# The Change of the TS LCO on Reactor Coolant System Specific Activity

Min Kyung Kang, Yu Jong Lee*
*KEPCO E&C, 269, Hyeoksin-ro, Gimcheon-si, Gyeongsangbuk-do, Korea, 39660*
**Corresponding author: lyj6444@kepco-enc.com*

## 1. Introduction

The reactor coolant system(RCS) specific activity is defined as the Limiting Condition for Operation in Technical Specification(LCO). The purpose of the TS LCO on reactor coolant specific activity is to control the nuclide concentration less than the pre-determined specific activity in RCS during normal operation and to meet the dose criteria at exclusion area boundary(EAB) and low population zone(LPZ) in condition of design basis accidents.

The specific activity consists of dose equivalent I-131(DE I-131) concentration and gross specific activity. The reason why the concentration should be controlled by the two kinds of concentration is the concentration dominates thyroid dose from inhalation and whole body dose from immersion, respectively.

This paper introduces technical basis on change of gross specific activity into dose equivalent Xe-133(DE Xe-133) concentration.

## 2. Background

The dose criteria on design basis accidents are applied to thyroid dose and whole body dose. The doses at EAB and LPZ during design basis accident are calculated as follows;

$$D_{thy} = (x/Q) \cdot Q_{DEI-131} \cdot BR \cdot DCF_{thy,I\text{-}131} \quad (1)$$

$$D_{wb} = (x/Q) \cdot (Q_{DEI-131} \cdot DCF_{wb,I\text{-}131} + Q_{DEXe-133} \cdot DCF_{wb,Xe\text{-}133}) \quad (2)$$

where,
(x/Q) : atmospheric dispersion factor (sec/m$^3$),
Q : reactor coolant activity(DE I-131 and DE Xe-133) released during design basis accident (Bq),
BR : breathing rate (m$^3$/sec),
DCF : dose conversion factor for thyroid by I-131 (Sv/Bq), and for whole body by I-131 and Xe-133 (Sv-m$^3$/Bq-sec).

The thyroid dose is dominated by iodine and the representative nuclide of iodine is I-131. The whole body dose is dominated by gross beta and gross gamma specific activity. Therefore, in past, RCS specific activity was controlled by DE I-131 concentration and gross specific activity.

The gross specific activity is the total specific activity of all nuclides except iodine and tritium. The gross specific activity is determined by average energy($\bar{E}$) of nuclides in RCS which is average of summation of beta and gamma energy of nuclides weighted by nuclide concentration. The whole body dose is dominated by noble gases, not other nuclides, because the noble gases have high release from defected fuel and are not removed by engineered safety features.

When implement design basis accident analysis, $\bar{E}$ is determined using a design basis approach in which it is assumed that 1.0% of the fuel defects, $\bar{E}$ is dominated by Xe-133. The other nuclides have relatively small contributions. However, during normal operation there are typically only a small amount of fuel defects and the radioactive nuclide inventory can become dominated by corrosion and/or activation products. Therefore the $\bar{E}$ that is very different with that calculated using the design basis approach. The dose analyses become disconnected from plant operation and the LCO becomes essentially meaningless.

Recently, US Technical Specification Task Force (TSTF) had tried to change the LCO of RCS concentration from gross specific activity of 100/$\bar{E}$ (μCi/g) in which unit of energy is MeV into DE Xe-133 concentration of 280(μCi/g)[1]. The DE Xe-133 concentration was reflected in advanced light water reactors such as AP1000[2] and U.S.EPR[3], and in operating plants which revised license in US.

## 3. Determination of DE Xe-133

The DE Xe-133 is calculated as follow;

$$C_{DEXe\text{-}133} = \frac{1}{DCF_{wb,Xe-133}} \sum_{i=1}^{NG} (DCF_{wb,i} \cdot C_i) \quad (3)$$

where,
C : specific activity of noble gases in RCS.

In US advanced light water reactors, the DE Xe-133 concentration of 280(μCi/g) and 210(μCi/g) were defined as the LCO of RCS specific activity for AP1000 and U.S.EPR, respectively, based on 0.25% of fuel defects.

