Proceeding of the Korean Nuclear Society Spring Meeting
Kwangju, Korea, May 1997

FISSION PRODUCT RELEASE ASSESSMENT FOR A LARGE BREAK LOCA IN CANDU REACTOR LOADED WITH CANFLEX-NU FUEL BUNDLES

Dirk Joo Oh, Myeong Yong Ohn*, Kang Moon Lee** and Ho Chun Suk
Korea Atomic Energy Research Institute

ABSTRACT

Fission product release (FPR) assessment for 100% reactor outlet header (ROH) break in CANDU reactor loaded with CANFLEX-NU fuel bundles has been performed. The predicted results are compared with those for the reactor loaded with standard 37-element bundles.

The fuel failure thresholds for the CANFLEX and standard bundle elements are very similar. All the sheaths at the corresponding fuel failure thresholds for the CANFLEX and standard bundles fail due to the significant cracks in the surface oxide, except those for the CANFLEX inner element at burnups of 220 to 240 MW.h/kg(U), which fail due to the excessive diametral strain.

The fuel failure analysis predicts that the number of failed fuel elements for the CANFLEX bundle case is none, while that for the standard bundle case is 1827. The total (gap plus bound) I-131 releases for the CANFLEX and standard bundles are none and 5889 TBq, respectively. The significant reduction of the number of failed fuel elements and FPR for the CANFLEX fuel bundle is attributed to the lower linear power of the CANFLEX fuel bundle compared with the standard fuel bundle.

1. INTRODUCTION

Currently, the Korea Atomic Energy Research Institute (KAERI) and Atomic Energy of Canada Limited (AECL) are jointly developing an advanced Canada deuterium uranium (CANDU) fuel, called CANDU Flexible Fuelling (CANFLEX). The CANFLEX 43-element bundle design has two major design improvements over the standard CANDU-6 37-element bundle while maintaining compatibility with the existing CANDU reactor fuel-handling systems and all other fuel performance characteristics. First, the CANFLEX bundle contains 43 elements of two different diameters, thereby reducing peak linear element power by 20% (i.e., < 50 kW/m). The lower linear element power not only enables a 200% increase in average discharge burnup (i.e., 21000 MWD/MTU) with the use of slightly enriched uranium compared with the standard natural uranium bundle but also improves the safety margins of CANDU reactors. Second, the CANFLEX bundle has the attachment of critical heat flux enhancement pads called buttons. The buttons increase critical channel power by about 5%, which leads to the improvement of the operating margins for CANDU reactors.

This paper describes FPR assessment results for a large break LOCA in CANDU reactor loaded with CANFLEX-NU (Natural Uranium) fuel bundles compared with those of the reactor loaded with the standard bundles. The 100% ROH break is chosen for the

* Present Address: Korea Power Engineering Company
** Present Address: Korea Nuclear Fuel Company

analysis because it is the most limiting from the point of view of FPR (Reference 1).

2. ANALYSIS METHODOLOGY

The methodology to determine fission product releases for a postulated large LOCA is detailed in Reference 1. The methodology is briefly described in this section.

FPR estimate is obtained by determining which fuel elements are expected to fail following the accident and their times of failure. The inventories of FPR following the accident are estimated to be equal to the gap inventories of the failed fuel elements plus 1% of the grain-bound inventories of the failed fuel elements in the critical core pass. The latter inventories are added to the former to account for the possibility of additional releases of fission products from the fuel matrix due to diffusion, oxidation, Zircaloy-UO_2 interaction and UO_2 cracking.

The analysis is composed of four parts: (i) estimate of fission product inventories and distribution in the fuel elements in the reactor core at the time of the accident; (ii) estimate of fuel element failure thresholds of linear power at various burnups; (iii) estimate of the number of fuel elements expected to fail and their times of failure, and; (iv) estimate of the transient FPR from failed fuel elements.

ELESTRES (Reference 2) simulations using the ANS 5.4 gas release model (Reference 3) generate a list of the total and gap inventories for the complete operating ranges of fuel element linear power between 5 kW/m and 61 kW/m, and burnup between 10 MW.h/kg(U) and 240 MW.h/kg(U).

The fuel failure thresholds are defined as follows: for a given burnup, the fuel failure threshold is the maximum linear power (in kW/m) which would results in a prediction of fuel element not failing following a large LOCA. The fuel failure thresholds are determined for fuel element burnups ranging from 10 MW.h/kg(U) to 240 MW.h/kg(U) using the ELESTRES and ELOCA.MK5 (References 4 and 5) computer codes.

Simple and conservative criteria are used to determine whether a fuel element fails or not, based on the predictions of the ELOCA.MK5 code. These criteria are based on experimental data and experience with operating reactors. The criteria used here are listed below.

