Analysis of the necessity for inserting new surveillance capsule into the Kori Unit 1 RPV to monitor material fracture toughness

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1. Introduction

In association with monitoring of reactor pressure vessel (RPV) fracture toughness, surveillance capsule test specimens have been used to monitor the material property of nuclear reactor vessel. As far as Kori Unit 1 is concerned, 6 capsules were put into the vessel before commercial operation of the plant. Up to now, all the six capsules have been withdrawn to test and monitor the fracture toughness of RPV material.

The last capsule has been withdrawn on June this year, and the Kori unit 1 has been shut downed since July 2007 and will be shut downed until December this year for about 6 months, preparing the life extension of the plant to operate the plant 10 more years. With the situation that all the surveillance capsules have been withdrawn, public ask the following question, " To extend the life of Kori Unit 1 more than 10 years, is it necessary to insert new surveillance capsules into the Kori Unit 1 to monitor RPV material fracture toughness?"

In connection with this issue, planning project have been carried out since spring this year.

In this paper, it is described that inserting new surveillance capsule into the Kori Unit 1 RPV has some meaning in some public acceptance point of view and is not necessary in material engineering point of view.

2. Material Engineering Point of View

2.1. Fracture Toughness Criteria of RPV

There are three kinds of fracture toughness criteria in RPV material. One is upper shelf energy (USE) criterion, another is pressurized thermal shock (PTS) criterion, and the third is pressure/temperature limit. The following explains each of the criteria briefly.

2.1.1 Fracture toughness, USE

ASME B&PV Sec. XI App. G[1] and Reg. Guide 1.99 suggest that the fracture toughness test data in connection with the upper shelf energy should maintain its value above 50 ft-lb in the Sharpy energy and temperature curve. If it is not satisfied, then detailed fracture mechanics analysis should be done to prove the integrity of the pressure vessel.

2.1.2. Pressurized Thermal Shock (PTS)

10CFR50.61[1] says that RT_{PTS}(reference temperature of PTS) should not exceed 270˚F(=132℃) for base metal and longitudinal direction weld, and RT_{PTS} should not exceed 300˚F(=149℃) for base metal and longitudinal direction weld. If it is not satisfied, then detailed PTS analysis should be done to prove the integrity of the pressure vessel

2.1.3 PT limit Curve and LTOP

RPV temperature and pressure must be maintained within certain values to keep the RPV material from sudden failure coming from losing fracture toughness.

ASME [2] and Reg. Guide 1.99 suggests P-T limit curve to maintain fracture toughness of the RPV material and this curve is modified by Low Temperature Overpressure Protection (LTOP) system characteristics.

2.2. Research Results

KEPRI has performed life extension study of the Kori Unit 1 for more than 10 years by reviewing many reference data such as final report for the 5th surveillance test of the reactor pressure vessel material(CAPSULE P) and integrity assessment report of Kori Unit 1 RPV for low upper shelf toughness. [3,4,5,6]. KEPRI also performed PTS analysis[105] The following summarizes each research result and comments on the necessity for inserting new surveillance capsule was made with the research results.

2.2.1. Neutron Fluence and Fracture toughness (USE) Analysis Result

Table 1. Neutron Fluence Analysis Result

Capsule	Lead Factor	Fluence (1019 n/cm2)	Withdrawn EFPY	EFPY at Vessel ID	EFPY at 1/4T	EFPY at 3/4T
V	3.15	0.5087	1.13 EFPY	3.56	5.30	11.73
T	1.74	1.115	4.29 EFPY	7.46	11.10	24.58
S	1.67	1.228	5.08 EFPY	8.48	12.62	27.94
R	3.19	2.988	6.88 EFPY	21.95	32.66	72.33
P	1.98	3.938	15.49 EFPY	30.67	45.64	101.06

Table 1 shows neutron fluence analysis results, showing that 40 years operation(30.67EFPY) equivalent at vessel inner diameter and 60 year operation equivalent at 1/4T, which suggests that enough fluence data have been collected for 10 more years of operation of Kori Unit 1.

According to the 4th surveillance capsule test data, it was considered that the RPV material can not maintain its value above 50 ft-lb in the Sharpy energy and temperature curve. And so therefore, detailed fracture mechanics analysis have been done to prove the integrity of the pressure vessel, by proving that all the following safety standards are satisfied.

