Lead Factor Improvement of Surveillance Capsule Assembly in Reactor Vessel

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1. Introduction

The reactor vessel surveillance capsule assembly (SCA) is a structure installed on the inner wall of the reactor vessel to surveil the change in the material properties of the reactor vessel due to neutron irradiation during its lifetime. Surveillance specimens made of reactor vessel material are inserted in the SCA. The SCA installed in the reactor vessel is periodically pulled out, and changes in mechanical properties of the specimen due to neutron irradiation during the life of the reactor are surveilled. The SCA is installed close to the core so that it receives a greater dose of neutron irradiation than the inner wall of the reactor vessel. By allowing the surveillance specimen to receive more neutrons than the reactor vessel, it is possible to know in advance the material properties of the reactor vessel that will change in the future. As such, a lead factor is used as a parameter indicating the difference of the neutron irradiation dose between the reactor vessel and the surveillance specimen.

The lead factor is expressed as the ratio of the neutron irradiation dose irradiated on the surveillance to that on the inner wall of the reactor vessel. Therefore, as the lead factor is greater than 1, it is possible to predict the change in the material properties of the reactor vessel in the future farther from the surveillance specimen. In addition, the closer to 1, the closer the material property data to the point at which the surveillance specimen is withdrawn. In the case of the OPR1000 and APR1400, which are operating nuclear power plants in Korea, the lead factor is close to 1 because the SCA is installed relatively close to the inner wall of the reactor vessel. Therefore, it is difficult to predict changes in the material properties of the reactor vessel during long-term use. In this paper, we intend to improve the lead factor to predict the changes in the material properties of reactor vessels of the large nuclear power plant in the far future. For this purpose, the necessary lead factor has been calculated and the optimum location of the SCA has been set.

2. Lead Factor Calculation

2.1 Target Lead Factor

In order to secure the sufficient lead factor value of the large-scale nuclear power SCA, the lead factor margin was evaluated by reflecting various error factors that can affect the target lead factor. Therefore, the final necessary lead factor can be calculated as the sum of the target lead factor and the lead factor margin. In order to calculate the target lead factor, ASTM E185, which is presented as a standard in the relevant domestic notice (Nuclear Reactor Pressure Vessel Surveillance Test Standard) and the Unites States federal regulations (10CFR50 Appendix H) is reviewed. The requirements for the range of lead factor suggested in the domestic notice are in the range of 1.5 to 3.0. The requirements for the lead factor range suggested by ASTM E185 are greater than 1.0 and less than 3.0 from the 1982 version to the 2002 version, and have been changed from the 2010 version to less than 1.5 and less than 5.0 and have been maintained until the latest version (2016 edition). Therefore, the range of the target lead factor that satisfies both the notice and the revisions of the technical standard was determined to be between 1.5 and 3.0.

2.2 Necessary Lead Factor

In the previous section, the range of target lead factor was from 1.5 to 3.0. In the design stage, there is a difference between the lead factor value calculated by the system designer and the lead factor value determined by measuring the surveillance specimen after the power plant is operated. The causes of this difference include calculation method, change in core power distribution during operation, the various gaps between the inner wall of the reactor vessel and the SCA, and bias of measured values. In order to consider the effect of these causes, the margin of lead factor was determined as shown in Table 1 below.

Table I: Contributing causes to lead factor error.

Contributing causes to LF error	Error bound
Calculation method	0.12
Core power distribution	0.05
Gap between RV and SCA	0.19
Bias of measured values	0.04
Sum. of factors	0.40

Therefore, the final lead factor is 1.91, which is the value obtained by adding 0.4 of each margin to the target lead factor of 1.51. The final necessary lead factor of 1.91 is reasonable because it exists in the range of 1.5 to 3.0, which is the target lead factor.

3. Location of SCAs

3.1 Circumferential Installation angle of SCAs

The SCA is a structure attached to the inner wall of the reactor vessel. Based on the reactor vessel, the closer the SCA is to the core, the larger the neutron irradiation and the higher the lead factor. The SCA of large scale plant is located at 45° and 51° in the circumferential directions of reactor vessel in consideration of interference with the internal structure of the nuclear reactor and the fabrication of the supporting structure. At that location, the neutron transport calculation was performed for an appropriate radial position range using DORT, which is a two-dimensional angular segment transport code as shown in Fig. 1. In Fig. 1, as the distance between the center of the SCA and the cladding surface of the reactor vessel increases, the lead factor increases.

The SCA located at 45° and 51° in the circumferential direction of the reactor vessel must implement the minimum value of 1.91, which is the necessary lead factor. In Figure 1, at 45° in the circumferential direction, the distance between the surface of the reactor vessel cladding and the center of the SCA should be about 5.9 cm or more to secure the necessary lead factor. However, the lead factor of the SCA located at 51° is about 1.6, which cannot satisfy the necessary lead factor. Therefore, the clearance between the surface of the reactor vessel cladding and the center of the SCA was set to be about 7.4 cm or more, so that all the SCAs secures the necessary lead factor from a minimum of 1.91 to a maximum of 2.3.

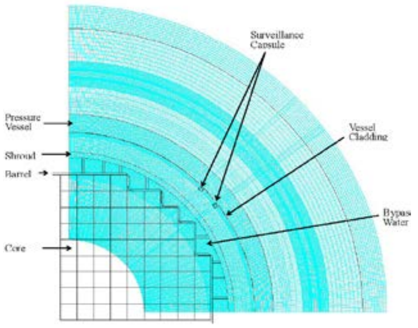

Fig. 1. Neutron transport calculation model.

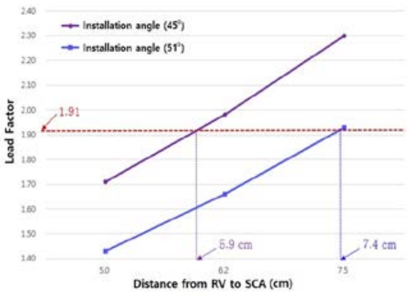

Fig. 2. Lead factors according to installation angle.

3.2 Interference Check

In order to improve the lead factor of the SCA, the location of the SCA was moved toward the nuclear fuel core compared to the previous one, and as a result, interference between the SCA and peripheral devices, the effect on the flow inside the reactor, and the shape change of the support structure of the SCA were evaluated. In consideration of the installation and withdrawal of the SCA, the interference between the reactor internals was evaluated. When considering the location of the SCA, both the circumferential and radial locations of the reactor vessel should be considered. In the radial position selected so that the SCA can secure the necessary lead factor, the circumferential position where interference with peripheral devices does not occur was confirmed. The location of SCA was evaluated for interference with the internal structure of the reactor when the SCA was installed and pulled out, and it was confirmed that no interference occurred.

Flow analysis was performed to evaluate the flow effect inside the reactor due to the change of the SCA location. The pressure drop between the inlet of reactor cold leg and the front end of core inlet, and the flow effect of the reactor core inlet were evaluated. And it was confirmed that even if the location of the SCA was changed to improve the lead factor, there was little effect on the pressure drop and the flow rate distribution at the core inlet.

4. Conclusions

In order to increase the utilization of large-scale nuclear power plant SCAs and to operate a stable surveillance program, the position of the SCA was positioned closer to the reactor core to increase the lead factor. As the SCA's lead factor increases, it is possible to reliably secure and utilize the material property change data of the nuclear reactor vessel due to neutron irradiation during the life time of the reactor vessel of large-scale nuclear power plants. And this improvement in the lead factor of large-scale nuclear power plants will not only increase the reliability of domestic operating plants but also contribute to strengthen the expert competitiveness of nuclear power plants in the future.

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