Assessment of Fission Product Release Following Stagnation Feeder Break in CANDU 6

Jong Yeob Jung and Joo Hwan Park
Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, 305-353, Korea
**Corresponding author: agahee@kaeri.re.kr*

1. Introduction

The objective of the fuel analysis is to estimate the quantity and timing of a fission product release from the fuels when a postulated single channel accident occurs in CANDU 6 reactors. Fission product release calculations consist of three parts, (i) the fission product inventory in the channel is estimated using the fuel performance evaluation code, (ii) based on the fuel temperatures following the accident, the fractional release of the different chemical species is estimated, and (iii) the release of different isotopes in the channel is determined by multiplying the fractional releases by the inventories.

In this study, a calculation of fission product releases following a stagnation feeder break accident was carried out and the results were compared to the case of Wolsong 2/3/4.

Feeder break is a single channel accident when the other channels remain intact in the CANDU core. For some ranges of a feeder break size, a flow in the channel can be stagnated due to a force balance between the upstream side and the downstream end. In the extreme, this can lead to a rapid fuel heat up and fuel damage, and the failure of a fuel channel. In this case, radionuclide can be released directly to the containment through the feeder break and to the moderator through the failed channel. This break scenario is called a stagnation feeder break.

A stagnation feeder break can be postulated to occur in any of 380 channels in the reactor at any time during the reactor's operating life. Because of this, a stagnation feeder break is assumed to occur in the high-powered 'limiting' channel for the conservative safety assessment. This limiting channel has a channel power of 7.3 MW and the two central bundles at 935 kW. Here, 7.3 MW and 935 kW are the LCO (Limiting Condition for Operation) power values for a fuel channel and a fuel bundle, respectively.

2. Calculation Methodology of Transient Release

The fission product inventory and distribution within the fuel during normal operation is calculated by using the ELESTRES code [1, 2]. The factors affecting the fission product inventory are the fuel power and burn up at the time of the accident. The fission products are created initially within the UO_2 matrix. They can migrate by thermal or irradiation diffusion processes. This redistributes the fission gases within the grains of the fuel pellet. Some of the fission gas atoms migrate to the grain boundaries. The fission products at the grain boundaries can also migrate out of the fuel pellet to the gaps between the UO_2 fuel pellets and the sheath, as well as to the cracks within the fuel pellets.

For calculation of fission product release during stagnation feeder break, it is assumed that all fuel sheaths in the channel are failed and the entire gap inventory is released instantaneously at the beginning of the accident. The additional release from in-grain bound inventory is estimated. The calculation of the transient fission product release from the fuel grains and grain boundary following feeder stagnation break is performed by applying the Gehl's release model [3]. Gehl's model correlates the percentage of fission gas release (Z_c) with the fuel centerline temperature ($T_{c/l}$) in K and the time-averaged centerline heating rate ($dT_{c/l}/dt$) in K/s as follows:

$$Z_c = 7.58 \times 10^{-19} T_{c/l}^{5.7} \left(\frac{dT_{c/l}}{dt} \right)^{-0.346}$$

Additional releases are superimposed on the transient release predicted using Gehl's model, to account for Zircaloy/UO_2 interaction and UO_2 oxidation. These releases are temperature dependent and calculated as a percentage release of fission products located within the grains of fuel and the grain boundary. They are based on estimates of the amount of UO_2 which can theoretically be dissolved by Zircaloy. The additional release fractions are added to the releases predicted by Gehl's model. Fuel rewet following the channel failure or injection of emergency core coolant can result in fuel pellet cracking and powdering due to induced thermal stresses. Therefore, the remaining fission gas which is stored on the grain boundaries is assumed to be released at the time of channel failure.

3. Results of Transient Fission Product Release

The channel is predicted to fail at 11.1 seconds based on the thermal hydraulic evaluation by CATHENA [4] code following the stagnation feeder break. To ensure that the releases are not under predicted, the transient releases were calculated based on fuel heat-up of 13.1 seconds. For these two additional seconds, the fuel cooling effect of the increased coolant flow through the ruptured channel is not taken into consideration.

Transient releases for each individual isotope considered to be a dose contributor are provided in Fig. 1 to Fig. 3. Fig. 1 shows the transient releases of Iodine and the total release of Iodine is 26,542 TBq. Fig. 2 shows the transient releases of Krypton and the total release of Krypton is 10,593 TBq. Fig. 3 shows the transient releases of Xenon and the total release of Xenon is 18,194 TBq. Total transient releases for all of Iodine, Krypton and Xenon are shown in Fig. 4. As shown in this figure, the remaining grain boundary inventories are released at the time of channel failure of 11.1 second. The total channel release at 13.1 seconds after the accident is calculated to be 55,329 TBq which is approximately 37% of the total inventory at the time of the stagnation feeder break accident. This amount of fission product release after stagnation feeder break is about 15 % smaller than the case of Wolsong 2/3/4 [5].

