

# Nuclear power plant life extension: Aging considerations for structures life

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## 1 INTRODUCTION

The escalating costs for new power plants and the uncertainties of load growth have made life extension of aging power plants an attractive option for the electric utilities in the United States. Life extension is being broadly applied to fossil-fired power plants, however, the practical application of life extension to nuclear power plants at this time, has been limited to programs for monitoring, maintaining, and refurbishing plant equipment to improve component reliability and plant availability. Actual plant operation, beyond the initial operating license period is being addressed in general terms through studies sponsored by the Electric Power Research Institute (EPRI) and the Department of Energy. Nuclear power plant life extension is a reasonable concept, and will become more important as current generation plants approach the end of their initial license period.

The methodology used to perform an overall plant life extension (PLEX) evaluation can be summarized in two phases.

The first phase includes an initial assessment of existing plant conditions including a review of data regarding as-built design and modification records, maintenance documents, operating and availability records, test reports, etc.

The second phase evaluation includes inspection and assessment of plant equipment and structures, identification of equipment and structures requiring maintenance in excess of industry norms, analyses of material and non-destructive testing on key components and structural elements and development of specific cost-effective measures to extend the life of the unit being evaluated. Corrective measures would be prioritized on the basis of anticipated benefit(s) and capital (installed) costs. Thus this phase will yield an assessment of the impact of corrective measures on plant life, operation and maintenance, and efficiency and availability.

The plant licensing is based on a 40 year evaluation of factors, such as projected power demand, alternate energy costs, environmental impact of construction and operation of the plant, environmental

qualification of the equipment and components, waste disposal, etc. In order to extend plant life beyond 40 years, the aforementioned factors must be reevaluated along with the effects of equipment aging due to degradation mechanisms, such as corrosion, erosion, fatigue, radiation, etc. Similarly, effects of structural aging due to stressors including, but not limited to freeze-thaw cycling, chloride and sulfate chemical attack, thermal loading and corrosion of reinforcing steel, should be evaluated.

Nuclear plant aging is under study by the US-NRC, EPRI, NSSS-Vendors, National Laboratories, A/Es, and other agencies. Research in this area is documented in several NUREGs, study reports and seminars. Since mechanical and electrical equipment and components are more vulnerable to aging, compared to plant structures, it is not surprising that the major efforts are directed towards research in that area. However, a panel of experts, as part of a PLEX study, ranked 30 components and structures of a PWR plant in sequence of importance to PLEX. The ranked structural items included: containment (including basemat) - second, RPV supports - third, intake and discharge structure - seventeenth, and other plant structures - twentieth. This and other studies point out a need for a systematic study of reinforced concrete aging to assure that structures will not become life limiting factors for PLEX.

## 2 NUCLEAR PLANT STRUCTURES

The containment structure, which houses the reactor vessel and associated NSSS equipment, is either a reinforced or a prestressed concrete structure or is a steel pressure vessel surrounded by a reinforced concrete shielding structure. In all cases the containment is supported by a reinforced concrete basemat. Other structures such as reactor, auxiliary and turbine buildings, intake and discharge structure, diesel and radwaste buildings are all reinforced concrete structures, although the turbine building and reactor building may have a steel superstructure.

## 3 AGING OF REINFORCED CONCRETE STRUCTURES

Concrete aging refers to the cumulative effects of stressors which would affect the physical and structural properties of the concrete, including reinforcing or prestressing steel. These factors, which contribute to the degradation of concrete structures, consist of environmental phenomena such as freeze-thaw cycling, chloride and sulphate chemical attacks, and corrosion of reinforcing steel. Effects of these stressors are briefly summarized here.

Freezing and thawing cycles especially affect concrete with a porous cement paste matrix that is not protected by entrained air. If concrete contains an excessive amount of hydrated calcium aluminate, it is more susceptible to sulphates which weakens the concrete. All these degradation mechanisms usually result in concrete cracking which not only reduces concrete compressive strength but also may provide easy access of moisture and deleterious chemicals such as chlorides to the reinforcing steel. The resulting corrosion process produces pressure on the surrounding concrete, resulting in spalling of the concrete which further exposes the reinforcing steel to corrosion.

Other factors which could affect the strength of concrete are temperature, thermal cycling, vibratory loading, alkali-aggregate reaction, creep, etc. However, concrete is also known to increase its strength as much as 40% to 50% with age counteracting the factors which tend to reduce its strength to some extent.

A stressor unique to nuclear power plants which affects the structural concrete is nuclear radiation. Laboratory experiments show that the compressive strength and modulus of elasticity of concrete is reduced by approximately 20 percent when subjected to a fluence of  $10^{21}$  neutrons/cm<sup>2</sup>/sec. With same amount of exposure, a reduction as high as 80 percent was noted in the concrete tensile strength (1). Conversely in the case of mild steel, radiation increased its yield strength more than 80 percent, however, the ductility is reduced giving a potential for brittle failure (2).

