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Economics and Policies of Nuclear Plant Life Management

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Abstract: NEA provides an opportunity for international exchange of information on the economics and policies of nuclear plant life management for governments and plant owners. The NEA Secretariat is finalising the "state-of-the-art report" on the economics and policies of nuclear plant life management, including the model approach and national summaries. In order to meet power supply obligations in the early 2000, taking into account energy security, environmental impact, and the economics of nuclear power plants whose lives have been extended, initiatives at national level must be taken to monitor, co-ordinate, and support the various industry programmes of nuclear plant life management by integrated and consistent policies, public acceptance, R&D, and international co-operation. Nuclear plant owners should establish an organisation and objectives to carry nuclear plant life management in the most economic and smoothest way taking into consideration internal and external influences. The organisation must identify the critical item and the ageing processes, and optimise equipment reliability and maintenance workload.

Keywords: life management, nuclear power plant, economics, policy, NEA.

I. INTRODUCTION

In OECD Member countries, nuclear power plants supplied around 24 per cent of total electricity generation in 1997, producing 8 245 TWh[1]. One third of these nuclear power plants have been in operation for over 20 years. In order to keep up with the growing demand for electricity and mitigate global warming, most nations will undoubtedly need to keep existing nuclear power plants operating as long as they can continue to function safely and economically. A number of safety studies at company, national and international level, such as the NEA (see Annex 2), contribute to the recognition and control of degradation mechanisms. 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.

NEA provides an opportunity for international exchange of information on the strategic and economic management of nuclear plant life management for governments and plant owners. The PLIM Expert Group held its first meeting in 1991. Members have discussed various types of information. An International Terminology for PLIM in five languages, based on the US-EPRI's work published in 1993[2], has been completed in co-operation with the IAEA and EC, and will be published by the end of 1998 (see Annex 1). A study on Refurbishment Costs of Nuclear Power Plants will be completed with the issuing of a working document by the end of 1998. At the PLIM Workshop in 1997, various papers on economic, technical and regulatory aspects of PLIM were presented and discussed. The NEA Secretariat is finalising the last draft of the report that has been discussed by the Expert Group. It consists of two different sections: a model approach and national programme summaries. This paper presents the outline of the former section.

II. NATIONAL LEVEL CONSIDERATIONS

It is clear that each nation's energy strategy should include 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.

Especially in the context of security, environment, and economy, nuclear plant life management should be considered. Nuclear power offers a diversity of supply to nations concerned with energy security and availability, and has reduced environmental impacts and carbon dioxide emissions. The economics of plant life management have become an important topic in the nuclear industry in the context of regulatory reform of the electricity market. A depreciated nuclear power plant with low fuel cost could be a price leader.

a) **Growing 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. Over the next decade, electricity capacity in the Member countries is expected to grow at a rate of about 1.4 % per year in order to keep up with demand.

Figure 1. **Estimates of Total and Nuclear Electricity Generation**

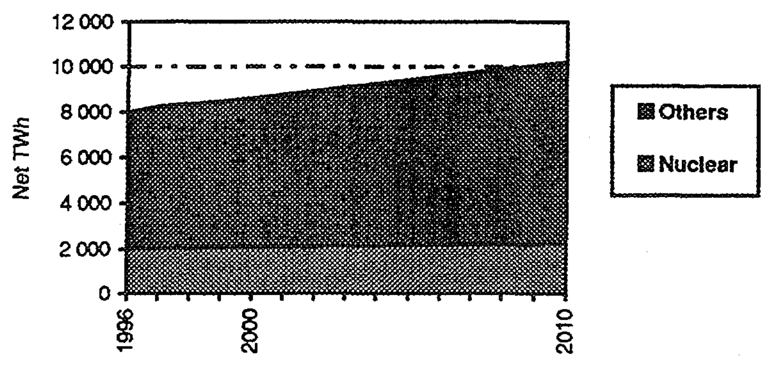
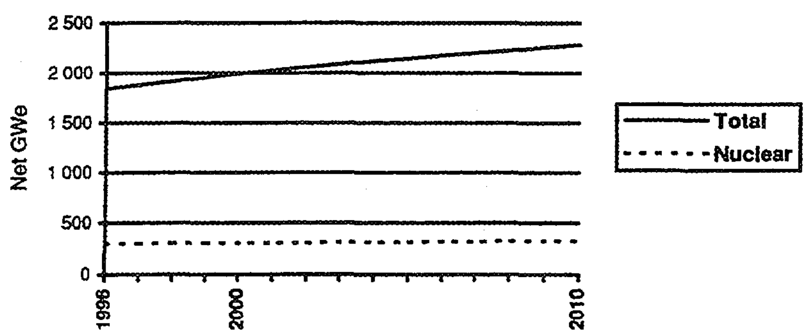


Figure 2. **Estimate of Total and Nuclear Electricity Capacity**



b) **Limitation of conservation and new site** – 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. 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 but also simply to increased public resistance to new industrial facilities as a whole (so called NIMBY).