In APR1400 for application of NRC design certification[4], the DE Xe-133 concentration of

300(μCi/g), comparable to specific activity based on 0.5% of fuel defects, was defined as the LCO of RCS specific activity. The DE Xe-133 concentration based on 0.25% fuel defects is shown in Table I.

Table I: DE Xe-133 Concentration Based on 0.25% Fuel Defects for APR1400

| Nuclides | RCS Specific Activity (Bq/g) | DCF ($Sv\text{-}m^3$/ Bq-sec)[5] | DE Xe-133 Specific Activity (Bq/g) |
|---|---|---|---|
| Kr-85m | 1.04E+04 | 7.48E-15 | 4.99E+04 |
| Kr-85 | 4.44E+04 | 1.19E-16 | 3.39E+03 |
| Kr-87 | 8.14E+03 | 4.12E-14 | 2.15E+05 |
| Kr-88 | 2.26E+04 | 1.02E-13 | 1.48E+06 |
| Xe-131m | 4.44E+04 | 3.89E-16 | 1.11E+04 |
| Xe-133m | 2.70E+03 | 1.37E-15 | 2.37E+03 |
| Xe-133 | 2.89E+06 | 1.56E-15 | 2.89E+06 |
| Xe-135m | 5.92E+03 | 2.04E-14 | 7.74E+04 |
| Xe-135 | 5.92E+04 | 1.19E-14 | 4.52E+05 |
| Xe-138 | 5.18E+03 | 5.77E-14 | 1.92E+05 |
| Total DE Xe-133 Specific Activity (Bq/g) | | | 5.37E+06 (1.45E+02 μCi/g) |

In case of operating plants in Korea, even though the LCO of RCS specific activity has given as 100/$\bar{E}$, dose analyses have been performed by specific activities based on 1.0% of fuel defects. The regulatory body request to be consistent with each other. So the utility wants to change the LCO from gross specific activity of 100/$\bar{E}$ into DE Xe-133 specific activity. The operating plants have chances to change the LCO during various license revisions in purpose of safety enhancement, such as replacement of main steam safety valves, replacement of steam generators, and application of HIPER fuel, etc.

## 4. Application of DE Xe-133

In actual, sample of the gross specific activities measured from operating plants in Korea and the estimated LCO from the sample are shown in Table II.

As shown in Table II, the contribution of Na-24 to the gross specific activity is about 70~80%, and also to the $\bar{E}$ is about 80% because of high decay energy of that nuclide. The gross specific activities are 0.01~0.02% of the estimated LCO of gross specific activities.

The same values with APR1400, DE Xe-133 concentration of 300(μCi/g), are applied to the operating PWR type plants because of the similar design features with APR1400 and for facilitation in TS maintenance and operation between the plants.

Table II: Sample of the Gross Specific Activity

| Contents | Plant A | Plant B |
|---|---|---|
| Gross Specific Activity (Bq/g) | 234.6 | 68.4 |
| Xe-133 Activity (Bq/g) | 1.98 | 1.65 |
| Na-24 Activity (Bq/g) | 189.7 | 46.4 |
| Average Energy $\bar{E}$ (MeV) | 3.910 | 3.695 |
| Na-24 Energy (γ+β) (MeV) | 4.673 | |
| Estimated LCO of Gross Specific Activity based on 3.7E6/$\bar{E}$ Bq/g (Bq/g) | 9.5E5 (26 μCi/g) | 1.0E6 (27 μCi/g) |

The changes of contents in TS are shown in Table III. The change includes only replacement of $\bar{E}$ and gross specific activity into DE Xe-133 specific activity to minimize impacts on license revision.

Advantages from the change of the LCO on reactor coolant specific activity are as follows;

- The designer can use a unit value of DE Xe-133 independent of fuel defect or average $\bar{E}$.
- The utility need not to estimate $\bar{E}$ from activity of all nuclides, except iodine and tritium, but to only measure activity of noble gases.
- The utility can control specific activity with a unit value of LCO(300 μCi/g), even though the $\bar{E}$ should be changed every 6 months.
- The most is that consistency between LCO of RCS specific activity and dose analysis basis is established.

