Research Activities for Nuclear Power Plant Aging Promoted by PLEC, JAPEIC, Japan*

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In order to perform research activity for aging countermeasure of nuclear power plant effectively, Plant Life Engineering Center (PLEC) was established in Japan Power Engineering and Inspection Corporation (JAPEIC) in April 2000 sponsored by Ministry of International Trade and Industry (MITI, presently METI). Outlined activities of PLEC are as follows. Results of technical survey for research and development for aging phenomena have been summarized in a table (Research Map) categorizing them into “inspection and monitoring”, “evaluation method for aging” and “preventive maintenances and refurbishment”. Necessary research themes have been extracted from the Research Map consulting to experts of the specified research area and they are summarized into Medium and Long-term Research Perspective (Research Perspective), which contains prioritized research themes and outlined specification of each theme. Several new research themes proposed by various organizations and selected by PLEC as effective for the regulation activities are identified and proposed to be funded by METI every year. This paper also provides outlines and obtained results of aging related research projects currently conducted by JAPEIC sponsored by METI.

Key Words: Stress Corrosion Cracking, Low Cycle Fatigue, Nondestructive Inspection, Aging Countermeasure, Research Map, Research Perspective, Verification Test

1. Introduction

By the end of January 2003, 52 commercial nuclear power plants have been operating in Japan and they generate about 35% of the gross capacity of 45.7 GWe. 4 plants constructed in the early 1970s have been operated for more than 30 years and 23 plants, including the above 4 plants, have been in operation for over 20 years. Thus, aging management of nuclear power plant has become a matter of increasing concern in Japan.

The regulatory bodies of Japan have endeavored to enhance the reliability and safety of aged nuclear power

plants⁽¹⁾.

The electric utility companies conduct technical evaluations in their periodical safety reviews concerning the aging phenomena of all safety related components and structures. From the viewpoint of aging management, the companies identified additional maintenance measures to reinforce their current maintenance procedures and summarized them as their long-term maintenance programs including the current and additional maintenance activities. Figure 1 shows aging phenomena in major components and structures for evaluation of PWR nuclear power plants. For the implementation and promotion of aging-related technology research, PLEC was established in April 2000 in JAPEIC sponsored by Ministry of International Trade and Industry (MITI), presently called as Ministry of Economy, Trade and Industry (METI).

Technology Advisory Committee composed of members from academics, electric utilities, manufacturers and prefecture and municipal governments relevant to nuclear power plant sites recommend the PLEC activity to concentrate national wide potentials and to secure transparency, openness and neutrality.

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Fig. 1 Aging phenomena in major components and structures (PWR)

(a) General activities

(b) Detailed activities for new theme identification

Fig. 2 Research activities promoted by PLEC

2. PLEC Activities

Assigned mission and roles of PLEC are as follows:

- (a) Coordinate planning of technology research on aging in cooperation with industry, government and academia
- (b) Integrate technology knowledge of aging for management and assessment
- (c) Promote practical application of obtained technical results by national projects
- (d) Promote holding of technology information in common

Schematic presentation of research activities is depicted in Fig. 2(a). Detailed activities in New Theme Identification are shown in Fig. 2(b).

2.1 Preparation of research map

Technical survey for research and development related to aging countermeasures are currently conducted and summarized in a type of matrix table that locates many existing researches on aging phenomena including 'neutron irradiation embrittlement', 'stress corrosion cracking', 'fatigue', 'thermal aging' and 'corrosion' categoriz-

Aging Phenomena		Irradiation Assisted Stress Corrosion Cracking								
Components	Parts	Environment (Irradiation)	Structural Materials	Current Maintenance Program and Countermeasures	Inspection and Monitoring	Evaluation Methods			Preventive Maintenance and Refurbishment	Remarks
						Crack Initiation Evaluation	Crack Growth Evaluation	Integrity Evaluation		
Reactor Internals										

Fig. 3 Example of the research map for aging

ing them into three fields of 'inspection and monitoring', 'evaluation method for aging', and 'preventive maintenances and refurbishment'. Figure 3 shows a format example of the research map.

From these tables, necessary research items for safety regulation and facility maintenance management are extracted by experts of the specified research area.

2.2 Development of medium and long-term research perspective (Research Perspective)

In order to carry out researches effectively, efficiently and in a timely manner under the restriction of resources and period, Research Perspective has been established. It contains research themes prioritized based on their necessity and effectiveness as shown in Table 1. It also contains outlined research specification of each theme. One example of them for IGSCC in austenitic stainless steel is shown in Table 2.

