Transactions of the Korean Nuclear Society Virtual spring Meeting
May 13-14, 2021

Radiation shielding strategy for material testing of PWR reactor internal components

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1. Introduction

Domestic nuclear power plants have a very safe operation history and have been boasting a high utilization rate. Nuclear power, which accounts for about 25% of the total domestic power generation, is an energy source that contributes to the reduction of carbon dioxide emissions and plays a large role as a base-load power source for national energy. However, material degradation management, which inevitably occurs as the number of years of operation increases, is an essential item for the safety improvement of the power plants.

As one of the strategies for improving the operational safety of power plants, research and development projects are being conducted to evaluate the changes in the properties of reactor internal materials by neutron irradiation of a Korean nuclear power plant, which has been operating for 40 years. An essential area for this research is a setup of research facility for material research that can handle radioactive isotopes(RI), and is a radiation work area construction including a hot cell. In this facility, it is possible to perform irradiation assisted stress corrosion cracking (IASCC) tests, precise microstructure analysis tests by using transmission electron microscopy (TEM), and mechanical properties tests by using instrumented indentation techniques (IIT) and universal testing machine.

The purpose of this paper is to introduce an overview of this research facility being built in Korea and a strategy to reduce radiation exposure of researchers.

2. Background

As a part of research using dismantled nuclear power plant materials, research facilities are being built to safely handle high-radiation specimens. Research to find the cause of the defects found in the internal structure bolts (baffle former bolt, BFB) of a pressurized water reactor(PWR) in Korea is currently in operation as well as in terms of nuclear safety regulations, and this is necessary to collect data for securing material integrity of other operating power plants.[1] The Korean government recognizes this need and supports mid to long-term research for 5 years.[2]

Many research institutes around the world have high-temperature, high-pressure stress corrosion testing facilities and technologies in general experimental areas for non-radioactive components. However, no technology has been developed in Korea regarding the IASCC testing for medium and low-level materials irradiated by neutrons and there are no related facilities.

As the operation time of plants increases, the importance of degradation management of the structure inside the reactor is highlighted, and the Material Aging Management Program (AMP) is developed and applied based on the EPRI MRP-227 report.[3] USNRC and EPRI are working on a government led project to assess material degradation characteristics by using harvested materials from decommissioned nuclear power plants to secure technical evidence for decommissioning old plants and safe operation of operating plants.[4]

The test for identifying the cause of failure of the internal structure of the reactor shall be conducted in the same high-temperature and high-pressure environment as the plant operating conditions. This study requires a hot cell with autoclave and slow strain rate tester (SSRT), but is not installed in Korea yet.

3. Outline of the research facility

The purpose of use of this facility is the IASCC demonstration test and microstructure analysis, the production and analysis of micro specimens for the precision analysis of radioactive structural nuclear materials, the tensile test for the evaluation of the material properties of metal and non-metal materials irradiated at commercially operated nuclear power plants and research reactor. It will also be a space for analysis for additional radioisotope testing.

In the basement of this research facility, a small lead(Pb) hot cell capable of performing the IASCC test as shown in Figure 1 will be installed. The core facility of this test facility is the SSRT (Slow Strain Rate Tester), which can evaluate the crack initiation and growth of radioactive specimens under the temperature and pressure that satisfies the operating conditions of the primary water of PWRs. Two specimens for crack evaluation are shown in Figures 2 and 3 below.

The test building shown in Figure 4 is divided into a general area and a radiation control area, and the storage and use of radioactive samples is carried out within the control area.

At the entrance of the radiation control area, a clothes changing room, a radiation control room, a pollution inspection room, and an emergency shower room are designed to enable radiation safety management. The radiation control area on each floor includes a laboratory for sample preparation, measurement of isotopes, and a storage room for waste storage.

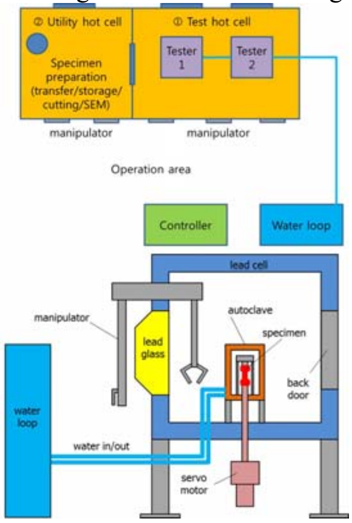

Fig. 1. Schematic of lead(Pb) shielding hot cell and test facility for IASCC

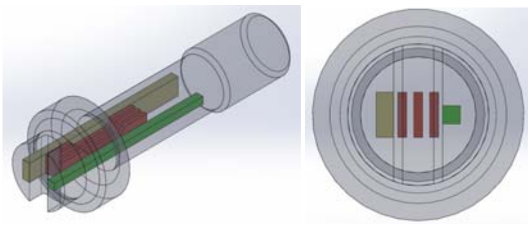

Fig. 2. Specimen design for tensile test from BFB

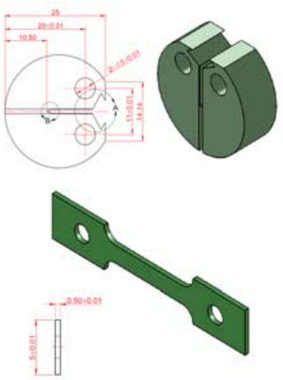

Fig. 3. Specimen design for crack growth and tensile test

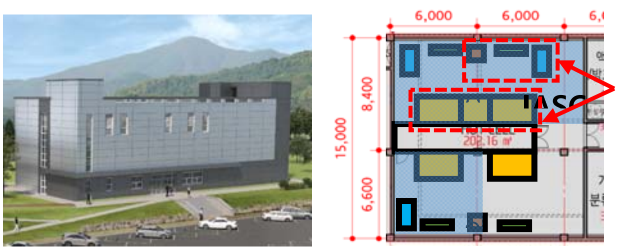

Fig. 4. Research building and layout of lead hot cell

Various facilities installed according to the purpose of the construction of this facility are located in each room according to their function.

