts. The primary manufacturers of our units include FRAMATOME and GEC-ALSTHOM) and, to a lesser extent, the *Commissariat à l'Énergie Atomique* (CEA) acting within the scope of specific co-operative agreements.

A working programme was formulated and launched in 1989. The areas it covered include improvement of knowledge; evaluation of time-based damage for each of the sensitive components in the NPP and determination of related corrective measures (repair, replacement, changes to the surveillance and maintenance programme, etc.).

Safety authorities involved in this programme are regularly notified of its progress. In specific areas such as power cables, a special purpose study programme is implemented by the *Institut de Protection et de Sûreté Nucléaire* (IPSN). They may, if considered necessary, propose guidelines or changes of direction.

Unlike the United States, these regulatory bodies are not at the centre of the units lifetime management process (that is, within the scope of a licence renewal every 40 years). Statutory limits are not set out arbitrarily, however, and authorities can at any time restrict unit operation if they deem safety to be inadequate.

EDF co-operates with a number of foreign utilities with regard to the Plant Life Programme, and participates in activities run by international organisations such as the IAEA and OECD/NEA.

Regulatory processes

a) Safety regulation

In France, the safety authority is the *Direction de la Sûreté des Installations Nucléaires* (DSIN), which is attached to the Ministry of Industry and the Ministry of the Environment. In decision-making, the DSIN relies upon the *Institut de Protection et de Sûreté Nucléaires* (IPSN), and on expert groups (permanent groups in charge of reactors and the Nuclear Permanent Section). In addition, the *Office Parlementaire des Choix Scientifiques et Technologiques* uses public hearings to perform the evaluation tasks it considers necessary.

In all matters concerning the main primary system, a special regulation has been instituted (Government *Arrêté*, dated 26 February 1974). The statutory texts governing pressure-retaining vessels (*Décret*, 1926) are also applicable. The DSIN enforces this law, mainly with its *Bureau de Contrôle et de la Construction Nucléaire* (BCCN) and the regional industry, research and environment directorates.

No specific regulations exist in France governing NPP lifetime. The authorisation to proceed, which is granted to the utility by the DSIN at the beginning of the lifetime, comprises no time limit. But it can be withdrawn at any time if the governing authority deems that safety is not respected or even that the utility does not provide proof that safety is respected.

Ageing is only one of the issues influencing the safety factor. In practice, the governing authority orders the utility to perform periodic safety reviews which are currently combined with the statutory 10-year outage programmes of our NPPs.

Ageing impacts the safety level in two ways:

- Each component ages, and its performance decreases with time if care is not taken. It is necessary to ensure, through properly conceived maintenance, that the basic requirements are always met (RCM approach).
- The design itself evolves in the same way as the applicable safety rules. The role of safety reviews is, among other things, to highlight all deviations, in order to find out if they are acceptable by our safety authorities and, if not, to correct them through special purpose studies or adaptations.

b) Economic regulation

In France, there are no economic regulations governing lifetime management. EDF is a publicly-owned company, whose only shareholder is the French State. In view of this fact, the Ministry of Industry and the Ministry of Finance ensure that the investments made are optimised. EDF’s task is to supply its customers with kWh at a competitive cost. Accordingly, the company has embarked upon lifetime extension studies, solely for economic reasons. The decision to extend operation or to decommission a unit is taken in light of the economic situation at the time (fuel cost, cost of substitute kWh, cost of building a new unit, failure cost of one kWh, etc.).

Objectives and strategies

Because of the importance of PWR life cycle management represents for EDF, a “Plant Life Program” was created as early as 198S to prepare regular reports on ageing [2, 3, 4]. This overall generic programme makes use of all skills available within EDF and the manufacturers, and guarantees consistent and complete follow up analysis by making use of numerous expert areas. Beyond most pieces of equipment which can be maintained during maintenance activities, there are what EDF consider as non-replaceable components. The former can usually be replaced within a given time period at a controlled radiation exposure and a reduced cost. For instance, at the end of 1997, EDF replaced the steam generators in seven units and twenty four reactor vessel heads.

Although all aspects of Life Cycle Management are closely intertwined, EDF have decided to present them one after the other to make thing clearer, but EDF will not forget to emphasise their interactions. The technical aspect of this issue requires accounting for other factors such as design, manufacturing. Operation, maintenance, industrial policy and R & D.

From a **technical** point of view, the behaviour of equipment and systems in time depends on the various degradation modes that may inhibit the functions they are designed to provide. Components' ageing makes it necessary to account for the conditions in which such components are operated and maintained: their impact on the life of the facility depends on how difficult it is to replace them. EDF must therefore distinguish between components that may be completely or partially replaced (such as steam generators, reactor vessel internals, pressurisers, cast elbows, instrument and control (I&C), other primary circuit pipes, electrical cables, main generators, turbines, etc.), even if it means heavy and costly maintenance operations, and those which cannot be replaced, such as the reactor vessel and the containment of the reactor building, implying necessary behaviour monitoring as time passes.

Significant R&D programmes arc dedicated to identifying and analysing degradation mechanisms and trends: erosion, corrosion, fatigue, wear, thermal and irradiation-induced ageing. Moreover, the criteria identified for such mechanisms make it possible to optimise maintenance and operating policies. Expert survey programmes performed on real equipment have been launched in order to confirm the assumptions resulting from R&D studies and validate the results of destructive tests through reviews.

Components and systems have to safely fulfil their designated functions. Compared with the originally set limits, the existing margins may be “burdened” by the component's behaviour in time (such as plugging of steam generator tubes), or “used up” in order to have operating conditions evolve (such as modification of cycle lengths). Periodic safety reviews associated with monitoring of plant compliance with stabilised reference guidelines make it possible to periodically check compliance of safety-related margins. With these aspects in mind and with a 40-year plant life prospect, this is how second ten-yearly outages of our 900 MWe are currently being prepared. These outages, which are due to begin as early as 1998 and 1999, include the following operations: detailed control of facilities and maintenance activities; and integration of safety-improvement work packages.

Periodic reports on PWR plant life of units in operation are regularly done with the following objectives:

- firstly, to report the main conclusions drawn from follow up analysis done between the publication of reports;
- secondly, to validate assumptions made in terms of the plant life of 900 and 1 300 MWe units; and
- finally, to define or confirm actions taken to anticipate technical and industrial trends, maintenance and R&D support, based on the various degradation modes of components.

EDF will also need to take into account the **industrial environment** prevailing-today and tomorrow-in the operation of French NPPs and the strategies selected, because maintaining knowledge, skills and manufacturing capability is a pre-requisite to long-term operations.

EDF will also need to take international **experience feedback** into account as well as plant life of foreign plants. New trends in safety requirements abroad would necessarily impact our own plants.

As a result of their standardisation, French NPPs enjoy a unique safety-related experience feedback and they were able to boast a total of 750 reactor years by the end of l 997.

Finally, the **economic** factor also has an impact on plant life of units in operation. The cost of generating power at French NPPs needs to remain competitive compared to competing generating units, all this in spite of induced maintenance costs arising to counter ageing effects and those connected with potentially new safety requirements. Which means that EDF need to control and correctly assess probable trends in routine and exceptional maintenance costs (refurbishments, replacements). Currently, numerous components can be replaced in a limited amount of time and cost. For instance, our steam generators are replaced within 35 days with controlled radiation exposure.

This also means that sometime in the future, we will need to identify what the constraints are in connection with decommissioning of plants and the renewal of our NPPs, in terms of costs, manufacturing deadlines and therefore dates of decision.

Our future choice, due in about ten years, will depend on two types of decisions:

- on the one hand, authorised investment (i.e. maintenance, replacement of components, ten-year maintenance packages) to carry on operations.

- On the other hand, choosing the type of facilities to replace decommissioned plants. Since conventional units, which involve a limited building period (less than 3 or 4 years), may well replace our current reactors, it is a guarantee of freedom of decision as regards safety.

Decision and economic analysis

The economic choice between shutdown and continued operation of an electricity production unity (nuclear plant unit or otherwise), is made on the basis of the "usage value" of the unit. This value corresponds to the upgraded security measures the facility will provide for in its remaining life period. The calculation is made on a yearly basis, simulating the probable operation of the unit in question as well as the rest of the generating capacity:

- fuel saving (e.g. extra cost of fossil fuel relative to nuclear fuel); and
- failure saving (this is in fact the optimum utilisation of the available power) from which is deducted overhead and exceptional expenditure (heavy-duty work, replacements, etc.).

A positive usage value means that it is profitable to continue operation. This calculation method is the one used over the past years to decommission old thermal power plants or old-generation graphite gas nuclear power plants.

Safety only plays an indirect role in this process. Despite high costs in situations of drastic design change, allowances should be made in maintaining the safety level of old power plants, or even improving them so that they are of the same order as modern power plants.

Conclusions drawn from the numerical approaches indicate that lifetime extension of French PWR units is very profitable, even if extensive work has to be performed to achieve this end. It would take drastic alteration of regulations and ensuing radical changes, to contradict this statement.

As a numerical example, in 1997, about 400 million Francs per 900 MWe unit were needed for "routine" and "exceptional" maintenance and as a consequence of reasonable safety reassessments, during the second 10-year outages.

Programmes

a) EDF maintenance activities

Operating 56 standardised PWR units from various reactor series requires a maintenance strategy for protecting the operator from generic-type defects which may have a significant impact on safety and availability of units in operation.

Maintenance activities are divided up into two main categories:

- preventive maintenance: it minimises the potential or confirmed degradation of equipment and its impact on the availability of the system guaranteeing overall safety of the installations. The objective is to act before detection of an actual defect ("Optimized Reliability Centered Maintenance");

- corrective maintenance: it restores the operating capacity of equipment subject to a functional defect

More specifically. EDF gives priority to routine and exceptional preventive maintenance activities because both imply a so-called "anticipation approach". The objective of this approach is to first identify and assess generic-type defects of components and systems prevailing in all French NPPs in operation. This relates to functional faults or degradation, component ageing, and manufacturer diminished skills. Based on this method, the objective is to offer adequate solutions (study files, spare parts, tools, etc.) by assessing their technical and economic impact on the defective units.

Routine maintenance refers to periodic maintenance activities with a limited scope (in terms of implementation and cost), based on maintenance policies and programmes. The defective equipment is serviced, repaired or even replaced.

Exceptional maintenance involves sporadic though possibly generic activities. These activities are usually performed once in a plant life and involve significant resources and cost. Because EDF's units are standardised, this type of maintenance usually implies generic-type activities co-ordinated at corporate level. In this case, it involves refurbishment activities (such as partial replacement) or large-scale replacement (full replacement of main components).

The "anticipation approach" covers the overall scope of plant life. It starts of with first level anticipation, i.e. scheduled short and mid-term routine maintenance (from 3 to 10 years), but also involves long-term prospects (end of life). The transition is ensured by exceptional maintenance/related anticipation actions (from 5 to 20 years).

b) Research and development and expert survey programmes

The key to life cycle management is to be familiar with long-term equipment behaviour. R & D efforts in this area started as early as the commissioning of French NPPs and were subsequently geared to the equipment sensitive areas. This effort, combined with accrued experience feedback, made it possible to know more about degradation phenomena. By comparing situations and behaviour it was then possible to extend the investigation scope to a large range of equipment and risk-prone areas.

Beyond the analysis of equipment ageing [5, 6, 7], overall generic approaches are being developed. These studies focus on specific generic-type damage: irradiation/embrittlement, vibrations and wear, corrosion/erosion, fatigue, non ductile failure, stress corrosion, and non-destructive measurement of material degradation (through ageing).

To achieve this objective, significant resources are available within EDF, both in terms of computing tools and experimental means. EDF has also launched a large scale external co-operation policy.

Some pending large-scale investigations are shown in Table 1.

Table 1. **Major research and development for plant life management**

Effect of irradiation on austenitic steel (core internal equipment)
An extensive programme of tests performed in a research reactor has been launched in order to prevent a potential embrittlement, hazard due to irradiation of stainless austenitic steel. In 2001, EDF will have "end-of-life" type ageing results regarding internal equipment steel.
Probabilistic approach to damage risks (reactor vessels)
The objective here is to develop a probabilistic model in order to assess the potential life of a PWR reactor vessel and to apply this model to a concrete case [8]. The model will consider embrittlement of irradiated vessel as a degradation phenomenon as well as main parameters and associated uncertainties: transients and their occurrence, technical characteristics of materials and content of embrittling components, defects, neutron fluence, fuel management and predicting changed transition temperatures.

Table 1. **Major research and development for plant life management (continued)**

Non destructive assessment methods
Among the few methods currently investigated in the world, the thermoelectric power process (involving assessment of average diffraction pattern and hence evaluation of austenoferritic steel ageing) is being developed.
Reactor containment mock-up [9]
The MAEVA mock-up has been built at Civaux NPP and the first tests are due to be carried out in 1998. The objective of this project is to become familiar with the following features: - containment behaviour in case of a LOCA or other serious accidents, - leaktightness of the containment wall when in presence with air-steam combination, - behaviour of composite-made coating.

Table 2 is a brief overview of the significant progress obtained so far.

Table 2. **The significant progress of research and development for plant life management.**

Modelled and predicted behaviour of cast austenoferritic steel [10]
A theoretical and experimental method has been developed in order to assess the risk of non ductile failure of cast austenoferritic steel components. From a theoretical point of view, the general mechanical ASTER code has been completed in order to account for behaviour laws governing materials entailed in the collapse type investigated and fine tune the actual physical problem. On an experimental point of view, two main actions have been launched. Steel toughness was determined based on sampling of a small test specimen. SEM4 tests performed on a defective elbow (at a 2/3 scale and at full pressure and temperature) confirmed that the methodology of “leak before break” is fully justified. These test results confirm theoretical assumptions and validate the model namely in terms of the significance of crack stabilised spread. The whole study confirmed that there are indeed significant margins: leak before break, stabilised and arrest crack growth.
Steam generator probabilistic maintenance study
The model for assessing the probability of a SG tube rupture and, for a set safety level, the lifetime depending upon maintenance strategies and monitoring programmes has been completed so as to account for newly appeared SG defects. This model has been used as part of the SG replacement program.
Irradiation/embrittlement
As a result of tests carried out in a research reactor, assumptions made when assessing the impact of neutronic spectrum on vessel steel ageing have been validated. These tests confirm that only neutrons with an energy level exceeding 1 MeV are to be taken in consideration.
Expert survey program
To confirm R & D assumptions and validate non-destructive test results through review, expert survey programmes may enhance what we know about the various phenomena involved. In this regard an extensive programme was launched after the Chooz A NPP was decommissioned in 1991 after 24 years of operation [11]. As an example the survey performed in the reactor vessel confirmed the assumption of the existing monitory programme [12].

Public acceptance

The public is not directly involved in decisions concerning the lifetime of nuclear plant units. Nevertheless, its acceptance is indispensable.

The acceptability of lifetime extension, but also, more generally, nuclear acceptability, may deteriorate or improve depending on the gravity of any future accidents liable to occur anywhere in the world, or depending on various events promoting the penetration of nuclear energy (advertising campaign, procurement cost of competitor fuels). Nuclear acceptability will be all the greater if EDF can safely produce a kWh for a competitive price, and optimisation of unit longevity is one way of reaching this goal.

The acceptability of nuclear plant unit lifetime extension by the French public will be all the greater if the utilities of the other countries take a similar approach; hence, the importance of international meetings, such as those organised by the OECD.

Critical components

When the "Plant Life Program" was first launched, "sensitive equipment" meant "the equipment whose replacement cannot be scheduled as part of base maintenance programmes and involving massive, difficult and expensive activities". In this regard, equipment was included which might be part of exceptional maintenance. The "Plant Life Programme" selected the following 18 'sensitive' components as shown in Table 3.

Table 3. **Eighteen sensitive components.**

Nuclear Power Supply System	Main Primary System	• Reactor vessels • Main primary system pipes with a large diameter • Other pipes of the main primary system • Steam generators • Casing of a primary pump • Pressuriser
	Other Mechanical Components	• Safety Class 2 or 3 pipes • Control rod drive mechanisms • Reactor vessel internals
Ex-Nuclear Power Supply System	Containment and Civil Engineering	• Containment and penetrations • Reactor pit • Anchoring
	Turbogenerator Set	• Turbine • A.C. Generator
	Control and Instrumentation	•
	Electrical Equipment	• Electrical cables
	Cooling Towers	•
	Miscellaneous	• Revolving Crane

Nowadays, some equipment is considered as "Sensitive" because it is irreplaceable or requires large scale repair or replacement. This type of equipment is usually identified in the countries with a nuclear power generation program. To identify them, a certain number of criteria are used such as (without any priority order):

- knowledge of degradation phenomena,
- impact of various maintenance activities on availability during plant life,
- significant replacement or repair cost of activities,
- assumed or confirmed impossibility to replace equipment,
- safety-related confining role of equipment.

A specific study accounts for all available aspects involving each equipment in order to assess their potential life: design rules, construction and operations-related experience feedback, and R & D.

By applying maintenance programmes based on experience feedback and enhance knowledge, it is possible to prevent ageing phenomena. By complying with operating procedures and technical specifications and performing periodic testing, ongoing safety functions of active and passive components can be enhanced as part of NPPs yearly safety reports and periodic equipment reports (namely those scheduled during ten-yearly outages).

Meanwhile, thanks to experience feedback, the concept of “sensitive” components has evolved: all components and pieces of equipment whose replacement is a possibility are or will be dealt with as part of (routine and exceptional) maintenance. In the regard, such equipment can no longer be considered as “sensitive” as described in the “Plant Life Program”. Consequently, components or pieces of equipment whose replacement is considered as not possible are closely reviewed in the follow up analysis on life cycle management. Today, only two components still belong in the so-called “sensitive” category, i.e. the reactor vessel and reactor building containment. All other have been considered as replaceable or possibly replaced.

REFERENCES

[1] OECD/NEA (1998), *Nuclear Energy Data 1998*, Paris.

[2] B. Dupraz, P. Lecocq, R. Godin, *Life Management of the French Nuclear Power Plants* – PLIM.PLEX 95, Nice, 1995.

[3] G. Serviere, EDF *Wiews on the Safety and Economical Aspects of Plant Life Management* – PLIM.PLEX 95, Nice, 1995.

[4] J.F. Dubois, M. Sabaton, L. Valibus, *Plant Life Management of French NPPs* – ICONE 5, Nice, 1997.

[5] J. Branchu, *Longevity of PWR Internal Structures* – PLIM.PLEX 95, Nice, 1995.

[6] C. Rieg, C. Pichon, A. Teissier, *EDF Programme on Ageing Mechanisms of Primary System Components* – PLIM.PLEX 95, Nice, 1995.

[7] L. Valibus, J. Branchu, *Durée de Vie des Équipements du CPP (NSSS'Components life)* – SFEN.ST7., 1996.

[8] M. Persoz, J.M. Frund, *Scatter Modelling of Fracture Toughness Data for RPV Structural Integrity Assessement* – ICONE 5, Nice, 1997.

[9] D. Chauvel, C. Coladant, H. Roussel, *Monitoring Nuclear Power Plant Engineering Structures* – AIM – 13th Congress on Electrical Power Stations, Liege, 1997.

[10] G. Bezdikian and als, *Life Evaluation of Cast Duplex Stainless Elbows on PWR Primary Circuit* – ICONE 5, Nice, 1997.

[11] R. Godin, B. Koudriavtsev, *Chooz An Expert Survey Program – Reactor Vessel and Vessel Internals* – PLIM.PLEX 95, Nice, 1995.

[12] M. Cuisinier, F. de Keroulas, L. Valibus, *Plant Life Management of French NPPs and the CHOOZ An Expert Survey Program* – PLIM.PLEX 97, Prague, 1997.

GERMANY

In 1998, nineteen nuclear power plants with a total net capacity of 21.1 GWe supplied 33.1% of all the electric power produced in Germany. Operating licences of nuclear power plants have no time limit. Control of ageing is a part of Quality Assurance. The oldest plant, PWR at Obrigheim, has been operated over 30 years. The electric utilities have the following interests of plant life management: Reduction of maintenance costs, Optimisation of shut down periods; Reduction of operations costs; Reduction of costs for waste management and amount of waste; Man-rem-reduction; Increase of safety and reliability; Increase of efficiency and availability; Optimised operation; and Plant-life extension.

Organisation and their responsibilities

At present, there is no special organisation set up in Germany to deal with issues of nuclear plant ageing, life management and plant life extension. All government, industry and research organisations already involved in the nuclear field can also, in principle, be involved in plant ageing, life management and life extension matters, whereby the competences/experience or legal authorisation treats the specific task/order/part. Co-ordination is done by the authorities and the utilities involved in the specific issue.

