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# MCR Safety Dose Assessment in LOCA Condition of Westinghouse Type NPP

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## 1. INTRODUCTION

MCR(Main Control Room) habitability is important since operators remain in MCR even for accident conditions. The major criteria for MCR habitability is MCR dose. The MCR dose assessment is performed assuming LOCA(Loss Of Coolant Accident) which is the most limiting design basis accident and assumes the largest fission product release to the containment[1-4]. For MCR dose assessment, some input parameters are needed. They are onsite atmospheric dispersion factor, accumulated break flow from each break point, initial condition for LOCA and etc. In this paper, ARCON96, RADTRAD and SCALE6.1 are used as analysis tools.

In 2014, the Korea Hydro Nuclear Power Co.(KHNP) developed a methodology to assess MCR habitability. Papers on onsite atmospheric dispersion factor and ARCON96 were presented at previous KNS meetings [5-7].

In this work, onsite atmospheric dispersion factor, atmosphere stability, wind speed category, LOCA condition of MCR assessment and analysis assumptions are introduced for MCR habitability results in the view of safety dose assessment in LOCA.

In the NUREG 0737, the requirement of MCR habitability is the dose assessment of MCR in LOCA condition. This requirement is originated from TMI accident issue and the lesson. In 2003, the additional requirement is published by GL 2003-01. According to the documents, the additional requirement is the experimental data acquisition and the data check for the criteria of MCR habitability from MCR leakage test [1 -7].

## 2. METHODOLOGY

### *2.1. LOCA condition for MCR assessment*

According to FSAR, the source term of LOCA is introduced and the information is based on the calculation results using the ORIGEN or the SCALE 6.1. This result is used for the dose assessment. In LOCA, the total inventory of source term assumes 100% fuel failure by RG1.4 and RG 1.195.

The fission products behavior from the failed fuels is confined by each case of DBA (Design Basic Accidents). LOCA is the ultimate case to release the maximum fission products.

Because of that, LOCA is the limiting case for evaluating the MCR habitability.

The vaporized fission products escaped through the cladding crack from the failed fuels are moved to the RCS cold-leg break location and into the containment atmosphere. In containment atmosphere, the fission products experience various phenomena such as wall deposition, turbulent flow, spray droplet collision, Brown's mechanical behaviors. Some physical behaviors can remove the fission products.

According to RG 1.195, the fission products of the containment atmosphere are removed up to 50% by wall deposition. In addition, these fission products are removed up to 50% in RCS coolant water. Therefore 25% of the original fission product inventory will remain in the containment atmosphere. For noble gases, 100% of the inventories are released from RCS to containment atmosphere [8-10].

### *2.2. Release simulation of Onsite Fission Products*

Since NUREG 0737, onsite behavior of fission products is simulated by ARCON96 code. This code simulates ground diffusion, vent release and stack dispersion in the distance closer to containment or release source term.

Input for ARCON96 includes a direction, wind direction toward receptor of MCR, and an angular width.

They are specified in units of angular degrees. All parameters are effectively changed by the code to represent winds coming from direction.

Table 1. Input parameters for X/Q in ARCON96

| Input | Values |
|---|---|
| Basic parameters | Surface roughness length : 0.1m<br>Angular width : 360 degree<br>Threshold wind speed : 0.5m/sec<br>Sector-average width : 4 or 90 degree<br>σ-x, σ-z : 0, 0~1. 5<br>Averaged durations : 1 hour~ 720 hours |
| Meteorological Conditions | Wind Speed : 14 categories<br>Stability class : 7 categories (delta T/delta Z)<br>Detector tower : 10m and 58m |
| Source parameters | Release type, Release height : Ground, 0~10 m<br>Building area : 2100 $m^2$<br>Velocity, Stack radius : default |
| Receptor parameters | Distance to receptor : 28m ~ 32m<br>Intake height : 0~5m<br>Elevation difference : 0~1.8m<br>Direction to source : 180 degree or 90 degree |

Table 1 shows the necessary information for the input parameters for X/Q in ARCON 96.

All other non-calm winds are excluded from calculations for the sector. The default value for the angular width in ARCON96 is 90°. Distributions of the χ/Q values for each of several averaging periods ranging from 1 hour to 720 hours may be calculated for n sectors, each of width 360/n degrees( n: the number of sectors), where the position of each sector is defined by the direction of its centerline. Direction-independent values of χ/Q (including winds from all directions) may be calculated by setting as180 and changing the value of the window 0 to 360. This feature is not described in the code manual but was determined by analysis to satisfy the requirements of RG 1.145, position 3.

ARCON96 does not use the plum rise, so a ground level release is the significant dispersion model. This approach is more conservative than any other similar to plum rise model [3-7].

