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REMNANT LIFE PRESERVATION OF LWR PLANT STRUCTURES

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ABSTRACT

The safe and long-term performance of commercial nuclear power plants is contingent on suitable performance by the population of structural elements and buildings involved in the facility. Primary concrete and structural steel structures are of particular importance but are often neglected from plant maintenance or other preservation-oriented programs. To date, the performance histories of structural elements and buildings at U.S. light water reactor (LWR) plant sites have been supportive of long-term plant performance goals without much attention. However, the accumulation of environmental exposure time and instances of age-related degradation may lead to reduced function. This paper presents an overview of the work that has been conducted by Multiple Dynamics Corporation (MDC) in remnant life preservation of nuclear plants, with a particular focus on concrete safety-related structures. The results of MDC's condition surveys at operating NPPs is examined. Methods for evaluating structural degradation and expansion of current industry positions on structural aging are also presented.

INTRODUCTION

The concrete structures at nuclear power plants (NPPs) have historically been designed and constructed in accordance with industry accepted codes and standard practices. In addition, quality control programs have generally been instituted at each NPP for proper materials selection, validation of plant construction, and assurance of suitable performance. The specified design life for NPPs has traditionally been defined as 40 years; achievement of this life goal, or an extended operating life of 60 years or greater, is not expected to be limited by the aging of concrete structures. However, accurate prediction or validation of the remaining service life of concrete structures is not easily accomplished at this time. Research studies have been conducted to address this subject by both industry and regulatory agencies (EPRI 1990, Naus 1986, Hookham, et.al. 1993). Primary conclusions from these studies suggest that, with the exception of several potential degradation mechanisms and conditions, concrete structures should be quite durable to aging. Aging mechanisms of primary concern are chemical attack of concrete and reinforcing steel corrosion with subgrade structures having the greatest sensitivity.

Many NPP owners in the U.S. have examined the technical and economical feasibility of extending the current 40 year plant life via renewal of their operating license. The technical rules for NPP license renewal were published in the Federal Register and Code of Federal Regulations (10CFR54, January 13, 1992). Parallel to any license renewal planning, <u>all</u> NPP owners must comply with the U.S. NRC's Maintenance Rule (published in 10CFR50.65). This Rule specifies that a maintenance program be developed for plant systems, structures, and components determined to be sensitive to aging which will be used for the balance of the current (and extended) operating license period. To address each of these issues, NPP owners must provide a means of technically addressing the performance of structural elements, including concrete structures, and either the absence or manageable presence of age-related degradation.

Management of aging and continued performance verification of structures must also be conducted in an economically prudent fashion, as numerous other critical NPP components must also be maintained. This is especially important in the U.S. where operating and maintenance costs must be minimized to preserve economic viability of nuclear power generation. MDC has established a program for NPP owners to meet the technical requirements of aging management while minimizing costs. Termed "remnant life preservation", this program provides a prioritized and focussed means of preserving structural life. Attributes of this program are discussed in the following paragraphs.

OBSERVATIONS AT OPERATING PLANTS

As part of life extension studies and other work in NPPs, MDC has conducted numerous condition surveys and testing of concrete structures. The results of these surveys indicate that the collective performance of concrete has been quite favorable. However, as noted in Table 1, local observation of various degradation mechanisms has been very common. This table contains a cross section of concrete structures in U.S. and foreign NPPs located in several different climatic conditions. Further definition of each degradation mechanism including published thresholds and ultimate structural effect may be found in other reports (Hookham 1991, Naus 1986).

