Nuclear power plant ageing and life extension: Safety aspects

An overview of issues and the IAEA's symposium

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Experience with large fossil-fired electrical generating units, as well as in all process industries, shows that plants begin to deteriorate with age after approximately 10 years of operation. Similar phenomena will prevail for nuclear plants, and it is reasonable to postulate that their availability will be affected, as will their safety, if appropriate measures are not taken.

It is evident that the average age of power reactors in the IAEA's Member States is increasing. *(See accompanying graphs.)* By 2000, more than 50 nuclear plants will have been providing electricity for 25 years or longer. Most nuclear power plants have operating lifetimes of between 20 and 40 years.

Ageing is defined as a continuing time-dependent degradation of material due to service conditions, including normal operation and transient conditions. It is common experience that over long periods of time, there is a gradual change in the properties of materials. These changes can affect the capability of engineered components, systems, or structures to perform their required function. Not all changes are deleterious, but it is commonly observed that ageing processes normally involve a gradual reduction in performance capability.

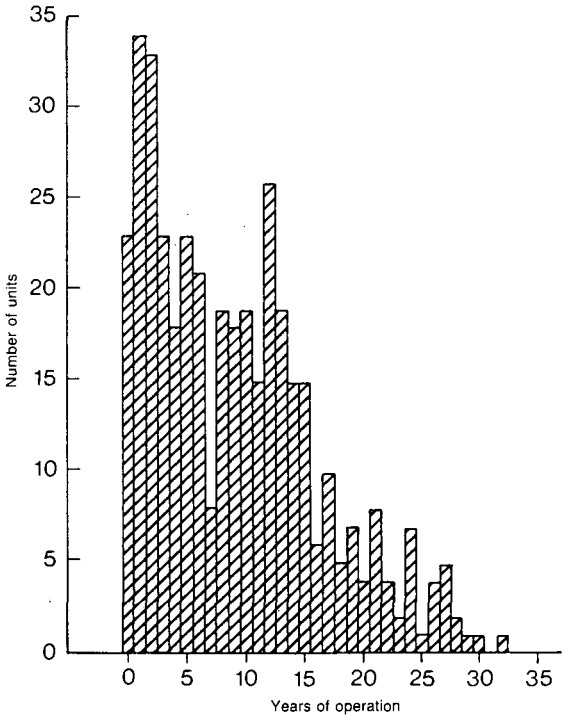
All materials in a nuclear power plant can suffer from ageing and can partially or totally lose their designed function. Ageing is not only of concern for active components (for which the probability of malfunction increases with time) but also for passive ones, since the safety margin is being reduced towards the lowest allowable level.

Effects of plant ageing

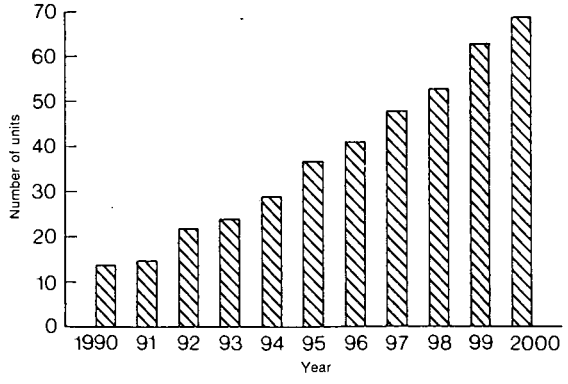
The main ageing effects of concern are changes in physical properties (e.g., electric conductivity); irradiation embrittlement; thermal embrittlement; creep; fatigue; corrosion (including erosion and cracking assisted by corrosion); wear (e.g., fretting and cracking assisted by wear, such as fretting fatigue).

The term "ageing" thus represents the cumulative changes over time that may occur within a component or structure because of one or more of these factors. From this perspective, it is clear that this is a complex process that begins as soon as a component or structure is produced and continues throughout its service life.

Age distribution of nuclear power plants



Projected numbers of nuclear power reactors reaching 30 years of operation 1990–2000.



(Source: IAEA Power Reactor Information System.)

