Proactive plant life management for safe nuclear energy

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Abstract: Ageing of System, Structure, and Components (SSCs) can have impacts on the safety and performance of nuclear power plants. Proactive plant life management is a key element to ensure long term safe, economic and reliable operation of nuclear power plants. Ageing must be systematically taken into account throughout the full plant's lifetime. In China, since two old nuclear power plants of Qinshan-I and Daya Bay are approaching their design life, it is a great concern in China how to establish an effective ageing management program for the both plants. In addition, operating experience accumulated from the both plants should be learned and reflected to the new-built plants. In this paper, the proactive plant life management recommended by International Atomic Energy Agency (IAEA) is first summarized and then explain briefly how this IAEA recommended approaches are applied the current plant life management activities in China.
Keyword: proactive plant life management; plant ageing management

1 Introduction

The rapid economic development in China results in growing demand for energy. Previously, the electricity generation in China had been heavily relying on fossil fuels, but in recent years, the development of nuclear energy has been put on the agenda. Nuclear energy has three advantages that attract the attention of Chinese government: first, the stable and high power output of electricity at a relatively low cost; second, the very few carbon emission during operation which lessens air pollution and greenhouse effect; and third, the pressure relieved in national transport system due to the reduced amount of coal to be transported for electricity generation [1][2].

In 2013, only 2% of the total energy generated in China comes from nuclear energy, which is considered to be too small a percentage. As the first step, the Chinese government is planning to reach 58GWe nuclear power capacity till 2020. Therefore, by now (October, 2015), 28 nuclear power plants are operating, and 24 more are under construction [1].

The Fukushima Daiichi accident in 2011 warned us again on the safety issues of nuclear power plants. Strictly speaking, China is not a newcomer in the field of nuclear energy safety, as it has the experience of operating Qinshan-I and Daya Bay nuclear power plants since 1991 and 1993, but as the nuclear energy in China is currently developing rapidly, China faces new challenges.

The first challenge comes from the old nuclear power plants in China. When the first reactor Qinshan-I was designed and constructed in China in 1991, its designed lifetime was set to be 30 years. It will soon reach its designed lifetime in the future years, and will need evaluation for life extension or decommission. This will be the first time for China to preform license renewal evaluation. Similarly, Daya Bay nuclear power plant will also reach its designed lifetime in 2033.

The second challenge is about the new types of nuclear power plants being constructed in China, including Generation III reactors such as AP1000 and CPR1000. Although these Generation III reactors are based on the classic Generation II PWRs and are designed to have more and better safety features, new types of reactors may encounter new problems.

For nuclear power plants that are approaching their designed lifetime, how the ageing of the plant should be managed adequately and effectively will be a major concern in order to maintain safe and reliable operation of these plants. Meanwhile, those lessons

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learned and accumulated from the past ageing problem should be appropriately reflected to the new-built plants. In this paper, ageing effect on plant safety is described and proactive plant life management program recommended by International Atomic Energy Agency (IAEA) is introduced. In addition, plant life management activities in China are also introduced briefly.

2 Proactive plant life management

2.1 Overview of ageing and its effect on plant safety

Ageing is a natural phenomenon in any engineered system such as a bridge, a building or an aircraft and so on. Certainly, nuclear power plants also experience ageing to various degrees. Ageing of system, structure, components (SSCs) in nuclear power plants would result in degradation of their physical characteristics which may increase the probability of various failures in SSCs. Managing ageing is essential to ensure the plant safety.

Examples of major ageing degradation in nuclear power plants are described as following. In the nuclear environment, some SSCs such as reactor pressure vessel or reactor core components are exposed to special conditions, especially to high energy neutron produced by the fission reaction in the nuclear core, which can cause embrittlement in reactor pressure vessel or irradiation-assisted stress corrosion cracking in reactor core austenitic stainless steel components[3][4][5][6].

Reactor pressure vessel is generally considered to be the most critical component as it houses the reactor core and has direct safety significance, and is considered irreplaceable. Every effort must be made to protect age related degradation of the mechanical properties of the RPV steels.

Besides, the ageing degradation mechanisms in steam generator of the pressurized water reactor include primary water stress corrosion cracking, fretting, thinning, pitting, high cycle fatigue, corrosion and so on, which could have a significant effect on its safety function, *e.g.* any leakage from defects in the steam generator tubes could result in the release of radioactivity to the environment outside the reactor containment through the secondary system [7].