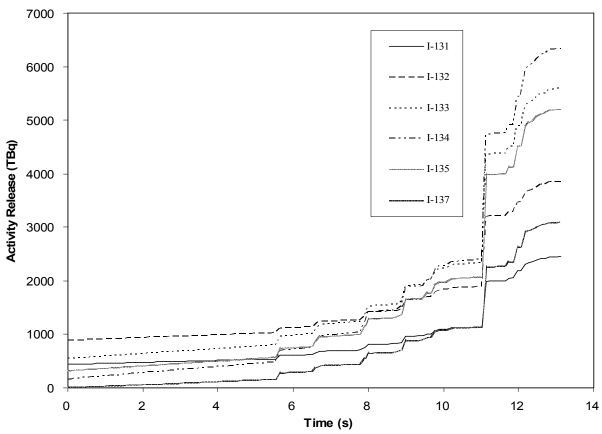

Fig. 1 Iodine releases following stagnation feeder break.

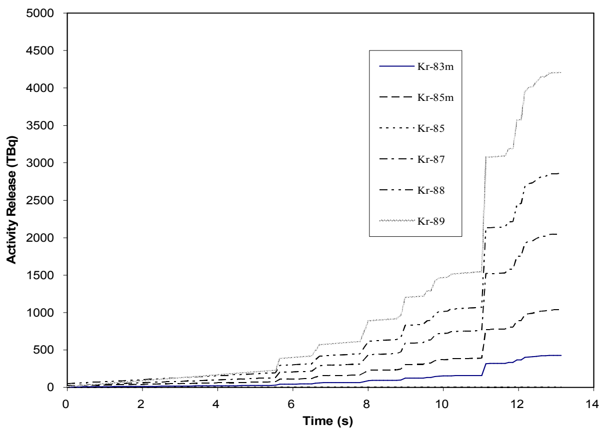

Fig. 2 Krypton releases following stagnation feeder break.

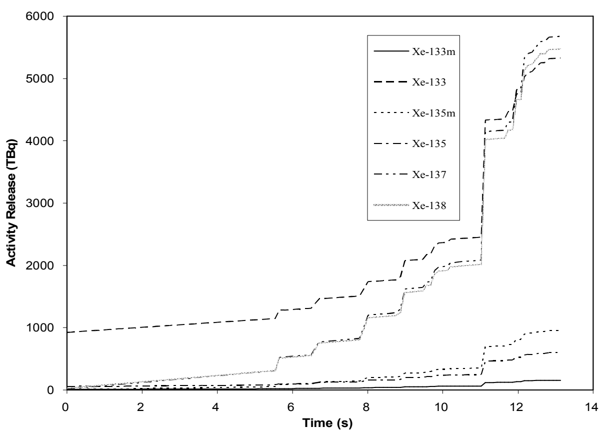

Fig. 3 Xenon releases following stagnation feeder break.

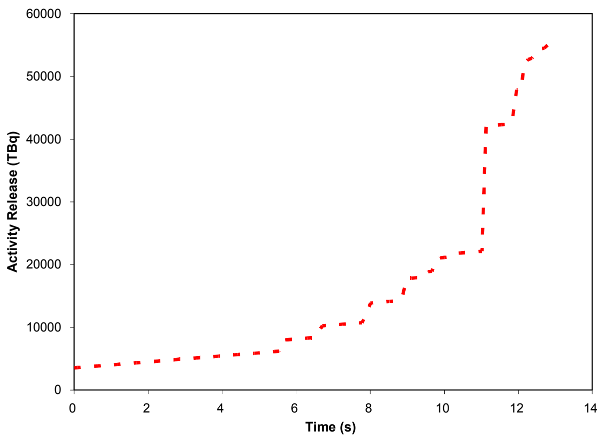

Fig. 4 Total transient releases for all of Iodine, Krypton, and Xenon following stagnation feeder break.

4. Conclusions

The fission product inventories under normal operating condition were calculated by using ELESTRES code. The fission product releases following the stagnation feeder break accident were evaluated by using Gehl's model based on the fission product inventory and thermal hydraulic data from CATHENA code. Fission product releases of Iodine, Krypton, and Xenon which are used as a dose contributor in the following dose calculation were evaluated. The total amount of fission product release of these isotopes after stagnation feeder break was found out to be smaller about 15 % than the case of Wolsong 2/3/4.

REFERENCES

[1] G.G. Chassie, "User's Manual, ELESTRES-IST " 153-113370-UM-001, AECL, October 2006.

[2] G.G. Chassie, "Theory Manual, ELESTRES-IST " 153-113370-STM-001, AECL, November 2006.

[3] S.M. Gehl, The Release of Fission Gas during Transient Heating of LWR Fuel, ANL-80-108, Report from Argonne National Lab. March 1981.

[4] S. Lam, "CATHENA Fuel Channel Model", 86-03500-AR-009 Revision 0, May 1992.

[5] Final Safety Analysis Report, Wolsong 2/3/4, KEPCO, 1996.