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Current Capabilities of a Fission Product Release Analysis Code COPA-FPREL

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1. Introduction

In a high temperature gas-cooled reactor (HTGR), solid and gaseous fission products are produced in the fuel element, released into a coolant, and deposited in a primary circuit. Rigorous estimation of a fission product release is essential for the safe design and operation of a HTGR under normal and accident conditions. It is necessary to develop a computer code to simulate the fission product release from a fuel element into a coolant. A HTGR fuel performance analysis code COPA is presently being developed in the Korea Atomic Energy Research Institute (KAERI). The COPA-FPREL is one of nine modules of the COPA code. It treats a fission product release from intact and failed coated particles and a fission product migration through a fuel element. This study summarizes the current status in the development of the COPA-FPREL.

2. Structure and Functions of COPA-FPREL

The COPA code consists of nine modules: MECH, FAIL, TEMTR, TEMPEB, TEMBL, FPREL, MPRO, BURN, and ABAQ. Every module has its own functions and models. Among those modules, the COPA-FPREL simulates the fission product releases from a fuel element into a coolant in the existing pebble-bed and prismatic HTGRs. It also simulates the fission product releases from a fuel element under some irradiation and heating experiments. The COPA-FPREL is a FORTRAN program consisting of about 5000 lines.

Calculation flow in the COPA-FPREL is summarized in Fig. 1. At a certain point in time, the fluence, fuel burnup and coolant temperature are calculated in sequence. The temperature distribution of a fuel element is calculated using the coolant temperature. The material properties such as the diffusivity, sorption isotherm parameters, mass transfer coefficient etc. are updated according to the temperature distribution in a fuel element. Source terms including the fission product release rates from the intact and defective coated particles and the fission product generation rate from the uranium contaminations are calculated. New concentration distribution in the fuel element is calculated iteratively since the finite difference equations are nonlinear.

In order to calculate a source term due to the fission product release rates from the coated particles, a finite difference analysis is applied to the coated particles, too. The temperature and concentration distributions in the intact and defective coated particles are calculated through a finite difference analysis. The fission products in the layers of a coated particle are generated from nuclear fissions in a kernel and a uranium contamination at the particle surface, and recoils in the adjacent layers

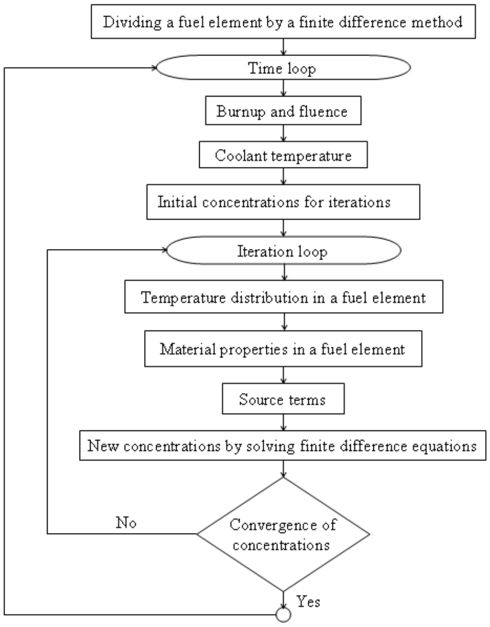

Fig. 1. Calculation flow of COPA-FPREL.

Table I shows the major subroutines and functions of the COPA-FPREL. The subroutines TEMTR, TEMPEB, TEMBL and MPRO which were originally modules of the COPA code were inserted into the COPA-FPREL. The subroutine PREPROC reads the related data of the reactor, time and finite difference division, irradiation or heating history, isotopes, partition factors, defect fractions, and control variables. The time-dependent defect fraction of the coated particles under operational reactor conditions is calculated using the COPA-FAIL and then is inputted into the COPA-FPREL in the form of a stepwise function of the time. The subroutine TEMTR calculates the temperature distribution in a coated particle. The subroutine FPREL_CP calculates the concentration distributions in the intact and defective coated particles and then the release rates from the coated particles. The subroutines TEMPEB and TEMBL calculate the temperature distributions in a pebble and a fuel block, respectively. The main subroutine FPREL calculates the concentration distribution in a fuel element and then the released amount or fractional release. The subroutine OUTPUT records the temperature, concentration, mass current within the fuel element and the coated particles at every printing time step, and the integrated and fractional releases with the time. The subroutine MPRO calculates the material properties.