Table 1. STATUS OF NUCLEAR POWER PLANTS (Net GWe)

COUNTRY	Connected to the grid		Under Construction		Firmly committed		Planned	
	Units	Capacity	Units	Capacity	Units	Capacity	Units	Capacity
Belgium	7	5.7	0	0.0	0	0.0	0	0.0
Canada	21	15.5	0	0.0	0	0.0	0	0.0
Czech Republic	4	1.6	2	1.8	0	0.0	0	0.0
Finland	4	2.4	0	0.0	0	0.0	0	0.0
France	59	62.9	1	1.4	0	0.0	0	0.0
Germany	19	21.1	0	0.0	0	0.0	0	0.0
Hungary	4	1.8	0	0.0	0	0.0	1	0.6
Japan	54	43.6	1	0.8	4	4.7	17	18.4
Korea	12	10.3	6	5.4	2	2.0	8	9.2
Mexico	2	1.3	0	0.0	0	0.0	0	0.0
Netherlands	1	0.5	0	0.0	0	0.0	0	0.0
Spain	9	7.3	0	0.0	0	0.0	0	0.0
Sweden	12	10.1	0	0.0	0	0.0	0	0.0
Switzerland	5	3.1	0	0.0	0	0.0	0	0.0
Turkey	0	0.0	0	0.0	0	0.0	10	6.5
United Kingdom	35	12.7	0	0.0	0	0.0	0	0.0
United States	110	101.0	0	0.0	0	0.0	0	0.0
TOTAL	358	300.9	10	9.4	6	6.7	36	34.7

c) **Energy mix** – Nuclear power offers a diversity of supply to nations concerned with energy security and availability. Unaffected by oil supply or price 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. Strong nuclear programmes offset the equivalent of about 10 million barrels of oil per day in OECD Member countries with the accompanying benefits of lower oil prices and energy security/availability.

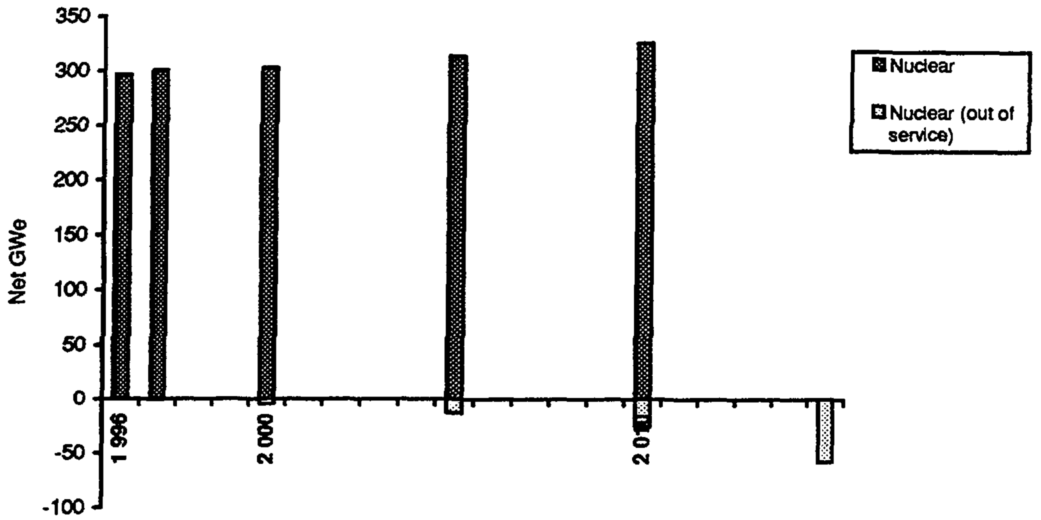
d) **Environment** - Nuclear power plants have been pivotal in reducing the use of oil, gas, and coal for electrical generation and hence have reduced environmental pollution and carbon dioxide. Nuclear power plants in OECD Member countries reduce 400 million tons of carbon.

e) **Retirements** - Until the year 2015, 100 nuclear power plants whose total net capacity is 58 GWe, 20 per cent of the present total net capacity, are planned 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, offering energy security and reducing environmental impacts more than retirements.

