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Regulation considerations for zinc application into reactor coolants of SMR

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1. Introduction

Korean innovative SMR has been implemented developing with improved safety/economy and i-SMR technology development project to secure a competitive edge in SMR. For nuclear power plants, according to the revision of the Nuclear Safety Act (2013.6), it is mandatory to be reflected in the aging management program of nuclear power plants, and the aging management and regulation of major nuclear power plants are being strengthened. For i-SMR, chemistry environment and management strategy is essential to mitigate corrosion and radiation fields, since it has compacted and integrated module designs.

In 1994, zinc injection into the reactor coolant system (RCS) was applied more than 100 PWRs in the world to mitigate primary water stress corrosion cracking (PWSCC) and to reduce out-of-core radiation fields. In domestic NPPs, 7 units have been applying zinc injection and had up to 90% radiation field reductions.

For this reason, i-SMR need to apply zinc injection for chemistry strategy. To apply zinc injection in i-SMR, safety analysis is required and added to Safety Analysis Report (SAR) in advance. Therefore, in this report, we review the regulation environment, FSARs, and strategy for zinc application in i-SMR.

2. Regulation and zinc application

In this section, material and chemical environment for corrosion compared between NPPs and i-SMR are described (2.1). The regulation system was analyzed to develop new FSAR for zinc injection (2.2).

2.1 The materials for primary systems and zinc injection effects

In a typical PWRs, the wetted RCS surface area consists of approximately 25% zirconium alloy fuel cladding, 65% nickel based alloys (primarily steam generator tubing), and 10% stainless steel [1]. To mitigate corrosion, chemistry strategy is related to materials. I-SMR will design PWR's similar material circumstance and chemistry environments.

According to material environment of i-SMR, zinc injection is effective as NPPs for primary materials. NPPs were adding zinc to the primary coolant at levels ranging from about 5 ppb to 40 ppb. Utilities use the higher levels (15 ppb to 40 ppb) at plants to mitigate PWSCC in Alloy 600 materials. The primary objective of adding zinc at lower levels (5 ppb to 10 ppb) has been to reduce plant radiation fields.

Zinc is incorporated into the oxide films of wetted surfaces in an operating PWR changing the morphology and composition of firm oxide films, thereby changing the corrosion characteristics [2]. In addition, zinc displaces nickel and radioactive cobalt-58/60 from the crystalline lattice sites in the oxide layer of system surfaces [3,4,5]. Therefore, zinc oxide has much more resistance for the corrosion than before.

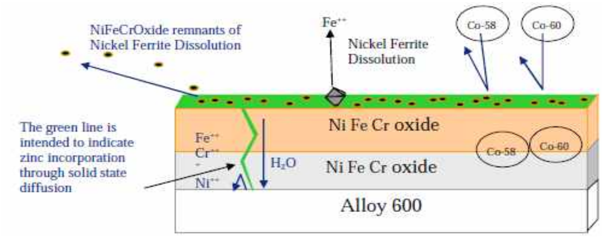

Fig. 1. Zinc Incorporated into Plant Surfaces.

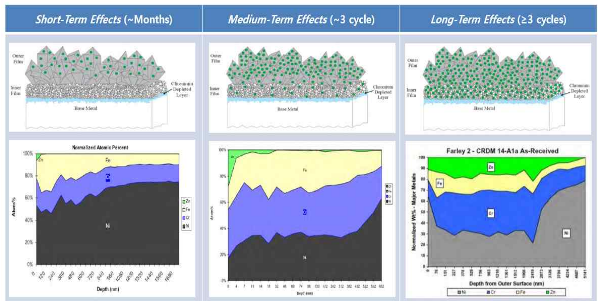

Fig. 2 Schematic and composition of the Corrosion Film with Zinc Incorporation for each period

2.2 IAEA Requirement

According to IAEA safety of nuclear power plants design specific safety requirements (SSR), ageing management (Requirement 31) should be prepared. The design life of items important to safety at a nuclear power plant shall be determined. Appropriate margins shall be provided in the design to take due account of relevant mechanisms of ageing throughout their design life [6].

Therefore, zinc injection for corrosion mitigation strategy should be considered to meet ageing management of design life for i-SMR environments, compact and dense arrangement of systems.

2.3 Analysis of regulation system of zinc injection for i-SMR

Legal regulation framework mainly consists of nuclear safety act, enforcement degree of the act, regulation of the act, and notice of Nuclear Safety and Security commission(NSSC). Major licensing steps are related to nuclear safety act. For major licensing steps are as below [7,8].