Table 1. Condition Survey Results for Various NPP Concrete Structures

LOCAL DEGRADATION MECHANISMS	PLANT									
	A	B	C	D	E	F	G	H	I	J
CONCRETE										
CHEMICAL ATTACK	b,c	c	b	c	c	c	c	c		
EFFLORESCENCE AND LEACHING		b,c,d	b,c		b,d	b,d	d	b,d,f	a,b, c,d	b,f
ALKALI-AGGREGATE REACTION										a
FREEZE/THAW CYCLING	d			a,d			d	f		
THERMAL EXPOSURE			c	c	c			c		
ABRASION/EROSION			c				c,d			
FATIGUE/VIBRATION		c								
CRACKING	c,d, f,g	a,b, c,d	c,d,g	c,d	a,b, c,d,g	b,e, d,f,g	b,f	b,c, d,f	b,c, d,f	b,f,g
CONVENTIONAL REINFORCING										
CORROSION	b,d	b,d	b		b,d	b		b,d	b	b,f
PRESTRESSING SYSTEM										
CORROSION	n/a	e (note 1)	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
BLOCK WALLS										
EXCESSIVE CRACKING		c			d		c	a		
STRUCTURAL STEEL AND LINERS										
CORROSION	d	e	c,d				c,e		e	g
SOIL/STRUCTURE ISSUES										
DIFFERENTIAL SETTLEMENT	c									
SOIL EROSION (SCOUR)	d									

Key:

a - External Structure (Power Block)
b - Subgrade Structure (Power Block)
c - Internal Structure (Power Block)
d - Water Control Structure (Intake, Discharge, Etc.)
e - Containment Vessel
f - Other Site Structure
g - Equipment Supports

Notes:

1. Corrosion limited to exposed grease can and bearing plate surfaces (no tendon corrosion noted)

These surveys were performed by a team of certified inspectors and registered structural engineers using a standardized condition survey procedure and hand-held measuring and detection equipment. General acceptance criteria for visible degradation were established in accordance with American Concrete Institute and other industry guidelines. All accessible surfaces of NPP concrete structures were included in these surveys; no excavation or enhanced testing was initially performed.

Interpretation of the data in this table provides several important insights:

(1) Virtually all NPPs have experienced cracking in concrete structures that exceed typical acceptance criteria for width and length. The source of these cracks include shrinkage (primary cause), local settlement, reinforcing corrosion, creep, thermal expansion, and other conditions.
(2) Numerous NPPs presently have groundwater intrusion occurring through power block and other subsurface structures, with associated leaching and local reinforcing steel corrosion. Propagation of damage from this condition may become important to long-term performance of the afflicted structures.
(3) Few NPPs currently have a program for conducting periodic structural inspections or for maintaining protective coatings and sealers.
(4) Aging effects on subsurface concrete structures is an important concern for many NPPs, as the physical condition cannot be easily verified.