To evaluate the effects of degradation mechanisms on the plant structure and to then determine the remaining useful life of the plant it is necessary to establish a relationship between reduction in the load carrying capacity (degradation) and time. To establish such a relationship, all data from structures which have experienced such degradations singularly or in various combinations must be considered.

#### 4 STRUCTURAL EVALUATION PLAN

To assure that the structures will continue to perform their intended functions for an extended period of time, beyond the licensed 40 years, it is necessary to establish a systematic approach of inspection and evaluation after the decision to extend the plant life is made (at time  $T_0$ ).

Figure 1 shows the proposed approach as a flow chart which is briefly described below.

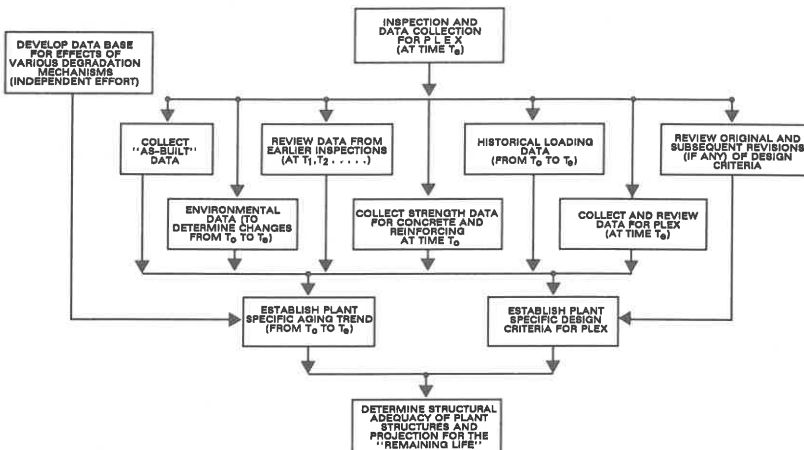


Figure 1 AN APPROACH FOR INSPECTION, DATA COLLECTION AND EVALUATION FOR PLEX

Collect "as-built" data for locations of the actual loads from pipe and cable tray supports, equipment loads, etc. These are likely to be different from those used in the original design which may have assumed these loads conservatively for design purposes.

Collect data for concrete compressive strength from the cylinder strengths recorded during construction (at time  $T_0$ ). Similarly, data from mill certificates for reinforcing steel should be compiled.

Historical loading data from events such as system transients which may have imposed loads on structures, temperature variations and associated thermal loads, or extreme events such as earthquakes and tornadoes, etc., should be compiled along with the structural evaluation studies.

Environmental changes that may have occurred from  $T_0$  to  $T_e$  should be compiled. For example, data for the chemical composition of the ground water should be compiled because the chemical contents (chlorides, sulphates) of the ground water may have changed over time and may have had a detrimental effect on the concrete strength of the basemat and walls below grade level.

Since the plant started operating, plant structures may have been inspected as part of a planned in-service inspection program, or for other specific reasons. These inspections may have found degradation of structures and they may have been repaired. This data is valuable to help establish a site specific trend in the degradation of physical properties of reinforced concrete.

Comprehensive inspections may be required at time  $T_e$  to determine the condition of the plant structures, and to provide a basis for evaluating their adequacy for an extended period. The strength data for concrete could be obtained by nondestructive tests such as the Schmidt hammer or Windsor probe with core tests for correlation purposes or for detailed investigation. Strength data for reinforcing steel is not considered necessary. Half cell tests could be performed to assure that there is no probability of corrosion.

Develop a data base from the reinforced concrete industry on an ongoing basis that would include laboratory test data which could establish a relationship between various degradation mechanisms affecting material strengths and time. This effort is independent of a plant specific investigation and should be done on a generic basis.

Review the original design criteria to assure its applicability for PLEX. The original design criteria (at  $T_0$ ) was probably revised during plant operating period, (from  $T_0$  to  $T_1$ ) because of changes in regulatory positions, identification of new loads or events such as TMI. Structural evaluation reports for the revised design requirements should be reviewed.

## 5 STRUCTURAL EVALUATION AND PROJECTED LIFE

If a plant has performed periodic inspections and tests (at  $T_1$ ,  $T_2$ ...) the load carrying capacity at these times could be calculated. When plotted against time a trend in reduction (or increase) in load carrying capacity would be established (line c in Figure 2). Based on the as-built data, and a revised design criteria which would include the latest regulatory positions such as reduction in piping loads due to higher allowable damping or elimination of pipe whip and jet impingement loads, etc., a minimum acceptable load carrying capacity

of the structural elements could be established (represented by horizontal line "b" in Figure 2). This value could be further refined by considering the probabilities of various loads and load combinations occurring during a finite period of time considered for plant life extension. The point of intersection of line "b" and trend line "c" denotes the age beyond which the plant structures will not meet the minimum load carrying capacity requirements. This procedure appears viable since it provides a plant unique aging trend considering cumulative effects of all degradation mechanisms which may have affected the specific plant. The major concern is the availability of a comprehensive, well documented inspection and test data for all structural elements which is required to develop a trend curve similar to the one shown in Figure 2. Secondly, the plant structures are usually inspected and any deterioration, if found, is repaired thus making it difficult to construct a unique trend curve.