Regulatory processes

a) Safety regulation

In Germany, there is no life extension programme to date. The licence for operation is not limited in time. The term life management, if understood as plant operation management, is a task entrusted entirely to the utility of each separate power plant station. Plant ageing of systems, structures and components relevant for plant safety is taken care of within the normal process of maintenance by the operator and within the process of surveillance by the competent state authority (an appointed state ministry differing from state to state) together with appointed independent advisory organisations such as the local Technischer Überwachungsverein (TÜV), Gesellschaft für Anlagen und Reaktorsicherheit (GRS) or the German Reactor Safety Commission (RSK), on behalf of the Federal Ministry of the Environment, Nature Conservation and Reactor Safety (BMU).

The TÜV is checking and certifying on behalf of the authority the specified tests and in-service inspections, conducted during the refuelling and overhaul outages, and that the plant is in safe condition.

GRS acts as independent expert advisor, especially for BMU. During the last years GRS has also dealt with the question of whether the ageing observed for technical equipment installed in German NPP is within the expected acceptable limits and whether the ageing management as practised is sufficient [1]. The overall conclusion was that the technical and organisational measures for limiting the effects of the physical ageing of the technical equipment installed in German NPP are sufficient at present. The further development of ageing management was identified as an issue, to intensify and widen the basis for the technical expert advise provided for the BMU.

The RSK is an honorary advisory commission, nominated by the federal authority, considering major and more generic safety issues. Conclusions of the RSK sessions are commonly published in the Federal Gazette “Bundesanzeiger”, issued by the German Federal Ministry of the Environment, Nature Conservation and Reactor Safety (BMU), permitting the organisation an official administrative role.

The only formal task to date regarding the issues of plant ageing, life management and life extension is the 1988 proposal by RSK, stipulating periodic safety reviews of each nuclear power plant at service life intervals of about 10 years.

German (safety) authorities undoubtedly request that older plants be backfitted as far as is reasonably possible to the latest safety level according to the state of the art. Despite the fact that this desire is not covered by the German Atomic Energy Act, that licence shall protect the investment on the basis of the safety standards at the time the licence was granted, all German nuclear power plants have continuously been, and are still, subjected to extensive safety upgrading measures on a more or less voluntary basis.

b) Economic regulation

There is no economic regulator for nuclear plant management. The operation of a nuclear power plant is completely the responsibility of the specific power plant management with the overall business policy defined by the owner utility. The relevant utilities are public/private stock corporations with at least a major portion of capital shares in the possession/control of the local state, municipal or communal administration.

Decision and economic analysis

As already mentioned, economic decision-making is the responsibility of the utilities which use different evaluation methods, based on a wealth of examinations and proposals by the suppliers, and on indicative statements from the authorities or independent experts if involved in the specific case, to come up with their final conclusions.

Cost/benefit analysis applies especially to the case in question concerning further plant operation after backfitting versus plant retirement. Risk must be recognised and evaluated in order to obtain a license for planned/proposed and calculated backfitting measures.

Decisions on whether or not to backfit or upgrade certain components nowadays in German plants are of no relevance and are made on a purely economic basis.

The balance between preventive maintenance and corrective maintenance is constant if the unscheduled outages of the power station due to component failures are negligible, and if time and cost expenditures on preventive maintenance work is minimised. The latter can be accommodated by using operating experience.

Decisions on whether to repair, replace or re-design certain components and systems nowadays in German power stations are not very relevant due to their rather good quality and will probably be taken on the basis of normal economic considerations and operational practicability.

Authorities in Germany are interested in safety, not in economics, and are therefore not involved in commercial judgments. Changes in requirements for electrical cables, for example, are mainly due to safety (fire protection) or other operational factors.

Programmes

Again, it must be emphasised that there are presently no special age-related managing programmes in Germany for surveillance, testing, etc. of critical components, systems and structures other than those developed in the course of normal plant operation and maintenance due to experience and test findings or to special examinations requested by authorities subsequent to disclosure of weak points in other nuclear power plants. Ageing management is part of the regular activities of the individual utilities related to maintenance, backfitting, and quality assurance. The large amount of activities in this field have been summarised in a report, issued by the German association of power plant operators (Technische Vereinigung der Großkraftwerkbetreiber, VGB) [2]. Elimination of weak points from the standpoint of safety was the main objective during many plant specific back-fitting and refurbishment activities, by which the plant status was currently adapted to the today's state of the art in safety and technology. Due to this preoccupation, all German nuclear power stations are now practically free of any major restraints due to age-related degradation.

Ageing monitoring systems, for instance the fatigue monitoring system (FAMOS) introduced in all German pressurised water reactors at the request of the authorities, primarily serve as safety assurance with respect to primary pressure boundary integrity over the service life.

If applicable, output obtained from the monitoring systems is used for more sensitive operations of the nuclear power station in order to achieve even greater safety margins with respect to ageing.

Fracture mechanics safety analysis of reactor pressure vessels are commonly performed on basis of advanced PTS-analysis and up-dated results of irradiation surveillance programmes, with the result that even for the RPVs of the first generation plants (KWO, KKS) safe operation is possible even beyond the originally designed life.

Industry

The German association of power plant operators (Technische Vereinigung der Großkraftwerkbetreiber, VGB) takes part in relevant international programmes related to NPP ageing and life management (e. g. ICG-EAC, Halden-project, EPRI-CIR-project, etc.).

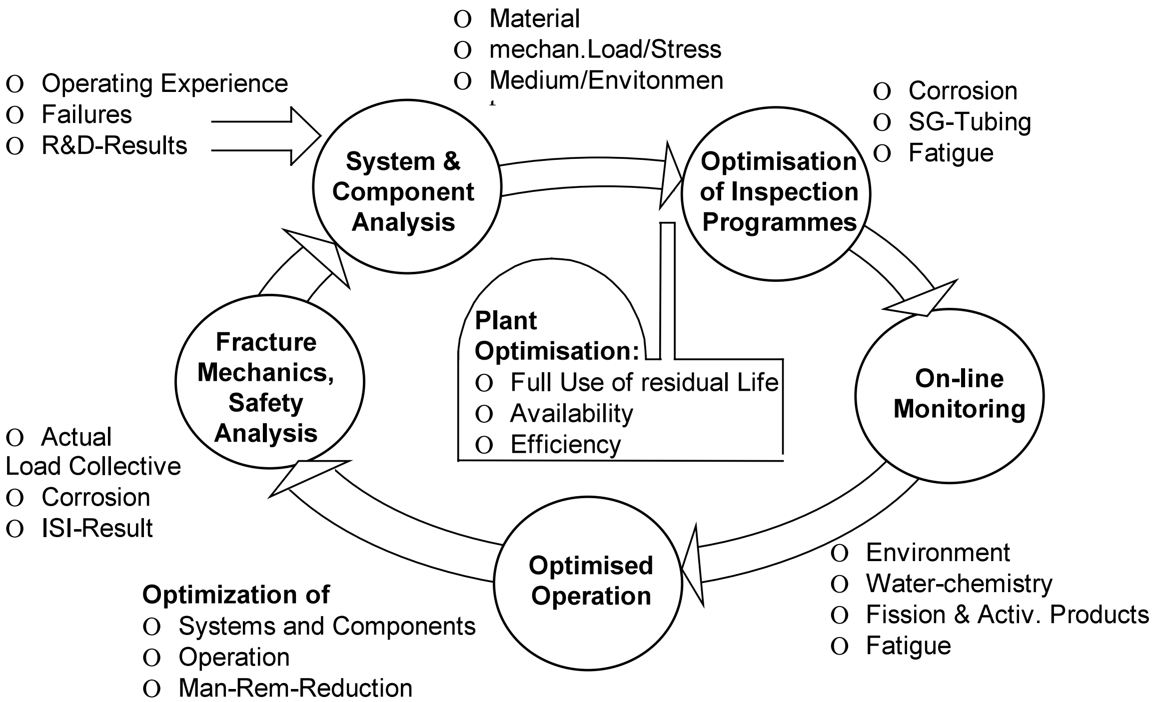
Siemens as vendor and architect engineer of all German NPP, currently in operation, has developed "an overall approach for an economically and technically effective procedure of plant life management", with the major individual technical aspects indicated, shown in Figure 1 in the form of a feedback loop [3]. Siemens is involved in respective work performed in the plants in Germany and in abroad. Siemens also takes part in major international activities in the field of ageing and plant life management (e. g. IAEA, EC-networks like AMES, NESC, EPLAF) and is performing research work on this topic on its own expense.

GRS investigates the effects of long-term operation on the safety of the technical systems of nuclear power plants on behalf of BMU in a current project. The work covers ageing of passive and active components, instrumentation and control systems, and structural systems. In this framework, reference criteria and approaches for the judgement of ageing-related reliability losses of technical systems are worked out. To enlarge the basis of knowledge, GRS is therefore tightly incorporated in the international co-operation with the IAEA, OECD/NEAQ and CEC. An intense bilateral co-operation takes place with the French partner organisation IPSN.

Public acceptance

Public acceptance of nuclear power is increasing during the discussions on the question of rest lifetime of operating NPP which was raised by the government.

Figure 1. **Ageing and Plant Life Management Programme**



REFERENCES

[1] GRS Cologne, "*The Effects of Long-Term Operation on The Safety of German Nuclear Power Plants from the Viewpoint of GRS*", Germany, September 1997.

[2] M. Alt, M. Fuchs, H. Krapf, U. Peter, H. Schalk, M. Seevers, M. Wenk, "*Alterungsmanagement in Deutschen Kernkraftwerken*", VGB 1997.

[3] Manfred Erve, *Ageing and Lifetime Management*, Proceedings of IAEA Specialist Meeting "*Strategies and Policies for Nuclear Power Plant Life Management*", Vienna, Austria, 1998.

HUNGARY

In 1998, four nuclear power plants of the WWER-440/213 type, with a total net capacity of 1.7 GWe supplied 36.8% of all the electric power produced in Hungary.

The new Atomic Energy Law issued in December 1996 established the provisions for fixed-term operation licences. The licence shall be renewed every 12 years, and it requires a comprehensive nuclear safety review. It includes the determination of the lifetime of systems and components as one of the most important and time-dependent safety factors.

In general, the plant is designed for an operation lifetime of 30 years. This was not, however, specified in the original documentation provided by the designer. There are large differences between the lifetimes of main components if such a parameter is available in the plant documentation. For example, the design life of the reactor pressure vessel is 40 years, while for the pressuriser it is just 25 years. Therefore, no legal limitation exists with respect to the overall lifetime of Paks units.

The perceived goals of lifetime extension are in accordance with the "renewing power plant construction strategy" developed recently by the Hungarian Power Company Ltd, namely the further exploitation of the productive capacities at the existing site (which is envisaged); maintaining the existing site accepted by the public; and, the improved utilisation of the present infrastructure.

Objectives and strategies

LTM shall provide the long-term operation of the high-value or critical components of the plant with an economically optimal standard and in compliance with the safety requirements. Also, it shall provide the basis to avoid unexpected malfunctions and operation failures with severe consequences. The final objective is to allow the plant to operate beyond 30 years, even if main component replacement is necessary.

There are technical, safety and local conditions that need to be met to operate a power plant, even within the planned lifetime. However, all these conditions are not sufficient, if the economical requirement to produce electricity at a competitive price is not met. Therefore, lifetime extension procedures as well as plant operation economics need to be considered.

Technical aspects

The change in the regulatory requirements is an important factor that needs to be considered in the LTM. However, there is the internal need to identify the problems at an early stage and to take the corrective actions in a timely manner. Actions shall be taken when there is still a chance to choose among alternative solutions. In general, the LTM needs thorough monitoring and trend analysis for component and system conditions. Another consideration is whether the most important data and information on these components are collected and their processing is adequate. Experience has shown that the original configuration of the I&C system just partially meets the requirements of a lifetime monitoring oriented system. Therefore, additional capabilities are necessary to study the expiration of the lifetime of different components.

The revision of the original design calculation on the technical level of the 1990s appeared in parallel with the safety enhancements in the frame of the Advanced General and New Re-Evaluation of Safety (AGNES) project. The general goal of such revision is to find the most stressed regions of critical components and to provide the most appropriate determination of data collection points for ageing monitoring.

Economic conditions

Decisions to be made within the lifetime management shall have a sound basis from an economic point of view. Decisions involving significant financial investments can be expected if the return of expenditure can be proved within acceptable uncertainty margins.

Long-term planning allows for scheduling of costs so that they can be spread out over several years. The financing forms for the necessary investment will hopefully be selected well in advance in parallel with the maintenance of the company's competitiveness.

An exact calculation of the economically optimal lifetime is not possible because of the relatively long time-period of the remaining design life, the frequent changes in the legal and monetary framework, uncertainties regarding the privatisation process and finally, changes in energy prices in Hungary. However the process of harmonisation of the Hungarian political, legal and economical environment with the European Union is under way. Therefore, uncertainties associated with the transition period should diminish in the near future.

Safety enhancement

During the history of the plant, major activities were oriented on the maintenance of safety and competitiveness. All the above-mentioned activities were based on the company's safety policy and goals on economics. As in other OECD Member countries, in Hungary, the review of the design basis of the nuclear power plant became necessary. For this reason, in the late 1980s, a safety upgrade process started, and this activity involved more than 120 separate actions. In 1993, the AGNES project was completed and all the remaining actions were re-ranked based on Probabilistic Safety Assessment (PSA) and economics. In 1996, the regulatory environment also changed with the issuing of the new Atomic Energy Act, which was more in line with regulations in Western countries. Since 1996, the new act requires re-licensing every 12 years. As a first step, Paks completed the documentation and safety evaluation in 1996 and the Hungarian Atomic Energy Commission renewed the operating licence of the first 2 units for 12 years. The licence renewal process has already started for the 3rd and 4th units. The original safety upgrading programme will be completed in a few years. As a result the Paks units will be operated on a safety level which is in accordance with the Western European standards.

Ageing and license renewal

In Hungary, the first programmes focused on the investigation of the ageing phenomena started in the late 1980s (except in the case of the reactor pressure vessel, where a surveillance programme started in parallel with the operation start-up of the units). These programmes, partially initiated by the IAEA, domestic institutes and the Paks operator, concentrated on the operation licence renewal process.

The objective is to save the reactor pressure vessel and investigate degradation mechanism induced effects for the equipment that remained in the frame of the LTM programme after the selection process. Generally, it can be stated that the reactor vessel determines the plant lifetime, and the operability of the rest of the components will be managed with periodical refurbishment or replacement. The reactor and the pressuriser were constructed by the Czech Skoda Works under Russian licence. Based on the results of the destructive testing of the probes, non-destructive testing of the vessels, and after a careful thermohydraulic analysis, the fracture mechanic assessment proved that the operational lifetime of 30 years is reliable without any lifetime management. With some further action, the lifetime of the reactor pressure vessels (RPVs) can be doubled without annealing under the same operating circumstances as during the accumulated 48 reactor-years.

After the AGNES project, safety re-classification of all systems and components was undertaken in the frame of the licence renewal process.

The process contained the following steps related to equipment: revision of thermohydraulic analysis and fracture mechanics assessments; unique database for material tests and lifetime management purposes; determination of necessary modification of measurement system for ageing monitoring; expert system for ageing monitoring; data collection; and preparation of the necessary actions for refurbishment, reconstruction or replacement.

The programme requires the co-operation of experts from different professions and different areas (technical background, operation, maintenance). Consequently, one of the most important tasks is the training of the people involved.

The second important task is to collect the necessary information and experience from the nuclear operators using the existing communication channels maintained by different international organisations like the IAEA, WANO, OECD/NEA or the WWER-440 Club through technical co-operation, conferences, technical visits, independent reviews, sponsoring of regional projects, etc.

The programme needs to be run under the control and agreement of the national authority. Based on the legal requirements, the Hungarian Atomic Energy Commission started the preparation for the licence renewal process in 1993. After two years of preparation, the internal process at the Paks NPP also started to prepare the necessary documentation in 1995. After the completion of this documentation, Paks received the approval for a further operation period of the 1st and 2nd units, until 2008. Each step provided by Paks is under control and in agreement with the authority in the area of lifetime management.

Strategic goals of development

Since the late 1980s, Paks NPP has started a permanent process of safety enhancement, designed to meet the internationally accepted safety requirements. This process has been reviewed by different international organisations. After the results of the first level PSA analysis of the units, Paks started to implement the most important actions from the point of Core Damage Frequency (CDF) value reduction. After a period of 5 years, the reconstruction of all 4 units against earthquakes is planned, as it is the most serious external hazard.

Waste management is also a task which requires certain development actions on site and also in the region. There are existing solutions for spent-fuel waste management on site.

There are a great variety of different solutions to manage all the problems related to safety upgrading, waste management, operation and maintenance. The only limiting factor is the long-term competitiveness of the plant that could prolong the implementation of tasks.

JAPAN

In 1998, 53 nuclear power plants including 28 BWRs and 23 PWRs with a total net capacity of 43.5 GWe supplied 34.4% of all electric power produced in Japan [1]. The Japanese central theme on energy policy is to create and maintain an energy supply structure that is stable, economical and with low environmental impact because of lack of energy resources and enormous energy consumption. Because nuclear power generation provides superior characteristics in terms of supply stability, economy and environmental load, it is recognised as one of the essential energy sources in Japan's energy supply policy. The development of nuclear power generation has been steadily increasing since the commission of Japan's first commercial nuclear power plant in July 1966. The total capacity of nuclear power generation in the year 2010 is expected to be approximately 70 million kW.

Following growing public interest and concern on ageing nuclear plants in the near future, an interim report issued in June, 1994 by the Nuclear Power Committee of the General Council on Energy addressed the importance of countermeasures against the ageing of nuclear plants based on the consideration on items including the current status of the plants. The Ministry of International Trade and Industries (MITI) issued a report named "Basic Policy on Aged Nuclear Power Plant", in April, 1996, to provide basic concepts regarding aged plants through examinations on how to evaluate the integrity of aged nuclear power plants and how to address problems of the aged plants in future.

Organisations and their responsibilities

The Ministry of International Trade and Industries (MITI) provides regulatory procedures and guidelines, and reviews the license applications of commercial nuclear power plants. MITI also provides the basic strategy, establishes and conducts research and development projects on plant life management.

The Japan Atomic Energy Research Institute (JAERI), a national research institute, conducts research on material degradation of pressure vessels and electrical cables based on fundamental research. The Japan Power Engineering and Inspection Corporation (JAPEIC) and the Nuclear Power Engineering Corporation (NUPEC), both public-service corporations, are entrusted with conducting research and development projects to establish and demonstrate technologies whose developments take a long time and require a large budget, to conduct material verification tests, develop life prediction, and to evaluate life and ageing diagnosis technologies related to ageing issues by MITI. These technologies are generally applicable to individual nuclear plants.

The Central Research Institute of Electrical Power Industry (CRIEPI), sponsored by electric utilities, conducts research and development programmes on cost/benefit analysis, structural integrity evaluation and material degradation of pressure vessel, reactor internals, and steam generator. Plant manufacturers are engaged in co-operative research programmes for plant life management. Utilities conduct the detailed technical assessment of integrity on each component and structure including replaceable components, followed by the government reviews.

Regulatory processes

a) Safety regulation

The sole regulatory and supervisory authority on commercial nuclear power plants is MITI. Under Japan’s legal provisions, a nuclear power plant licence is granted for an indefinite period. However, the periodical inspection system is defined, and a nuclear power plant is shut down for inspection by MITI once a year. MITI endorses the safety of a plant as long as it meets the safety standards at the time. The electrical utilities also implement inspections on their own initiative during this plant shutdown period.

Japan’s nuclear power generation facility components must be maintained and managed to meet those technical standards specified precisely in ministerial ordinances and notifications. Japan’s current technical standards are, however, based on ASME Code Sec. III. On the other hand, due to the recent developments in fracture mechanics, the integrity of structures and components has been quantitatively evaluated. This concept has already been introduced in ASME Code Sec.XI. Since this latest information is not yet fully reflected in Japanese technical standards, the studies on the matter will be promoted with the Ministerial Ordinances and Notifications subsequently reviewed as required. The study regarding facility maintenance standards such as ASME Code Sec.XI. has been carried out and is still under preparation. This research is consigned to the JAPEIC by MITI. The results of the research were summarised in March 1996 as the first draft standards of the Nuclear Plant Operation and Maintenance Standards (POMS), that is the technical standards for the maintenance of nuclear power generation facilities (Draft). The draft consists of items of the In-service Inspection (ISI), Evaluation, and Repair/Replacement and so on.

b) Economic regulation

Regulations governing the electrical utility industry and authorisation of the electricity rate (tariff) are under the jurisdiction of MITI. Economic issues involved in ageing, etc., are assessed by the utility companies.

At present, there is no economic regulatory policy or requirement relevant to plant life extension in Japan.