$J_{applied} < J_{0.1}$

Where, $J_{applied}$ = applied fracture toughness during plant operation mode (heat-up / cool-down, 1.15 times of thermal load and pressure load)

$J_{0.1}$ = material fracture toughness (0.1 inch crack assumed)

$$(dJ_{applied}/da)\langle(dJ_{material}/da)$$

Kori Unit 1 detailed fracture toughness analysis was done by utilizing 4th surveillance data (the capsule R data) and this data indicated 40.2 ft-lbs when the neutron fluence was $2.988*10^{19}/cm^2$. 5th surveillance data (capsule N) indicated USE as 40.4 ft-lbs which is above the 4th and neutron fluence was $3.938*10^{19}/cm^2$ and this is equivalent 59 years of operation(45.64 EFPY) at 1/4T location. Therefore, this tells us that enough proof has been achieved for 10 more operation of the unit.

2.2.2. PTS Analysis Result

Surveillance capsule report suggested that it exceeds the PTS reference temperature. However, detailed PTS analysis has been done as the following table 2.

As shown in Table 2, Kori Unit 1 doesn't exceed the RG 1.154 failure frequency criteria of the $5*10^{-6}$/Rx-yr.

Table 2. Detailed PTS(Through wall Cracking Frequency) analysis results

Transient Category	TWC Freq.(/yr), at 40 yrs	TWC Freq.(/yr), at 60 yrs
Small MSLB at FP	$2.20x10^{-10}$	$2.25x10^{-9}$
Small MSLB at HZP	$1.22x10^{-9}$	$1.03x10^{-8}$
Large MSLB at FP	$7.21x10^{-9}$	$4.55x10^{-8}$
Large MSLB at HZP	$2.09x10^{-10}$	$1.21x10^{-9}$
SGTR at FP	$5.89x10^{-9}$	$5.67x10^{-8}$
SGTR at HZP	$3.41x10^{-7}$	$8.63x10^{-7}$
LOMFW	$1.38x10^{-8}$	$1.38x10^{-8}$
LOHS	$7.26x10^{-9}$	$2.53x10^{-8}$
SBLOCA at FP	$9.21x10^{-8}$	$5.60x10^{-7}$
Total	$4.70x10^{-7}$	$1.58x10^{-6}$

2.2.3 PT limit Curve and LTOP results

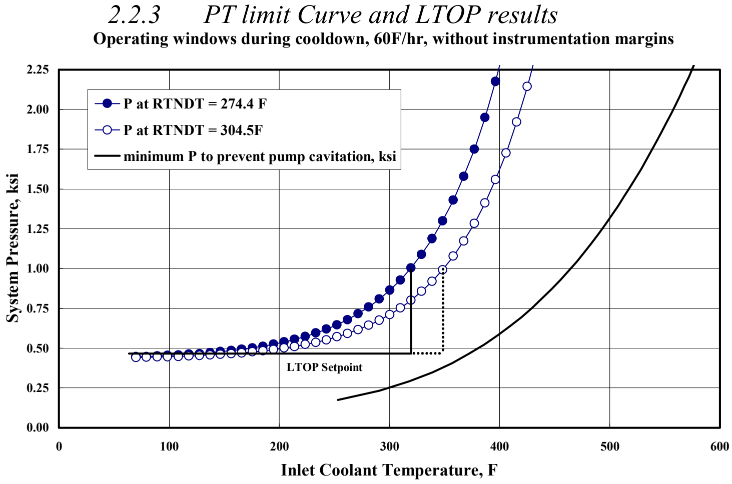

Figure 1. PT limit Curve and LTOP results

Figure 1 shows 24 EFPY and 46.4 EFPY Pressure-Temperature curves and LTOP set-point(RHRS valve set points) changes. As the plant operation year increases from 30 to 60 years, the operation window is reduced to some degree, however enough operability remains though. By adding some pressure relief system such as pressurizer pressure relief valve, LTOP set points can be modified to get some more operation window.

3. Public Acceptance Point of View

Although it has been proved that no need was found in inserting new surveillance capsule into Kori Unit 1 in the material engineering point of view, some necessity exists in regard of public acceptance point of view. Neutron fluence detectors are included in the surveillance capsule and this fluence detector will ensure neutron fluence and flux of the pressure vessel in the future. With adding new surveillance capsules people will be satisfied thinking that continuous neutron fluence monitoring is going to be continued in the future.

4. Conclusion

In this paper, it is described that inserting new surveillance capsule into the Kori Unit 1 RPV has some meaning in some public acceptance point of view and is not necessary in material engineering point of view by reviewing the following research results thoroughly.

- Neutron flux and fluence analysis result
- Upper shelf energy analysis result
- Detailed fracture toughness analysis result
- Detailed pressure thermal shock analysis result
- P-T curve result
- LTOP set-point result

All the research results show that 60 years of operation can be plausible in the material engineering point of view by valid RPV test data which is produced by the specimens which is considered to have equivalent neutron fluence of 60 years of operation of the Kori Unit 1.

REFERENCES

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