2.3 New themes identification

Every October PLEC receives new research proposal from universities, manufacturers and research institutes such as JAERI (Japan Atomic Energy Research Institute) and CRIEPI (Central Research Institute of Electric Power Industry). Their order of priority is decided by the subcommittee from the viewpoints of consistency with Research Perspective, urgency of the research, importance of the relevant component and effectiveness of the research to safety regulation. Selected themes are proposed as candidates for national projects.

There are two types of national project in the framework of aging related research of METI. One is called as Verification Test whose purpose is to establish essential database for a specified aging phenomenon and countermeasure technologies. A Verification Test is in many cases scheduled to be completed in several years. The other is called as Study of Safety-related Advanced Technology (SAT Study) whose purpose is to obtain basic data of aging phenomena, to recognize its general tendency or to understand its mechanism. A SAT study is to be completed in a year.

Table 1 Themes in Research Perspective Note

*P: Priority, H: High, M: Middle

**ASS: Austenitic stainless steel

Research Items	P*
IRRADIATION EMBRITTLEMENT	
Monitoring specimen reconstitution	H
Integrity evaluation of USE<68J materials	H
Effect evaluation of accelerated irradiation	M
Embrittlement estimation by mechanism	M
SCC IN Ni-BASED ALLOY	
SCC detection/sizing by UT	H
SCC detection/sizing by ECT	M
SCC growth data	H
SCC growth by constant load/displacement	H
Effect of radiolytic products on SCC	M
Mechanism of generation/growth of SCC	M
Surface improvement for SCC	M
FATIGUE	
Crack detection/sizing by UT for Ni alloy	M
Crack detection/sizing by ECT for Ni alloy	H
Precision of crack detection/sizing by NDT	M
Fatigue life data in reactor coolant	M
Fatigue crack growth data in reactor coolant	M
IASCC	
SCC generation/growth data	H
SCC growth by constant load/displacement	H
Load variation effect on generation of SCC	M
Effect evaluation of accelerated irradiation	M
SCC data under irradiation	M
Effect of radiolytic products on SCC	M
He accumulation effect on material	M
Irradiation effects on creep and stress relaxation	M
Simulation of degradation by irradiation	M
Weld repair for irradiated materials	M
Surface improvement for SCC	M
Repair for highly irradiated materials	M
IGSCC	
NDT for small crack in low carbon ASS**	M
SCC data in reactor coolant	M
SCC generation mechanism	M
Weld repair for irradiated materials	M
Surface improvement for SCC	M
Repair for highly irradiated materials	M
Integrity of repair weld of irradiated materials	M
Irradiation effect on repaired weld	M
THERMAL AGING	
Thermal embrittlement evaluation	H
SG TUBE DAMAGE	
SCC growth data of Ni based alloy	H
Fracture evaluation of cracked thin tube	H
CABLE INSULATION DEGRADATION	
Application of NDT to cable in plants	M
Evaluation by accelerated degradation data	H
CONCRETE STRENGTH DECREASE	
NDT for accurate strength prediction	M
Strength decrease data by heating	M
Strength decrease data by irradiation	M
CONCRETE SHIELDING ABILITY DECREASE	
Monitoring of concrete shielding performance	M
Concrete shielding ability data	M

3. National Project Promoted by PLEC

3.1 Verification test

The following themes are proposed in 2000 and 2001 as candidates of Verification Test.

(a) Research on NDT of SCC on Ni based alloy weld

This research was started in 2002 as verification test named NNW Project. Its outline is as follows. The detectability and sizing precision of UT and ECT for SCC

Table 2 Research specification of "SCC data in reactor coolant"

theme	SCC data in reactor coolant
components	primary piping(B), core internals(B)
purpose	obtain generation and growth data of IGSCC in components made of ASS, especially low-C ASS which has been developed and used as anti-SCC material
outline	solve following parameter effects on IGSCC: 1. materials : SUS304, SUS316 SUS304L, SUS316L 2. stress: distribution including residual stress 3. environments: temperature, water, radiation
period	in 5 years
target output	establish techniques to predict generation and growth rate of IGSCC

Fig. 4 SCC detection by phased array UT probe in Ni-based alloy shroud support

on Ni based alloy weld are going to be studied. Phased array UT probes are scheduled to be introduced. In order to optimize defect detectability and sizing precision, numerical simulation for ultrasonic wave propagation of UT and distribution of electro magnetic field generated by ECT are planned to be quoted. The conceptual arrangement of UT for shroud support plate is given in Fig. 4.