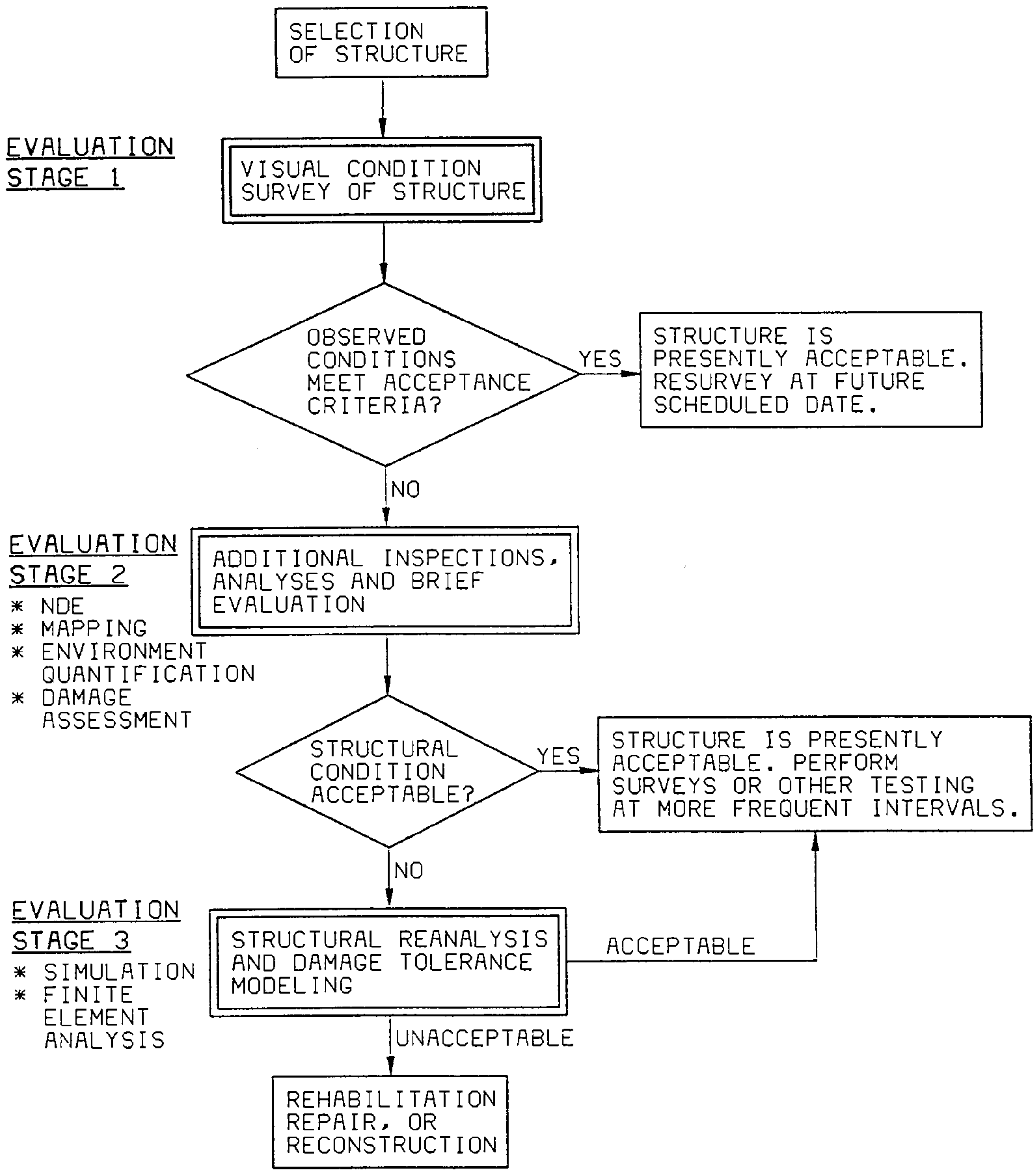
Collectively, the observations made by MDC and by others (Naus 1986, FIP 1982, Lewis 1985) suggest that periodic inspections, evaluations, and maintenance and repair are needed elements in the aging management of NPP structures. Proper evaluation of observed degradation, such as that reported in Table 1, is necessarily important to long-term plant operations. Any degradation caused by a mechanism which is likely to propagate should be treated at an early stage, as full-scale repair of massive structural concrete sections is labor and cost intensive and will likely require an extended plant outage. Evaluation techniques to be used in a preservation program are summarized in the following section.

EVALUATION OF STRUCTURAL AGING

The "evaluation" of nuclear concrete structures is defined in the 1993 draft of ACI Report 349.2R to include "an engineered review with the purpose of determining physical condition and functionality, including condition surveys, testing, maintenance, structural analysis, and repair". Evaluations are needed to examine and properly disposition any observed structural degradation and aging which exceeds established acceptance criteria. With respect to concrete nuclear structures, determination of a common acceptance criteria is difficult because of differing materials, functional requirements, behavior characteristics, and other conditions. As such, the establishment of plant acceptance criteria and performance of evaluations should be under the direction of a qualified engineer.

