Current Issues and Challenges for Irradiation Embrittlement of RPVs in Korea

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PWRs in Korea have a spectrum in their RPV design and materials from a viewpoint of radiation embrittlement. Among a total of 19 operating PWR units, 5 units of Westinghouse type reactors have RPVs made of SA533-B1 plates except the first unit, Kori-1, which has an SA508-Gr.2 forged RPV welded circumferentially using a high copper Linde 80 flux SAW process. Other units are two C/E types, two units of Framatome type, and nine units of the Korean standard OPR-1000, where all units have similar RPV material specification of SA508-Gr.3 forging. As shown in Fig. 1, two units are more than 30 years old and seven units are more than 20 years old. Currently, all PWR units have been operated under a 40 year license after the first unit Kori-1 renewed its initial license period of 30 years with another 10 year continued operation license in 2007.

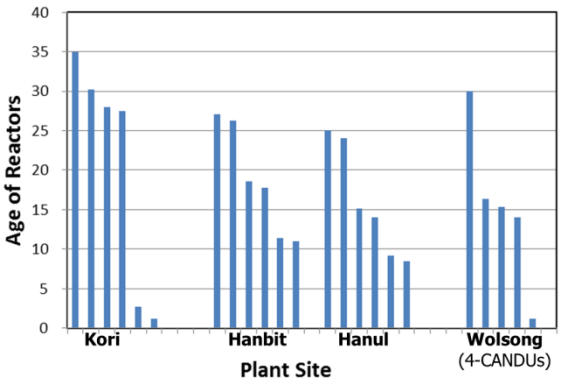

Fig. 1. Age of operating nuclear power plants in Korea

Until the end of 2012, 48 surveillance tests were carried out for 16 PWRs, where the fluence ranges are about 0.4 to 5.9 n/cm^2 (E>1 MeV). Fig. 2 summarizes the transition temperature shift data for RPV steels and welds where the measured values are compared to the values predicted by a chemistry model of RG-1.99 Rev.2. The chemistry model tends to under-predict the measured shifts for domestic materials while there are large scatter. The

10CFR50.61a model also gave similar trend but slightly better prediction. Those results emphasize an importance of surveillance tests even though the range of the shifts is not very large except one plant.

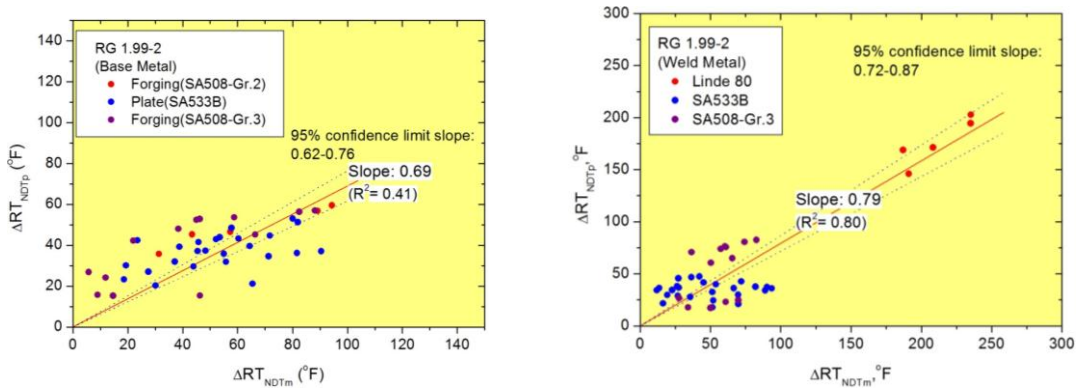

Fig. 2. Transition temperature shift data from surveillance tests compared with RG-1.99 Rev.2 model prediction

Based on the chemistry of RPV steels and welds, all operating PWRs have copper contents lower than 0.07 wt.% except the Kori-1 beltline circumferential weld which is a Linde 80 flux weld with high copper contents about 0.23 wt.%. The main issue of the Kori-1 was a radiation embrittlement of the beltline weld for the continued operation. The safety margins against the low upper shelf energy and high RT_{PTS} value were demonstrated by the state-of-the-art fracture mechanics technology such as J-R curve testing and master curve testing using reconstituted surveillance specimens.

After the incident at Fukushima in 2011, the safety of nuclear power plants has become a real concern to people in Korea. In particular, the aging issues of older reactors have been emphasized and the safety of embrittled RPV against PTS (pressurized thermal shock) has been questioned by several anti-nuclear groups. In principle, the challenges can only be overcome by a proactive development of advanced technology and database beyond the current codes and regulations.

The lead factor of OPR-1000 plants is small, and the surveillance program should therefore be modified to predict the state of embrittlement adequately for long-term operation. Several options are under consideration for different types of RPVs, which will hopefully improve the public acceptance of the nuclear industry in Korea. These options will probably be composed of a more efficient flux reduction program, ex-vessel dosimetry, supplemental surveillance capsules, and thermal annealing of the RPV beltline accompanied by irradiation/recovery/re-irradiation experiments using surrogate materials.