

RECEIVED BY TIC FEB 27 1979

CONF-790816--3

FRAP-GCFR: A Code For the Transient Analysis
of Gas-Cooled Fast Reactors

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ABSTRACT

The fuel rod analysis computer program (FRAP-T) has been modified to analyze transient fuel rod behavior in the gas cooled fast reactor (GCFR). Major features modeled include the effects of helium coolant, ribbed cladding, pressure equalization system, and 316 stainless-steel material properties. The code capabilities include models of elastic-plastic-creep deformation behavior, two-dimensional heat conduction, rod ballooning, and transient axial gas flow. The models are particularly relevant to GCFR transient analysis in that partial or full blockage of the pressure equalization system could cause a significant pressure differential to exist during a helium depressurization, the GCFR design basis accident. An analysis of the design basis accident illustrating the predictive capabilities of the code is presented.

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SUMMARY

The fuel rod analysis program (FRAP-T)^[1] [a] has been modified to analyze transient fuel rod behavior in gas cooled fast reactors (GCFR). The FRAP-T code is a FORTRAN IV computer code developed for the U.S. Nuclear Regulatory Commission to describe the transient behavior of light water reactor (LWR) fuel rods. The code includes all the major coupled effects of thermal, mechanical, internal gas response and temperature dependent material properties in the analysis of fuel rod behavior. Previous GCFR transient analyses have been directed at the core thermal hydraulic response^[2] or the effects of a core disruptive accident^[3]. These analyses considered only simple models of the core behavior. The conversion of FRAP-T to GCFR capabilities provides a complete package for the analysis of the complex phenomena occurring during GCFR transient events. Additionally, since FRAP-T has been developed in a modular format with each type of computation and analytical model being a separate module or subroutine, conversion of the code for GCFR analysis was straightforward and inexpensive when compared to the development of a new code.

FRAP-T includes mechanical models that incrementally find elastic-plastic-creep solutions for both fuel and cladding. Arbitrary (work-hardening) stress-strain relations are considered, and arbitrary transient and steady-state creep laws can be accommodated. In addition, FRAP-T optionally has the capability of calculating two dimensional heat conduction in both fuel and cladding at each axial node. When cladding temperature and pressure differentials are such that the cladding instability strain is reached, the cladding stresses and strains are automatically computed by a ballooning subcode. This subcode allows the computation of large changes in cladding diameter which can cause flow blockage. In this context, the axial gas flow model in FRAP-T is especially relevant to GCFR transient analysis in that partial

[a] FRAP-T5, Version 12/5/78, Code Configuration Control Number H007441B.

or full blockage of the pressure equalization system could cause a significant pressure differential to exist during a depressurization accident with the potential of fuel rod ballooning.

The FRAP-T code has recently been interactively linked with the COBRA-IV thermal hydraulic code. The COBRA code performs a two-dimensional, thermal-hydraulic analysis at each axial elevation of a cluster of fuel rods. Coolant mixing is provided by varying friction factors in each coolant channel with elevation. The FRAP-T/COBRA link provides for fully coupled rod-coolant calculations in multirod clusters.

Although considerable differences exist in fuel rod design and operating environment between LWRs and GCFRs, the modular structure and transient analysis capabilities of the FRAP-T code made modification of the code for GCFR analysis relatively simple. The primary advantage of using FRAP-T as the basis for the GCFR analysis code is that no modifications were necessary to handle the complex transient conditions that arise in GCFR safety analysis, even though the conditions that constitute a serious accident for a GCFR differ somewhat from those of an LWR for which the FRAP code was developed. Since the transient capabilities of the code did not need to be changed, the modifications necessary to analyze GCFR fuel behavior consisted primarily of including GCFR material properties and modeling specific design features.

The differences between the two fuel rod designs include fuel and cladding dimensions, fuel enrichment, oxide constituents, cladding material and design, the existence of a natural uranium blanket in the GCFR fuel rod and the GCFR fuel rod venting system. The dimensional differences, high fuel enrichment and presence of plutonia in the GCFR fuel rods posed no problem for FRAP as these parameters were already considered variable in the input of the light water reactor version of FRAP-T.

The major modification of FRAP was the replacement of the zircaloy cladding models of water reactors with the stainless steel cladding models used in the GCFRs. Adding stainless steel cladding to FRAP consisted of replacing the zircaloy material properties package, MATPRO, with a new package of 316 stainless steel properties.

The GCFR cladding is "ribbed", that is, the exterior surface of the cladding is spatially interrupted by ridges or ribs to promote turbulent flow of the coolant. The turbulence increases heat transfer from the fuel rod to the coolant. The thermal hydraulic effects of the ribs were simulated by including appropriate friction factors and heat transfer coefficient modifications.

The GCFR pressure equalization system is used to relieve fuel rod internal pressure buildup due to a fission gas release during operation, and to maintain a balance with the system pressure during plant depressurization. Each fuel rod is equipped with a vent line that connects the fuel rod interior with the core outlet via a helium purification system. The vent system contains charcoal filters to delay fission products prior to venting. FRAP-T was modified to reflect the pressure equalization system by equating the rod internal pressure to the coolant bulk pressure.

Operating environments between the two reactor types vary in the type of coolant used, coolant flow direction, and neutron flux spectrum. Probably the most significant difference between the reactor types is the use of helium as the primary reactor coolant in GCFRs. FRAP-GCFR considers helium on both interior and exterior surfaces of the cladding. Normal flow direction for the helium coolant is downward in the GCFR. In LWRs the coolant normally flows in the upward direction. The difference in flow directions for the two reactors posed no modeling problem in FRAP-GCFR as the transient capability of the code provides for flow in either direction through the core.

To demonstrate the analytic capabilities of the modified FRAP-GCFR code, an analysis of the GCFR design basis accident (DBA), has been completed. The DBA consists of a postulated reactor coolant depressurization caused by failure of a reactor cavity closure. Calculations are presented illustrating the consequences of zero, partial, and full blockage of the pressure equalization system.

REFERENCES

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3. Gas-Cooled Fast Reactor Core Disruption Accidents, ANL/RAS/GCFR-76-1, November 1976.