Evaluations should be conducted using an iterative process, as depicted in Figure 1. The state of degradation may be examined initially by visual condition survey and comparison of the results to a quantitative acceptance criteria (Stage 1 Evaluation). If this criteria is exceeded, additional testing, analyses, and evaluations (Stage 2 Evaluation) must be conducted to further evaluate the current status of degradation and whether the condition of the structure

FIGURE 1



EVALUATION PROCESS FOR AGE-RELATED DEGRADATION IN CONCRETE STRUCTURES is adequate for all load combinations and functions. In the event that this evaluation stage is inconclusive or the condition of the structure is of concern, further evaluation (Stage 3) must be performed. Additional structural analysis is often necessary in this stage to assess remaining material and structure capacity, degree of integrity lost, effects of degradation propagation, and suitable disposition (acceptance, repair, or other). Notably, the cost to conduct Stage 2 and 3 evaluations is much greater than the initial visual condition survey.

At the initial Stage 1 evaluation, the acceptance criteria used are quite stringent. Presence of such conditions as leaching/efflorescence, reinforcing steel corrosion, chemical attack, or evidence suggesting degradation are considered unacceptable. The quantitative crack width limits are expressed on the basis of activity and environment and range from 0.2 to 1.5 mm. in width and 0 to 4 m. in length. Other defects such as spalls, scaling, and popouts are similarly assigned threshold depth and surface dimensions of 10 mm. and 100 mm., respectively. Should these criteria be exceeded, a Stage 2 evaluation is performed. The acceptance criteria for Stage 2 evaluations are slightly relaxed in lieu of further analysis to accept existing damage. For example, passive cracks in a structure exposed to a non-aggressive environment may be acceptable up to 2.0 mm. in width and 5.0 m. in length if a protective coating is applied. For Stage 3 evaluations, the acceptance criteria becomes maximum allowable stress limits for the degraded or rehabilitated structure. Supplemental analytical tools such as finite element analysis may be used to better characterize material and structural differences.

REMNANT LIFE PRESERVATION

In the U.S. nuclear industry, two issues of importance are currently drawing attention to plant aging. Plant life extension, or License Renewal, and compliance with the U.S. Nuclear Regulatory Commission's (NRC) Maintenance Rule, both require that the NPP owner examine the sensitivity of plant systems, <u>structures</u> and components to age-related degradation and to set up programs to manage aging. The preservation of remaining, or remnant, life of safety-related concrete structures is an important part of plant life extension and aging management.

Fundamental to remnant life preservation is the concept of "inspection" or "condition surveys". The non-homogeneity and massive size of nuclear concrete structures makes accurate deterministic prediction of remaining life virtually impossible. The use of periodic inspections may be used in lieu of life prediction as a means of giving greater assurance of structural behavior and performance. Previous reports (Hookham 1991, Ellingwood and Mori 1992) have examined the use of condition surveys and inspection on either a "critical" structure listing or statistical/stochastic basis to provide a technical basis for suitable long-term performance. Selection of structures to include within the scope of a preservation program should accommodate those required in the aforementioned license renewal and maintenance programs, as well as any others found to be critical in probabilistic risk assessments (PRA) or other safety analysis. From an initial listing of plant structures, a listing of those most sensitive to aging may be developed and ranked.

After ranking structures, scheduling of the Stage 1 condition surveys may occur. Incorporating this work into the NPP outage schedule may also be necessary. Determination of the scope of inspection and preparation of a plant-specific procedure and acceptance criteria is also necessary. Following the Stage 1 evaluations, the need for further Stage 2 and 3 evaluations may be determined. In summary, the key elements of a preservation program are the selection of structures for inclusion, establishing acceptance criteria, and conducting the Stage 1 surveys. Trending of the results from the initial surveys may provide a baseline for further evaluations (scope, frequency, etc.). The use of statistics may also support this effort by defining the minimum quantity of structures to be considered, degree of inspections required, frequency and other information (Ellingwood and Mori 1992).

CONCLUSIONS

Preparation of a remnant life preservation program for nuclear power plant structures is a necessary ingredient in optimizing plant safety, reducing costs, and preserving long-term operation. Instituting a program which focusses on a set of critical and aging-sensitive plant structures provides a means for meeting maintenance program goals, justifying life extension, and controlling costs. Remnant life preservation provides the mechanism for early degradation identification, suitable evaluations, and rehabilitative actions if needed.

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