(b) Research on fatigue crack growth rate in PWR reactor coolant water environment

As well as fatigue life, fatigue crack growth rate is influenced by the environmental effect. Fatigue crack growth of carbon steel and austenitic stainless steel in BWR coolant condition was studied in a national project. This newly proposed research intends to establish a database of fatigue crack growth rate of austenitic stainless steel and nickel-based alloy in PWR primary coolant condition.

(c) Research on SCC growth rate under constant displacement condition

SCC growth rate is generally recognized to change whether the test is conducted under constant load condition or constant displacement condition. The former corresponds to K-increase condition and the latter to K-decrease condition where K means stress intensity factor composed of crack depth and stress. It is easy to do SCC

test under constant load condition, but many real components in a nuclear power plant are situated under K-decrease condition. In order to evaluate crack growth rate of austenitic stainless steel or nickel based alloy on more real condition this research has been proposed.

3.2 SAT study

In 2001, several research themes were performed as SAT study. Results of two researches are described below briefly.

(a) Nondestructive evaluation of neutron irradiation embrittlement of monitoring specimen

There seems to be two ways of solution to avoid the deficiency of monitoring specimens after 40 years of designed operation. One is to reconstitute specimen using broken ones, another is to introduce nondestructive method to measure the embrittlement. Positron annihilation (PA) method and ultrasonic attenuation measurement are assumed to be such candidates. Basic studies related to these methods were performed by Prof. Matsui, Tohoku University in Japan. Following results are obtained:

Coincidence Doppler broadening (CDB) technique decreases background noise as shown in Fig. 5(a). PA count ratio of Fe-0.1wt%Cu alloy to that of pure Fe in Fig. 5(b) shows that PA behavior of the alloy approaches from that of pure Fe to that of pure Cu as thermal aging time increases, which suggests Cu atoms coalesce to form precipitation with aging time.

Techniques to photograph continuously the movement of dislocation line in a test specimen located in the vacuum chamber of an electron microscope and loaded with tension load, was established. The techniques can be regarded as useful to understand dislocation interaction with point defects such as vacancy under vibration field caused by ultrasonic wave propagation.

(b) Dpa calculation by PC

Displacement per atom (dpa), which includes energy dependence of cross section and neutron energy spectrum of a reactor, can stand for the neutron irradiation damage of reactor materials more precisely than accumulated fluence. To calculate dpa, these quantities as function of energy and precise calculation technique to cover resonance integral are needed.

Through this research performed by Prof. Sekimura, Tokyo University in Japan, dpa calculations code based on ASTM-E693, which can be executed on personal computer, has been developed.

Developed code can be downloaded from the following Web site:

<http://marie.q.t.u-tokyo.ac.jp/nprim/>

In 2002 FY (from April 2002 to March 2003), the following researches have been carried out:

(a) Mechanism study of environmental effect on environment assisted crack growth

(a) Doppler Broadening (DB) of Fe with and without coincidence

(b) CDB (ratio to Fe) change of Fe-1.0wt% Cu due to thermal aging time at 550°C

Fig. 5 Positron annihilation technology

(b) Evaluation of accelerated irradiation effect based on micro mechanism consideration

(c) Effect of neutron flux on irradiation damage of austenitic stainless steel utilizing removed parts from a real plant

4. Another National Project Related to Aging in Japan

Adding to the researches described in section 3, following research activities have been performed by each project in JAPEIC.

(1) Fatigue life data of carbon steel, low alloy steel and austenitic stainless steel under reactor coolant condition⁽²⁾⁻⁽⁴⁾

(2) Countermeasure for irradiation embrittlement of RPV steel

—Upper shelf energy evaluation method^{(5),(6)}

—Reconstitution technology of surveillance specimen^{(7),(8)}

(3) Surface treatment to prevent SCC by laser technology

(4) Repair welding technology for irradiated materials

(5) SCC growth data in Ni based alloy weld

(6) Initiation and growth data of irradiation assisted SCC

(7) Integrity assessment of flawed components with structural discontinuity.^{(9), (10)}

(8) Assessment of cable aging

Obtained results have been referred world widely.

5. Conclusions

The number of nuclear power plants operating more than 30 years has increased in Japan. Various aging related activities have been performed in Japan. To assure and improve the safety and reliability of aged nuclear power plants, it is important to continue and conduct research activities for evaluation methods of aging, inspection and monitoring method for aged components, preventive maintenance and refurbishment, in an effective manner and to apply the results of these research to aging management strategy.

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