### *2.3. Dose Conversion Factors and Atmospheric Stability*

For checking the effect of DCF (Dose Conversion Factors), FGR11/12 and FGR13/ICRP72 are used. Both of DCFs are compared each other. Generally FGR 13/ICRP 72 DCFs is conservative. Because of that, the safety margin is reviewed by the comparison between FGR11/12 and FGR13/ICRP72.

Atmospheric stability class is used to describe the behavior of air stream of meteorological condition.

This has 7 classes: A, B, C, D, E, F, G.

A : Extremely unstable
B : Moderately unstable
C : Slightly unstable
D : Neutral
E : Slightly stable
F : Moderately stable
G: Extremely stable

Here, A class has a very strong air-mobility, otherwise G class has a very low air-mobility. The categories of A ~ C translate to low value of atmospheric dispersion factors. The categories of E ~ G translate to high value of atmospheric dispersion factors.

A high atmospheric dispersion factor means low mobility in air strong radiation dose to humans. A low atmospheric dispersion factor means low radiation dose [11-13].

### *2.4. Basic Parameters for LOCA*

For LOCA, the basic parameters are selected. Table2 shows the basic information including a fission products type, a chemical and physical state and distribution, release rate and mixing rate in containment.
Containment release rate (or leakage rate) is conservatively is selected from the maximum value of Technical Specification in NPP such as Table2.

Table 2. Basic parameters for LOCA

| Input | Values |
|---|---|
| Release to Containment | Nobel gas : 100%<br>Iodine : 50% |
| Type of Iodine | Elemental : 91%<br>Particulate : 5%<br>Organic:4% |
| Release Rate | 0-24hours : 0.1%/day<br>24hours~720hours : 0.05%/day |
| Mixing rate | Two turnovers of CV volume per 2hours |

## 3. RESULTS AND DISCUSSIONS

### *3.1. Onsite Dispersion Factors and Atmospheric Stability Distributions*

Table 3 and Table 4 show on-site dispersion factors based on meteorological data collected over two year duration(Case 1) and four year duration(Case 2) respectively. Case 1 is more conservative than Case2 in the duration time of 0~8 hours.

From Case1 and Case 2, MCR dose can be calculated. From these two cases, Case 1 is more conservative than Case 2. Generally speaking, the release fraction of fission products is very strong in the beginning of accidents such as duration time of 0~2 hours. The initial release is heavily weighted in dose assessment.

Table5 shows the atmospheric stability distributions between Case 1 and Case 2.

From Table5, we know that Case2 is more unstable than Case 1. This means that Case2 is very efficient in air mobility.

Table 3. On-site dispersion factors (Case 1)

| χ/Q (sec/m$^3$) | | | |
|---|---|---|---|
| Meteorological duration : 2012~ 2013 | | | |
| Time(h) | MCR-Center | MCR-Left | MCR-Right |
| 0～2 | 4.08E-03 | 2.22E-03 | 2.22E-03 |
| 2～8 | 2.59E-03 | 1.44E-03 | 1.44E-03 |
| 8～24 | 8.96E-04 | 5.46E-04 | 5.46E-04 |
| 24～96 | 9.55E-04 | 5.44E-04 | 5.44E-04 |
| 96～720 | 6.54E-04 | 3.67E-04 | 3.67E-04 |

Table 4. On-site dispersion factors (Case 2)

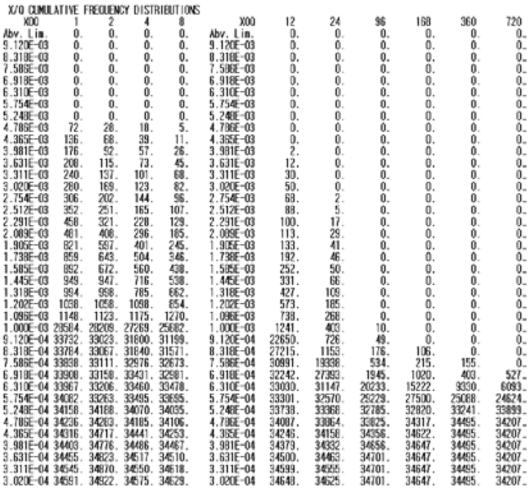
| χ/Q (sec/m$^3$) | | | |
|---|---|---|---|
| Meteorological duration : 2013 ~ 2016 | | | |
| Time(h) | MCR-Center | MCR-Left | MCR-Right |
| 0～2 | 1.58E-03 | 1.44E-03 | 1.44E-03 |
| 2～8 | 1.58E-03 | 1.44E-03 | 1.44E-03 |
| 8～24 | 7.11E-04 | 8.14E-04 | 8.14E-04 |
| 24～96 | 6.50E-04 | 5.44E-04 | 5.44E-04 |
| 96～720 | 5.01E-04 | 4.71E-04 | 4.71E-04 |