Strategy

MITI issued a report entitled “Basic Policy on Aged Nuclear Power Plants”, in April 1996, to provide basic concepts regarding aged nuclear power plants through examination on how to evaluate their integrity and address the problems in future. Figure 1 schematically illustrates the approaches and measures to address nuclear plant ageing. At first, three lead plants were selected. The technical evaluation of the major components/structures of these plants and the basic concept for dealing with the aged plants are considered to be phase one (Part 1 Evaluation). In the second phase, the utilities conduct the detailed technical assessment of integrity on each component and structure including replaceable components, followed by the government reviews (Part 2 Evaluation). Upon completion of phase two, the identified important factors will be reflected in the long-term maintenance programme of the utilities and in the periodical inspections conducted by the government (see Figure 2). The comprehensive long-term maintenance programmes of the aged plants are scheduled to be established when they reach 30 years of service. The same programmes will be conducted at the other plants one by one.

a) Lead nuclear power plants

Lead nuclear power plants with longer operating times were selected for the Part 1 and 2 evaluations as follows:

(BWR) Tsuruga unit-1 of the Japan Atomic Power Company (JAPC) commissioned in March 1970 has been in service for 29 years.
Fukushima Daiich unit-1 of the Tokyo Electric Power Company (TEPCO) commissioned in March 1971 has been in service for 28 years.

(PWR) Mihama unit-1 of the Kansai Electric Power Company (KEPCO) commissioned in November 1970 has been in service for 28 years.

The technical evaluation is based on an assumed operation period of 60 years. This period does not seem to be a problem for the engineering assessment of the past with a history of about 30 years' operation. The actual number of operational years should be determined by various aspects including technical factors as well as economic elements.

b) Part 1 technical evaluation

The main purpose of the Part 1 technical evaluation is to assess whether the current maintenance activities including periodic inspections are effective in dealing with the aged nuclear power plants. Figure 3 shows the Part 1 technical evaluation process.

The major components and structures (CSs) to be evaluated are identified by considering the following factors: 1) safety related CSs, 2) not easy to repair and replace, and 3) long-term ageing issue to be considered. The components and structures identified are 8 components and one structure for PWR, and 6 components and one structure for BWR.

To conclude, it is believed that plant integrity can be maintained for a period exceeding 60 years from a technical standpoint through continued proper inspection and maintenance activities. The evaluation showed that major components and structures provide sufficient tolerance against most ageing phenomena. There are, however, some phenomena, including stress corrosion cracking which cannot rule out the possibility of future actualisation, and items have been extracted which are required for fulfilment of inspection and examination in the future.

c) Part 2 technical evaluation

In Part 2 of the evaluation, Japanese electric utilities make a technical assessment of a wider range of components (consisting of thousands of items) of the above-mentioned three leading power plants, taking into account not only a safety point of view, but also the perspective of avoiding an unscheduled shutdown in order to develop measures against ageing degradation. Based on this assessment, the utilities review the completeness of integral components which are important for the safe and continuous operation of these power plants. Also, the methods and periods of inspection and maintenance can be evaluated from this assessment for future implementation.

An outline of Part 2 evaluation is summarised in Figure 4 [2]. Aiming to further improve the reliability of nuclear power plants, the components to be assessed are classified into two categories: "Important Components for Safe Operation" and "Important Components for Continuous Operation". The components chosen for assessment amount to thousands of items. Therefore, to make a rational assessment, they were divided into groups of similar items, such as type, construction, operating circumstance (which include operating location, fluid properties, etc.) and materials. Typical components were then selected from these groups by considering their importance, operating conditions (pressure, temperature) and other critical conditions.

The typical components selected are broken down to parts level and technically assessed by considering the phenomena of ageing degradation. This technical assessment verifies plant integrity and the appropriateness of current inspection maintenance programmes (additional items may be required or not), assuming that the plants are to remain in long-term service.

The next step is to apply the results of the assessment of the typical components to other components in each group with consideration to the differences between components.

Through the evaluation of numerous components, systems and structures (CSSs) in the Part 2 evaluation, those items susceptible to ageing degradation are identified. With this knowledge, it is possible to develop rationally inspection and maintenance methods for aged nuclear power plants. The conclusions and summary were published on 8 February 1999 after the review by the MITI.

Decision and economic analysis

Cost/benefit analyses are the responsibility of the electrical utility company in charge. At present, research on evaluative methodology is being conducted. For example, the Central Research Institute of Electrical Power Industry (CRIEPI), sponsored by electrical utility industries, has developed a computer software for macroscopic economic evaluations. Approximate unit generating cost can be calculated by taking into account the cost of decommissioning a nuclear reactor, the cost of implementing life extension measures, etc.

Since backfitting is not legally required, no official evaluation methodology has been established. Such a decision would generally be made by a comprehensive judgement mainly based on the economic calculation of (1) the cost of backfitting a certain component, and (2) the cost of upgrading the existing component. In exercising such a judgement, the evaluations of radiation exposure and component reliability are also important factors to consider.

Preventive measures are performed as a matter of principle. Judgements are based on experience and plant performance records.

Economic calculations are performed on: (1) cost and time required for repair work and frequency of repairs anticipated, (2) cost and time required for replacement and the anticipated frequency of replacement; and (3) cost required for re-design and re-evaluation etc. Comprehensive judgement is exercised by taking into account the amount of radiation exposure, reliability of components, etc.

No official methodology has been developed but there is interest in developing a generic methodology. Safety supersedes all other factors when it comes to modifying nuclear plants.

The most significant result of cost/benefit analysis to date was performed on a computer code developed by CRIEPI [3], in which costs of re-building a PWR plant designed to operate for 60 and 30 years, respectively, were calculated. It was concluded that the overall cost for re-building within a 30-year period was 10% more expensive.

Research and development projects

The government and the private sectors have been extensively carrying out research and development related to plant ageing. Table 1 shows the plant ageing-related major research and development programmes in JAPEIC and NUPEC (Nuclear Power Engineering Corporation) under the sponsorship of MITI. The technology category is roughly grouped into three areas according to the classification of the MITI report.

The Plant Life Extension Technology Development Project (PLEX) has been conducted to develop the methodology for evaluation of the life and integrity of the major components and structures. Some of the results and evaluation methods obtained from the PLEX project are applied to the technical evaluation addressed by the MITI report. After MITI had published the report, JAPEIC newly started three plant-ageing-related projects, namely the Nuclear Power Plant Life Management Technology Project (PLIM), the Nuclear Power Plant Maintenance Technology Project (PMT) from 1996, and the Repair-Welding Technology of Irradiated Materials Project (WIM) from 1997. In the PLIM project, objectives are to develop the evaluation methodologies for the neutron irradiation embattlement in the upper shelf energy region of the reactor pressure vessel, the thermal embattlement of duplex stainless steel components and the propagation of stress corrosion cracking in Ni-based alloys, and to develop the technology for reconstitution of RPV/RV surveillance test pieces. The PMT project: to verify the effectiveness of surface treatment processes such as Laser treatment to improve its corrosion resistance. The verification test items include the surface modification technology for reactor pressure vessel internals and primary coolant pressure boundary equipment. The WIM project: to develop repair-welding techniques for irradiated materials such as austenitic stainless steels and low alloy steels, and to prove the availability of techniques for core internals and reactor pressure vessel. The results of these R&Ds will be reflected to update the Technical Rules and Standards.

The Nuclear Plant Rejuvenation Technology Reliability Test Project, conducted by the NUPEC, intends to demonstrate the reliability of reactor internals replacement methods. This project covers six replacement methods for in-core monitoring housing (BWR), core shroud (BWR), control rod drive housing and stub tube (BWR), jet pump riser brace (BWR), core barrel (PWR) and bottom mounted instrumentation adapter (PWR).

REFERENCES

[1] OECD/NEA, *Nuclear Energy Data 1998*, Paris, 1998.

[2] S. Kosugiyama and K. Takeuchi, *Plant Life Management Activities of LWR Plants in Japan*, Proceedings of the 7th International Conference on Nuclear Engineering (ICONE-7), April 19-23, 1999, Tokyo Japan, ICONE-7290, pp. 1-10.

[3] T. Takao and N. Soneda, Computer Programmes to Map Out Economic Strategies, Proceedings of International Conference on Plant Life Management and Extension (PLIM+PLEX 95), Nice, 1995, pp. 291-299.

Figure 1. **Approach and Measures for the ageing Nuclear Power Plants.**

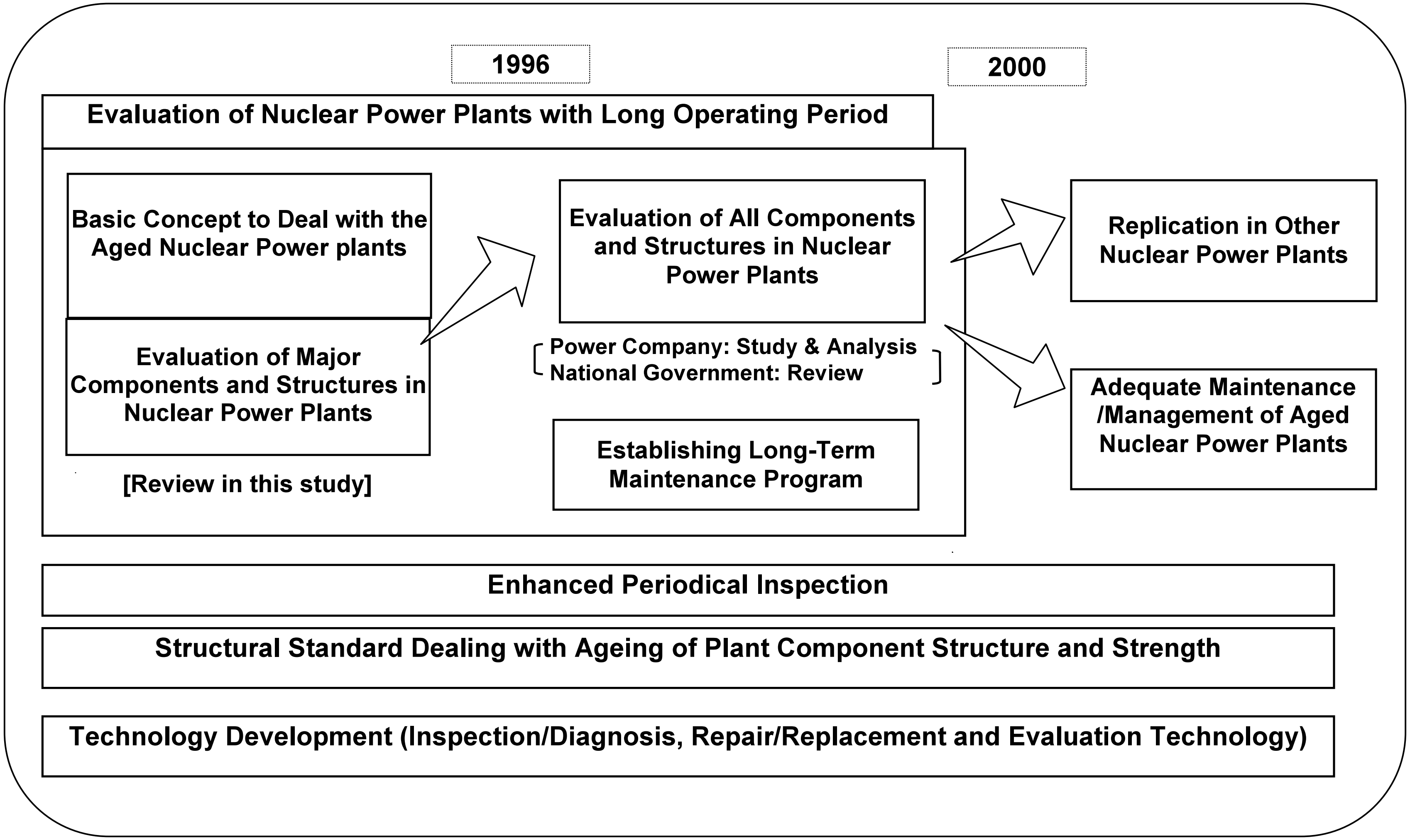
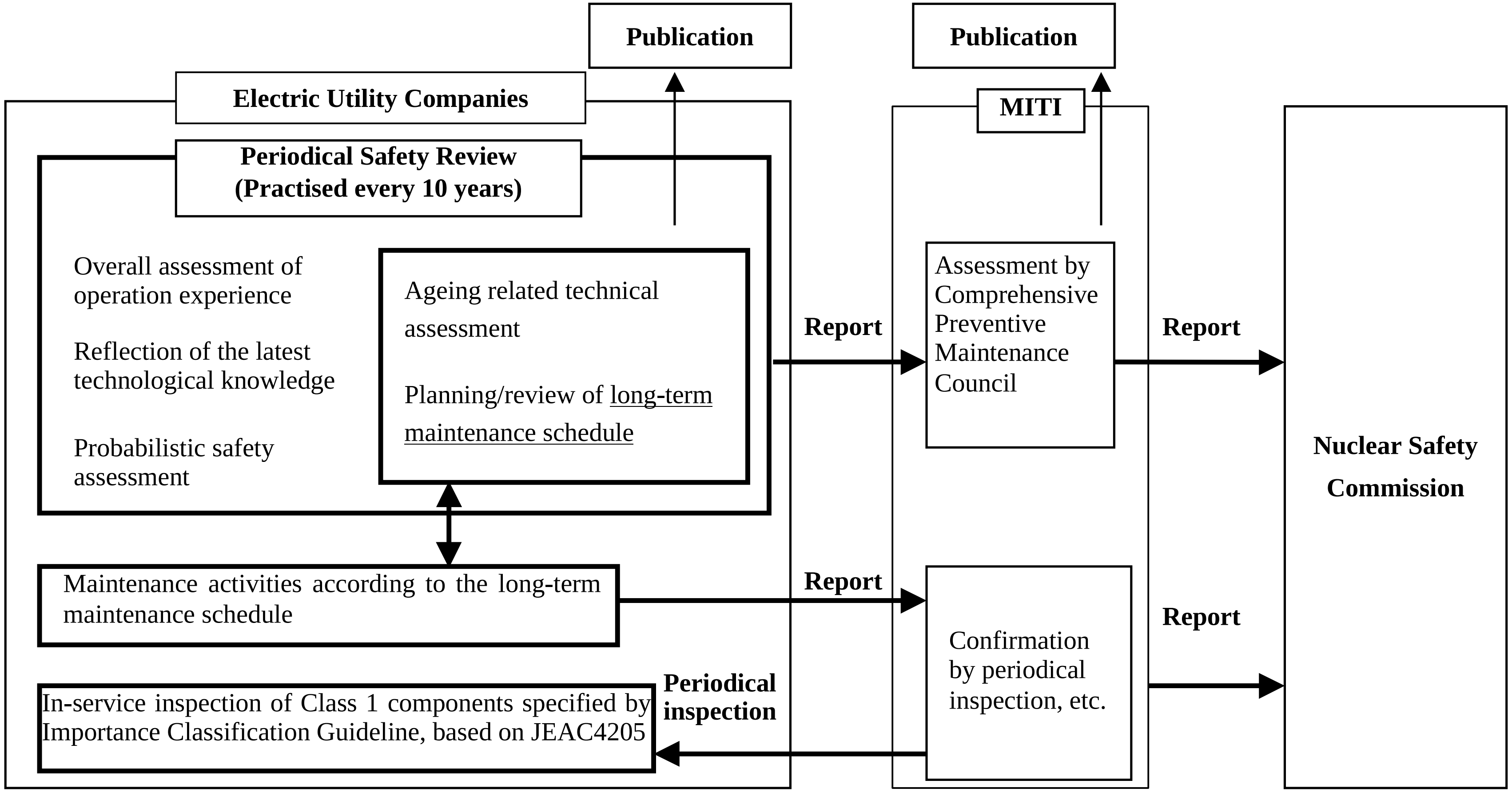


Figure 2. **Comprehensive Facility Management System.**



1. Periodical safety review (PSR) shall be conducted at each plant at approximately 10-year intervals.
2. Technical assessment and establishment of long-term maintenance schedule shall be included in the PSR for plants subjected to PSR based upon 30-year operation as a standard. Such technical assessment and long-term maintenance schedule shall be reviewed at 10-year intervals thereafter.
3. Technical assessment and long-term maintenance schedule shall be assessed by the MITI and reported to the Nuclear Safety Commission.
4. Progress state of long-term maintenance schedule shall be followed up at periodical inspection, etc.

Figure 3**. The Flow of Technical Evaluation.**

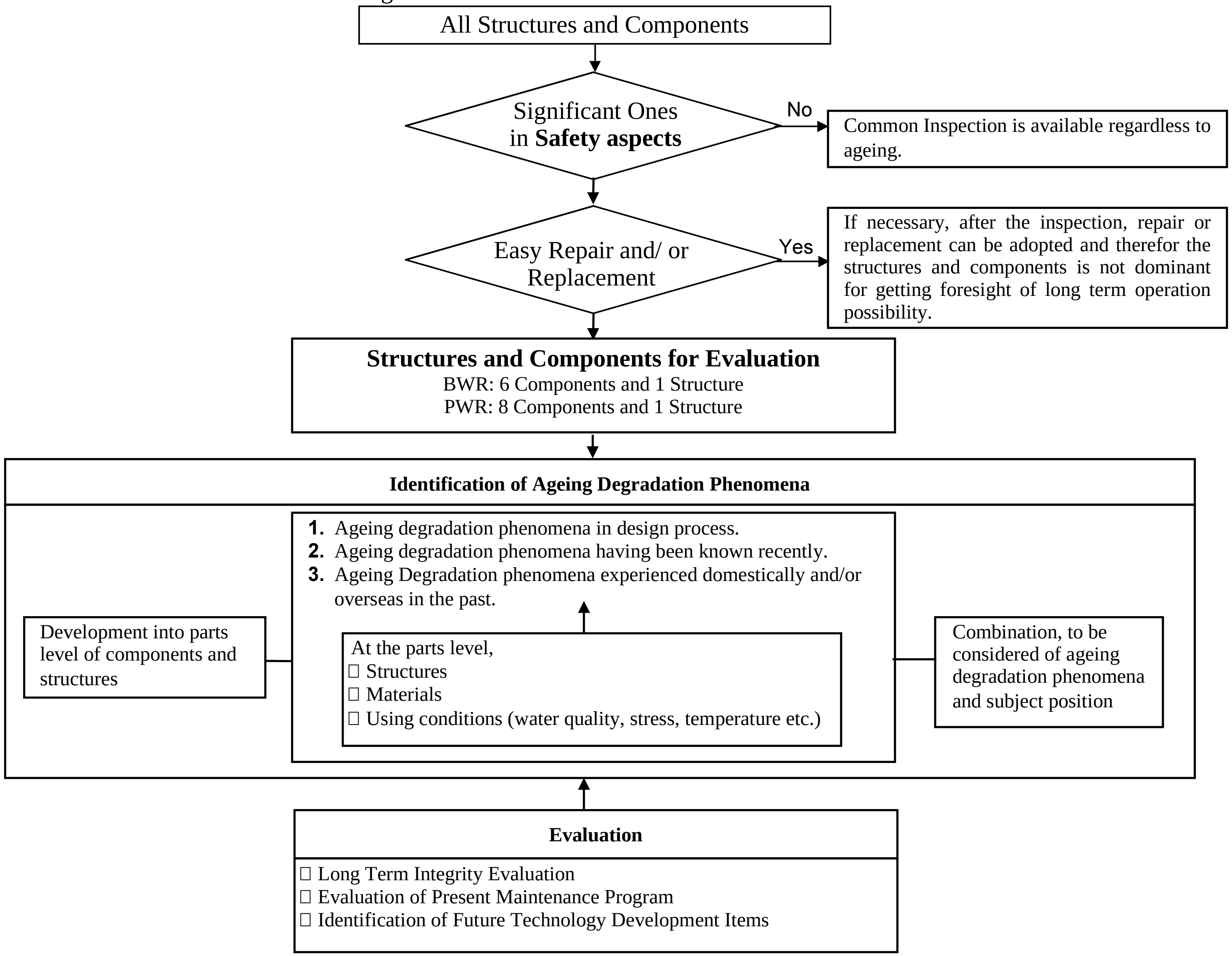
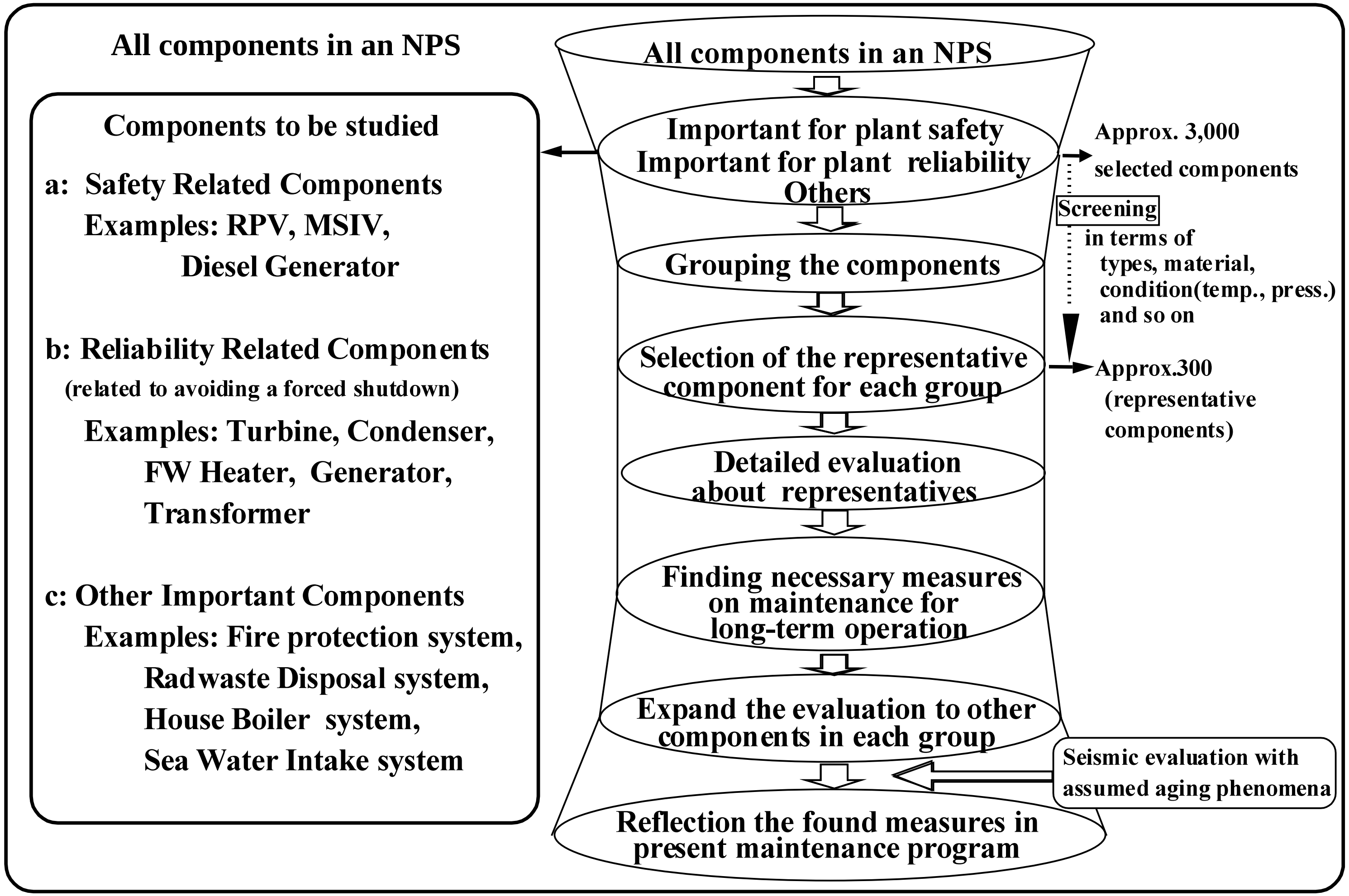


