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Fabrication of the Supplemental Surveillance Capsules to Construct the Data of High-dose Irradiation Embrittlement

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1. Introduction

The reactor pressure vessel(RPV) which contains the nuclear fuels in nuclear power plant are made of thick steel plates or forgings that are welded together. The fast neutrons(E≥ 1.0MeV) from the fuel in the reactor irradiate the vessel as the reactor is operated. This can embrittle the steel, or make it less tough, and less capable of withstanding flaws which may be present in the vessel. Embrittlement usually occurs at a vessel's beltline, that directly surrounds the effective height of the reactor core. Pressurized water reactors(PWRs) are more susceptible to embrittlement than boiling water reactors(BWRs). BWR vessels generally experience less neutron irradiation and therefore less embrittlement. Steels with higher proportions of copper and nickel will tend to be more susceptible to embrittlement than steels with lower proportions of these two elements. In order to monitor the neutron irradiation embrittlement of the reactor vessel material, the surveillance program should be implemented during the reactor operation through the plant life. This surveillance program requires the surveillance capsules which contain the various test specimens, thermal monitors, and neutron dosimeters.

For PWRs in Korea, total six surveillance capsules are installed before plant operation and are programmed to be withdrawn and tested periodically in accordance with the surveillance program. The surveillance capsules are typically installed in the downcomer region and are located closer to the reactor core than the vessel wall in order to get more accelerated embrittlement characteristics of the vessel material. The lead factor is defined as the ratio of the neutron flux(E≥ 1.0MeV) at the specimens in a surveillance capsule to the neutron flux(E≥ 1.0MeV) at the reactor pressure vessel inside surface peak fluence location. A higher lead factor(3 to 5) make it possible to estimate the vessel embrittlement characteristics in advance for the extended plant life as well as for the end of plant life. However it is difficult for the surveillance capsules of small lead factor(less than 2) to obtain a high fluence embrittlement data during the plant life. One or two surveillance capsules were withdrawn and tested for Korea Standard Nuclear Power Plants(KSNPs). The resultant lead factors were estimated as about 1.3, whereas those of Westinghouse type plants were estimated as about 3.0.

Recently to overcome the small lead factors of KSNP plants and construct the high fluence database of the extended plant life, the supplemental surveillance capsules were fabricated and installed at the Westinghouse type plants. In this study, the mechanical test specimens, thermal monitors, and neutron dosimeters contained in the supplemental surveillance capsules are discussed.

2. Supplemental Surveillance Capsules

The supplemental surveillance capsules contain mechanical test specimens, neutron dosimeters and thermal monitors.

2.1 Mechanical Test Specimens

The mechanical test specimens are manufactured in accordance with ASTM E185[1] and Nuclear Safety and Security Commission Notification No.2014-14 section 7[2]. The specimens manufacturing standards are discussed below.

The specimens representing the base metal should be removed from the quarter-thickness(1/4T) locations. The specimens are machined in both longitudinal and transverse orientations. The notchs of Charpy V-notch impact specimens are machined in the vertical direction to the surface of material. The specimens representing weld metal should be removed at all locations throughout the thickness with the exception of locations within 12.7 mm(1/2 in.) from the root or surfaces of the welds. The weld heat-affected-zone(HAZ) should be removed from about the quarter-thickness(1/4T) locations. The notch roots in the HAZ Charpy V-notch specimens should be at a standard distance of approximately 0.8 mm(1/32 in.) from the weld fusion line.

The mechanical test specimens are composed of Charpy V-notch impact specimens, tensile specimens and fracture toughness specimens (1/2T CT specimens). The number of specimens should be equal or greater than the number of table 1[2].

The shape and size of specimens should be satisfied the requirements. The Charpy V-notch impact specimens should be fabricated in accordance with ASTM E23[3], Type A. The tensile specimens should be fabricated in accordance with ASTM E8[4]. The 1/2T CT specimens should be fabricated in accordance with ASTM E1820[5].