Table 5. Atmosphere stability distribution in each case

| Stability | Case 1 | Case 2 |
|---|---|---|
| A | 7.2 % | 10.1% |
| B | 10.5% | 11.2% |
| C | 15.7% | 15.9% |
| D | 33% | 32% |
| E | 18.5% | 17.2% |
| F | 8.8% | 8.1% |
| G | 6.3% | 5.5% |

*3.2. Results of Meteorological Data Preparations*

Fig.1 shows the distributions of each dispersion factor frequency which is consist of the sorted onsite atmospheric dispersion factors, time duration and joint frequency.


X/Q CUMULATIVE FREQUENCY DISTRIBUTIONS

| XOQ | 1 | 2 | 4 | 8 |
|---|---|---|---|---|
| Abv. Lim. | 0. | 0. | 0. | 0. |
| 9.120E-03 | 0. | 0. | 0. | 0. |
| 8.318E-03 | 0. | 0. | 0. | 0. |
| 7.586E-03 | 0. | 0. | 0. | 0. |
| 6.918E-03 | 0. | 0. | 0. | 0. |
| 6.310E-03 | 0. | 0. | 0. | 0. |
| 5.754E-03 | 0. | 0. | 0. | 0. |
| 5.248E-03 | 0. | 0. | 0. | 0. |
| 4.786E-03 | 72. | 28. | 18. | 5. |
| 4.365E-03 | 136. | 68. | 39. | 11. |
| 3.981E-03 | 176. | 92. | 57. | 26. |
| 3.631E-03 | 208. | 115. | 73. | 45. |
| 3.311E-03 | 240. | 137. | 101. | 68. |
| 3.020E-03 | 280. | 169. | 123. | 82. |
| 2.754E-03 | 306. | 202. | 144. | 96. |
| 2.512E-03 | 352. | 251. | 165. | 107. |
| 2.291E-03 | 458. | 321. | 228. | 129. |
| 2.089E-03 | 481. | 408. | 296. | 185. |
| 1.905E-03 | 821. | 597. | 401. | 245. |
| 1.738E-03 | 859. | 643. | 504. | 346. |
| 1.585E-03 | 892. | 672. | 560. | 438. |
| 1.445E-03 | 949. | 947. | 716. | 538. |
| 1.318E-03 | 994. | 998. | 785. | 662. |
| 1.202E-03 | 1038. | 1058. | 1098. | 854. |
| 1.096E-03 | 1148. | 1123. | 1175. | 1270. |
| 1.000E-03 | 28584. | 28209. | 27269. | 25682. |
| 9.120E-04 | 33732. | 33023. | 31800. | 31199. |
| 8.318E-04 | 33784. | 33067. | 31840. | 31571. |
| 7.586E-04 | 33838. | 33111. | 32976. | 32673. |
| 6.918E-04 | 33908. | 33158. | 33431. | 32981. |
| 6.310E-04 | 33967. | 33206. | 33460. | 33478. |
| 5.754E-04 | 34082. | 33263. | 33495. | 33695. |
| 5.248E-04 | 34158. | 34188. | 34070. | 34035. |
| 4.786E-04 | 34236. | 34283. | 34185. | 34106. |
| 4.365E-04 | 34316. | 34717. | 34441. | 34253. |
| 3.981E-04 | 34403. | 34776. | 34486. | 34467. |
| 3.631E-04 | 34455. | 34823. | 34517. | 34510. |
| 3.311E-04 | 34545. | 34870. | 34550. | 34618. |
| 3.020E-04 | 34591. | 34922. | 34575. | 34629. |