Figure 4**. Outline of Part 2 Evaluation Process.**



Reference: S. Kosugiyama, K.Takeuchi, Icone-7290, ICONE-7, Tokyo, Japan, April 19-23,1999

Table 1 **Plant Ageing-related Major Research and Development Programmes under the Budget of Agency of Natural Resources and Energy (ANRE) in the Ministry of International Trade and Industry (MITI)**

(1/3)

Technology Category	Research & Development Projects	Period (JFY)	Outline	Conducting Organisation
Inspection and Monitoring	Ageing General Evaluation (AGE) - Material Ageing Detection Technology (DT)	1990-1997	Technology to detect thermal embrittlement of duplex stainless steels, neutron irradiation embrittlement and fatigue damage by non-destructive tests.	JAPEIC
	Steam Generator Fatigue (SGF)	1992-2003	Development of non-destructive inspection technology for fretting fatigue cracks of steam generator tubes. Establishment of "standards unified for non-destructive inspection of welded components".	JAPEIC
	Nuclear Power Plant Life Management Technology (PLIM)	1996-2005	Reconstitution technology of RPV surveillance specimens.	JAPEIC
Preventive Maintenance and Repair	AGE - Repair Technology for Aged Materials (RT)	1990-1997	Repair welding for thermally embrittled materials and irradiation embrittled materials. Repair welding by temper bead method. Underwater welding to reduce radiation exposure.	JAPEIC
	Reliability Test for Reactor Vessel and Internals Repair and Replacement	1995-2002	Objective is to establish countermeasures for ageing of reactor vessel and internals. Test contents include to verify reliability of replacement for in-core monitoring housing (PWR, BWR), core shroud (PWR, BWR), control rod drive housing stub/tube (BWR), and jet pump riser brace.	NUPEC
	Nuclear Power Plant Maintenance Technology (PMT)	1996-2002	Purpose is to verify the effectiveness of surface treatment processes such as Laser treatment to improve its corrosion resistance. Verification test items include the surface modification technology for reactor pressure vessel internals, the surface modification technology for primary coolant pressure boundary equipment, and the overall evaluation for surface modification technology.	JAPEIC
	Repair-Welding Technology of Irradiated Materials of Nuclear Power Plants (WIM)	1997-2003	To develop repair-welding techniques for neutron irradiated materials including austenitic stainless steels and low alloy steels. To prove the availability of techniques for core internals and reactor (pressure) vessel.	JAPEIC
	Advanced Technology Development of Water Chemistry Control	(In plan)	To develop advanced technology for control of dissolved hydrogen concentration to reduce susceptibility of PWSCC in PWR. To understand effects on structural materials of noble metal injected to reduce SCC with hydrogen injection into BWR reactor water.	(To be decided)

Table 1. **Plant Ageing-related Major Research and Development Programmes under the Budget of Agency of Natural Resources and Energy (ANRE) in the Ministry of International Trade and Industry (MITI).**

(2/3)

Technology Category	Research & Development Projects	Period (JFY)	Outline	Conducting Organisation
Ageing/ Degradation Evaluation	Pressurised Thermal Shock Test for Nuclear Reactor Pressure Vessel (PTS)	1983-1991	Evaluation methodology for neutron irradiation embrittlement at transition region (PTS).	JAPEIC
	Plant Life Extension Technology Development (PLEX)	1985-1997	Material property of thermally aged materials and irradiated stainless steels in air and under simulated LWR water environment. Development of prediction model of embrittlement of thermally aged duplex stainless steels and development of evaluation methodology for thermal embrittlement of duplex stainless steel components. Development of the prediction model for embrittlement of irradiated stainless steels. Development of the prediction model for crack growth rate due to IASCC. And, Understanding susceptibility of IASCC under the PWR water environment. Development of methodology for evaluation of the Integrity / life of major structures and components.	JAPEIC
	Structural Assessment of Flawed Equipment (SAF)	1991-2000	Project to conduct fracture mechanics experiments and analysis concerning hypothesized small flaws on power plant structures and to prove the integrity of nuclear power plant equipment and piping during their service life.	JAPEIC
	Environmental Fatigue Tests of Nuclear Power Plant Materials for Reliability Verification (EFT)	1994-2006	Project to establish the environmental fatigue evaluation method for the LWR plant components.	JAPEIC
	Nuclear Power Plant Life Management Technology (PLIM)	1996-2005	Verification of evaluation methodology for thermal embrittlement of duplex stainless steel components by using large-scale piping model. Verification of evaluation methodology for neutron irradiation embrittlement at upper shelf region.	JAPEIC
	Technology Development for Evaluation of Irradiation Assisted Stress Corrosion Cracking	1999-2008	Regarding Evaluation of Irradiation Assisted Stress Corrosion Cracking (IASCC) of austenitic stainless steels, to understand IASCC initiation and susceptibility vs factors (fluence and stress), to understand effects of factors (stress, fluence, BWR/PWR environments, materials) on IASCC crack growth rate, and to understand material properties including fracture toughness of irradiated materials.	1998: IAE (The Institute of Applied Energy) 2000-: to be decided

Table 1**. Plant Ageing-related Major Research and Development Programmes under the Budget of Agency of Natural Resources and Energy (ANRE) in the Ministry of International Trade and Industry (MITI).**

(3/3)

Technology Category	Research & Development Projects	Period (JFY)	Outline	Conducting Organisation
Ageing / Degradation Evaluation	Development of Evaluation Methodology of SCC Crack Growth Rate for Ni based Alloys	(In plan)	To study the effects of material properties, environments and stress on crack growth rate of Ni based alloys.	(To be decided)
	Technology Development for Ageing Evaluation of Cables in Nuclear Power Plants	(In plan)	To develop the integrity evaluation methodology of cables under irradiation conditions.	(To be decided)
	Technology Development for Evaluation of Ageing Phenomena including Stress Corrosion Cracking	(In plan)	To develop the evaluation methodology of residual stress related to crack growth rate and the assessment criteria of stress intensity factor under the residual stress. To establish the evaluation technology of stress corrosion cracking including IASCC of stainless steels and SCC of Ni based alloys.	(To be decided)
	Structural Assessment of Flawed Equipment with Complex Structure	(In plan)	Verification tests for understanding crack propagation and fracture behaviour and to develop the assessment methodology for flawed components with complex structures.	(To be decided)

KOREA

Introduction

Kori Unit 1, the oldest nuclear power plant in Korea, started operation in 1978. With the accumulation of operating experience over the years, Korea Electric Power Corporation (KEPCO) has maintained a good performance record in the operation of nuclear power plants (NPPs). However, like other systems, NPPs are also destined to be degraded over the years by various ageing mechanisms. To cope with the degradation of plants, a timely plant lifetime management (PLIM) programme has to be established especially for old NPPs [1]. Kori Unit 1, the first NPP in Korea, was scheduled to be decommissioned in 2008 in accordance with the government's (Ministry of Commerce, Industry and Energy) Long-Term Electric Power Supply Plan. KEPCO had performed a PLIM (I) task for Kori Unit 1 to evaluate the feasibility of plant life extension by ageing assessment and economic evaluation. A three-year feasibility study concluded in 1996 that continued operation of Kori Unit 1 beyond its design life was technically and economically feasible [2]. Based on the result, the subsequent PLIM (II) programme was launched in 1998, focusing on the life evaluation of major structures and components (SCs), development of diagnosis and monitoring techniques and establishment of ageing management programmes to ensure plant safety and reliability during the latter half of lifetime. The purpose of this report is to introduce the experience, current status, and technical strategies of the lifetime management studies for Kori Unit 1.

General description of PLIM programme

PLIM is to do with activities such as operating, maintaining, upgrading NPPs and finding cost-effective solutions to ageing problems. The activities of the PLIM programme and the relationship between license renewal (LR) and periodic safety review (PSR) are described in Figure 1. A detailed explanation of these PLIM programmes will be given in the next chapter. CP and OL stand for construction permit and operation license, respectively. Plant ageing management requires comprehensive technologies and methodology to be applied to NPPs: preventive maintenance, component replacement, backfitting, etc. All the data produced during PLIM implementation will be kept and continuously updated in a database system throughout lifetime. Obstacles to life extension are operating performance, safety, power production cost, and environmental effects.

Regulatory rules of nuclear PLIM

The US Nuclear Regulatory Commission (NRC) LR 10CFR54 was established in 1991 for the review and approval of the US domestic nuclear utilities applications for the continued operation of 20-year periods after the initial license of 40 years. Basic concept of the LR is to maintain the current license basis and to have the intended functions of systems, structures and components (SSCs) available during the life extension period.

The application can be licensed if the back-fitting requirements are implemented and the ageing management programme to mitigate plant ageing and degradation can be maintained throughout its lifetime. Baltimore Gas and Electric and Duke Power submitted technical reports and official applications for the LR of Calvert Cliffs Unit 1 and 2 and Oconee Units 1, 2, 3 and 4, in 1997 and 1998 respectively. Other utilities such as Northern State Power Co., PEPCO Energy, Southern Nuclear Operating Co., Virginia Power, and Carolina Power and Light show the intention to NRC that they plan to apply for license extension.

Figure 1. **General description of PLIM**

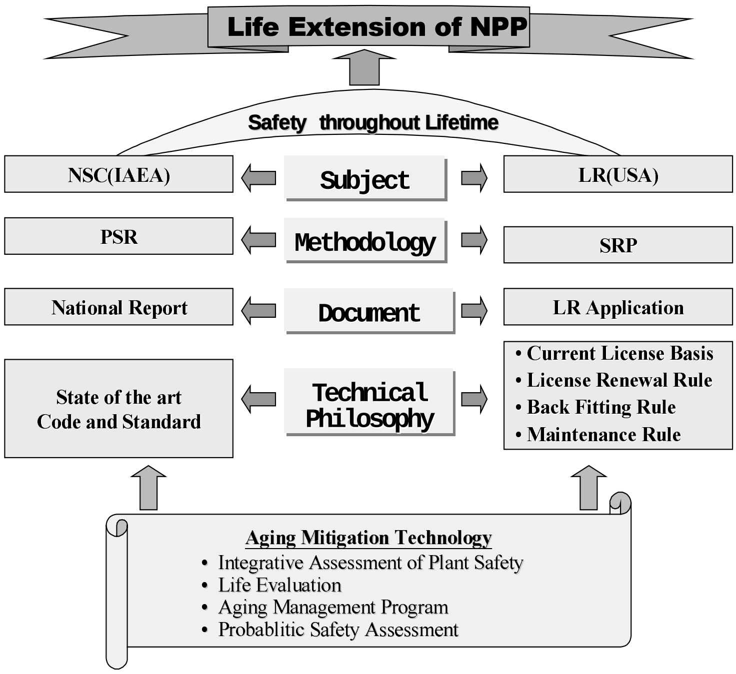
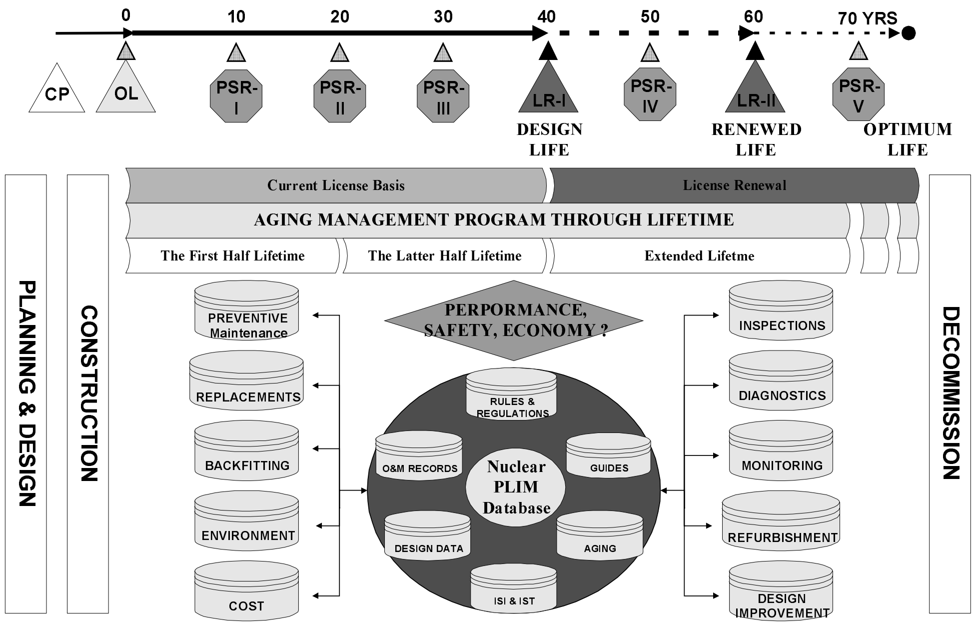


Figure 2. **Nuclear PLIM regulatory rules**



According to IAEA Safety Series No. 50-SG-12, PSR is a systematic & periodic safety assessment of an operating NPP to deal with the cumulative effects of plant ageing, modification, operating experience and technical developments, which aimed at high level of safety throughout the plant service life. European countries issued the need for this regulation from the late 1970s. The regulatory body and utilities realised that an ageing management programme for old NPPs is necessary to mitigate plant deterioration from ageing. Most members of the IAEA except the United States have employed PSRs. PSRs require operational NPPs to evaluate the following eleven safety factors: actual physical condition, safety analysis, equipment qualification, management of ageing, safety performance, use of experience from other plants and research findings, procedures, organisation and administration, human factors, emergency planning, and environmental impact. The technical bottom line of PSRs is similar to the LR if backfitting and maintenance rules are added to the LR of the United States. In the United Kingdom, Magnox NPPs, Calder Hall and Chapelcross stations (the oldest plants), were relicensed to operate 50 years using the PSR system.

In order to achieve and maintain a high level of world-wide nuclear safety and effective defences against potential radiological hazards and to prevent and mitigate accidents with radiological consequences, IAEA drew up the Convention on Nuclear Safety (CNS). It prescribes to contracting states comprehensive and systematic safety assessment evaluations to be performed before construction and operation of an NPP throughout its life. Korea ratified the convention in September 1995 and submitted a national report to IAEA in 1998.

Guidelines regarding national reports under the CNS recommends to report a summary of essential generic results of continued monitoring and PSR using deterministic and probabilistic safety analyses, as appropriate. The result of reviewing the three regulatory systems used in the present world was that basic technical philosophy of the PLIM and safety regulatory rules are similar and closely related to each other.

There is no explicit domestic regulatory rule on either periodic safety review or license renewal for life extension of old NPPs. Since becoming a member of the IAEA’s CNS, it is fundamentally clear for Korea to implement a PSR programme for domestic NPPs. The Ministry of Science and Technology have plans to fix the policy of PSRs by this year after hearing from KEPCO and the Korean Institute of Nuclear Safety. Both have been working independently to study how to implement the PSR programme in the Korean nuclear industry [3].

PSR has to be investigated carefully before regulation for the reasonably practical regulatory system. The costs for a comprehensive review and design modifications to upgrade safety are huge and consequently make NPPs less competitive in the field of power production. The UK regulator, Nuclear Installations and Inspection, estimated the basic safety improvements which included bringing the Magnox plants more into line with modern standards at a cost of about USD 30 million per station and the substantial resource in the order of 50-100 engineering man years per station. Things to be defined are the safety review scope, depth, and the periodic interval to reflect design features and operation and maintenance practices from plant to plant.

KEPCO strategy for PLIM

The primary goal of KEPCO’s PLIM is to operate nuclear power plants safely and economically for the original design life of the plants. If this first goal is achieved, then the research operation of nuclear power plants beyond the original design life will be pursued as the second goal. The second goal of the PLIM programme is to operate plants for their optimum lifetime. As shown in Figure 3, a plant specific feasibility study will be developed to evaluate each plant's optimum lifetime, which will become the plant target life for the PLIM efforts. If the optimum lifetime for a plant is longer than the original design life, then additional activities to extend the lifetime will be incorporated into the long-term preventive or predictive maintenance programmes for the plant.

The master plan for PLIM, including the life extension of Kori Unit 1 and other nuclear power plants in Korea beyond their original design life, is composed of three phases as shown in Table 1. Kori Unit 1 is the leading plant for technology development for the PWR NPP PLIM programme and Wolsung Unit 1 for the

PHWR. Such categorisation generically stems from the level of details and refinement that are to be accomplished during each phase of the project. The PLIM implementation plan for phase III will be developed later based on results obtained in the preceding phases. For the PLIM of PHWR, literature survey had done to start the life extension feasibility study of Wolsung Unit 1 in 2000.

Table 1. **Three phases of PLIM programme**

Phases	Period	Contents
Phase I	1993~1996	Feasibility study • Feasibility evaluation method and techniques • Kori Unit 1 LMNPP feasibility • Phase II planning
Phase II	1998~2001	Detail evaluation and engineering • Kori Unit 1 detailed inspection and residual life evaluation • Documentation for license renewal • Planning for life extension
Phase III	2002~2008	• Refurbishment, replacement and maintenance • Implementation • Advanced technology development

PLIM (I) of Kori Unit 1

As shown in Table 1, the major scope of work of this task involves overall project planning and a literature search for the basis of the original design life of Kori Unit 1. The basis for the 30-year design life of Kori Unit 1 is specifically re-examined, together with the provision of feasible amendments of its original design life from 30 to 40 years. According to the archival document surveys completed to date, the design life of major components in Kori Unit 1 including the reactor pressure vessel is confirmed to be 40 years.

Identification of critical components for ageing evaluation is an important part of the PLIM phase I efforts, because identification of these components is necessary at the beginning of the PLIM programme to ensure the proper focus of phase I efforts. The screening process applies safety-related criteria based upon the US license renewal rule (LR) and the maintenance rule (MR), described in 10CFR54 and 10CFR50.65 respectively. The screening process also applies power production (PP) related criteria based on plant availability and other safety requirements. Critical components for Kori Unit 1 were identified through the application of screening by the Westinghouse Owners Group and prioritisation criteria for systems, structures and components which apply the LR, MR and PP criteria.

After screening the Kori Unit 1 systems and structures, critical components and structures were identified and prioritised to determine their relative importance. Critical components were prioritised utilising ten attributes selected to assess the impact of component replacement or refurbishment on life extension. These attributes included cost to replacement or refurbishment, impact on plant availability, radiation dose, etc.

