Calculation of IAEA CRP-6 Benchmark Cases for Accident Conditions using COPA-FPREL

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1. Introduction

IAEA CRP-6 is a coordinated research program of the IAEA on advances in HTGR fuel technology which was started in 2002 [1]. It treats (1) fuel design, fabrication, QA/QC and licensing, (2) fuel irradiation, testing, operation performance, and spent fuel disposition, (3) fuel characterization data and performance modeling. Thirteen countries are taking part in CRP-6.

The evaluation of fission product releases under core heatup accident conditions is one of the CRP-6 performance modeling studies. The participating Member States are developing their own fission product analysis computer codes. The Korea Atomic Energy Research Institute (KAERI) is also making a fission product analysis code named COPA-FPREL [2]. This study presents the calculation results of the benchmark cases using the COPA-FPREL and a comparison of them with the results of a German code FRESCO-II [3].

2. IAEA CRP-6 Benchmark Cases for Accident Conditions

The IAEA CRP-6 benchmark cases consist of three parts [4]: code verification that establishes the correspondence of code work with the underlying physical, chemical and mathematical laws, code validation that establishes reasonable agreement with the existing experimental data base, predictive calculations for future heating tests and/or reactor concepts. Table I describes the benchmark cases for accident conditions. Cases 1 – 5, 6 – 9, 10 – 11 in Table I are the parts of code verification, code validation and code prediction, respectively.

The fuel particle for the code verification consists of a 500 μm diameter oxide fuel kernel with 8 % enriched uranium surrounded by subsequent buffer and coating layers. The thicknesses of the buffer, inner pyrocarbon, silicon carbide, and outer pyrocarbon are 100, 40, 35, 40 μm, respectively. For the parts of the code validation and prediction, the size data were selected according to the real fuel used in the tests. The benchmark calculation used the German data for the diffusion coefficients of the fission products in the fuel materials [5]. The fractions of the uranium contamination in the buffer, inner pyrocarbon, silicon carbide, outer pyrocarbon, and matrix graphite were assumed to be 1×10^{-3}, 1×10^{-4}, 1×10^{-6}, 1×10^{-6}, and 1×10^{-6}, respectively

Table I: IAEA CRP-6 benchmark cases for accident conditions

Cases	Descriptions
1	cesium release from bare kernel heated at 1200 °C and 1600 °C, no irradiation phase
2	cesium release from kernel+buffer+IPyC layer heated at 1200 °C and 1600 °C, no irradiation phase
3	cesium release from a TRISO particle heated at 1600 °C and 1800 °C, no irradiation phase
4	cesium and silver release from a TRISO particle heated at 1600 °C and 1800 °C, and assuming a preceding 500-day irradiation phase at 1000 °C
5	cesium and silver release from a TRISO particle heated at 1600 °C and 1800 °C, and assuming a preceding 1000-day irradiation phase consisting of 10 temperatures cycles between 600 and 1250 °C
6	**HFR-P4**, the capsules 1-12 and 3-7, irradiated over 351 days at 940 °C and 1075 °C, respectively, and both heated at 1600 °C
7	**HRB-22**, tests 3 and 4, containing Japanese fuel particles, irradiated over 89 days at 1103°C, both reaching 4.8 %FIMA and 2.1×10^{25} m^{-2}, E>0.1 MeV, and then heated at 1700 °C and 1800 °C, respectively
8	**HFR-K3**, the pebbles 1 and 3, irradiated over 359 days at 1020 °C and 700 °C, respectively, and then heated at 1600 °C and 1800 °C, respectively
9	**HFR-K6**, pebble 3, irradiated over 634 days at 1140 °C, and heated at 1600 °C, 1700 °C, and 1800 °C
10	**HFR-EU1bis**, pebble 1, irradiated over 249 days at 1100 °C, to be heated at 1250 °C, 1600 °C, 1700 °C, and 1800 °C
11	**HTR-PM**, a pebble according to the design of the next generation Chinese HTGR assuming for the sphere studied here to be irradiated over 1000 days at 1000 °C, to have a burnup of 9 %FIMA and a fast neutron fluence of 2×10^{25} m^{-2}, E>0.1 MeV, and to be heated at 1600 °C, 1650 °C, 1700 °C, and 1800 °C

3. Calculation Results

The KAERI calculated the fractional releases for Cases 1 – 11 with the COPA-FPREL and presented them at the CRP-6 [6]. Fig. 1 shows the fractional releases of the fission products from a TRISO-coated fuel particle under a heating. The cesium releases of COPA-FPREL are little higher than those of FRESCO-II at the early stage of a heating and vice versa for the silver release. The two results, however, are in good agreement over the whole range of a heating. Fig. 2 presents the fractional releases of the fission products from a pebble during the heating test of HFR-K3. For silver, the COPA-FPREL overestimated the fractional release at the early stage of heating while the FRESCO-II underestimated them. At the mid and later stages of a heating, the two code results agree well with the experimental results. For the cesium release, the COPA-FPREL result is higher than the FRESCO-II and the experimental results. For the strontium release, there are large discrepancies between the experimental and the code results. The COPA-FPREL results are much higher than the FRESCO ones at the early stage of a heating. Fig. 3 displays the predictions of the fractional releases through the COPA-FPREL and FRESCO-II. For the silver release, the two results are in very good agreement. For the cesium and strontium releases, the COPA-FPREL and FRESCO-II results are in very good agreement after the early stage of a heating at which the COPA-FPREL result is much larger than the FRESCO-II ones.