Table 1: The quantity of tensile specimens

Materials \ Type of specimens		Impact test specimen	Tensile test specimen	Fracture toughness specimens
Base metal	Longitudinal	12	3	4
	Transverse	12	3	4
Weld metal		12	3	4
HAZ		12		

The archive materials of the base metal, weld, and heat-affected-zone(HAZ) are stored at the plant site in the form of full-thickness sections. Basically these archive materials are identical to the specimen materials used in the surveillance capsules fabrication. ASTM E185[1] recommends that these archive materials of the quantity for at least two additional surveillance capsules be retained at the plant site.

The specimens of the supplemental surveillance capsules, such as Charpy V-notch impact specimen, tensile specimen, and 1/2T CT specimen, were fabricated by using the archive materials of Hanbit 3 and 4. In accordance with ASTM E185[1], all test specimens were removed from the quarter-thickness(1/4T) location of the archive material sections.

2.1.1 Charpy V-notch impact specimens

Charpy V-notch impact specimens were produced in accordance with ASTM E23[3]. For base metal impact specimens were selected and machined in both orientations of longitudinal and transverse. The impact specimens of weld metal were oriented normal to the welding direction, and the notch was machined such that the direction of crack propagation would be the welding direction. When the supplemental surveillance capsules are withdrawn, Charpy V-notch specimens will be tested in accordance with the ASTM E185[1] and ASTM A370[6]. Table 1 delineates the number of Charpy V-notch impact specimens contained in the supplemental surveillance capsules for base metal longitudinal(B-L), base metal trnasverse(B-T), weld metal, and HAZ. Fig. 1 shows Charpy V-notch specimen of supplemental surveillance capsules.

2.1.2 Tensile specimens

Tensile specimens were produced in accordance with ASTM E8[5]. Tensile specimens of base metal were selected and machined in both orientations of longitudinal and transverse. Tensile specimens from the weld metal were oriented normal to the welding direction. When the supplemental surveillance capsules are withdrawn, tensile specimens will be tested in accordance with the ASTM E185[1], ASTM E8[5] and ASTM E21[7]. Table 2 delineates the quantity and the type of each tensile specimen. Fig. 2 shows the tensile specimen of supplemental surveillance capsules.

2.1.3 1/2T CT specimens

1/2T CT specimens were produced in accordance with ASTM E1820[5]. 1/2T CT specimens of base metal were machined in both the longitudinal and transverse orientations. 1/2T CT specimens from the weld metal were machined with the notch oriented in the direction of welding. When the supplemental surveillance capsules withdrawals, 1/2T CT specimens will be tested in accordance with the ASTM E399[8] and ASTM E1152[9]. Table 3 delineates the quantity and the identification and type of 1/2T CT specimen. Fig. 3 shows the 1/2T CT specimen of supplemental surveillance capsules.

Table 2: The quantity of Charpy V-notch impact specimens

Material type	Quantity
B-L	15
B-T	15
Weld metal	15
HAZ	15

Table 3: The quantity of tensile specimens

Material type	Quantity
B-L	3
B-T	3
Weld metal	3

Table 4: The quantity of 1/2T CT specimens

Material type	Quantity
B-L	4
B-T	4
Weld metal	4

2.2 Neutron Dosimeters and Thermal Monitors

In the supplemental surveillance capsules the neutron dosimeters were installed in order to determine the neutron spectrum and neutron fluence($E \geq 1.0$MEV) irradiated to the specimens. The dosimeter wires such as iron, nickel, copper, aluminum-cobalt(Al-Co) (0.15% cobalt) shielded with cadmium tubing and Al-Co (0.15% cobalt) without cadmium shielding were selected for this purpose. The dosimeter wires were inserted in the drilled holes of the spacers, and were sealed by the fitting plugs. In addition to the dosimeter wires, two fission monitors of neptunium dioxide(Np-237) and uranium dioxide(U-238) were contained in the dosimeter block[10].