The typical purpose is the material characteristic analysis experiment described above. The facility will include RI classification room, the RI storage room, the solid waste storage room, the liquid waste storage room, the health physics room, the sample pretreatment room, the whole body counting room, the strong acid fume hood room, the destructive characterization laboratory, and micro structure analysis room, etc.

4. Radiation safety calculation

Korean government organization notified the nuclear law enforcement regulations called Radiation Safety Report Preparation Guidelines. It is being asked to obtain permission before conducting radioactive materials handling work.

The contents contained in this report are 1) Size and capacity of the radiation source, 2) Annual usage permit, 3) Basis for calculating the amount of permits for analysis specimens, 4) Characteristics of the work environment around the facility, 5) Installation plan of the facility, 6) Facility and equipment construction schedule, 7) Radiation source purchase and arrangement plan, 8) Expected use and storage of the radioactive materials, 9) Radiation source specifications and characteristics, 10) Radiation source safety devices, 11) Safety facilities and systems, 12) Radiation handling methods and radiation safety management plan, 13) evaluation of expected radiation dose, 14) radiation impact on the surrounding environment, and 15) generation and treatment of radioactive waste.

Radiation shielding strategies from hotcells containing radioactive materials will be discussed later in other paper. We only deal with the design method of a storage container that satisfies the storage capacity of the opened source to be installed in the radiation work area in this article.

The most important part is the storage box (structure and specifications, location, shielding, size) and storage capacity of the opened source. All storage boxes used in this test building will be systematically managed in the corresponding area, and each storage box will be thoroughly managed with individual locking devices. Storage bins with appropriate shape, size and sufficient storage capacity for each research field will be used and managed. In the case of the IASCC experimental process as an example, the contents are as follows.

1) Pb container: Lead cask cylindrical storage box with 23 cm thickness or cabinet type square specimen storage box with thickness of 23 cm, 56 cm wide, 56 cm long, 58 cm high.

2) Structure and specifications of storage box:

There is a cylindrical storage container with a lead thickness of 23 cm and a cabinet-type storage container with a lead thickness of 23 cm (cylindrical cylinder of about 1.4 tons, cabinet type of about 2.4 tons). The required total amount of annual license for open source in the radioisotope test building is about 1.86×10^6 MBq.

3) Calculation of storage capacity:
Representative radioisotope: Co-60
:Gamma ray constant: 13.2 rem.cm^2.mCi^{-1}.hr^{-1},
:Half value layer of lead for Co-60: 12 mm,
:Dose limit at the surface of the container: 0.0025 rem/h (X) (Sources are supposed to be in contact with the inner wall of the storage box.)

$$X=(\Gamma*S)/(r^2)*(1/2)^n$$

Storage capacity (S, mCi):
$$S = (X*r^2)/\Gamma*(2)^n$$

Where,
S : Storage capacity (mCi)
X : Dose limit at the surface of the container (0.0025 rem/hr)
r : Thickness of the container(cm)
Γ : Gamma ray constant of Co-60 (13.2 rem.cm^2.mCi^{-1}.hr$^{-1)}$
n : number of Half value layer of Co-60

S (Lead cask cylindrical)
$= (0.0025*23^2)/13.2*2^{19.16}$
$= 58{,}961$ mCi $= 2.18\times10^6$ MBq
S (Lead cask cabinet type)
$= (0.0025*23^2)/13.2*2^{19.16}$
$= 58{,}961$ mCi $= 2.18\times10^6$ MBq

Therefore, the storage capacity of a cylindrical storage box and a cabinet-type storage box made of lead can be calculated as 2.18×10^6 MBq based on Co-60. The required total of the annual license for open source in this facility is about 1.86×10^6 MBq, so the storage capacity of the storage boxes is satisfactory (see Figure 5).

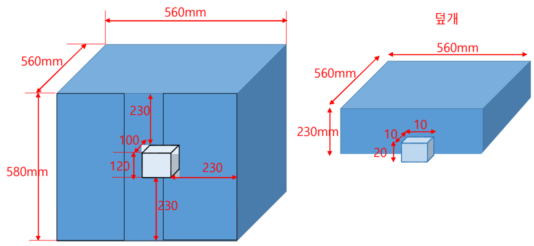

Fig. 5. Example of the Lead cask cabinet type

5. Summary

- Research to find the cause of the defects found in the BFB is requested by Korean regulator and it is also necessary to collect data by using decommissioned materials for securing material integrity of other operating nuclear power plants.
- As the operation time of plants increases, the importance of degradation management of the structure inside the reactor is highlighted worldwide.
- A hot cell with autoclave and slow strain rate tester (SSRT) is not installed in Korea. It is planned to establish the IASCC verification test facilities with small scale hot cell.
- Radiation shielding capacity of storage box made with Lead was calculated as 2.18×10^6 MBq based on Co-60. The required total of the annual license for open source in this facility is about 1.86×10^6 MBq, so the storage capacity of the storage boxes is satisfactory.

ACKNOWLEDGEMENTS

This work was partly supported by Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant, funded by the Korea government (MOTIE) (20191510301140, Development of Failure and Degradation Analysis Technologies of Reactor Internal Baffle Former Bolts from Decommissioning NPP), and the National Research Foundation (NRF) grant, funded by the Korea government (Ministry of Science and ICT) (2017M2A8A4015155, Evaluation of corrosion cracking initiation and counteracting technology development for nuclear structural materials).

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