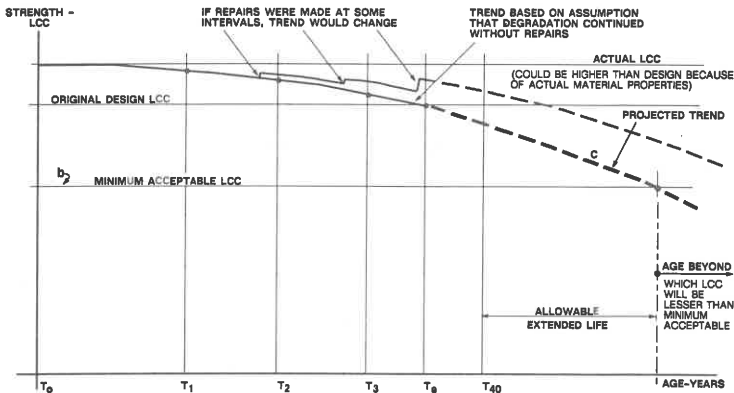


Figure 2 DEVELOPING DEGRADATION VERSUS TIME CURVE USING DATA  $T_1, T_2, T_3, T_4$

An alternate approach would involve laboratory research, oriented towards determining characteristics of various degradation mechanisms with respect to time. The research need to concentrate on degradation mechanisms prevailing in the nuclear plants such as temperatures ranging from about 50°F to about 130°F (normal operating temperatures in a typical containment), thermal cycling due to shut down for refueling, irradiation, or corrosion of reinforcing steel due to chlorides. Some of this data is available in the industry and should be systematically compiled and reviewed to determine applicability for nuclear plant.

When load carrying capacity versus time relationships for individual degradation factors are established, either from the curves or from mathematical equations, the loss (or gain) in load carrying capacity at any given time could be established. As an example (Figure 3), if  $+\Delta a$ ,  $-\Delta t$  and  $-\Delta r$  represent gain in load carrying capacity due to age and loss due to temperature and radiation respectively, these effects could be combined as follows:

$$\Delta_{cum_i} = + \Delta a_i - \Delta t_i - \Delta r_i \quad \text{where } \Delta_{cum_i} \text{ is total loss in strength at } T_i$$

Alternatively, when effects of all factors result in loss in load carrying capacity (at  $T_j$ ) they could be combined as follows:

$$\Delta_{cumj} = \sqrt{\Delta_{aj}^2 + \Delta_{rj}^2 + \Delta_{tj}^2}$$

It should be noted that in the case  $+\Delta a$  and  $-\Delta t$ , algebraic addition appears logical.

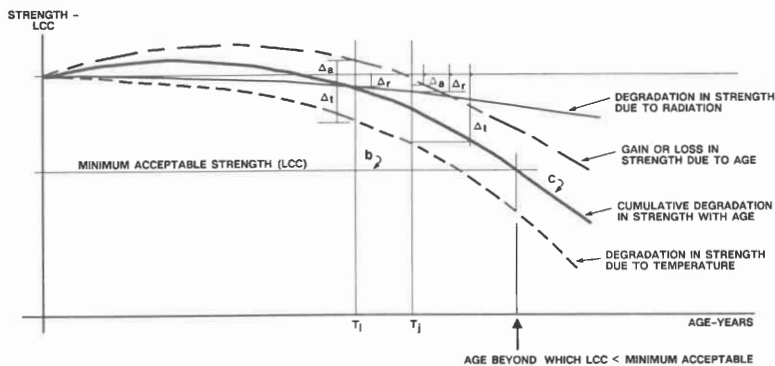


Figure 3 EXAMPLE TO ILLUSTRATE HOW DEGRADATION IN STRENGTH BECAUSE OF INDIVIDUAL FACTORS (AGE, RADIATION AND TEMPERATURE) COULD BE COMBINED TO ARRIVE AT CUMULATIVE LOSS IN STRENGTH

Based on this approach, a composite (cumulative) loss in load carrying capacity could be computed based on plant unique degradation factors at various time intervals to develop a trend curve. Then, following the procedure of calculating minimum acceptable load carrying capacity described earlier, the age beyond which the plant structures will not be able to meet the minimum load carrying capacity requirement can be established.

## 6 CONCLUSIONS AND RECOMMENDATIONS

- o A systematic study of various degradation mechanisms and their effects with respect to time needs to be conducted with emphasis on their applicability to nuclear power plants.
- o Methodologies described in this paper are presented as potential ideas and require in-depth research and development.
- o Substantial time will be required to arrive at techniques and methodologies acceptable to regulatory agencies. Therefore, research and development of methodologies needs to be started in very near future so that they will be available to plants which will be considering plant life extension in another 10 years.

## SELECT REFERENCES:

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2. Cowan and Nichols, "Effect of Irradiation on Steels Used in Pressure Vessels" Group D Paper 20 Prestressed Concrete Pressure Vessels, The Institution of Civil Engineers, London, 1968.