As a prerequisite to the evaluation of the plant ageing status, a voluminous amount of Kori Unit 1 design and field data, accumulated since commercial operation, should be surveyed and reviewed. This is necessary even though it requires a tremendous amount of manpower to reproduce useful data from the raw materials. The data survey is the most important element in the process of compiling operating transient data. The data required for the PLIM (I) programme can be classified and databased as follows: general methodology and technical references; operating transient history data; component design specification and manufacturing data; and maintenance and in-service inspection data.

In order to evaluate the ageing status of Kori Unit 1, 13 major components were selected at the beginning of PLIM (I). The degradation sites, failure mechanisms, failure modes, present condition and component operating histories are identified through technical evaluation and the appropriate testing. The results of this task are a quantitative evaluation of the plausible age-related degradation mechanisms and present state of the components. This task was accomplished with the aid of proven technical papers collected by literature surveys and generic technical procedures published by the offshore organisations that performed previous life management studies [4].

As a result of the feasibility study for life extension, it was found that this was technically and economically feasible for Kori Unit 1 with a value of 2.4 for the benefit/cost ratio. Another positive fact for life extension is that KEPCO had already replaced the rotors and diaphragms of the low pressure turbine in 1997 and the steam generators and the plant control I&C systems to sustain the operational capability.

Plant-specific pressurised thermal shock

A plant-specific PTS (pressurised thermal shock) analysis has been conducted following the methodology and procedures suggested in Regulation Guide No. 1.154. The plant-specific PTS analysis covers identification of PTS-significant sequences, T/H analysis, mixing analysis, and PFM analysis to quantify the associated risk of RPV failure with various PTS transients. The step-by-step procedure and lessons learned through the analysis were described in detail. The overall flow of the plant-specific PTS analysis of the specific NPP is shown in Figure 4. First, PTS initiating events should be identified and event-trees are then constructed by carefully analysing plant specific data. Next, the event frequencies of the sequences are quantified by probabilistic risk analysis technique [5].

The PTS significant transient sequences are classified and grouped based on the similarity in the thermal-hydraulic (T/H) nature and frequency of the sequence. For the selected transient sequences, T/H analyses are performed using transient analysis codes, such as RELAP5 and RETRAN. If thermal stratification within the cold leg is suspected, mixing analyses are needed to obtain localised temperature near the RPV wall in the downcomer region. The next step is the probabilistic fracture mechanics (PFM) analysis. As shown in Figure 4, downcomer pressure, fluid temperature near the RPV wall, and heat transfer coefficient obtained from T/H and mixing analyses are provided as inputs to PFM analyses. The specific vessel data, such as physical material properties, geometry, and surveillance capsule data, etc are also needed. Through the PFM analysis, conditional through wall crack (TWC) probability, P(F/E) for each transient sequence is calculated. TWC frequency at the event of specific PTS sequence is calculated by multiplying the sequence frequency and P(F/E). Finally, the total TWC frequency is found by simply adding the vessel failure frequencies of all the transient sequences analysed. Throughout this PTS analysis, at least two analysis codes were used in T/H analysis, mixing analysis, and PFM analysis. By taking this approach, the advantages and disadvantages of each code are studied in detail. Commercial CFD (computerised fluid dynamics) codes would be an appropriate choice for mixing analysis. Also, appropriate steps would be necessary to reduce over-conservatism in using VISA-II as a PFM code to calculate the PTS risk. Through the detailed analysis, it is now expected that RPV can maintain enough safety margin against pressurised thermal shock during its design life.

Figure 3. **Work flow chart of PLIM phase I**

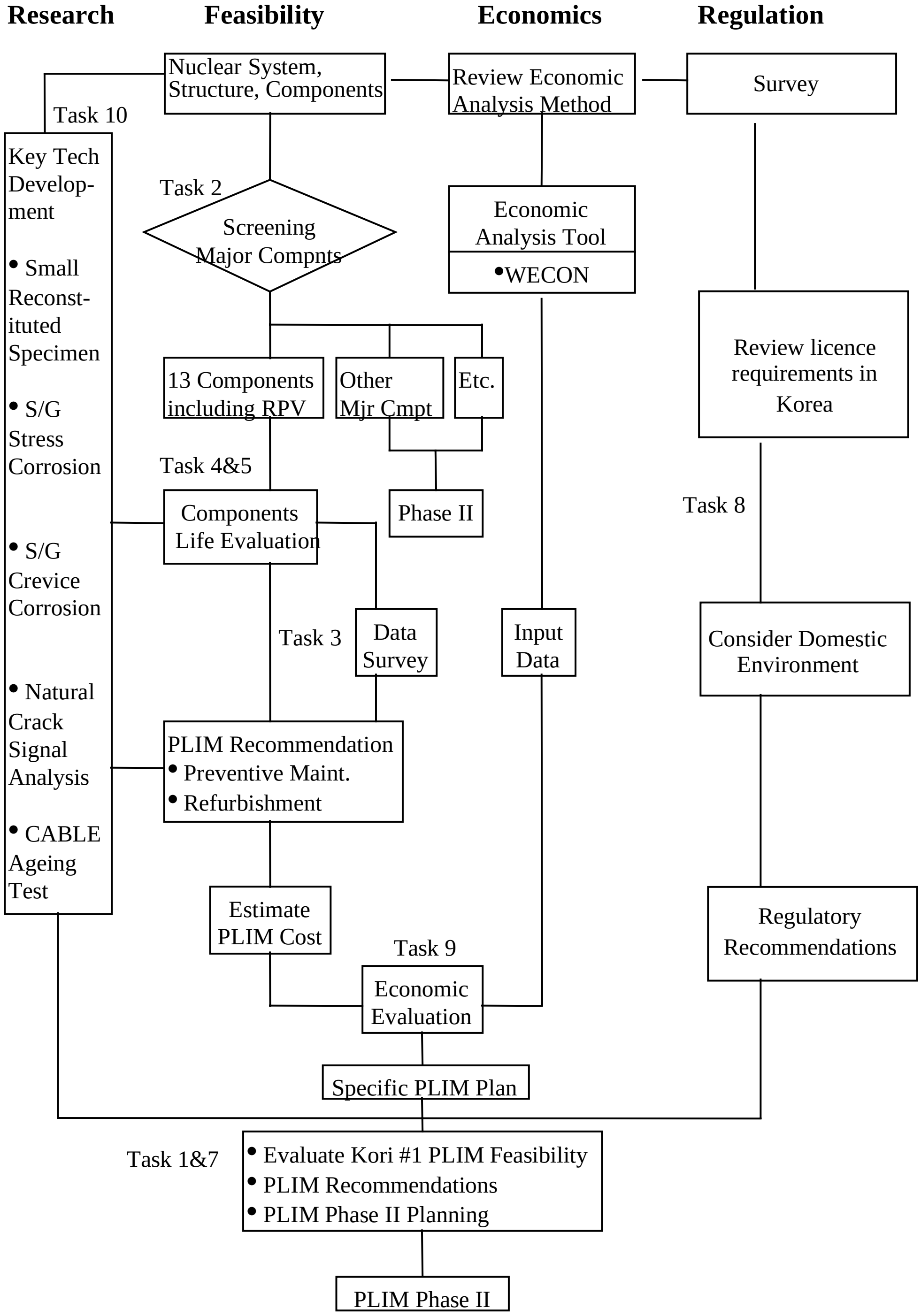
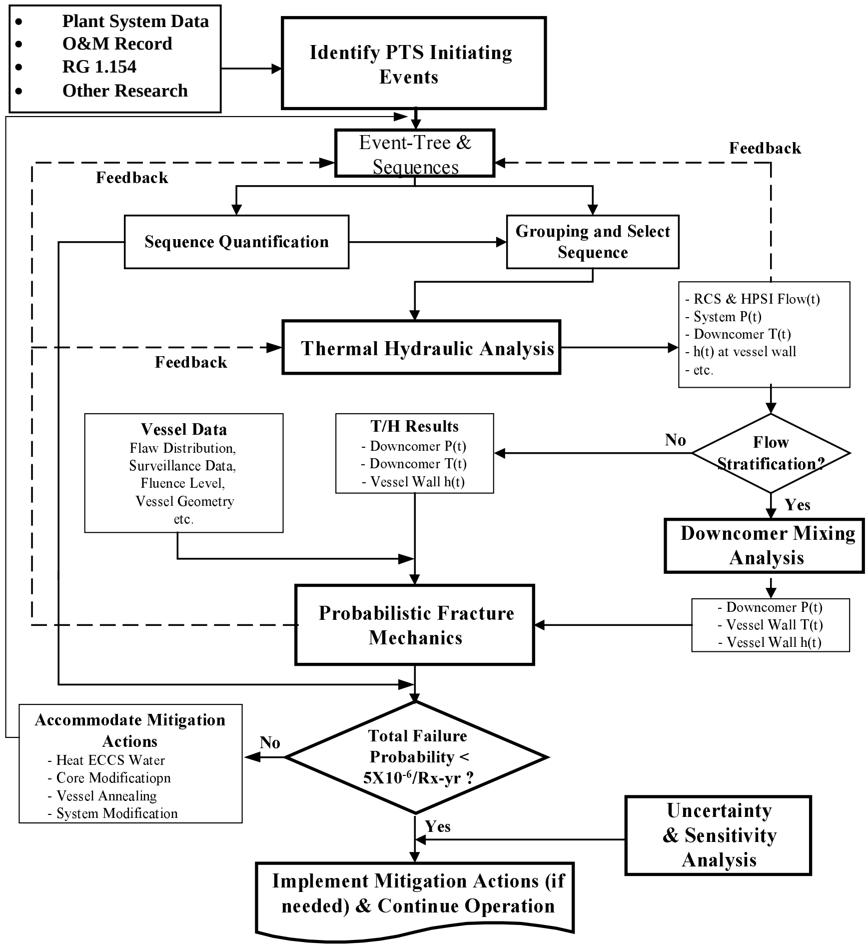


Figure 4. **Overall flow of plant-specific PTS analysis**

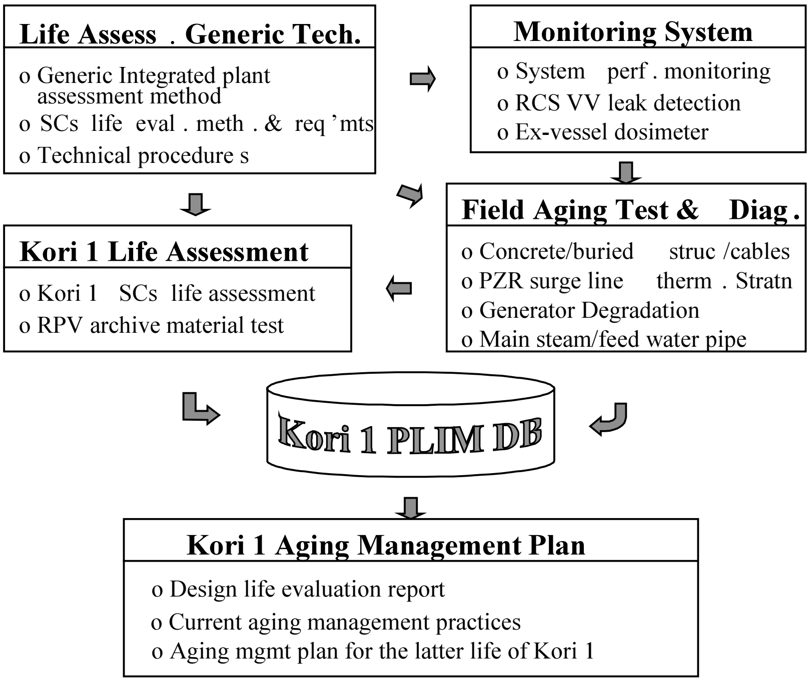


PLIM (II) of Kori Unit 1

Although the Korean regulatory rule for life extension has not been fixed yet, KEPCO decided to start PLIM (II) to develop a life evaluation methodology for the aged NPPs and to provide an ageing management programme for Kori Unit 1. Tasks scoped in PLIM (II) are diagrammed in Figure 5 which explains the relationship between tasks. PLIM (II) study focused mainly on the ageing management of old NPPs which is also referred to in safety factor No. 4 of IAEA Safety Series No. 50-SG-12.

Developed generic life assessment technology is to be applied to Kori Unit 1 to evaluate degradation of major SCs and optimum lifetime of the plant. Major SCs are classified as eleven components or groups based on the previous experiences: reactor pressure vessel (RPV), RPV internals, pressuriser, safety class 1 pipes, pipe/valve/pump group, safety class 1 supports, heat exchanger group, pressure vessel group, cable, electric equipments and structures, and structures. Life evaluation of the SCs will be processed with screening of scope, analysis of ageing mechanism, evaluation of present status and estimation of residual life. Qualitative and quantitative life evaluation practices and methodology used in other PLIM programmes are utilised for technology development. Based on the result of the life evaluation, field walk down and investigation and O&M experiences from other plants, the proper ageing management programme for the plant SSCs will be established and maintained to mitigate the deterioration during the current license period and extended life.

Figure 5. **PLIM (II) programme of Kori Unit 1**



To support life evaluation of SCs, field walk down, inspections and ageing tests should be carried out. For the life evaluation of buried facilities and cables, special diagnosis techniques and measuring devices are necessary. PLIM (II) tests erosion and vibration of main steam and feed lines and visual or non-destructive examinations for the buried structures. New non-destructive ageing test methodology by using cable ageing tester (CAT), which measures the hardness of cable surface to evaluate the cable ageing, will be employed for cable life assessment. Monitoring systems for timely detection of ageing synopsis will be developed and installed in Kori Unit 1 as follows: operation transient monitoring system to evaluate the fatigue life of the plant system, in-service test parameter and system performance monitoring system to assure the plant operability, reactor coolant system (RCS) leak detection system to keep the integrity of RCS isolation valves, pressuriser surge line temperature monitoring system to prevent the thermal stratification, and ex-vessel neutron dosimeter to improve the accuracy of the RPV neutron fluence calculation.

However it is feasible and possible to extend plant lifetime from a technical assessment viewpoint but continued operation is not feasible if it is not cost effective. Economic risk assessment model will be used to determine the most optimum strategies of ageing management programmes of SCs and plant life extension. To evaluate economic life with economic risk assessment, nuclear asset management, probabilistic cost of equipment replacement and refurbishment, and safety upgrade cost experience will be incorporated. By combining the above factors and domestic policy on nuclear PLIM, a suitable ageing management programme, schedule of the replacement and system design modifications during the service life of Kori Unit 1 will be delivered.

All the data produced, evaluating procedures and tools from the PLIM (II) study will be stored and controlled by the nuclear PLIM database (NPD). NPD is useful not only for Kori Unit 1 but also for other domestic NPPs. KEPCO will develop it in the form of a web-based intranet database system which can share the PLIM (II) study results through the network. A geographic information system will be employed to display plant geometry and environment conditions of inside areas. Information on ageing mechanism, failure history, result of life evaluation and ageing management programme for major SCs, strategies of nuclear PLIM will be helpful to participants in the study, utility managers, regulatory bodies and the public. NPD will be continuously updated even while the other nuclear PLIM study continues to keep it a standard ageing management information system.

Conclusion

Plant lifetime management is so important in the competitiveness and operation safety of old NPPs that KEPCO has been involved in a PLIM study of Kori Unit 1 since 1993. PLIM (I) for the Kori Unit 1 life extension feasibility study concluded that the technical and economical aspects make it possible to continue operation beyond its design life. Based on the result of PLIM (I), the subsequent PLIM (II) programme was launched for the evaluation of the residual life of major SCs and the establishment of ageing management programmes.

This report introduced the experience and technical strategies of lifetime management studies for Kori Unit 1. The general concept of nuclear PLIM and its regulatory status and perspective were discussed. KEPCO’s PLIM strategy, scope and purpose of the on-going PLIM (II) programme were also explained. PLIM (II) study will be helpful not only for Kori Unit 1 but also for the other domestic operating NPPs to improve plant safety and integrity.

REFERENCES

[1] Ill-Seok Jeong and Sung-Yull Hong, *Nuclear PLIM Program of Korea Electric Power Corporation*, PLIM+PLEX 95, Nice, 1995.

[2] Sung-Yull Hong and Ill-Seok Jeong, *Recent Strategy and progress in Korean Nuclear PLIM Program*, Nuclear Engineering and Design, 174 (1997) 25-32.

[3] Ill-Seok Jeong, Chun-Woo Lee, and Wi-Soo Kim *Nuclear Power Plant Lifetime and Periodic Safety Review*, PLIM+PLEX 99, Madrid, 1999.

[4] Ill-Seok Jeong and Changhuei Jang, *Major Component Life Evaluation for Nuclear PLiM Study*, Proceedings of the 15th SMiRT International Conference, Seoul, 1999.

[5] Ill-Seok Jeong, Changhuei Jang, and Jun-Hyun Park, “*Analysis on Plant -Specific PTS Integrity for a Pressurized Water Reactor Vessel*, Proceedings of the 9th ICPVT, Sydney, 2000.

NETHERLANDS

In 1997, one nuclear power plants, a PWR (Siemens KWU, 1973 design), with a total net capacity of 0.5 GWe supplied 2.9% of all the electric power produced in Netherlands, and no more plants under construction. The financial responsibility of operations of both plants is sublet to the Dutch Utility Board, SEP, ("Samenwerkende Elektriciteits Productiebedrijven").

With respect to economical arguments, it is decided by SEP to take the BWR (General Electric, 1969 design) of 56 MWe out of service in 1997. This decision was also confirmed by:

- the political decision to shut down the PWR (NPP Borssele) in 2003;
- the absence of the nuclear option in the intended Dutch electricity generating plan;
- the necessary investments to be made for the renewal of the license;
- the EEC decisions with respect to a free electricity market.

The license renewal for both plants was introduced by the decision of the Dutch government to enforce the licensees of nuclear power plants to implement the IAEA codes and guides for exploitation.

Organisation and their responsibilities

The main organisations involved are governmental regulatory bodies, such as:

- Kernfysische Dienst (KFD)
- Ministry for Environment (VROM)
- Dienst voor het Stoomwezen (DWS)

Research institutions include:

- Energy Research Foundation (ECN)
- Reactor designers, e.g., Siemens/KWU; Westinghouse
- Utilities - EPZ, owner of the Borssele plant
- Other government institutions with responsibilities according to Dutch law and regulations
- the ECN, an independent research organisation sometimes used by KFD to verify resulting analyses
- KEMA, a utility research institution for industry

The authorities co-ordinate licensing procedures internationally with German and Belgium firms, as well as with German and Belgian authorities (TUV, Vinçotte).

Regulatory processes

KFD, ECN, KEMA and DSW, as well as governmental bodies, are among the regulatory processes.

In order to evaluate consequences of the political decision to introduce the IAEA regulations in the Netherlands, an internal IAEA OSAR team was invited by the Dutch government to investigate the NPP. Recommendations were mentioned with reference to quality-assurance and the management of information and documentation. The demand that the existing nuclear power plant must be "as reasonable" in compliance with the IAEA codes and guides for design and operation made a comparison and evaluation with new plants necessary. This study resulted in the proposal for the project “Modificaties” that was accepted in □□□□□as a basis for license renewal

The new regulations also demand an additional periodic evaluation of the technical operation, the human actions and information management. Every ten years the exploitation will be evaluated by the Dutch inspectorate with regard to nuclear safety and radioactive protection to continue the license. Every two years, the evaluation will be repeated to check the safety level in the areas mentioned in the 10-years evaluation.

Objectives and strategies

The main concerns and objectives of the government, industry and research organisations are public safety and economics. Government strategy, together with input from original construction firms, is to conform to international standards based on IAEA requirements. Structural licensing standards are revised every 10 years. Experience of utilities and original construction firms are employed in planning. Organisations involved include government authorities, original construction firms, utilities, KEMA and ECN.

Decision and economic analysis

Supported by the Dutch government for the exploitation, involved organisations EPZ and SEP intended to continue nuclear power generation to maintain this special knowledge and experience. Eventual investments, however, should be bounded by the decision that for a fixed lifetime of 10 years (until 2007) the total kWh cost may not exceed 8 ct/kWh which is comparable with gas fired plants.

In the meantime, the Dutch government decided to limit the operation license to 2004 and to compensate EPZ and SEP financially. In 1996, the SEP decided to shut down the demonstration NPP GKN in 1997 on economical grounds, supported by the government.

It may be concluded that survival of the NPP Borssele strongly depends on the economic exploitation in the future.

For the NPP Borssele, it was calculated that a forced shutdown in 1994, before any investigations for license renewal or obligations for power delivery would cost circa F. 500 E^6. Of this amount, 30% was necessary for salaries, etc., 25% for the restvalue of the installation and 30% for conservation. The cost for normal operation and fuel required circa 6.2 ct/kWh on a fifty/fifty basis. From the maximum allowable amount of 8 ct/kWh with respect to deduction, reservation etc., a permissible extra investment of F. 475 E^6 for a license renewal granted for 10 years of operation, was calculated. After careful investigation, it was determined that with a turn-key contract to Siemens-KWU, together with a maximum effort of EPZ, the project “Modificaties” could be realised for circa. 467 MHFL (295 $).