In addition, significant ageing mechanisms including thermal fatigue, vibratory fatigue, thermal ageing, stress corrosion cracking and boric acid corrosion in primary system piping could lead to small, intermediate or large break loss of coolant accidents. To maintain plant safety it is very important to understand, detect and predict ageing of SSCs [8]. An effective ageing management program must be implemented in nuclear power plants.

2.2 Proactive plant life management

Based on International Atomic Energy Agency Safety Reports Series No.62 [9], a proactive management of ageing for nuclear power plants is recommended for member states. A proactive ageing management program is one that properly takes ageing into account at the entire life cycle of the plants (design, fabrication, construction, commissioning, operation and decommissioning). Ageing of SSCs can be slowed by proactive measures at each stage of the plant life cycle. Proactive ageing management entails a continuous learning and improvement process based on lessons learned from the operation of the plant itself as well as from other nuclear power plants, in order to avoid recurrent problems and to improve plant operation techniques. Regulatory requirements for ageing management must be developed. Ageing issues must be identified and documented in the safety analysis report and periodically updated throughout the plant lifetime.

IAEA recommends the development of Plan-Do-Check-Act [10] cycle for the systematic ageing management of SCC. This approach provides a framework to coordinate activities and programs relating to understanding, control, monitoring and mitigation of ageing effects of an SCC. Prediction of future SCC ageing is the key to proactive ageing management. It enables the optimization of engineering, operation, inspection and maintenance activities. This predictability depends on the degree of technical and scientific understanding of ageing mechanisms and operating experience. For example, neutron irradiation causes embrittlement of reactor

pressure vessel steels, which is one of the most important issues affecting safe operation of reactors. Extensive researches by using various microstructural techniques such as three dimensional atom probe, transmission electron microscopy, positron annihilation spectroscopy, can reveal the details of microstructural evolution under neutron irradiation in order to predict irradiation embrittlement. Besides the good predictability of already known ageing degradation, efforts must be made to detect unknown new ageing mechanisms.

3 Plant life management activities in China

Currently, Chinese regulatory body of National Nuclear Safety Administration (NNSA) requests for NPP operators that ageing state as one of safety factors should be reviewed during Periodic Safety Review of their NPPs. Safety regulatory system are also under development at NNSA for operation license extension and full life cycle ageing management.

Ageing management activities in Qinshan-I and Daya Bay nuclear power plants, are being carried out, for example, to establish a systematic approach of Plan-Do-Check-Act cycle for effective ageing management: This is a development of ageing management program for major SSCs important to safety by establishing a data collection and record keeping system, where according to the principles recommended by IAEA, the scoping and screening of SSCs for ageing management program was performed. As a result, ageing program for reactor pressure vessel, steam generator, pressurized surge line, instrumental and control cables, and concrete containment are developed [11]. In addition, operating experience for ageing management accumulated from Qinshan and Daya Bay nuclear power plants should be learned and effectively reflected to the operation of new-built nuclear power plants in China. To this end, the research and practice of accelerated ageing management (AAM) has been conducted at Daya Bay nuclear power plant. For the details of this AAM project at Daya Bay plant, please see the Ref. [12] in this IJNS.

National research projects on technical and/or scientific understanding of the ageing mechanisms of SSCs important to safety are also conducting [2]. In order to provide a common platform of technical knowledge sharing, domestic technical working group on plant life management is established. In addition, China has also actively participated in many international collaboration projects on ageing management, such as the International Group on Radiation Damage Mechanisms (IGRDM) in Reactor Pressure Vessel Steels, Technical Working Group on Life Management of Nuclear Power Plant (TWG-LMNPP), International Generic Ageing Lessons Learned (IGALL), and other activities coordinated by the IAEA Coordinated Research Projects (CRP).

4 Conclusion

Ageing of SSCs can have impacts on the safety and performance of nuclear power plants. Proactive plant life management is a key element to achieve long term safe, economic and reliable operation of nuclear power plants. Ageing must be systematically taken into account throughout the full plant's lifetime, including design, fabrication and construction, commissioning, operation and decommissioning. This predictability on ageing should be improved with technical and scientific understanding of ageing mechanisms and accumulated operating experience.

Nuclear energy will take an important portion in electricity supply in China. Proactive plant life management is implemented and will be continuously improved in China.

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