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Ageing is certainly a significant factor in determining the limits of nuclear plant lifetime or life extensions. No nuclear plant, including those still under construction or being mothballed, should be considered immune from its effects.

The rate of ageing depends strongly on both the service conditions and the material sensitivity to those conditions. Therefore, consideration about ageing must start in the design phase by selecting adequate materials and it should be continued throughout its complete life cycle.

Although nuclear plant ageing could have an impact on the efficiency of electric power generation, safety could be affected as well — if degradation of key components or structures is not detected before loss of functional capability, and if timely corrective action is not taken. What must be understood is how the ageing process may change the likelihood of component failures in systems designed to mitigate transients and accidents (and therefore reduce safety margins), and how age degradation can cause such events to be initiated.

Concerns about ageing of equipment stem from the fact that failure can occur simultaneously (or effectively so) in redundant safety systems. Redundancy (coupled with diversity) is the principal means of guarding against the consequences of random failures of equipment and providing assurance that at least one complete chain of safety systems is functional at all times during plant operation. The required protection would not be provided if equipment ageing degrades the functional capability to the point where the increase in stress levels associated with a design basis event could cause simultaneous failure of redundant systems (or their failure within a critical interval of time).

Monitoring and detection

Operating organizations have been using different programmes or methods to prevent, detect, correct, and mitigate failures of systems and components from any cause including the effects of ageing degradation. These methods include preventive maintenance programmes, significant event reporting systems, and periodic reviews of plant performance. They have been under continuous development (based on lessons learned and new knowledge), and overall they are quite effective in the detection and mitigation of ageing effects.

In the past, ageing was considered just one of many possible causes of component failures. Ageing research was primarily in response to experienced operational problems or failures. However, in recent years, the industry, regulatory bodies, and international organizations have recognized that as the average age of nuclear plants increases, an enhancement of existing programmes with new technology would lead to a more systematic and pro-active approach. As a result, a number of programmes or projects have been initiated by different Member States to understand ageing and the new methods available to manage its effects. This has led to an increased effort in the review and development of monitoring, testing, and inspection methods to ensure timely detection of ageing degradation.

Coping with the ageing process of nuclear power plants requires a systematic approach in analysing these phenomena. Experimental and theoretical methods should be developed to evaluate its impact on plant performance. Effective methods of inspection, surveillance, and monitoring should be implemented during operation to evaluate the "qualified life" of the components, systems, and structures. This should be the basis for their timely and effective maintenance, repair, and replacement, with particular attention to systems and components important to safety.

International symposium

Just as the proper management of plant ageing is drawing increasing interest, so are the economic aspects of extending the lifetimes of nuclear power plants. The IAEA gives attention to both topics in its programmes.

Recently, the Agency organized the International Symposium on Safety Aspects of Ageing and Maintenance of Nuclear Power Plants, which was held in Vienna, from 29 June to 3 July 1987.* It was the first one organized by the IAEA on this subject and it was therefore directed at a broad spectrum of participants — technical and managerial staff engaged in nuclear power plant operation, regulatory body staff, consulting and architect-engineering organizations, vendor technical and management staff, and nuclear power plant technical and managerial staff involved in maintenance activities. It was attended by 140 participants from 30 countries and three international organizations. Important topics addressed at the symposium are highlighted in the following paragraphs.

National efforts

In some countries, several programmes have been started that encompass studies aimed at achieving an understanding of nuclear plant ageing, its potential effects on safety, and methods for its detection and mitigation. As an example, the US Nuclear Regulatory Commission (NRC) has a programme called Nuclear Plant Ageing Research (NPAR). It involves (1) identification and selection of components whose ageing has a high impact on safety performance; (2) review of design-basis safety margins, qualification testing, operating experience, experts' opinions, development of methods for surveillance, inspection, monitoring, and maintenance; (3) engineering studies including verification of inspection, surveillance, monitoring, and maintenance methods, *in-situ* examinations, collection of data from operating equipment, post-service examinations, tests of naturally-aged equipment, and cost-benefit analyses. The programme really shows the complexity of the ageing question.

* Proceedings have been published by the IAEA.