Perhaps it is interesting to notice that level l PSA analyses demonstrated an improvement of the Total Core Damage Frequency from 5.6 E-5 to 4.7 E-6 per year. So, for a decrease of the TCDF of 1 E-5, an investment of 90 MHFL seemed necessary. These kinds of amounts are unthinkable for other industrial activities with respect to safety.

From the political point of view of the government, it should be very important that the employment for the NPP involve circa 700 jobs and the project “Modificaties” creates circa 2000 man year support.

It may be expected that because of the project, the presented big amount of information together with the partial increased quality of the installation must open possibilities for decreasing the exploitation costs.

Programmes

Project "modificaties" for Borssele NPP

In the project proposal, new additional design basis was mentioned like: earthquake; airplane crash; feed and bleed of vapour, fluid and mixtures of PORV's and defence of in-depth philosophy like separation of redundancies, e.g. and LBB measurements.

The backfitting of the following systems was introduced: additional redundant decay heat removal with a ground. water system; emergency power supply; fire safety; containment venting; primary safety and relief valves; emergency control room; feed water and steam supply.

The time schedule of the most important targets:

- Agreement between utility (economic point of view) and the authorities (licensing) about project scope, December 1994.
- Engineering and manufacturing of components and systems, 1995-1996.
- Implementing and testing in the plant, February-June 1997.

Public acceptance

The public is not as such involved in issues like plant ageing or life extension. After extensive backfitting the plant has to obtain a new licence. A procedure under investigation is to permit the public to be informed of plant actions at the time the plant wishes to obtain a new licence. In this way, the public will be able to influence plant issues.

SPAIN

In 1998, 9 nuclear power plants, with a total net capacity of 7 637 GWe supplied 32% of all the electric energy produced in Spain. Spanish power plants do not have a defined life and their technical life will depend on their being completely safe and economically attractive. The operating license granted by the Regulatory Body is open, regarding duration, and is renewable periodically. While the main components of Spanish nuclear power plants were theoretically designed for a 40-year life, studies and projects on the ageing of critical components and national and international experience have shown that the number and severity of experimental transients are less than those considered in the design. International experience and Spanish pilot projects have also shown the technical feasibility of extending life beyond 40 years.

Organisation and their responsibilities

The Spanish energy policy for the current decade is defined by the Government in the *Plan Energético Nacional* 1991-2000 (National Energy Plan, NEP). Among its objectives are the long-term development of the Spanish electrical section. Life extension of nuclear power plants is considered an important alternative within the NEP.

There is presently a global life management programme, that is being implemented by the Spanish NPPs to achieve the 40-year life while keeping the option of extending the life beyond 40 years.

The legal framework which establishes design, construction and operation of nuclear power plants is the *Subdirección General de Energía Nuclear* (Nuclear Power Department) pertaining to the Ministry of Industry and Energy. The regulatory body is the *Consejo de Seguridad Nuclear* (Nuclear Safety Council, NSC), a public law entity independent of Public Administration. The operating licence granted in Spain is temporary and has to be renewed periodically. Following international practices future operation permits will be granted for longer periods.

Unidad Eléctrica, S.A. (UNESA) is an organisation comprised of electric companies, which represents 98% of the electrical power generated in Spain. One of the functions carried out by this organisation is the study and analysis of all technical or economical issues concerning the companies of the Spanish electrical sector. UNESA's nuclear group created the "Commission for Nuclear Power Plant Life Extension" in 1986 for this purpose.

Regulatory processes

Safety regulation

The component regulatory bodies on safety issues are the *Consejo Nuclear de Seguridad* (Nuclear Safety Council), and the *Dirección General de la Energía del Ministerio de Industria y Energía* (Department of Energy of the Ministry of Industry and Energy, MIE).

The NSC follows plant life management life extension activities with particular interest, not only for their impact on furthering design life, but also for their effect on current maintenance practices and their direct impact on the improvement of the power plant safety level. The Spanish industry has developed guides and methodology to implement Life Management Programmes in their NPPs.

The operating license is open regarding its duration, therefore there are no legal restrictions for extending the life cycle by renewing operating licenses. The NSC has requested a management plan for the ageing of important components of the plants, by means of the PEPs. Safety Guide 1.10 on Periodical Safety Reviews establishes the requisites relating to the control of ageing in important components. The current continuous evaluation and periodical safety review processes will make it possible to renew the operating license for a given period of time up to 40 years.

Strategy

Background

Diversification

The guarantee of supply is a *sine qua non* condition of any energy policy. In a world where the market and policies of the supply of raw materials is unstable, diversification is a fundamental strategy to guarantee the prices and supply of electricity.

In Spain, the energy deriving from the nuclear field plays a very important role in achieving diversification in energy supply sources. Since almost a decade ago, approximately one third of the electrical energy generated in our country has come from the nuclear field. This, of course, has enabled us to reduce our dependence on oil and to contribute to the stability of prices in this raw material which would have otherwise soared to unthinkable heights.

The plant life management programmes of the nuclear power plants will contribute to maintaining this diversification policy which will continue being fundamental in guaranteeing the price and supply of electricity.

Economical attractiveness

The life cycle of nuclear power plants depends on both their short-term and long-term economical profitability, that is, on their competitiveness in a free market in which the tendency is for the price of the Kw/hour to fall.

Environment

The main factors which determine the choice of fuel for generating electricity will continue to focus on their economical attractiveness, though after taking into consideration the repercussions on the environment both locally and regionally.

Public opinion may think it strange that nuclear energy claims to be respectful towards the environment because all they recall is the Chernobyl accident and the question of high energy waste storage.

Little by little, concern about emissions from other sources is growing, and especially the emission of CO_2 and its effect on climate change. In Europe, as in Spain, approximately one third of the electricity generated comes from the nuclear sector. This proportion avoids the emission of 700 million tons of CO_2 every year in the European Community countries. Consequently, government organisations are setting stricter and stricter objectives to limit these emissions.

This reality should gradually improve the position of nuclear energy as a necessary alternative in order to be able to achieve these objectives.

Objectives

As a consequence of the attractiveness of life cycle extension of nuclear power plants, the nuclear sector has established the following objectives:

Strategic objective: to extend the life cycle of nuclear power plants maintaining their levels of safety and efficiency.

Current objectives: to monitor and control the ageing of important components to guarantee a life cycle of 40 years.

To keep the possibility of extending beyond 40 years technically prepared and open.

In order to make these objectives feasible the sector has included the following fundamental actions in its joint action plan:

- Development and methodology of maintenance practice evaluation.
- Development of techniques for evaluating, inspecting, mitigating, repairing, and/or replacing important components (vessel, internals and other critical components).

The first action has been developed and is being applied at each of the power plants. With this action the Regulatory Body's requisite that all power plants initiate ageing management programmes for important components is complied with.

The second action, which is very important in the medium term and long term, reflects the need to have a more profound knowledge of the ageing mechanisms of important components that could condition the feasibility of extending the life cycle of the plants.

A Plant Life Management programme is nothing new nor is it magical; it is simply an integrated management of current maintenance and engineering activities. The main novelty is that the planning horizon is long term and it identifies the objectives and priorities that are necessary to make the long-term business vision feasible.

During the first stage of the life of a power plant (0-25 years) a life cycle management programme does not have to bear important investments (apart from very specific matters such as steam generators). This stage features the evaluation and improvement of current operating, inspection, maintenance, data and information acquisition practices in order to evaluate and monitor ageing in important components.

The investment cycle as such begins around the years 20-25, when the plant has practically depreciated. At this time important investments will be necessary for inspecting, repairing, replacing and modernising plant components and systems. The value of these investments has already been commented and seems to be compatible with the economical attractiveness and expected profitability at that time.

Decision and economic analysis

Generally, investments required to keep the life extension option valid are moderate. Certain significant specific investments require a cost/benefit analysis of all their alternatives, e.g., repair or replacement of important turbine components, repair or replacement of recirculation pipes, repair or replacement of steam generators. These investments are generally undertaken independently of the plant life extension consideration, since the components involved would have aged prematurely.

Programmes

Qualified equipment

To ensure supply of adequate equipment and spare parts to nuclear power plants, the definition of a practical methodology, adaptable to the evolution of the market and at a standard approved by the Spanish authorities (Nuclear Safety Council), needs to be established. Under no conditions should this methodology degrade the quality of safety-related equipment.

The acquisition of equipment, components and spare parts is a constant activity throughout the useful life of a nuclear power plant. However, reduction of the nuclear market in Spain and in the United States has resulted in many suppliers abandoning the component replacing.

To palliate this problem and adapt to current market conditions, the Spanish nuclear sector is carrying out the following measures:

Homogenise as much as possible types of spares (conventional), and prepare brief technical requirement sheets for each type of spare. Requirement sheets can thus be updated as a function of the market situation. This update establishes new competition between manufacturers, e.g., matching spares or technological novelties, which in turn guarantees minimum stock.

Use commercial-grade components in the replacement process of safety-related components. Commercial-grade components can also be used in purchases motivated by design modifications. To meet this objective, it is necessary to apply a consistent allocation procedure in the technical evaluation and acceptance process undergone by commercial-grade components before they are used as basic components.

The Spanish Nuclear Society and the AENOR Technical Committee on Standardisation CTN-73 (UNE Spanish standards) prepare regulations for the acquisition of equipment by nuclear power plants, stated in standards such as UNE 73-401 “Quality Assurance in Nuclear Power Plants”, UNE 73-403 “Utilisation of commercial-grade elements in safety-related applications for nuclear installations”, PNE 77-104 “Commercial-grade component allocation in nuclear power plants”, SNE-6A “Seismic Qualification of Equipment” and SNE “Environmental Qualification of Equipment”.

Qualified manpower

Although there are presently companies with sufficient technical competence for global development of support activities required in the operation of nuclear power plants, the lack of large projects is causing a loss in qualified human resources over other industrial fields. Once the change has been effected, return to the nuclear field would appear quite difficult.

The groups of owners are concerned that this constant reduction of the work force, in particular servicing expertise, will weaken the support required by plants, and ultimately inhibit advances in nuclear technology.

Even though there is no government training, there are companies who do so, and who benefit from a favourable tax policy. The *Plan de Investigación y Desarrollo Tecnológico Electrotécnico* (PIE) (Electrotechnical Technology Research and Development Plan), with government and industry participation, provides a means of qualifying technicians within new areas of the nuclear technology such as life expansion.

Universities provide qualified personnel, while companies organise permanent training courses with a view toward the necessary disciplines.

Other programmes

Since 1986, when the Spanish nuclear industry first took the initiative in the area of life extension, different programmes were developed to address the ageing monitoring of critical components, systems and structures. Several programmes are outlined below:

- Remaining Life Management Programme (Santa María de Garoña NPP).
- Book of events.
- Definition of operation records (temporary) required in the evaluation of components, establishment of selection criteria, and compilation of these records in accordance with plant operation history (events).
- Collection procedure of aged samples, PWR and BWR plants.
- Acquisition procedure for vibration parameters in emergency diesel generators.
- Definition of a methodology for data acquisition on the diesel generator vibration status for its evaluation, and application of this methodology in the different diesel generator models in-service in the Spanish power plants.
- Procedure for the evaluation of concrete structures.
- Definition of critical structures and inspections required for their evaluation.
- Monitoring programme on the condition of electrical cables.
- Recommendations related to methodologies for monitoring and ageing evaluation of electrical cables.
- PIE research project on steam generators. This project was developed in 1987-1990 to provide preventive and corrective solutions for the corrosion problems in the steam generators of the Spanish PWR power plants. In the course of this project techniques on the behaviour of materials under corrosion, and potential mitigation techniques against degradation phenomenon and repairs, were evaluated and acceptance criteria in non-destructive tests established.
- The main objective of the research project on intergranular corrosion is to obtain a calculation tool suitable for the automatic evaluation of defects detected in austenitic stainless steel pipes which go beyond the ASME XI standards, and to estimate the remaining life of the component in view of this evaluation.
- Forecasts inspection and evaluation of the erosion-corrosion phenomenon in carbon steel piping.
- Development of robotised tools to inspect and repair some internal vessel components.

- Development and installation of an on-line monitoring system of vessel fatigue.
- Follow-up and assessment of neutron embrittlement of steam vessels (tests on the specimens installed in the vessels).
- Study on the thermal embrittlement of cast stainless steel.
- Mitigation of residual stresses in the stainless steel welds (MSIP).
- Mitigation of the intergranular corrosion in the recirculation circuit and vessel by injecting H2.
- Development and implementation of an integrated system capable of managing all data and information related to the plant life management programme and capable of predicting the remaining life of the critical components.

Critical components

The list of critical components was actually prepared for several nuclear power plants. Two methods have been used for the selection of critical components.

One of these methodologies, applied in two GE BWR plants, is based on the comparison of a list of candidate components with evaluation criteria. The selection of candidate components (120) is made in accordance with their potential impact on plant life extension. These 120 components are evaluated according to thirty (30) criteria, divided into six (6) categories.

Category	Relative importance (%)
General criteria	32.5
Service conditions	16
Licensing factors	18
History of operation	11.5
Life extension potential	11.5
Reliability considerations	10

The evaluation of the candidate components was performed by a group of engineers from various disciplines, including nuclear power plant design, licensing, operation and maintenance. Each candidate component was granted a mark for each criterion on a scale from 1 to 10, resulting in the final ranking of 120 components, out of which the first 24 components are considered as critical. Although the rest of the components are not critical, this does not mean they are less important for plant life extension. All components must be taken into consideration in the management of a plant’s remaining life. The methodology, nonetheless, permits identification of components which require the greatest assessment effort to begin with.

The other methodology applied in a Westinghouse PWR plant is based on the classification of each plant element in one of the following six categories: no limitation of plant life: justification required; long life: high potential impact on plant life; long life: impact on plant life; short life: no impact on plant life; limited life: no impact on plant life; new components installed during the 1982-1985 SEP. The components included in the first three categories are considered as potentially critical and require further evaluation. The components comprised in categories 4, 5 and 6 are non-critical to power plant life extension.

Tables 1 and 2 contain the list of critical components corresponding respectively to a PWR of 160 MW (José Cabrera NPP), and to a BWR of 450 (Santa María de Garoña NPP). There are no generic concerns on this issue. Each power plant has its own specific requirements according to the ageing evolution of its components.

Table 1. **Potentially critical plant elements per category of José Cabrera nuclear power plant (PWR-160 MW)**

Category 1	Category 2	Category 3
Reactor vessel supports Reactor vessel insulation Containment concrete structure Containment building mat Spent fuel pool and liner Auxiliary building concrete Control building concrete structure Turbine building structure Turbine foundation Service water intake structure Service water inlet/outlet canals	Reactor vessel Full-length CRDM housing Reactor vessel lower internals assembly Steam generator Pressuriser Reactor coolant loop piping Pressuriser surge line Incore thimble guide tubing RCP casing High pressure turbine Low pressure turbine Containment steam liner and dome Electrical cables inside containment (original only)	Reactor vessel upper internals assembly Control rod drive mechanism Steam generator supports Pressuriser supports RCP supports Charging pumps Main turbine generator Main transformers Equipment access hatch Personnel access hatch Main control room equipment (original only) Electrical cables outside containment (original only) Major piping (secondary side)

Table 2. **Listing and relative ranking of components: Importance for plant life extension of Santa Maria de Garoña nuclear power plant (BWR-450 MW)**

Rank	Component/Structure/Component grouping description	Rank	Component/Structure/Component grouping description
1.	Reactor vessel pressure boundary	2.	Reactor vessel pedestal
3.	Drywell metal shell foundation	4.	Biological shield
5.	Reactor building basemat	6.	Fuel pool slabs and walls
7.	Sacrificial shield wall	8.	Dry wall metal shell
9.	Suppression chamber including supports	10.	Reactor vessel support girder and bolts
11.	Reactor building floor slabs and walls	12.	Plant control centre (areas of the control room, cable room, nuclear instrument room, battery room, switchgear room, etc.)
13.	CRD housings external	14.	CRD housings internal
15.	Turbine pedestal	16.	Reactor vessel core shroud
17.	Reactor vessel core support plate	18.	Reactor vessel core top and bottom grid
19.	Drywell vent lines including bellows	20.	Suppression chamber vent headers and downcomers
21.	Emergency diesel engines	22.	Reactor recirculation piping
23.	Reactor vessel jet pumps	24.	Reactor vessel nozzle safe ends
25.	ECCS piping inside primary containment (LPCI/shutdown, core spray and HPCI)	26.	Main steam and isolation condenser piping inside primary containment
27.	Equipment foundations	28.	Main turbine

Rank	Component/Structure/Component grouping description	Rank	Component/Structure/Component grouping description
29.	Drywell radial steel	30.	HPCI turbine
31.	Isolation condenser	32.	Radwaste building walls and slabs
33.	Compressible material between the drywell metal shell and sacrificial shield wall	34.	Main condenser
35.	Primary containment penetration assemblies	36.	Intake structure
37.	Cable in-trays	38.	CRD insert and withdrawal lines
39.	Turbine building slabs and walls	40.	Nuclear instruments
41.	Reactor vessel feedwater and core spray spargers	42.	Refueling and drywell bellows
43.	Main steam isolation valves	44.	Reactor recirculation pumps
45.	Emergency diesel generator structure/room	46.	Spent fuel pool liner
47.	Control room panels	48.	Reactor building crane
49.	Essential signal cables	50.	Cable in conduit
51.	Instrument tubing/sensing lines inside primary containment	52.	Primary containment personnel airlock and equipment hatches
53.	ECCS piping inside secondary containment	54.	Reactor building structural steel
55.	LPCI/containment heat exchanger	56.	Discharge structure and canal
57.	Surface coating systems, concrete structures	58.	Inboard primary containment, isolation valves
59.	Isolation condenser piping inside secondary containment	60.	Essential instrument racks
61.	Essential switchgear	62.	Reactor recirculation suction and discharge valves
63.	LPCI/containment pumps	64.	Vent (offgas) stack
65.	LPCI/containment service water piping	66.	Core spray pumps
67.	Main steam - relief valves inside primary containment	68.	HPCI pump and booster pump
69.	Sensing instruments	70.	Moisture separators
71.	Turbine construction crane	72.	Underground offgas piping
73.	Coating systems, primary containment components	74.	Protective relaying
75.	Turbine building structural steel	76.	Circulating water pumping
77.	Main generator	78.	Main steam stop and throttle valves
79.	Motor control centres	80.	Essential local control panels
81.	Electrical buses	82.	Reactor vessel steam separator and dryer assemblies
83.	Reactor feed pumps	84.	Shutdown cooling water heat exchangers
85.	High and low pressure feedwater heaters	86.	Large bore check valves
87.	Emergency diesel generators	88.	Reactor vessel insulation
89.	Pipe whip restraints	90.	Primary containment air handling units
91.	LPCI/containment service water pumps	92.	LPCI/containment pump motors
93.	Radwater solids handling systems separator, sludge and receiving tanks	94.	CRD hydraulic control units
95.	Core spray pump motors	96.	Reactor vessel stabiliser system
97.	Motor-operated valves	98.	Station transformers

Rank	Component/Structure/Component grouping description	Rank	Component/Structure/Component grouping description
99.	Underground fire prevention piping	100.	Plant computer, SOEF, SPDS
101.	DRW floor drain collector, sample and chemical waste tanks	102.	CRW waster collector, surge and sample tanks
103.	Shutdown cooling water pumps	104.	Recirculation pump motors
105.	LPCI/containment service water pump motors	106.	RBCCW heat exchangers
107.	Condensate storage tanks	108.	Reactor recirculation motor generator set
109.	Main turbine controls	110.	Essential HVAC dampers
111.	Condensate demineraliser and ion exchange vessels	112.	Major offgas system components
113.	Reactor building to turbine building isolation seal	114.	Circulating water pumps
115.	Reactor feed pump motor	116.	RWCU regenerative and nonregenerative heat exchangers
117.	Lube oil reservoir and storage tanks	118.	Circulating water pump motors
119.	Shutdown cooling water pump motors	120.	

SWEDEN

In 1998, 12 nuclear power plants, 9 BWRs of ABB Atom design and 3 of Westinghouse design, located at four sites: Forsmark, Oskarshamn, Ringhals and Barsebäck, with a total net capacity of 10.1 GWe supplied 45.7% of all the electric power produced in Sweden. The nuclear utilities in Sweden are the Swedish State Power Board, Sydkraft AB and OKG AB.

Organisations and their responsibilities

Nuclear power is regulated by the Swedish Nuclear Power Inspectorate (SKI). The National Board of Radiation Protection (SSI) has specific regulatory power in their matters of their expertise. These inspectorates are the traditional regulatory bodies. The utility operating organisations are responsible for the safe operation of their plants. SKI monitors plant operation in a number of ways. The utilities are required to submit safety analysis reports for each plant on a periodic basis. Monitoring is achieved by daily operation reports regarding any event of safety significance (e.g., relating to a deviation from prescribed limits) submitted by the plant operating organisation to SKI.

There is no dedicated national plant for plant life management in Sweden. There is a parliamentary decision to phase out nuclear power by the year 2010, but this decision is subject to current political inclinations.