Table 2. **PLANTS TO BE TAKEN OUT OF SERVICE** (Net GWe)

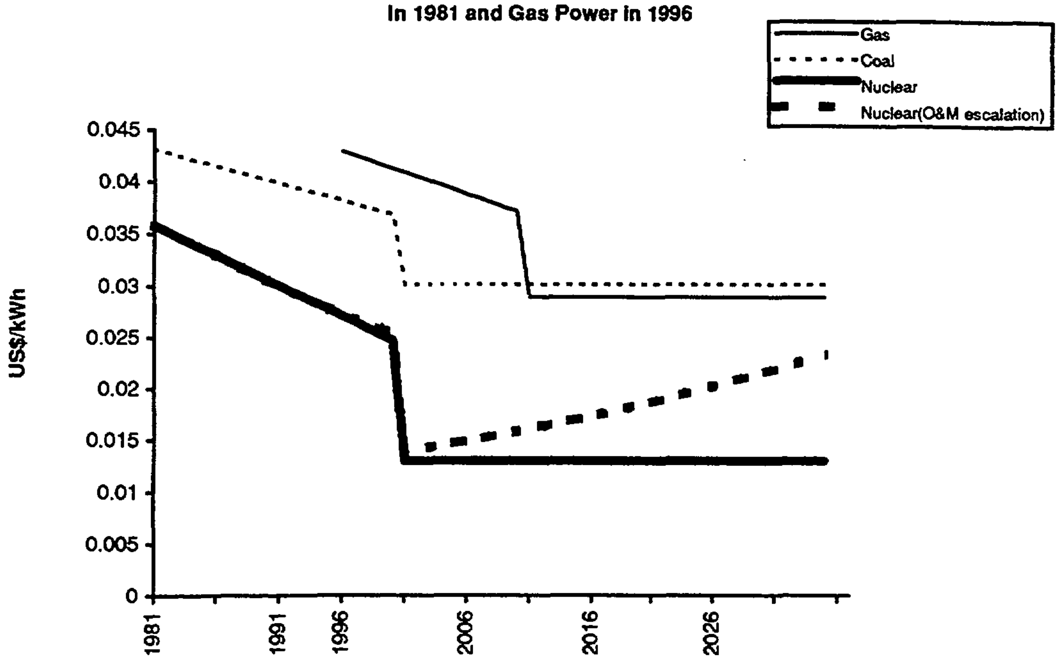
COUNTRY	2000			2005			2010			2015		
	Units	Capacity	Lifetime	Units	Capacity	Lifetime	Units	Capacity	Lifetime	Units	Capacity	Lifetime
Belgium												
Canada							2	1.0	32	4	2.0	35
Czech Republic												
Finland												
France	1	1.2	12	1	0.2	32						
Germany												
Hungary												
Japan	1	0.1	32	1	0.1	25						
Korea							1	0.6	32			
Mexico												
Netherlands				1	0.5	30						
Spain							1	0.2	40	2	0.6	40
Sweden	1	0.6	34	1	0.6	34						
Switzerland												
Turkey												
United Kingdom	4	0.7	34	16	2.8	40	4	2.3	30	6	3.3	30
United States	3	1.3	33	5	4.5	30	12	8.8	36	33	26.2	39
TOTAL	10	3.9	27	25	8.7	33	20	12.9	34	45	32.1	38

Figure 3. **Nuclear Electricity Capacity to be Estimated and to be taken out of service**



f) **Economic competition** – The economics of plant life management have become an important focus for discussion in the nuclear industry. This issue gains added interest in the light of questions as to whether aged nuclear power plants can compete with other sources of electricity generation in the context of regulatory reform of electricity market. A depreciated nuclear power plant with low cost of fuel is a price leader as shown in Figure 4. Increasing operation and *maintenance cost increases annual costs of nuclear power plants.* The escalation of 2 per cent per annum of operation and maintenance costs of a nuclear power plant makes its annual costs double by 2035, which is still lower than that of gas and coal.