The fuel sheath is considered to remain intact if the following are satisfied:

1. No fuel centerline melting (Reference 6). A fuel element will be assumed to fail if centerline melting (2840 °C) is reached, due to volume expansion causing excessive sheath strain.
2. No excessive diametral strain. The uniform sheath strain shall remain less than 5 percent for sheath temperatures lower than 1000 °C (References 7 and 8).
3. No significant cracks in the surface oxide. The uniform sheath strain shall remain less than 2 percent for sheath temperatures higher than 1000 °C (Reference 9).
4. No oxygen embrittlement. Oxygen concentration shall remain less than 0.7 weight percent over half the sheath thickness (Reference 10).
5. No sheath failure by beryllium-braze penetration at bearing pad and spacer pad locations (Reference 11).

The number of fuel elements expected to fail is estimated by adding the number of fuel elements in each power/burnup group where the power is equal to or greater than the fuel failure threshold at that burnup.

For each power/burnup group considered as failed, the timing of fuel failure is estimated, based on the corresponding ELOCA.MK5 predictions.

3. ANALYSIS RESULTS

Figure 1 shows the fuel failure thresholds. The fuel failure thresholds for the CANFLEX and standard bundle elements are very similar because both bundles have the same fuel material (natural UO_2) and the nearly same sheath radius to thickness ratio, and undergo the nearly same hydraulic transients following the accident (i.e., the nearly same coolant pressure and sheath-to-coolant heat transfer coefficient transients). All the sheaths at the corresponding failure thresholds for the CANFLEX and standard bundles fail by criterion 3 in Section 2, except those for the CANFLEX inner elements at burnups of 220 to 240 MW.h/kg(U), which fail by criterion 4. The limiting power envelope for the CANFLEX bundle elements is lower than by about 10 kW/m than that for the standard bundle elements and the limiting power at each burnup for the CANFLEX bundle elements are always lower than the corresponding fuel failure threshold, as shown in Figure 6. Therefore, it is expected that almost no fuel failure will be observed for the CANFLEX bundle elements. Indeed, the fuel failure analysis predicts that the number of failed fuel elements for the CANFLEX bundle case is none, while that for the standard bundle case is 1827. The failed fuel elements for the standard bundle case belong to the outer ring of the high power bundles 4 to 9. The total (gap plus bound) I-131 releases for the CANFLEX and standard bundles are none and 5889 TBq, respectively. The significant reduction of the number of failed fuel elements and FPR for the CANFLEX fuel bundle is attributed to the lower linear power of the CANFLEX fuel bundle, compared with the standard fuel bundle.

4. SUMMARY & CONCLUSIONS

FPR assessment for 100% ROH break in CANDU reactor loaded with CANFLEX-NU fuel bundles has been performed. The predicted results are compared with those for the reactor loaded with standard 37-element bundles.

The fuel failure thresholds for the CANFLEX and standard bundle elements are very similar. All the sheaths at the corresponding fuel failure thresholds for the CANFLEX and standard bundles fail due to the significant cracks in the surface oxide, except those for the CANFLEX inner element at burnups of 220 to 240 MW.h/kg(U), which fail due to the excessive diametral strain.

The fuel failure analysis predicts that the number of failed fuel elements for the CANFLEX bundle case is none, while that for the standard bundle case is 1827. The total (gap plus bound) I-131 releases for the CANFLEX and standard bundles are none and 5889 TBq, respectively. The significant reduction of the number of failed fuel elements and FPR for the CANFLEX fuel bundle is attributed to the lower linear power of the CANFLEX fuel bundle compared with the standard fuel bundle.

The predicted results show that the CANFLEX-NU fuel bundle would enhance the safety margin for radionuclide release in CANDU-6 reactor, compared with the standard

37-element bundle.