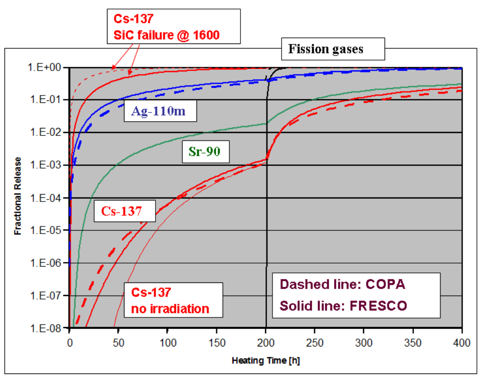

Fig. 1. Fractional releases from a TRISO under heating.

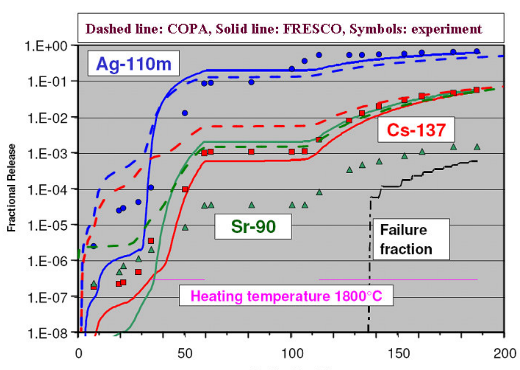

Fig. 2. Fractional releases from a pebble during heating of past experiment HFR-K3.

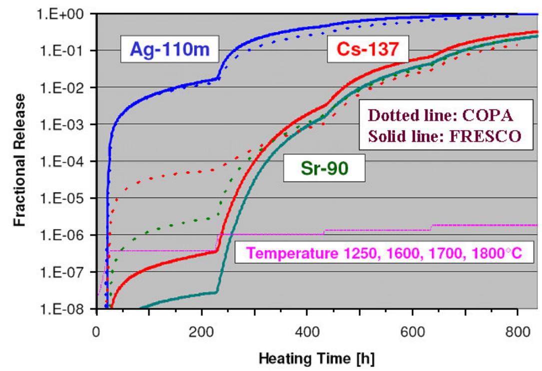

Fig. 3. Fractional releases from a pebble during heating of future experiment HFR-EU1bis.

4. Conclusion

The 11 benchmark cases of IAEA CRP-6 for accident conditions were calculated by COPA-FPREL, KAERI's fission product release analysis code. The COPA-FPREL showed higher fractional releases than a German code FRESCO-II at the early stage of a heating, after which the two results were in good agreement. For the strontium release obtained through the previously performed heating test, both COPA-FPREL and FRESCO-II overestimated the fractional release of the strontium. The discrepancy at the early stage of a heating and the strontium overestimation are being scrutinized.

REFERENCES

[1] K. Verfondern and Y. W. Lee, "Advances in HTGR Fuel Technology – A New IAEA Coordinated Research Program," *2005 International Congress on Advances in Nuclear Power Plants (ICAPP05)*, May 15 - 19, 2005, Seoul, Korea.

[2] Y. M. Kim, M. S. Cho, Y. W. Lee and W. J. Lee, "Development of a Fission Product Release Analysis Code COPA-FPREL," *2008 International Congress on Advances in Nuclear Power Plants (ICAPP08)*, June 8 - 12, 2008, Anaheim, CA, USA.

[3] H. Krohn and R. Finken, FRESCO-II: Ein Rechenprogramm zur Berechnung der Spaltproduktfreisetzung aus kugelformigen HTR-Brennelementen in Bestrahlungsund Ausheizexperimenten, Jul-Spez-212 (1983).

[4] K. Verfondern and H. Nabielek, "Fission Product Release From Htgr Fuel under Core Heatup Accident Conditions," Proceedings of the 4th International Topical Meeting on High Temperature Reactor Technology (HTR-2008), September 28 - October 1, 2008, Washington D.C., USA.

[5] *Fuel Performance and Fission Product Behaviour in Gas Cooled Reactors*, IAEA/TECDOC-978 (1997).

[6] Kim Young Min, "Calculations of CRP-6 Benchmark Accident Cases with COPA-FPREL," unnumbered document, IAEA CRP-6 RCM5 CD-ROM (2008).