Figure 4. **Annual costs of Nuclear and Coal Powers established In 1981 and Gas Power In 1996**



	Nuclear	Coal	Gas
Investment at 1981	1 540 US$/kWe	880 US$/kWe	
Investment at 1996			880 US$/kWe
Amortisation period	20 years	20 years	15 years
Load Factor	75%	75%	75%
Thermal Efficiency	34%	34%	52%
O & M cost at 1996	58.6 US$/kWe/year	52.5 US$/kWe/year	27.0 US$/kWe/year
Coal & Gas		2.09 US$/Gjoule	3.58 US$/Gjoule
Uranium	50.2 US$/kg		
Enrichment	103.8 US$/SWU		
Fabrication	310.5 US$/kg		

III. GOVERNMENTAL CO-ORDINATION

In order to meet power supply obligations in the early 2000, taking into account energy security, environmental impact, and the economics of nuclear power plants whose lives have been extended, initiatives at national level must be taken to monitor, co-ordinate, and support the various industry programmes of nuclear plant life management.

a) **Integrated and consistent policies** – Nuclear power plant lifetimes are, for the most part, driven by cost and revenue considerations. Governmental regulatory policies on nuclear plant safety exert a significant influence on operating and maintenance costs (O&M), as well as on the capital additions needed to comply with evolving safety standards. Nuclear plant revenues are also heavily influenced by governmental economic regulation (rate setting). In most countries, however, safety and economic regulation is not tightly integrated. As a result, the existing base of electricity generating plants, and nuclear plants in particular (due to a heavier degree of safety regulation), may be threatened by a de-coupled cost-revenue scheme. In addition, uncertainties on future regulation make decision making of plant owners difficult. Policymakers are encouraged to examine more carefully the current levels of inter-governmental co-ordination in the regulatory process and make consistent policies.

b) **Public acceptance** – Over the years, the public has adopted an increasing role in the decision making process for nuclear electricity generation. A number of experts feel that public attitudes towards ageing nuclear power plants will be key in terms of gaining public acceptance for continued or extended operation. Concerns may arise that the safety levels of the plants are deteriorating with time or the level of uncertainty in safety is rising with time. The policy should include provisions for ensuring that the safety issues are transparent and that the solutions are readily understandable to the local community and opinion leaders. A more open dialogue is encouraged.

c) **R&D** – 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 industry. Accordingly, 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 generically applicable to many plants in the nation, and where sustained electrical capacity is vital to national interests, governments may play a role in co-ordinating and supporting industry initiatives. Accordingly, a key element of national framework for plant life management is the development of suitable industry-governmental co-ordination mechanisms.

d) **International co-operation** – Ageing experience have 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 which affect nuclear power decision making and economics. Clearly, there is a wealth of data, experience and advice available to those willing to tap this resource. As a result, several international efforts are underway in the area of plant ageing and life-cycle management. These programmes are inter-governmentally organised (e.g., OECD/NEA, CEC, IAEA) or industry-based (e.g., WANO, UNIPEDE) or a combination of the two.

IV. INDUSTRIAL LEVEL CONSIDERATIONS

Nuclear plant owners should establish an organisation and objectives to carry nuclear plant life management in the most economic and smoothest way taking into consideration internal and external influences.

a) **Steering committee** - The first step in developing a PLIM programme is to establish a Steering committee of key individuals to prepare the PLIM programme plan. The Steering committee has to meet the PLIM programme objectives and provide a suitable basis for plant life decision making. Additionally, it would ensure that a coherent stance is taken by the company in external relations regarding these subjects.

A Steering committee is composed of a core of high-level individuals from the following areas of concern:

a) generation planning;
b) operations;
c) design and engineering;
d) maintenance;
e) inspections and testing;
f) research;
g) legal affairs; and
h) public relations.

The chief responsibility of the Steering Committee is to ensure that the Plant Life Management (PLIM) Programme is consistent with the corporate goals and the requirements of the overall plant life-cycle decision making process. The Steering Committee directs the PLIM programme and research activities, co-ordinates complimentary projects, and monitors progress.

b) **Overall programme plan** – An essential element of an effective PLIM programme is an Overall Programme Plan which defines the objectives, management organisation and processes. The Overall Programme Plan should typically include the following elements:

Objectives – The objectives of the PLIM Programme should be stated clearly at the onset and endorsed by top management. Objectives to be considered might include:

a) the continued assurance of safety;
b) minimising the cost and maximising the profit;
c) maintaining a balance of energy generation mix; and
d) managing risk and uncertainty (e.g., unexpected technical degradation or changes in standards).

Management organisation and resource plan – In addition to the Steering Committee, a suitable management organisation and resource plan should be established in order to carry out the PLIM Programme. Depending on the foreseen schedule, either a full time PLIM management organisation should be assembled or else a full-time PLIM co-ordinator (project manager) should be assigned with the balance of the staff being co-ordinated on an ad-hoc basis via a matrix organisation.

The management organisation should identify:

1) the required personnel to be dedicated to the project as well as personnel with collateral responsibilities;
2) the percentage of time necessary to dedicate to the project;
3) external interfaces; and
4) office space, special equipment, laboratories, facilities and services needed to carry out the programme.