| XOQ | 12 | 24 | 96 | 168 | 360 | 720 |
|---|---|---|---|---|---|---|
| Abv. Lim. | 0. | 0. | 0. | 0. | 0. | 0. |
| 9.120E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 8.318E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 7.586E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 6.918E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 6.310E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 5.754E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 5.248E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 4.786E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 4.365E-03 | 0. | 0. | 0. | 0. | 0. | 0. |
| 3.981E-03 | 2. | 0. | 0. | 0. | 0. | 0. |
| 3.631E-03 | 12. | 0. | 0. | 0. | 0. | 0. |
| 3.311E-03 | 30. | 0. | 0. | 0. | 0. | 0. |
| 3.020E-03 | 50. | 0. | 0. | 0. | 0. | 0. |
| 2.754E-03 | 68. | 2. | 0. | 0. | 0. | 0. |
| 2.512E-03 | 88. | 5. | 0. | 0. | 0. | 0. |
| 2.291E-03 | 100. | 17. | 0. | 0. | 0. | 0. |
| 2.089E-03 | 113. | 29. | 0. | 0. | 0. | 0. |
| 1.905E-03 | 133. | 41. | 0. | 0. | 0. | 0. |
| 1.738E-03 | 192. | 46. | 0. | 0. | 0. | 0. |
| 1.585E-03 | 252. | 50. | 0. | 0. | 0. | 0. |
| 1.445E-03 | 331. | 66. | 0. | 0. | 0. | 0. |
| 1.318E-03 | 427. | 109. | 0. | 0. | 0. | 0. |
| 1.202E-03 | 573. | 185. | 0. | 0. | 0. | 0. |
| 1.096E-03 | 738. | 268. | 0. | 0. | 0. | 0. |
| 1.000E-03 | 1241. | 403. | 10. | 0. | 0. | 0. |
| 9.120E-04 | 22650. | 726. | 49. | 0. | 0. | 0. |
| 8.318E-04 | 27215. | 1153. | 176. | 106. | 0. | 0. |
| 7.586E-04 | 30991. | 19338. | 534. | 215. | 155. | 0. |
| 6.918E-04 | 32242. | 27393. | 1945. | 1020. | 403. | 527. |
| 6.310E-04 | 33030. | 31147. | 20233. | 15222. | 9330. | 6093. |
| 5.754E-04 | 33301. | 32570. | 29229. | 27500. | 25088. | 24624. |
| 5.248E-04 | 33738. | 33368. | 32785. | 32820. | 33241. | 33899. |
| 4.786E-04 | 34087. | 33864. | 33825. | 34317. | 34495. | 34207. |
| 4.365E-04 | 34246. | 34158. | 34356. | 34622. | 34495. | 34207. |
| 3.981E-04 | 34379. | 34332. | 34656. | 34647. | 34495. | 34207. |
| 3.631E-04 | 34500. | 34463. | 34701. | 34647. | 34495. | 34207. |
| 3.311E-04 | 34599. | 34555. | 34701. | 34647. | 34495. | 34207. |
| 3.020E-04 | 34648. | 34625. | 34701. | 34647. | 34495. | 34207. |

Fig. 1 X/Q distributions in each time durations

*3.3. Dose Assessments*

Table 6 and Table 7 are results from dose calculations. Here, Table 6 is based on Regulatory Guide 1.4 and Regulatory Guide 1.195. Table 7 is based on Regulatory Guide 1.195 only and the comparison results between FGR11/12 and FGR13/ICRP72.

In these results, Case 1 is more conservative than Case 2 in the case of the atmospheric dispersion factors and the unstable frequency of atmosphere stability.

The reason why Case 1 is more conservative can be inferred from the results of Table 3, Table 4 and Table 5.

From Table 3, Table 4 and Table 5, comparing Case 1 with Case 2, X/Q and atmospheric stable frequency of Case 1 is more convenient than Case 2.

In addition, the dose conversion factor is more conservative in FGR13/ICRP72 comparing with FGR11/12.

Specially, the difference between “whole” and “FGR/ICRP72” from Table 6 and Table 7 is the reason based on “whole body gamma”, “TEDE” and dose conversion factors.

Table 6. Results of whole and thyroid

| | Case 1 | | Case 2 | |
|---|---|---|---|---|
| | Whole | Thyroid | Whole | Thyroid |
| Dose (mSv) | 4.43E+00 | 4.30E+02 | 3.37E+00 | 3.27E+02 |
| Criteria (mSv) | 5.0E+01 | 5.0E+02 | 5.0E+01 | 5.0E+02 |

Table 7. Results of FGR11/12 and FGR13/ICRP72

| | Case 1 | | Case 2 | |
|---|---|---|---|---|
| | FGR11/12 | FGR13 /ICRP72 | FGR11/12 | FGR13 /ICRP72 |
| Dose (mSv) | 11.68 | 12.77 | 9.71 | 16.28 |
| Criteria (mSv) | 50 | | | |

## 4. CONCLUSIONS

MCR dose assessment is carried out by calculations of onsite dispersion factor, LOCA fission products release analysis and dose conversion factors. From this study, we find some conclusions as below:

a. X/Q value at the early part of the accident has significant effect on MCR dose results
b. Atmospheric stability is important factor that affects the X/Q.
c. Categories (E~G) of atmosphere stability are the key factor in the case of X/Q value increase.
d. FGR13/ICRP72 is more conservative than FGR11/12.

From these conclusions we can find what major elements of MCR dose in LOCA could be considered to increase the safety margin.

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