The symposium further addressed the approach to ageing problems of other regulatory bodies. Important tools that were mentioned include programmes for periodical assessment based on broad operational data collection; programmes for preventive maintenance; continuous monitoring of nuclear power plant components; feedback from incident analyses; individual and component qualification; personnel education and training; external control and quality assurance. Procedures are now under development to quantify the risk from data related to ageing and component failure.

The collection and evaluation of operational data is likewise receiving more attention. The advantage of a computerized data collecting system was described that incorporates results of surveillance, testing, and maintenance programmes. It further collects data on all modes of operation which afterwards enables evaluation of the life of critical components. The role of operational feedback in developing test specifications for electrical and other equipment was also described.

There are several other tools that are being employed and under further development to understand ageing. These include probabilistic models of ageing conditions, the use of plant components from decommissioned nuclear units for ageing evaluation, and the use of methods that "artificially age" critical components to determine their useful lifetimes.

Steps can be taken to handle ageing phenomena during nuclear plant operation as well. Among those addressed at the symposium were the use of technical diagnostic equipment to trace system degradation and to estimate remaining lifetimes; water-chemistry monitoring to prevent corrosion; and the monitoring of radiation damage in the pressure vessel.

Plant life extension

Nuclear power plant life extension (technically known by the acronym Nuplex) was discussed at the symposium from several perspectives. Plant life extension programmes in France, Japan, and the USA were described. Even though different types of nuclear plants are involved, these programmes are similar. They all include a database of necessary operational information; performance of research and development; and information about the availability of suitable devices for replacement or repair of critical equipment. In the USA, a Nuplex Steering Committee was established whose main role is to advocate the timely establishment of a license renewal process by the NRC, to sponsor necessary regulatory studies, and to speak for nuclear utilities on proposed NRC policy and rules on license renewal.

Regarding the technological aspects of plant life extension, papers at the symposium were largely operations-oriented. The residual life assessment of major components for pressurized-water reactors (PWRs) was described by the Idaho National Engineering Laboratory, USA. The use of probabilistic risk assessment (PRA) techniques for performance monitoring to enhance the operational safety of nuclear power plants was presented by Sandia National Laboratories, USA. Technological aspects were further addressed in a paper reviewing the symposium on plant life extension organized in February 1987 by the Nuclear Energy Agency of the Organization for Economic Co-operation and Development, in co-operation with the IAEA.

In Japan, research has been done to determine the essential life of the reactor pressure vessel, and symposium participants were informed that results have been used to start development of engineering procedures to evaluate ageing. As a useful aid for meeting regulatory requirements, a paper from France described the accounting system for transients in the country's standardized PWRs.

The symposium also featured three panel discussions. At the first one, some issues concerning the ageing of active and passive components were presented. It was emphasized that the contribution to risk from the ageing of active components must be carefully considered. The database systems should be improved to collect more detailed data on failures, repairs, and maintenance. Among other points that were stressed: Ageing is not only an issue concerning the future, but one that concerns all operating nuclear plants. Current methods of testing, monitoring, and maintenance are not adequate for coping with the ageing issue. Quantification of the ageing impact is very important to assure the safe operation of nuclear plants and to supply proven data to the regulatory body. Prevention rather than corrective action should be used to manage ageing, and activities should concentrate on the most sensitive parts of nuclear power plants.

At the second panel session, emphasis was placed on an important operator activity, namely the systematic identification of ageing degradation for components and parts important to safety and reliability. Mechanisms must be understood to track the level of degradation and in such a way as to measure a certain deterioration. An adequate maintenance programme based on detailed data analyses (with the purpose of replacing items before their failure) was regarded as particularly important for managing the phenomena of ageing at operating nuclear power plants.

The third panel concentrated on the IAEA's role in international co-operation on this subject. The Agency's work in promoting dialogue and the exchange of information and experience was especially noted, as was its role in disseminating information through documents, guides, and other publications. Overall, an active role for the Agency was recommended, in view of the fact that a broad spectrum of technical, economic, and regulatory aspects still have to be learned before decisions can be taken in regard to the ageing and life extension of nuclear power plants.

The IAEA is now preparing a report for completion in 1988 that will take into account the results of symposia in 1987 on plant life extension and on plant ageing and maintenance.