Economic analysis – An economic analysis for decision making in carrying out PLIM, providing minimal maintenance, and retiring requires developing a set of competing scenarios and then testing the scenarios against such impacts as higher than foreseen O&M costs through the use of sensitive studies. The net present value (NPV) of different scenarios and different operating lifetimes is used to compare scenarios and also to optimise lifetime[4]. Scenarios assemble various costs including future O&M, and fuel, and 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 a short term cash flow is also important for management as a small electric company cannot afford a short term cost of raising funds for a long term business plan. The objective is to be determined by the preferred scenario for both the long and short term.

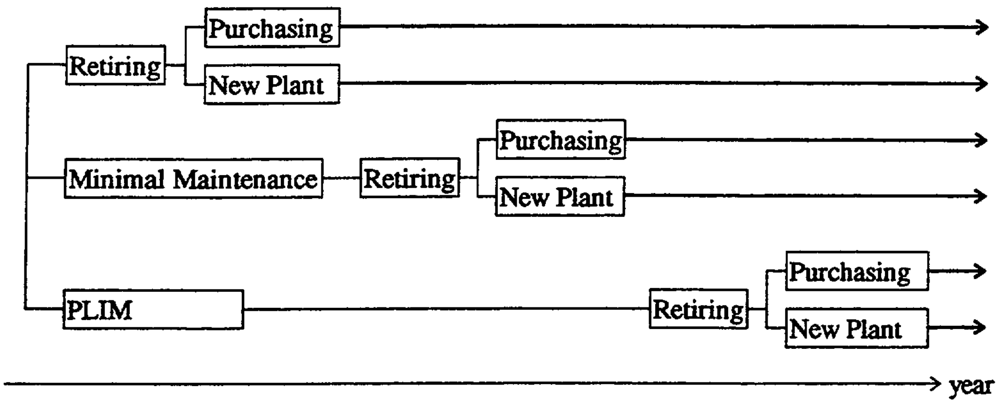


Figure 5. The set of scenarios

Licensing – Safety regulation instability is the major risk that contributes to plant life cycle decisions.

Public relations – The public information programme should be established to address safety, economics, and environmental impact by pro-active measures.

V. DETAILED PROJECT PLAN

Under the overall programme plan, the PLIM organisation must identify the critical item and the ageing processes, and optimise equipment reliability and maintenance workload.

a) **Critical item selection** – At the first onset, the PLIM organisation must identify the plant components to be included in the programme. Generally, "critical" and "non-critical" items are determined using a screening methodology normally specific to the plant technical and regulatory requirements. The critical items are categorised into category I, that is replaceable, and category II, that is not.

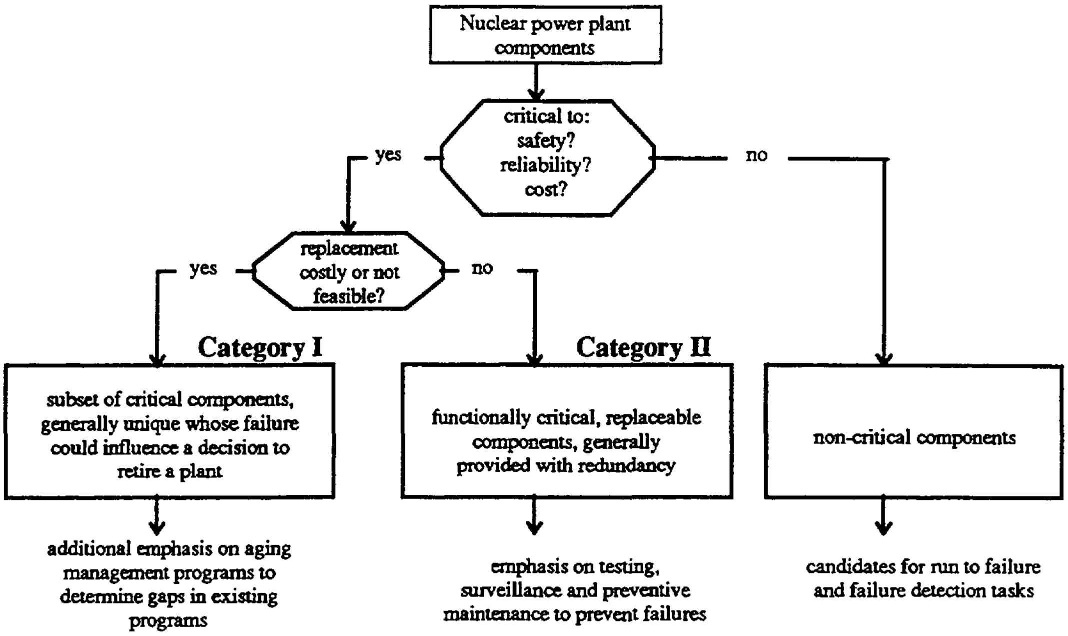


Figure 6. **Component Categories for Plant Life Management.**

b) **Present condition and ageing countermeasures** – The ageing processes that occur in Nuclear Power Plant structures, systems, and components should be identified. To predict lifetime accurately and reliably, an estimation including inspection and knowledge of degradation must be systematically applied for each sub-component for each degradation mechanism.