The individual nuclear plant utility or its operating organisation is responsible for plant life management strategies. However, there are several groups among the utilities which co-operate in providing guidance to individual organisations. The most important such group may be KAS (acronym for nuclear power, outage planning and co-ordination). KAS conducts long-term planning of all outages of the Swedish nuclear power plants including programmes for making the outages more effective. KAS is also involved in programmes for achieving increased plant availability and related matters. Through KAS, the utilities jointly make contracts with plant vendors for long-term assistance in areas of interest.

Regulatory process

Safety regulation

With regard to backfitting, there is no simple rule. One outcome of the post-TMI review in Sweden was the requirement that utilities must submit safety analysis reports (denoted ASAR) for each operating plant, on an intermittent basis every 8th to 10th year. These reports should include a probabilistic safety analysis that provides a “risk topography” for the plant. Such analyses bring out possible weak points in the “defence-in-depth” concept that should characterise the plant. As a result, a reasonable assessment of the need for safety improvement in any area is obtained. On this basis, the Nuclear Inspectorate and the utility concerned can be expected to agree as to what may be required in terms of plant upgrading (backfitting).

Another outcome of the post-TMI review was the requirement, established by Government decree, that all Swedish nuclear power plants should be furnished with arrangements for containment filtered venting systems and associated systems for severe accident mitigation. In this case the backfitting requirement was universal in the sense that it affected all units in the country, although different timetables were given to different plants.

Economic regulation

Utilities operate in a commercial environment, and there are no specific constraints relating to nuclear electricity. The utilities can make their own decisions on investments in plant improvements, including measures that have a bearing on life extension.

The nuclear utilities are obliged to contribute to funding for such things as regulation, final disposal of high-level waste, and plant decommissioning.

Objectives and strategy

It is unlikely that sites for new plants will be opened in the foreseeable future. The utilities are eager to keep the existing plants in the best possible conditions and also to consider their upgradings. Care of the plant, good housekeeping and first-class maintenance is done for the sake of high availability and safety as well as it being a means to keep the life extension option alive.

Power upgrading is a particular aspect of plant life management for Swedish plants. In the 1980s, all 9 BWR plants were upgraded between 6 and 10%. This upgrading was achieved with only minor hardware modifications. The whole operation was extremely profitable to the utilities. Power upgrading represents plant energy extension. Based on preliminary studies, there are plans among the utilities to explore the possibilities for further (larger) power upgradings of some of the twelve operating plants. In this case, substantial modifications, including replacements of major components, would be considered.

The Nuclear Power Inspectorate's main concern in relation to the topics discussed here is Quality Assurance in plant operation. Inspection of plant components is important for discovering faults that may need repair or replacement. Some years ago, the Inspectorate, in co-operation with the industry, modified the rules of in-service inspection (ISI) of the Swedish nuclear power plants. The new rules pay increased attention to the safety significance of the systems and components to be inspected. A piping system is given a "fracture index" that reflects the probability of pipe failure, and a "consequence index" determining the seriousness of a rupture to plant safety. The extent and frequency of ISI is then governed by both factors. As a result, there is a shift in inspection plans toward more emphasis on systems inside containment.

The need for early initiation of activities that monitor usage factors of plant components has been emphasised. It is necessary to keep record of plant transients that may subject primary pipes, pressure vessel studs and other components to stresses due to temperature shocks, vibration, or other phenomena. Utilities pay increased attention to record keeping in this area in order to determine fatigue history and realistic lifetime loads on the components of the reactor coolant pressure boundary.

One has become increasingly aware of ageing effects in the plants, particularly corrosion. Typical phenomena include intergranular stress corrosion cracking (IGSCC) in BWRs and various forms of steam generator corrosion in PWRs. Intensified inspection, water chemistry adjustment, repair and replacement constitute the prophylactic or remedial actions that have been or will be taken.

With respect to the BWR, ABB Atom, in co-operation with the Swedish utilities, has completed a long-term research programme, including studies of corrosion mechanisms and selection of means to inhibit IGSCC in primary piping. The recommended measure is to implement Hydrogen Water Chemistry (HWC) for reactor operation. This involves hydrogen injection to the feed water system which leads to a strong suppression of the oxidising species in the reactor coolant. There is a concurrent decrease of the electrochemical potential which is sufficient to inhibit IGSCC.

The HWC mode of operation was introduced in the early eighties in Swedish BWRs. At present, the Ringhals 1 and Forsmark 1 and 2 plants apply HWC operation on a routine basis, and another three plants are being prepared.

With respect to the PWR, steam generator replacement is the most conspicuous measure for plant upgrading. Thus, the steam generators of the first Swedish PWR, Ringhals 2, were replaced effectively and successfully in 1989. As a result of the operation, the nominal power of the unit could be increased by 9%. This upgrading is calculated to pay for the replacement costs in less that 5 years of further power operation.

In the field of electrical systems and components a multitude of measures related to life extension have been completed or are in progress, including the following examples:

- Environmental qualification of cables and components
- Cable replacement inside containment
- Investigation of electrical containment penetrations and their resistance to high pressure
- Measures to ensure electrical equipment cooling

Decision and economic analysis

Life cycle cost analysis (LCC) is applied in several cases in order to establish an optimal design configuration or develop the most effective scheme for maintenance. Probabilistic methods that include cost/benefit aspects have been applied in studies of the merits and safety implications of applying preventive maintenance of components during plant power operation.

Cost/benefit analysis is not normally practised for decisions regarding safety improvement. The regulator is likely to take the attitude that a modification of the plant should be made if it is agreed that it would enhance safety significantly and the cost is not perceived as “prohibitive”.

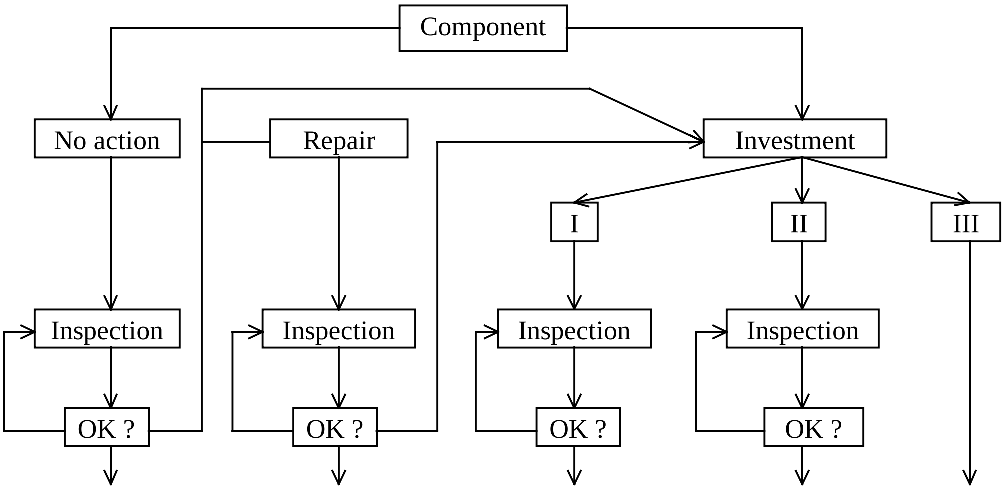
One may consider the most significant result of cost/benefit analysis of Swedish plants to be the power upgradings carried out in the 1980s (cf above).

ABB LCC model

ABB Atom has developed an LCC model to evaluate and compares different alternatives from an economical perspective to replace reactor internals before costly inspection, repairs, and other ageing problems occur. The model considers the many parameters: investment cost; inspection cost; repair; handling procedure; and dismantling and storage. The life cycle cost for different scenarios is calculated from Figure 1. The discounting factor $1/(i+r)^i$ is used to calculate the present value of a future cost for various alternatives (r= rate of discount, i=number of years).

The reference alternative is shown in Figure 1 to the left and implies that the old component is not replaced but is subject to applicable inspection demands in accordance with today’s standards. The second scenario includes repair measures after some years. The third alternative represents investment in a new component. This last alternative can be subdivided into different options [1].

Figure 1. **Calculation flow of ABB LCC model**



Critical components

Based on experience, the most critical components in LWRs as far as plant availability is concerned are the steam generators of a PWR, and the reactor pressure vessel studs and internal parts of a BWR.

Utilities co-operate with vendors in developing systematic methods for inspection, repair and replacement. Factors in such programmes include:

Risk analysis (considering material status, loads, environmental factors including radiations, etc.). This should yield estimates of probability and consequence of failure.

- Identification of “acceptable damage” with consideration of crack propagation.
- Proposals and implementation of improved inspection methods.
- Recommendations on methods for repair or replacement and execution of remedies.

REFERENCES

[1] S. Stridsberg, *Reduced Costs – Increased Safety. Exchange of BWR Reactor Internals from an Economical Perspective*, PLIM+PLEX 97, Prague, 1997.

UNITED KINGDOM

Overview

In the United Kingdom, there are 16 operating nuclear power stations (8 Magnox, 7 AGRs and 1 PWR) with a total capacity of about 13 GWe supplying about 28% of all the electricity produced in the UNITED KINGDOM. The Magnox reactors started operation between 1956 and 1971, the AGRs between 1976 and 1988 and the Sizewell B PWR became operational in 1995.

The nuclear generating industry is operating in an increasingly competitive market with ageing plant and with no commitment to new nuclear power plant construction. Nuclear utilities have therefore introduced plant life management arrangements to support continued operation of their plants. To ensure the integrity and performance of nuclear safety significant components, it is important that critical degradation mechanisms are identified and managed. For example, for steel pressure boundary components, these include understanding the effects of exposure to irradiation, elevated temperature, load cycling and reactor coolants on plant integrity. The environmental and loading conditions cause degradation of components by embrittlement, crack growth, creep strain, corrosion, oxidation and metallurgical changes.

This country report describes the UK position on plant operational life management and includes reference to the regulatory process and supporting technical programmes. Further details on the experiences gained in operating Magnox reactors is described in another UK contribution [1].

Organisation and responsibility

The Health and Safety Executive (HSE) is the United Kingdom’s nuclear installation licensing authority and regulates safety at all nuclear installations in the United Kingdom. HSE’s Nuclear Installations Inspectorate (NII) administers this licensing function on its behalf.

HSE makes it clear that safety law holds the licensee responsible for safety. The HSE sets safety goals (for example, Reference [2]) and it is for the licensees to set out how they will meet them. This policy ensures that the licensees accept responsibility, whilst allowing them to establish their own ways of meeting the needs.

There have been significant organisational changes within the nuclear industry in recent years. This has included the privatisation of the newer nuclear plants. The nuclear power plants in the United Kingdom are operated by four licensees. The Magnox Power Stations are operated by British Nuclear Fuels Ltd (BNFL) and BNFL Magnox Generation (previously Magnox Electric plc). In England and Wales, the AGRs and the PWR are operated by British Energy Generation Ltd (previously called Nuclear Electric Ltd) and in Scotland, the AGRs are operated by British Energy Generation (UK) Ltd (previously Scottish Nuclear Ltd).

In addition to requirements to produce safety cases before operations are commenced and maintain adequate safety cases during operation, the licensing regime requires licensees to review and re-assess the safety of their plants periodically and systematically. This includes a review of age-related degradation phenomena which might limit the future safe operation of the plant.

Regulatory processes

(a) Safety Regulation

The licensing regime requires licensees to review and re-assess the safety of their plants periodically and systematically. Periodic Safety Reviews (PSRs) meet this requirement and HSE makes its findings on the PSRs available to the public. The objectives of the PSRs are:

- to review the current safety case for the nuclear installation and confirm that it is adequate;
- to compare the safety case with modern standards, evaluate any deficiencies and implement any reasonably practicable improvements to enhance plant safety;
- to identify any ageing processes which may limit the operating lifetime of the installation;
- to revalidate the safety case until the next PSR, subject to the outcome of routine regulation.

Although the PSR may conclude that the safety case is adequate for another ten years, this will be dependent upon the continuing satisfactory results from routine inspections.

(b) Economic regulation

The Office of Electricity Supply (OFFER) is the regulatory body for the electricity supply industry in England, Wales and Scotland. Its functions include promoting competition in electricity generation and supply, ensuring all reasonable demands for electricity are met, promoting efficient use of electricity, and protecting customers interests in relation to prices, security of supply and quality of services.

The Department of Trade and Industry has a number of policy roles in respect of the nuclear industry. These include responsibility for energy policy generally (including the role of nuclear power). It is also responsible for those parts of the UK civil nuclear industry still owned by the Government (this includes BNFL).

Objectives and strategy

The licensees reviewed the safety of each Magnox station at about 25 years of operational life. These reviews were called Long-Term Safety Reviews (LTSRs) and were all completed between 1987 and 1995. For operation beyond 30 years and up to 40 years, each station had to have a further review, known as a Periodic Safety Review (PSR) and obtain HSE’s agreement to continued operation. For further operation beyond 40 years and up to 50 years, each station will carry out a further PSR and have to obtain HSE’s agreement for further operation. This third round of safety reviews has already been completed for the oldest Magnox reactors, Calder Hall and Chapelcross.

Like the Magnox stations, the AGR stations are subject to PSRs at 10 yearly intervals as part of the Licence requirements. To date, the Hinkley Point B, Hunterston B, Dungeness B, Hartlepool and Heysham 1 PSRs have been completed.

In all the PSRs reported to date, the HSE has concluded, after its assessment of the licensee’s review of the existing safety case that the licensee has:

- identified and is implementing reasonably practicable improvements to plant and procedures;
- carried out a systematic review of age-related degradation phenomena;
- ensured that suitable monitoring and surveillance schemes are in place.

In reaching these conclusions, HSE recognises that it is difficult to make long-term (i.e. 10 years) predictions in some areas and these will be subject to a programme of regular reviews throughout future operation. In relation to Plant Life Management, examples of specific areas where further work was identified included:

- steel reactor pressure vessel structural analysis and material properties;
- reheat cracking of stainless steel steam pipework;
- graphite core properties.

These issues may be addressed by plant surveillance, additional assessment and research. Also, maintenance activities compensate, to some extent, for time-dependent deterioration and maintain the plant in a condition that meets design safety assumptions and optimises commercial output. The activities which are relevant to plant integrity and reliability are recorded in the Plant Maintenance Schedule. Thus, specific ageing issues are dealt with under the arrangements made to comply with the licence. Prior to the start of a statutory outage, the NII agrees with the licensee the inspections to be undertaken and the ageing and degradation surveillance reviews which are required to be completed and updated before the reactor may return to service. Satisfactory completion of the outage programme is required before the NII will issue a Consent for a reactor to return to routine service after a statutory outage.

Decision and Economic Analysis

The operating lifetime of each nuclear installation is limited principally by the lifetime of items and systems which are uneconomic to replace (e.g. the graphite core, boilers and reactor internals of Magnox and AGRs reactors, reactor pressure boundary components). Account also has to be taken of the additional costs and worker radiation doses arising from increased inspection and maintenance associated with confirming the adequacy of the safety case for ageing structures.

For accountancy purposes, operators normally set a plant amortisation lifetime of about 25 years. This is then adjusted at any time to take account of the life-limiting issues (such as investigations into technical, operational or engineering issues) and unforeseen real plant events. As a result of these issues or events, a revised safety case or replacement of components may be necessary to demonstrate to the regulator that the nuclear installation can continue to be operated safely.

Licensees review the technical and economic factors for each nuclear power plant in order to decide whether continued operation is justified. The cost of maintaining nuclear safety for a plant can be a significant factor in the review. In addition, the sale price of electricity is important and recent measures to increase competition in the electricity market has led to a reduction in prices. To date, three commercial nuclear power plants have ceased generation and are being decommissioned.

Programmes

The licensees commission and undertake research and development to support the safe continued operation of their nuclear installations. Investigations of ageing mechanisms and mitigating the effects of ageing form a significant part of this work. In addition, in recent years, new methods of inspection and repair have been developed which take advantage of advances in technology.

Also, the UK Government has given the Health and Safety Commission (HSC) the responsibility to co-ordinate a long-term generic nuclear safety research programme. HSE directs the programme, on behalf of the HSC, by identifying safety issues which are compiled in the Nuclear Research Index (NRI). The licensees, through their Industry Management Committee, use this index as a focus for commissioning the research programme.

The overall strategy for the programme has evolved recognising the environment in which the nuclear generating industry is operating:

- Nuclear generation has to compete in the market place;
- Ageing plant with no commitment to new nuclear plant construction
- Unique technology

A major part of the programme addresses Plant Life Management issues for steel components and civil engineering structures.

Objectives of the research

Research in the Plant Life Management area is concerned with addressing safety issues which arise as a result of assessment of safety case submissions, underpinning existing safety cases, improving margins of safety, improving methodologies and data for future safety cases, and combating the effect of ageing on structures or components.

The work is primarily aimed at safety issues NII has raised in the NRI, but contains an element of work with a higher operational content.

Future direction of the work

The Magnox stations have successfully achieved over 40 years of operation which is towards the limits of knowledge of ageing effects. Thus increasing efforts are required to improve the understanding and confidence in the long-term materials behaviour. The effect of thermal neutrons and the significance of material composition are currently being given particular attention. These ageing effects compounded with a paucity of relevant data on fracture resistance at start of life can result in large uncertainties for assessment in the aged condition. Continued effort is needed in defining transition behaviour and evaluating the effects of constraint on initiation and post initiation crack stability. Advanced defect assessment methodologies and improved analysis techniques for data and structures require further development and evaluation.

AGR plant is now accumulating periods of high temperature operation where thermal ageing and environmental effects are becoming more evident. The operating conditions are being extended where possible to maximise the plant output and the drive to increase availability is pushing operators to seek longer periods between in-service inspection. These place more emphasis on predictive methods to ensure continuing safety. Even in this relatively modern plant, in-service inspection can be difficult and costly, so it is necessary to develop understanding of plant behaviour in order to target inspection resources by identifying the types and locations of possible degradation. Validation of defect assessment methodologies for high temperature components is also important as in-service inspection will inevitably identify defects of some size.

Understanding metallurgical effects is becoming increasingly important. The AGRs were built from a wide variety of materials, some of which have particular sensitivities to ageing phenomena , e.g. reheat cracking. Apparently small variations in composition, fabrication or loading can give rise to relatively rapid localised degradation. Significant effort is being expended in examining the magnitude and distribution of residual stresses, and their effect on structural integrity.

Effort on PWR specific issues currently has lower priority now that Sizewell B is settling into commercial operation. Work continues on primary and secondary circuit materials degradation, providing information on potential problems ahead of plant operation and for exchange with the international PWR community

It is anticipated that the research is likely to continue with little change in terms of the size and objectives of the programme.

International activities

The United Kingdom is involved in a wide range of international activities related to plant operation and research and development. For example, to obtain an international perspective on PWR ageing issues, British Energy has agreements with EPRI and EdF. The United Kingdom continues to support IAEA activities in Plant Life Management.

The United Kingdom is currently involved in international collaborative research programmes related to Plant Life Management, including the European 4th Framework programmes REFEREE, VORSAC, RESQUE and BIMET, and is considering collaborative research on the ageing of reactor materials under the 5th Framework.

The United Kingdom is also involved in European Networks, AMES, NESC and ENIQ, each of them dealing with a specific aspect of fitness for purpose of materials in ageing structural components

Public acceptance

The UK Government has a policy of openness and therefore HSE(NII) publish a number of reports which are freely available to the public. For example, PSRs findings are published and the reports are re-inforced by launching them at press conferences. NII has a commitment to answer all letters from members of the public. Press releases are issued for significant issues.

Similarly, results from the HSC Co-ordinated Nuclear Safety Research Programme are presented at conferences and published in the open literature.

The UK operators are responsible for communicating their policies to the public. One forum for this is the local community liaison committees which meet regularly at each site.

REFERENCES

[1] T Stokoe, *Magnox Plant Life Management*, 1999.

[2] HSE/HMSO, *Safety Assessment Principles for Nuclear Plants*, ISBN 0 11 882043 5, 1992.

UNITED STATES

In order to ensure a continued high standard of living for its citizens, the United States needs to maintain a diverse, secure energy portfolio of fossil fuels, nuclear energy, and renewables. A reliable and affordable electric power supply is a prerequisite for a strong economy and sustained growth. Nuclear power is an important component of the U.S. energy supply system and generates electricity without emitting any greenhouse gases or other harmful air pollutants such as sulphur dioxide and nitrogen oxides. In 1998, 104 nuclear power plants with a total net capacity of 97 GWe supplied 21% of all the electric utility generated electricity in the United States [1]. Currently solar and wind energy provide less than one tenth of 1% each of the total energy consumption in the United States. The share of electricity generation from non-hydroelectric renewable electric generators was 1.21% for 1997. Their share including co-generation was 2.1% in 1997 and is projected to grow to 3.23% in 2020.

Hydroelectric power currently supplies close to 10% of U.S. electricity needs but its expansion potential is very limited due to a lack of available new sites, high construction costs, growing environmental concerns, and competing uses of water resources. The share of hydroelectric generation is projected to decline from 9.96% in 1997 to 6.7% in 2020. Therefore, the strong role played by nuclear energy and specifically by operating nuclear power plants, in serving strategic national interests must continue.