## REFERENCES

[1] "TSTF-490, Revision 0, Deletion of E Bar Definition and Revision to RCS Specific Activity Tech Spec," TSTF, September 13, 2005.
[2] "AP1000 Design Control Document, Tech Spec," Rev.18, Westinghouse, December 2, 2010.
[3] "U.S.EPR Design Control Document, Tech Spec," Rev.5, AREVA, July 19, 2013.
[4] "APR1400 Design Control Document, Tech Spec," Rev.0, KEPCO/KHNP, December 23, 2014.
[5] "External Exposure to Radionuclides in Air, Water, and Soil," Federal Guidance Report 12, EPA-402-R-93-081, US EPA, 1993.

Table III: Change of LCO of RCS Specific Activity in TS (Shin-Kori Units 1 & 2)

<table>
<tr><th>TS Section/Title</th><th>Current</th><th>Revised</th></tr>
<tr><td>1.1/ Definitions</td><td>Ē – AVERAGE DISINTEGRATION ENERGY<br><br>Ē shall be the average (weighted in proportion to the concentration of each radionuclide in the reactor coolant at the time of sampling) of the sum of the average beta and gamma energies per disintegration (in MeV) for isotopes, other than iodines, with half lives > [15] minutes, making up at least 95% of the total noniodine activity in the coolant.</td><td>DOSE EQUIVALENT XE-133<br><br>Dose Equivalent Xe-133 shall be that concentration of Xe-133 (μCi/g) that alone would produce the same acute dose to the whole body as the combined activities of noble gas nuclides Kr-85m, Kr-85, Kr-87, Kr-88, Xe-131m, Xe-133m, Xe-133, Xe-135m, Xe-135 and Xe-138 actually present. If a specific noble gas nuclide is not detected, it should be assumed to be present at the minimum detectable activity. The determination of DE Xe-133 shall be performed using effective dose conversion factors for air submersion listed in Table III.1 of EPA Federal Guidance Report No. 12, "External Exposure to Radionuclides in Air, Water, and Soil," EPA 402-R-93-081, September 1993.</td></tr>
<tr><td>3.4.15/ RCS Specific Activity</td><td>LCO 3.4.15<br>The specific activity of the reactor coolant shall be limited to:<br>1. DE I-131 specific activity ≤ 3.7E4 Bq/g (1.0 μCi/g) and<br>2. Gross specific activity ≤ 3.7E6/Ē Bq/g (100/ Ē μCi/g)</td><td>LCO 3.4.15<br>The specific activity of the reactor coolant shall be limited to:<br>1. DE I-131 specific activity ≤ 3.7E4 Bq/g (1.0 μCi/g) and<br>2. DE Xe-133 specific activity ≤ 1.11E7 Bq/g (300 μCi/g)</td></tr>
<tr><td rowspan="6">LCO 3.4.15 Action</td><td>Condition 1</td><td colspan="3">1. DE I-131 > 3.7E4 Bq/g</td></tr>
<tr><td>Required Action 1 [Completion Time]</td><td colspan="3">1.1 Verify DE I-131 ≤ 2.2E6 Bq/g [Once per 4 hours]<br>AND<br>1.2 Restore DE I-131 to within limit. [48 hours]</td></tr>
<tr><td>Condition 2</td><td colspan="3">2. Required Action and associated Completion Time of Condition 1 not met.<br>OR<br>DE I-131 > 2.2E6 Bq/g</td></tr>
<tr><td>Required Action 2 [Completion Time]</td><td colspan="3">2.1 Be in Mode 3 with Cold Leg Temp. 260°C (500°F) [6 hour]</td></tr>
<tr><td>Condition 3</td><td>Required Action</td><td>Completion Time</td><td>Condition 3</td><td>Required Action</td><td>Completion Time</td></tr>
<tr><td>3. Gross specific activity > 3.7E6/Ē Bq/g</td><td>3.1 Verify DE I-131 ≤ 3.7E4 Bq/g<br>AND<br>3.2 Be in Mode 3 with Cold Leg Temp. 260°C (500°F)</td><td>4 hours<br><br>6 hours</td><td>3. DE Xe-133 > 1.11E7 Bq/g</td><td>3.1 Verify DE I-131 ≤ 3.7E4 Bq/g<br>AND<br>3.2 Be in Mode 3 with Cold Leg Temp. 260°C (500°F)</td><td>4 hours<br><br>6 hours</td></tr>
</table>

* *Italic are revised portions.*