If rate of degradation is not acceptable, plant owners should take the following ageing countermeasures: preventive maintenance measures; changes in operation; corrective maintenance measures; and modification or redesign.

c) **Maintenance strategy** – The primary role of maintenance is to allow nuclear operators to use all functions necessary for a safe and economic production, by keeping those functions 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 technically, it is possible that the modification programme is the most economical method, taking into consideration increasing performance.

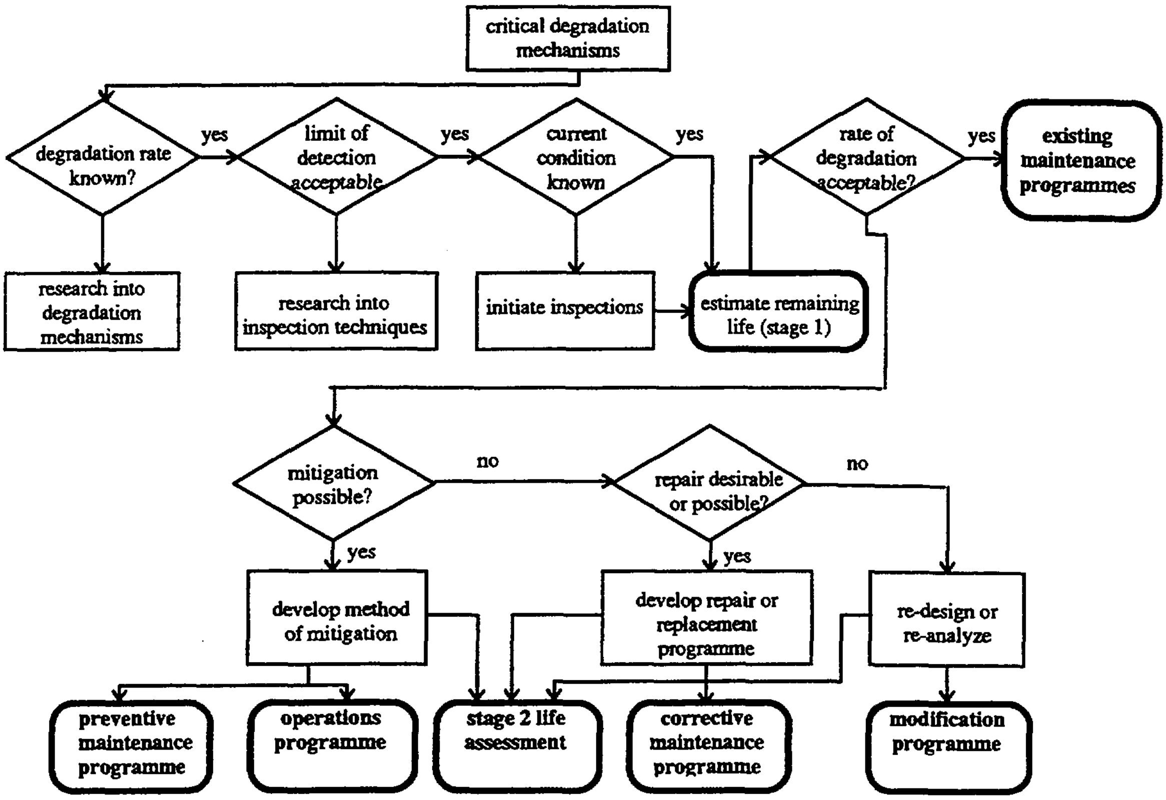


Figure 7. **Evaluation of present condition and ageing countermeasures.**

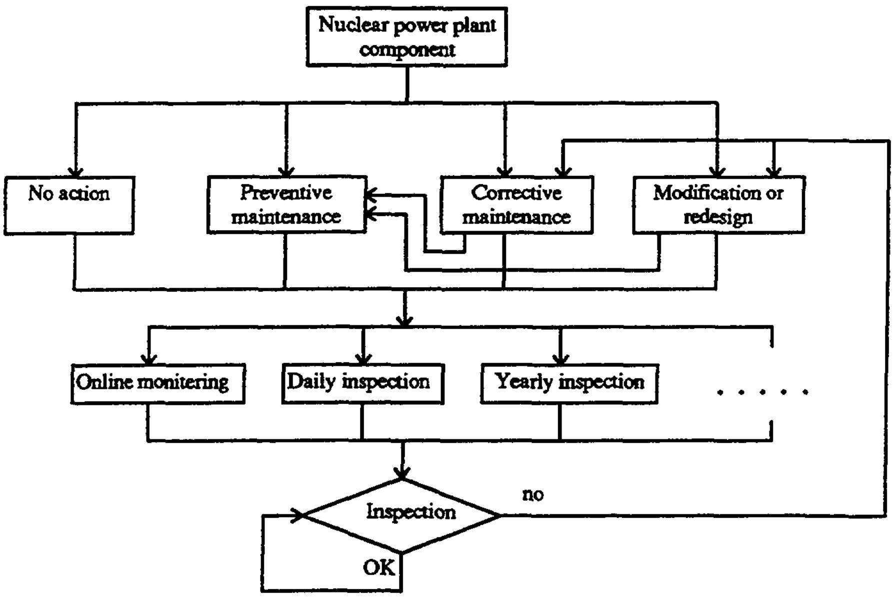


Figure 8. **Possible maintenance strategies.**

The maintenance strategy for each equipment in the plant consists in all combination of no action, preventive maintenance, corrective maintenance, modification, and inspection[5]. The expected net present value of each strategy can be calculated from Figure 9. For example, if the failure rate, *1-p(t),* is small and independent of time and corrective maintenance, the expected net present cost and value of preventive maintenance is obtained from the following simple formula:

$$\textit{The expected net present cost of preventive maintenance} = \sum (\textit{Inspection cost})/(1+r)^i$$
$$+\sum (\textit{Corrective maintenance cost})(1-p(t))^i \Big/ (1+r)^i$$

$$\textit{The expected net present value of prevenrive meaintenance} = \sum (\textit{revenue} - \textit{generating cost}) \Big/ (1+r)^i$$
$$-\textit{the expected net present cost of preventive maintenance}$$

where r is the discount rate.