Table I: Major subroutines and functions of COPA-FPREL

Subroutines	Functions
PREPROC	Input of data
TEMTR	Temperature distribution within a coated particle
FPREL_CP	Concentration distribution within a coated particle
TEMPEB	Temperature distribution within a pebble
TEMBL	Temperature distribution within a block
FPREL	Main module. Concentration distribution within a fuel element
MPRO	Material properties
OUTPUT	Output of results

3. Test Estimations of a Fission Product Migration

Some test calculations for Cs^{137} migrations were performed for a pebble-bed and a prismatic reactor under normal and accident conditions and for a pebble under a heating. The maximum irradiation fluence was assumed to be 3×10^{21} n/cm^2. The coolant temperature is 900 ^{o}C over the entire irradiation period in a normal operation case, and 1200 ^{o}C between 1.4×10^{21} and 1.6×10^{21} n/cm^2 and 900 ^{o}C at other fluences in an accident case. The diffusivities, sorption isotherm parameters, and mass transfer coefficient in helium for Cs^{137} were extracted from references [1-3]. Figs. 2 and 3 show the fractional releases of Cs^{137} in a pebble-bed and a prismatic reactor, respectively. The release increases abruptly at an accident interval. Fig. 4 shows the fractional releases of Cs^{137} from a pebble under a heating. The releases increase with the time and the temperature. However, the COPA-FPREL overestimates the releases of Cs^{137} in comparison with the German code FRESCO-II [4].

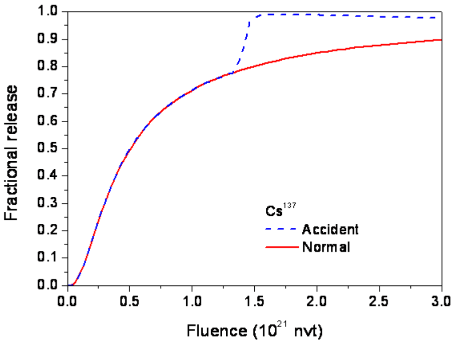

Fig. 2. Fractional release of Cs^{137} from a pebble-bed reactor core into a coolant.

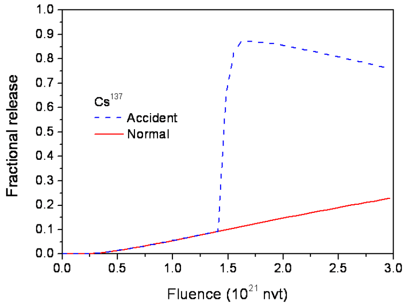

Fig. 3. Fractional release of Cs^{137} from a prismatic reactor core into a coolant.

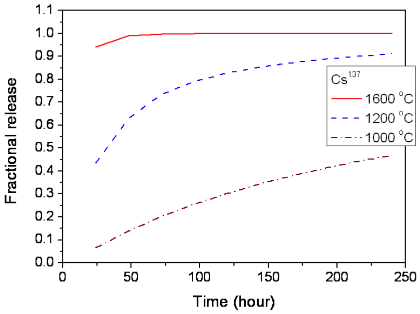

Fig. 4. Fractional release of Cs^{137} from a pebble under a heating.

4. Conclusion

A fission product release analysis code COPA-FPREL was developed to estimate the transport of fission products through a fuel element of a HTGR under reactor operations or post-irradiation experiments. Test calculations revealed that the code described the effects of the time and temperature on the release of Cs^{137} correctly, but it overestimated the fractional release. It is necessary to verify and validate the COPA-FPREL with the experimental data and the previously developed fission product analysis codes.

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