1. Standard Design Approval (SDA)
2. Early Site Approval (ESA)
3. Construction Permit (CP)
4. Operating License (OL)
5. Continued Operation (CO) after Period of Operating License

The submission documents and the criteria for permission according to the various licensing and permission of nuclear power plants regarding SAR are as shown in the figure below.

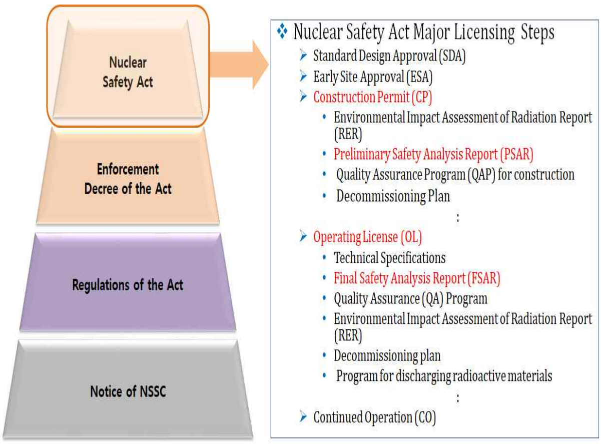

Fig. 3 Regulatory framework for domestic regulation for SAR

To obtain approval or permission for the construction, operation, or dismantlement of a nuclear power plant, licensee must submit all documents prescribed in the Nuclear Safety Act to the Nuclear Safety Commission, which is a nuclear safety regulator. All documents to be submitted are stipulated in the Enforcement Rules of the Nuclear Safety Act. The licensing standards for licensing review are stipulated in the Nuclear Safety Act, and detailed technical standards are stipulated in the Rules on Technical Standards for Nuclear Power Plant.

Permission related to nuclear power plants is largely divided into two stages: construction permit and operation permit. SAR is need to CP and OL as mandatory documents to be submitted to regulatory body. SAR normally consists of 18 chapters. For zinc injection, chapter 3 (design of structures, components, equipment, and systems) and chapter 9 (auxiliary systems are related and added).

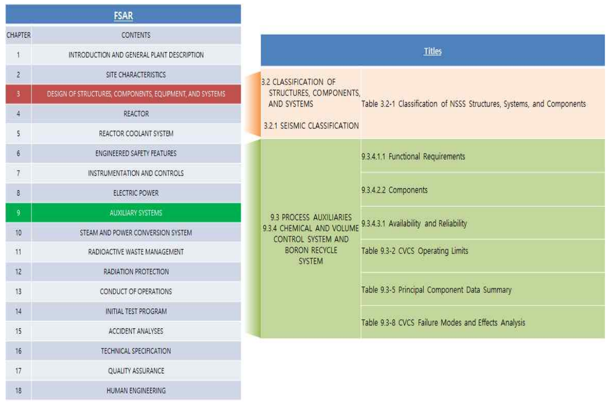

Fig. 4. SAR related to zinc injection

To add information on zinc injection at SAR, major contents are zinc injection skid, piping and valves connected to Chemistry and Volume Control System (CVCS), and CVCS operating limits for water chemistry. The detailed SAR related to zinc injection are as below.

3. Design of structures, components, equipment, and systems

3.2. Classification of structures, components, and systems

- Table 3.2-1 classification of NSSS structures, systems, and components

9. Auxiliary systems

9.3. Process auxiliaries

9.3.4. Chemical and volume control system and boron recycle system

- 9.3.4.1.1 Functional Requirements
- 9.3.4.2.2 Components
- 9.3.4.3.1 Availability and Reliability
- Table 9.3-2 CVCS Operating Limits
- Table 9.3-5 Principal Component Data Summary
- Table 9.3-8 CVCS Failure Modes and Effects Analysis

PWR zinc injection and i-SMR zinc injection will have similar licensing procedures. However, there will be differences in the scope of the device's safety or non-safety system and some design capacities and criteria.

3. Conclusions

i-SMR has been developing in Korea and should be considered chemistry control strategy for materials reliability. Corrosion is common and numerous risk to operate nuclear power plant especially for long term operation. For Zero-risk i-SMR, chemistry to mitigate corrosion strategy is essential.

Zinc is an effective moderator of oxide layers regarding corrosion and radiation field reductions. To apply zinc injection for i-SMR, CVCS deign and monitoring strategy should have developed at FSAR and chemistry document in advance. During the major licensing steps of CP and OL, major information of zinc skids and control concentration should be added to SAR. Major chapters of SAR are chapter 3 design of structures, components, equipment, and systems, and 9 auxiliary systems. Zinc injection for i-SMR will have similar licensing procedures as PWR except differences in some design capacities and criteria.

For risk-free i-SMR development, the application of zinc will be effective and bring sustainable reliability for corrosion strategy.

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