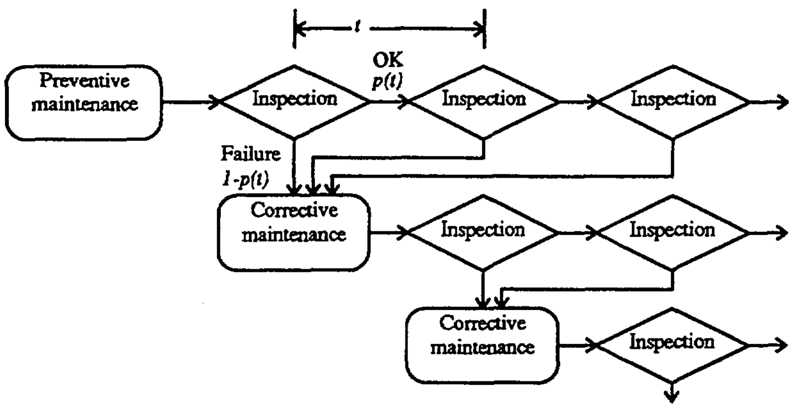


Figure 9. **Calculation flow of expected net present cost of preventive maintenance.**

VI. CONCLUSION

In order to meet power supply obligations in the early 2000, taking into account energy security, environmental impact, and the economics of nuclear power plants whose lives have been extended, nuclear plant life management should be considered. However, 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. NEA provides an opportunity for international exchange of information on the economics and policies of nuclear plant life management for governments and plant owners. The NEA Secretariat is finalising the "state-of-the-art report" on the economics and policies of nuclear plant life management, including the model approach and national summaries. The final draft will be circulated to Member countries late in 1998. An International Conference focusing on economic and managerial strategies for nuclear power plant life in the context of regulatory reform will be held in the year 2000.

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ANNEX 1

COMMON AGEING TERMINOLOGY

A Glossary Useful for Understanding and Managing the Ageing of Nuclear Power Plant Systems, Structures and Components

WHY COMMON AGEING TERMINOLOGY?

As the service life of operating nuclear power plants increases, potential misunderstanding of ageing degradation of systems, structures, or components (SSCs) is receiving more attention. Common ageing terminology has been developed to improve the understanding of ageing phenomena, facilitate the reporting of relevant plant failure data, and promote uniform interpretations of standards and regulations that address ageing.