5. REFERENCES

1. S. Lam et. al., "Large Loss of Coolant Accident", 86-03500-AR-029 Rev. 1, August 1994.
2. M. Tayal, "Modelling CANDU Fuel under Normal Operating Conditions: ELESTRES Code Description", AECL-9331, 1987, "Users' Manual for the M11C Version of the ELESTRES Code" TTR-234A, February 1989.
3. American National Standard Method for Calculating the Fractional Release of Volatile Fission Products from Oxide Fuel, ANSI/ANS-5.4-1982.
4. J.D. de Vaal, J.R. Walker, C. Wong and T.G. McGrady, "ELOCA.MK5: Users Manual", AECL Research Report COG-92-001B/RC-666, 1992.
5. J.R. Walker, J.D. de Vaal, V.I. Arimescu, T.G. McGrady, D.C.K. Wang and C. Wong, "ELOCA.MK5: Theory Manual", AECL Research Report COG-92-001C/RC-667, 1992.
6. M. Tayal, E. Kohn et al, "Dryout Fuel Behaviour in Loss of Regulation Accident Conditions of a CANDU 600 MW(e) Reactor", AECL Report TTR-61, September 1983.
7. AECL (M.R. Matthias) Submission to AECB (J.P. Marchildon, B.M. Ewing) with Attachment by E. Kohn, "Use of 5 Percent Uniform Strain for Activity Release Predictions", March 1, 1982.
8. C.E.L. Hunt, "The Limit of Uniform Strain, or Onset of Ballooning, in Fuel Sheath Ballooning Tests", AECL Report CRNL-1187, September 1974.
9. S. Sagat et al, "Deformation and Failure C.E.L. Hunt, "The Limit of Uniform Strain, or Onset of Ballooning, in Fuel Sheath Ballooning Tests", AECL Report CRNL-1187, September 1974.
10. A. Sawatzky, "A Proposed Criterion for the Oxygen Embrittlement of Zircaloy-4 Cladding", Zirconium in the Nuclear Industry (Fourth Conference), ASTM STP 681, pp. 479-496, 1979.
11. E. Kohn and S. Sagat, "Beryllium Assisted Cracking of Zircaloy", Sixth Canadian Fracture Conference, Harrison Hot Springs, B.C., Canada, June 1982.

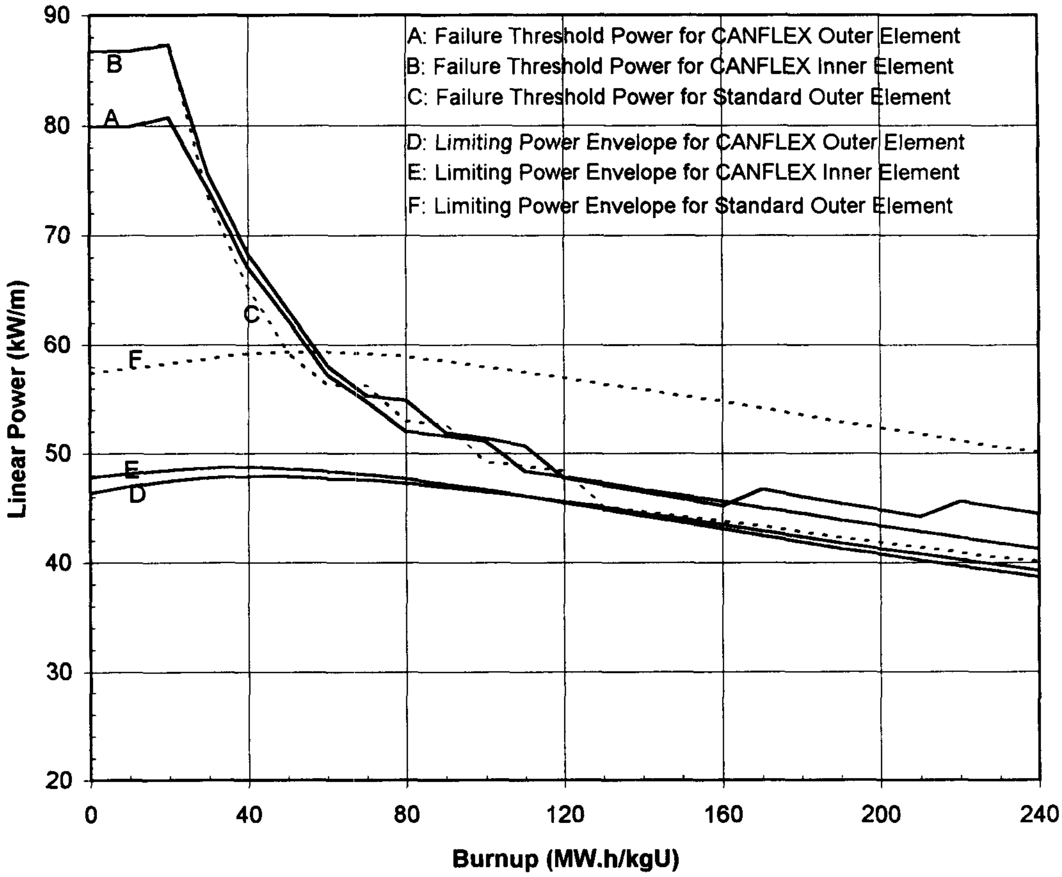

Figure 1: Fuel Element Failure Thresholds for 100% ROH Break; CANFLEX (soild line) & Standard 37-element Bundles