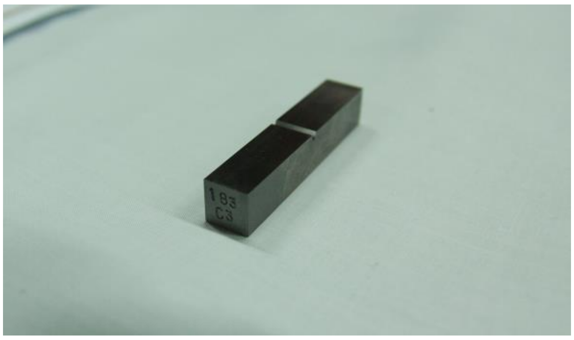

Fig. 1. Charpy V-notch specimen.

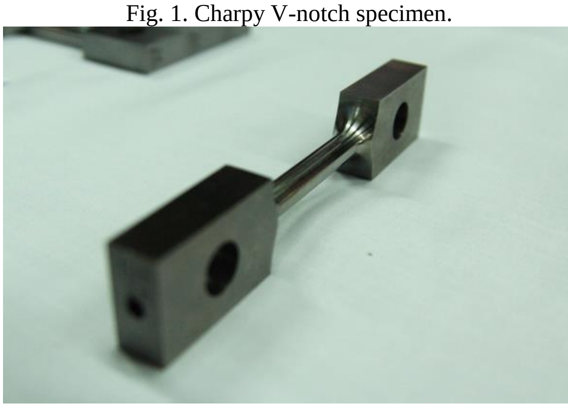

Fig. 2. Tensile specimen.

Fig. 3. 1/2T CT specimen.

Two different low-melting-point eutectic alloy thermal monitors are used to more accurately define the maximum temperature attained by the test specimens during irradiation. Each capsule contains two 579°F and one 590°F thermal monitor wires sealed in Pyrex tubes. The 590°F thermal monitor wires are distinguished from the 579°F thermal monitor wires by the presence of notches on the 590°F wires. The Pyrex tubes were then inserted into spacers by press fitting plugs into the holes. The thermal monitors were positioned at three axial locations within the capsule[10].

2.3 Capsule Fabrication

The supplemental capsules were designed and fabricated to have the same outside dimensions as the capsules originally installed into Hanbit Unit 1. The supplemental capsules were designed to maintain the specimens in an inert environment within a corrosion-resistant capsule. This will prevent deterioration of the surface of the specimens during radiation exposure. The supplemental capsule contains Charpy V-notch impact specimens, tensile specimens, 1/2T CT specimens, neutron dosimeters and thermal monitors. Fig. 4 describes the layout of the specimens[11], thermal monitor spacers, dosimeter block, and remaining spacers within the capsule assemblies. The supplemental capsules were assembled by Westinghouse at the hot cell. The supplemental capsules were installed at Hanbit Unit 1.

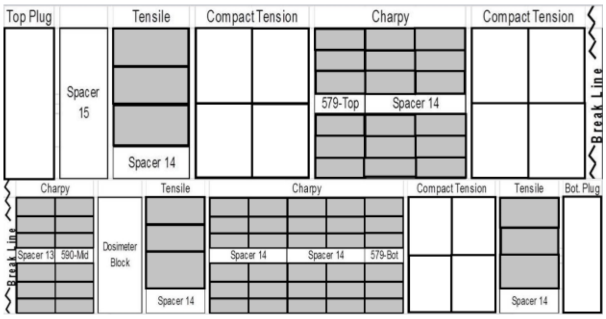

Fig. 4. Layout of supplemental capsules.

3. Conclusions

The supplemental surveillance capsules were fabricated to obtain the data of high-dose irradiation embrittlement. All test specimens in the capsules were made with the archive material of Hanbit Units 3 and 4. The supplemental capsules were designed to have the same outside dimensions as the capsules of Hanbit Unit 1 and were installed in Hanbit Unit 1. The withdrawal schedule will be calculated. After a certain period, the capsules will be withdrawn according to withdrawal schedule and will be evaluated. The evaluated data could significantly help to satisfy the regulations and to extend the life of the KSNPs.

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