The terminology should be useful in the areas of life and ageing management. Life management can minimise operations and maintenance costs and can support the option of extending the operating term of a plant from 40 to 60 years. More importantly, effective ageing management contributes to the maintenance of adequate plant safety margins.

Recognising the importance of clear communication in these areas, representatives from a cross-section of the industry have developed a uniform vocabulary of terms relating to ageing.

In view of the benefits to be gained, use of common ageing terminology is recommended in technical documents, failure reports, research reports, future regulations, and other documentation related to nuclear power plant ageing. Documentation would state that common ageing terminology is used except where noted. Appropriate exceptions would be cases for which the writer opts to use definitions from existing standards and regulations.

The main benefits from the use of common ageing terminology are:

- Improved reporting and interpretation of plant data on SSC degradation and failure, including accurate root cause identification.
- Improved interpretation and compliance with codes, standards, and regulations related to nuclear plant ageing.

WHY A POCKET GLOSSARY?

The NEA, CEC and IAEA have jointly published this pocket-size glossary, that follows closely a publication by EPRI (BR-101747) to whom we are grateful for support and advice in making available this international version, as a handy reference to facilitate and encourage widespread use of common ageing terminology. The goal is to provide plant personnel (and others who address ageing) with a common set of terms that have uniform, industry-wide meanings, and to facilitate discussion between experts from different countries.

In each language section, terms are listed alphabetically with sequential number. These numbers are repeated in the English language section thus allowing cross-reference between all languages.

In each language the glossary begins with an overview of all terms grouped into six categories. This is followed by an alphabetical listing of terms, definitions, and a few examples. The last pages of each section contain diagrams and a list of key ideas to help illuminate the terminology.

Table. Example of Common Ageing Terminology in five languages.

English

		French	German	Spanish	Russian
8	**ageing effects** net changes in characteristics of an SSC that occur with time or use and are due to ageing mechanisms • Examples: negative effects – see *ageing degradation*; positive effects – increase in concrete strength from curing; reduced vibration from wear-in of rotating machinery	49	6	40	96

French

		anglais	allemand	espagnol	russe
49	**effets du vieillissement** modifications nettes des caractéristiques d'un SSC qui se produisent avec le temps ou l'utilisation et qui sont dues aux mécanismes de vieillissement • Exemples: effet négatif – voir *dégradation par vieillissement*; effet positif -augmentation de la résistance du béton due au durcissement; moindre vibration par suite de l'usure des machines tournantes	8	6	40	96

German

		Englisch	Französisch	Spanisch	Russisch
6	**Alterungsauswirkungen** Anderungen der Eigenschaften von SSK, die durch Zeit oder Nutzung und Alterungsmechanismen hervorgerufen werden • Beispiele: negative Effekte: siehe **alterungsbedingte Abnutzung**; positive Effekte: Zunahme der Betonfestigkeit durch Aushärten, verringerte Vibration durch Einlaufen rotierender Maschinen	8	49	40	96

Spanish

		inglés	francés	alemán	ruso
40	**efectos de envejecimiento** cambios netos que producen el tiempo y el uso en las características de un SEC debidos a los mecanismos del envejecimiento • Ejemplos: efecdos negativos – ver *degradación por envejecimiento*; efectos positivos - aumento de la resistencia del hormigón por curado; disminución de la vibración por asentamiento de la maquinaria rotativa	8	49	6	96

Russian

96	эффекты старения - совокупные изменения характеристик СКК, которые возникают со временем или в результате использования и являются следствием действия механизмов старения • Примеры: отрицательные эффекты - см. *ухудшение свойств при старении;* положительные эффекты - повышение прочности бетона в результате твердения; снижение вибрации вследствие приработки вращающихся деталей	8	49	6	40

ANNEX 2

SAFETY ACTIVITIES RELEVANT TO PLANT LIFE MANAGEMEENT IN NEA

The Nuclear Safety Division 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 emphasis of the OECD/NEA safety programme is 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 (PWGs) is Integrity of Components and Structures, under PWG-3. This has sub groups on the integrity of metal components and structures, the ageing of concrete structures (especially containments) 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 (refs 1-5, available on request), 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.

CNRA has also considered relevant topics from the regulatory point of view. These include the topics of periodic safety reviews and the safety case for ageing plants, and it is currently preparing a report on the regulatory aspects of ageing reactors.

Although not specifically addressed at life management problems, probabilistic methods are increasingly used for this purpose. PWG3 has considered probabilistic aspects of structural integrity (ref 6), and CNRA has considered regulatory aspects of PSA (refs 7-8).

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