Deregulation of electricity production in the United States has increased economic uncertainties in the electricity sector. Existing and proposed environmental laws are causing the closure of older fossil-fuel plants. Similarly, we are at a critical juncture with regard to the continued operation of nuclear power plants in the United States. The operating licenses of 41 nuclear power plants whose capacity is nearly 40% of the present capacity will expire by the year 2015. Licenses for 13 plants representing some 11 700 MWe will expire in 2014 alone. The Atomic Energy Act of 1954, as amended, limits the operation of a nuclear power plant to 40 years, and allows the renewal of its license. The initial 40-year license period was selected on the basis of economic and antitrust considerations. It is not based on safety, technical or environmental limitations.

A few utilities have decided to close older, less efficient nuclear facilities before their license expiration date. Six reactors closed prematurely with the resultant loss of approximately 4,000 megawatts of U.S. generating capacity in the past three years. However, over the last couple of years the strategic landscape has started to change. The first license renewal application was submitted by Baltimore Gas and Electric Company in April 1998 for its two-unit Calvert Cliffs nuclear power plant. Two years ago, with electricity restructuring looming and concerns over regulatory uncertainty, the prediction was that existing nuclear generation capacity was doomed – that fewer plants would seek license renewals and that many would shut down prematurely. Without license renewal, loss of large amounts of electric capacity will damage U.S. energy supply stability and the environment, especially the latter, caused by increased carbon dioxide emissions, early in the 21st century. Today, with consolidations in ownership occurring and several plants proceeding and making good progress with license renewal, it is clear that there is a future for the majority of U.S. nuclear plants. However, for these plants to remain viable beyond 2020, both government and industry must take action –government reducing regulatory and other barriers to operation and industry, investing capital in upgrading their facilities for the future and investing in short-term R&D.

Organisations and their responsibilities

At present, there is no fully integrated and mutually agreed upon national strategy, plan, or organisation responsible for plant life management. However, the Department of Energy (DOE) issued a Comprehensive National Energy Strategy in April 98 which has as a goal to improve the reliability and performance of operating nuclear plants and to maintain a viable nuclear energy option. DOE Strategic

Plan includes an objective to improve nuclear power plant reliability and availability to increase the capacity factor of existing nuclear power plants to an average of 85% by 2010.

DOE promotes plant life management as a viable option by supporting R&D on age-related degradation of materials, and on developing technologies to improve the operation and optimise output of existing nuclear power plants. The Nuclear Regulatory Commission (NRC) regulates the Nation's civilian use of special nuclear materials to ensure adequate protection of public health and safety, to promote common defence and security, and to protect the environment. The NRC's scope of responsibility includes regulation of commercial nuclear power plants; research, test, and training reactors; fuel cycle facilities; medical, academic, and industrial uses of nuclear materials; and transport, storage, and disposal of nuclear materials and wastes. National and private Laboratories perform government and industry sponsored ageing research tasks. The Nuclear Energy Institute (NEI), the successor organisation to NUMARC, co-ordinates regulatory and licensing efforts associated with constructing or operating nuclear power plants of all nuclear utilities and other nuclear organisations with the NRC. The Electric Power Research Institute (EPRI) is the main electric utility research co-ordination organisation which performs collaborative research for its member utilities on all aspects of electricity, including plant life management. The Owners' Groups, which are classified by reactor vendor, perform generic evaluations that can be shared by a number of utilities, and work with the NRC to obtain NRC concurrence and/or approval. Individual Utilities perform evaluations required to support continued operation, prepare a License Renewal Application (LRA) and submit the LRA to the NRC.

Regulatory processes

Safety regulation

The Atomic Energy Act of 1954, as amended, Section 103.c limits the initial operating licenses of nuclear power plants to 40 years and allows their renewal. Plant owners may apply to renew the license after 20 years, before the expiration of the current license. The initial 40-year license term for nuclear power plants was selected by Congress because this period is a typical amortisation period generally used by electric utilities for large capital investment. License renewals are allowed in the same way as set out in the Communications Act of 1934 which limits the operation of radio stations to several years and allows the renewal of licenses.

In December 1991, the NRC issued the rule and associated documentation that describe the requirements a licensee must be able to demonstrate for the NRC to make a determination that the plant can continue to be operated for up to 20 additional years beyond its 40 year license term. 10 CFR Part 54 "Requirements for Renewal of Operating Licenses for Nuclear Power Plants" was revised in May 1995, to simplify and clarify the license renewal scope and process. The NRC has begun to develop regulatory guidance and standard review plans for license renewal. These plans are not expected to be finalised until after the first few applicants have gone through the process. May 1995 revision to the License Renewal Rule stresses managing the effect of ageing rather than managing ageing mechanisms and requires an Integrated Plant Assessment (IPA) and time-limited ageing analyses. The plant systems, structures and components within the scope of this part are (1) safety-related systems, structures, and components which are those relied upon to remain functional during and following design-basis events, (2) all non safety-related systems, structures, and components whose failure could prevent satisfactory accomplishment of safety-related functions, and (3) all systems, structures, and components relied on in safety analyses or plant evaluations to perform a function that demonstrates compliance with the Commission's Regulations for fire protection, environmental qualification, pressurised thermal shock, anticipated transients without scram, and station blackout. From this scope of equipment, long-lived passive structures and components are evaluated further in the IPA.

The IPA must demonstrate that the effects of ageing will be adequately managed so that the intended function(s) can be maintained in consistency with the Current Licensing Basis (CLB) for the period of extended operation for each long-lived passive structure and component, within the scope of this part

The time-limited ageing analyses must demonstrate that (1) they remain valid for the period of extended operation; (2) they have been projected to the end of the period of extended operation; or (3) the effects of ageing on the intended function(s) will be adequately managed for the period of extended operation. The NRC developed a draft of DG-1047 *Standard Format and Content for Applications to Renew Nuclear Power Plant Operating Licenses* in August 1996. The *Working Draft Standard Review Plan for License Renewal* (WD-SRP-LR) has been made publicly available since September 1997, and it will be continuously revised as it gains experience from future review activities and interactions with the industry.

The NRC has also revised the scope of the agency's environmental review process for reactor license renewal. 10 CFR (Codes of Federal Regulation) Part 51 "Environmental Protection Regulations for Domestic Licensing and Related Regulatory Functions" was amended in December 1996 to facilitate the environmental review for license renewal. This revision is based on NUREG - 1437, *Generic Environmental Impact Statement for License Renewal of Nuclear Plants* (GEIS). The GEIS identifies 92 environmental issues and reaches generic conclusions related to environmental impacts for 68 of these issues that apply to all plants or to plants with specific designs or site characteristics. Additional plant-specific review is required for the remaining issues. These plant-specific issues are required to be included in a supplement to the GEIS for each plant applying for license renewal. The NRC issued such a supplement for Calvert Cliffs Nuclear Power Plant in February 99 as a Draft Report for Comment**.**

Economic regulation

The federal economic regulating body is the Federal Energy Regulatory Commission (FERC). The FERC and the NRC are independent agencies. Safety issues and economic regulatory issues are decided independently. FERC regulates interstate and wholesale electric rates.

At the state level, a Commerce Commission (CC), Public Service Commission (PSC) or a Public Utility Commission (PUC) maintains economic approval authority of investor-owned utilities, including water, transportation, natural gas, electricity, and communication services. Investor-owned utilities define their cost basis for capital expenditures and submit the proposed basis to the public economic regulator in a forum known as a "rate case". The public economic regulator approves and/or adjusts the cost basis in the rate case, and determines the return on investment allowed.

Recently, the electric utility industry in the United States is being restructured. Under electricity restructuring, competition would replace regulation as the primary mechanism to determine the price of electricity at the generation plant. Utilities would be required to open up their distribution and transmission wires to all qualified sellers. The transmission and distribution of electricity would continue to be regulated because they will remain monopolies for the foreseeable future. Approximately twenty States have enacted legislation or promulgated regulations establishing retail competition programmes. Many of the remaining States have the matter under active consideration. On April 15, 1999, the Clinton Administration sent a proposed federal legislation for electricity restructuring to Congress. The proposed legislation described in the Comprehensive Electricity Competition Plan, embodies the overall agenda of the Clinton Administration to expand the economy and improve the environment.

No economic regulatory policies unique to nuclear plant ageing, life management or life extension have been adopted. However, the Energy Policy Act of 1992 requires all States to consider the Integrated Resource Planning (IRP) methodology. IRP is a process that privately owned utilities in many States must use to select the least-costly way to meet electrical demand. If large expenditures are anticipated for repairs to an existing generating plant, the IRP process would analyse this expenditure plus continued operating costs against building a new plant, or other power supply options [e.g. an Independent Power Producer (IPP)].

Programmes

DOE

For fiscal year 2000, DOE has proposed a new initiative, Nuclear Energy Plant Optimization (NEPO). The goal of NEPO programme is to ensure that current nuclear plants can continue to deliver adequate and affordable energy supplies up to and beyond their initial 40 year license period by developing technology to manage the long-term effects of plant ageing, and to improve overall plant reliability and productivity. To accomplish this goal, research will be conducted on key nuclear power plant component ageing phenomena so as to provide utilities and NRC with the information and methods needed to measure, predict and control long-term effects of material degradations. Critical materials research will be expanded in order to be prepared for new issues related to the extended performance of existing plant equipment (particularly, long-lived, passive components and structures). Technical issues of a generic nature that might arise during NRC review of the first group of license renewal applications will be resolved.

In addition, the NEPO programme will develop and apply advanced technology to enhance nuclear generation capability, efficiency, and productivity. The primary focus of this advanced technology development will be on digital I&C, information management systems, man-machine interface and human factors engineering, and inspection/repair.

In the past, DOE's Commercial Operating Light Water Reactor (COLWR) programme focused on activities described below:

Reactor Pressure Vessel (RPV) annealing programme

A number of operating plants may exceed the pressurised thermal shock screening criteria of NRC's requirement for assessing RPV embrittlement during a 20-year license renewal term. An indirect gas-fired furnace heating technology was demonstrated to establish a viable annealing option.

Industry reports (IRs)

DOE/EPRI sponsored License Renewal Industry Reports (IRs) are detailed, generic technical evaluations of ten groupings of systems, structures and components judged to be important to license renewal in the pilot plant studies. The IRs were submitted to the NRC and the key technical conclusions are documented in the Working Draft of the NRC License Renewal Standard Review Plan issued in September of 1997. The NRC plans to update the License Renewal Standard Review Plan later in 1999 to reflect the experience gained from Calvert Cliffs and Oconee license renewal applications.

The IRs cover:

- BWR Primary Containment
- BWR Primary Coolant Pressure Boundary
- BWR Reactor Pressure Vessel
- BWR Reactor Pressure Vessel Internals
- PWR Containment

- PWR Reactor Coolant System
- PWR Reactor Pressure Vessel
- PWR Reactor Pressure Vessel Internals
- Class I Structures
- Low-Voltage, Environmentally Qualified Cables

Ageing Management Guidelines (AMGs)

DOE sponsored Ageing Management Guidelines (AMGs) to generically perform detailed evaluations of ageing mechanisms and ageing management strategies for a number of equipment groups. AMGs, covering the following commodity groups, have been published [3].

- Battery Chargers, Inverters and Uninterruptible Power Supplies
- Batteries, Stationery
- Cables and Terminations, Electrical
- Heat Exchangers
- Motor Control Centres
- Pumps
- Switchgear, Electrical
- Transformers, Power and Distribution
- Tank and Pools

NEI

The NEI prepared an implementation guideline, NEI 95-10, for license renewal application, *Industry Guideline for Implementing the Requirements of 10CFR Part 54 – The License Renewal Rule*, that was demonstrated and evaluated by NRC staff and an industry peer review team in six nuclear power plants in 1996. The NRC, in August 1996, developed a draft of DG-1047 *Standard Format and Content for Applications to Renew Nuclear Power Plant Operating Licenses* that proposed to endorse the implementation guideline as an acceptable method of carrying out the license renewal rule. NEI also prepared NEI 98-06, an industry guideline for preparing an environmental report for license renewal in accordance with 10CFR51.53 (c).

EPRI

EPRI's Life Cycle Management and License Renewal (LCM/LR) programme that is closely co-ordinated with related programmes by the NEI and the DOE supports utilities with specific projects in PLIM areas. EPRI conducted initial life extension evaluation and planning studies during the period 1978-1982, which demonstrated technical feasibility and that operation beyond 40 years was economically attractive compared to other alternatives. EPRI, together with DOE, co-sponsored the Monticello and Surry Pilot Plant Life Extension projects, which confirmed earlier generic conclusions, and compiled ten IRs as mentioned above. In 1991, EPRI together with Baltimore Gas & Electric Co. initiated a long-term Life Cycle Management Programme for the Calvert Cliffs Nuclear Power Plant. This programme including both technical and economic evaluations, has resulted in the development and implementation of a strategic plan for operation of Calvert Cliffs and led to the preparation and submittal of the first license renewal application for a U.S. nuclear power plant. EPRI's current programme includes resolution of generic license renewal technical issues, demonstration of life cycle management implementation as several U.S. nuclear plants, application of Strategic Asset Management to nuclear plant business decisions, acquisition of ageing effects data from shutdown nuclear plants, and license renewal workshops and training for U.S. utilities.

Lead Plant License Renewal Demonstration Programme for Monticello BWR and Yankee Rowe PWR were completed with the DOE, but were not submitted to the NRC. However, much valuable experience was gained and transferred to Calvert Cliffs License Renewal.

Owners groups

The Babcock & Wilcox Owners Group (BWOG), the Westinghouse Owners Group (WOG), and the Boiling Water Reactor Owners Group (BWROG) are pooling their technical resources, submitting generic license renewal reports to the NRC, and providing generic technical assistance to their owners.

Utilities

Baltimore Gas and Electric Company applied for the renewal of the operating licenses for Calvert Cliffs Nuclear Power Plant Units 1 and 2 on April 8, 1998 [7], and Duke Energy Corporation for Oconee Nuclear Station Units 1, 2 and 3 on July 6, 1998, requesting an extension of 20 years beyond the current expiration date. These applications are under NRC review.

Decision and economic analysis

Decisions on overall economics (plant operation versus retirement)

In the past decade, 12 plants have been shut down for economic reasons: Yankee Rowe, San Onofre Nuclear Generating Station Unit 1 (SONGS 1), Trojan, etc. Note that “economic” reasons are used in the broadest sense because these decisions are made in conjunction with the public economic regulator and the decision includes initial investment recovery and decommissioning costs. The decision to operate or shut down a plant is a business decision for the utility.

In simple terms, Yankee Rowe's cost benefit study showed that abundant power was available from Canada at approximately one-third of Yankee Rowe's production cost, the local economy was depressed, and natural gas was readily available. SONGS 1 prepared an Integrated Resource Plan (IRP) based on least-costly planning. The State of California PUC offered SONGS 1 two choices and the lowest economic risk option for the utility was plant shutdown. Trojan also prepared an IRP based on least-costly planning. Trojan's decision considered major, undefined expenses to replace steam generators, strong local intervenors, and ample hydroelectric and natural gas supplies.

Decisions on whether or not to backfit or upgrade certain components

The backfit requirements imposed by the NRC fall into two general categories. Backfits required to maintain adequate safety and protection are mandatory, while backfits required to substantially improve the overall plant safety must be justified by a cost/benefit analysis.

Upgrades planned by the Licensee (to improve efficiency, reliability, in response to an NRC suggestion, etc.) include a cost/benefit analysis to determine the appropriate course of action. Typically, a two (2) to three- (3) year payback is required before an upgrade is approved by utility management. Major upgrades (e.g. steam generator replacement) are evaluated over a longer period of time, and frequently involve the public economic regulator.

Decisions on how to balance the proper level of preventive maintenance versus corrective maintenance

The plant operator considers reliability and economic factors to balance the level of preventive and corrective maintenance. The maintenance rule (10 CFR 50.65) went into effect July 1996. Implementation of the maintenance rule includes the establishment of performance goals for plant systems, structures, and components. The performance of the plant equipment against these goals dictates the amount and type of preventive maintenance versus corrective maintenance that must be performed.

Decisions of whether to repair, replace or redesign certain components and systems

For low cost activities, the decision to repair, replace or re-design certain components and systems is made by the plant operator (same as preventive and corrective maintenance decisions). For high cost items (e.g. steam generator replacement) that will significantly affect the cost basis for determining rates, the public economic regulator is generally consulted, and may include consideration of capacity alternatives and competitiveness in the deregulated market.

Cost/benefit analysis methodologies

The EPRI Life Cycle Management and License Renewal Programme is developing software tools for nuclear business decisions including license renewal. One such tool, the EPRI Nuclear Options Model, calculates the value of a nuclear power plant in a deregulated electricity market and provides management guidance for license renewal or early shutdown.

In addition to the cost/benefit and least-costly planning assessments discussed above, generic information on cost/benefit analysis methodologies applied to license renewal decisions is available in NUREG-1437, Generic Environmental Impact Statement for License Renewal of Nuclear Plants, Volume II, Appendix H, The Economics of License Renewal, Public acceptance

Safety

The public has numerous opportunities to be involved in virtually all aspects of nuclear longevity decisions. All regulation changes are open to public comment prior to final issuance. Public participation can also occur through public hearings at the local, state or federal level. The License Renewal Rule provides the opportunity for public hearings on matters related to age-related degradation of systems, structures, and components.

Economics

The current market trend in the commercial nuclear power segment is towards consolidation. As efforts to restructure the electric generating portion of the power industry continue and utilities' profitability becomes increasingly dependent on the marketplace, we see current plant owners splitting into two groups; those who wish to increase the number of nuclear plants they own, and those who wish to move out of the nuclear business altogether. It is likely to be less cost-effective to continue to own and operate a single nuclear unit, with its relatively large fixed costs, which can only be spread over a small production base. A large nuclear utility, however, could buy the single unit, add it to its total nuclear generating capacity and end up with a smaller unit operating cost, due to economy of scale. For example, Amergen, a holding company of British Energy and PECO Energy (Philadelphia), which owns and operates four nuclear units in Pennsylvania, is in the process of purchasing the undamaged unit at TMI. Similarly, Entergy, which now owns and operates five nuclear units in Louisiana, Arkansas, and Mississippi, is purchasing the Pilgrim plant from Boston Edison.

Although we have seen six nuclear units shut down prematurely in the past three years, we do not expect this trend to continue. The units that were shut down were, in general, smaller, older, less cost-efficient plants. The large majority of nuclear plants in operation today is larger units and can be operated competitively with fossil-fuelled and other sources for electricity generation in a deregulated marketplace. Depending upon how “stranded costs” are treated through legislation and State deregulation actions, many of the larger, newer, nuclear plants may have to write off some book value. This however will not lead to permanent shutdown, as these are past costs, not future costs; and current production costs at these plants are competitive.

REFERENCES

[1] Energy Information Administration, *Monthly Energy Review*, May 99

[2] Nuclear Regulatory Commission, NUREG 1350, 1998 edition.

[3] DOE and EPRI sponsored reports:

SAND 96-0343, Ageing Management Guideline for Commercial Nuclear Power Plants –Tanks and Pool, Sandia National Laboratories, March 1996.

SAND93-7046, Ageing Management Guideline for Commercial Nuclear Power Plants – Battery Chargers, Inverters and Uninterruptible Power Supplies, Sandia National Laboratories , February 1994.

SAND93-7071, Ageing Management Guideline for Commercial Nuclear Power Plants – Stationary Batteries, March 1994.

SAND96-0344, Ageing Management Guideline for Commercial Nuclear Power Plants – Electrical Cable and Terminations, Sandia National Laboratories, September 1996.

SAND93-7070, Ageing Management Guideline for Commercial Nuclear Power Plants – Heat Exchangers, Sandia National Laboratories, June 1994.

SAND93-7069, Ageing Management Guideline for Commercial Nuclear Power Plants – Motor Control Centers, Sandia National Laboratories, February 1994.

SAND93-7045, Ageing Management Guideline for Commercial Nuclear Power Plants – Pumps, Sandia National Laboratories, March 1994.

SAND93-7027, Ageing Management Guideline for Commercial Nuclear Power Plants – Switchgear, Electrical, Sandia National Laboratories, July 1993.

SAND96-0343, Ageing Management Guideline for Commercial Nuclear Power Plants – Tanks and Pools, Sandia National Laboratories, March 1996.

[4] DOE, *Comprehensive Nuclear Energy Strategy*, April 1998

[5] *Joint DOE-EPRI Strategic Research and Development Plan to Optimize U.S. Nuclear Power Plants*, March 1998

[6] NEI 95-10, *Industry Guideline for Implementing the Requirements of 10CFR Part 54 – The License Renewal Rule*

[7] Baltimore Gas and Electric Company, Calvert Cliffs Nuclear Power Plant Units 1 and 2; Docket No. 59-317 & 50-318 Application for License Renewal, April 8, 1998.