CONF-880532--6

BNL-NUREG-40361

DEPRESSURIZED CORE HEATUP ACCIDENT SCENARIOS IN ADVANCED MODULAR HIGH TEMPERATURE GAS COOLED REACTORS*

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DE88 002125

ABSTRACT

The decay heat removal by a passive air cooling system from a modular high temperature gas cooled reactor during depressurized core heatup accident scenarios was analyzed. The effects of several design and operating parameters on the peak fuel and vessel temperatures were established. The results indicate that fuel and vessel temperatures remain well below failure levels and that significant safety margins exist in the key variables of decay heat and core thermal conductivities.

*This work performed under the auspices of the Nuclear Regulatory Commission

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INTRODUCTION

The advanced gas cooled reactor, currently being developed under DOE contracts, uses a completely passive air cooled natural circulation loop, i.e., the reactor cavity cooling system (RCCS), as the ultimate heat sink under accident conditions. Details of the design of this modular high temperature gas cooled reactor (MHTGR) and the RCCS can be found in Ref. 1. A schematic of the reactor vessel and the RCCS is shown in Figure 1.

The reactor vessel is not thermally insulated, resulting in a permanent heat loss to the RCCS of about 0.8 MW during normal full power operations (about 0.3% of full power heat generation of 350 MW). During some of the worst case licensing basis events, the reactor is scrammed, all forced circulation is lost, and the primary loop is depressurized. Thereafter, decay heat removal is from the core predominantly by conduction and radiation to the reactor vessel and from there to the RCCS.

While variation of the RCCS performance under normal and accident conditions will be the subject of a separate paper, this paper will consider the core heatup and cooldown transients resulting from the above accident scenario, with the peak fuel temperatures and also the peak vessel temperature being

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t' items of most concern. Excessive fuel temperatures leading to fuel failures can result in increased fission product releases. Excessive vessel temperatures can affect vessel integrity and compromise restart capability after an accident transient.

THE MODEL

The analysis of such accident transients was performed with the THATCH code, analyzing transient conduction and radiation in the reactor vessel, coupled with the PASCOL code, which analyzes quasi-static RCCS flow and heat transfer conditions.

The THATCH code is a general purpose reactor code, which was applied here to the MHTGR reactor vessel geometry. It solves the conduction equation for all major solid capacitances, as nodalized by the user, applying an ADI numerical method, using prescribed temperature dependent property functions for all reactor components.

Heat transfer across internal gaps can be modelled as conduction, convection, and one-dimensional radiation, or any combination of these, as specified by the user. For larger internal volumes, multi-dimensional radiation can be prescribed, and is used here in the upper and lower plena.

Heat from the reactor vessel to the RCCS panel side facing the reactor is removed via natural convection and radiation. Heat transfer within the RCCS up-flow channel is by conduction and radiation to its internal fins and the back panel, and by convection from all metal surfaces to the upflowing air. The PASCOL code can, at each elevation, either model this combined conduction/convection/radiation heat transfer in detail, or use a prescribed fin effectiveness coefficient, computing local heat transfer from the panels to the coolant based on local panel temperatures. Sample applications have shown that detailed local fin conduction and radiation solutions are not warranted, since for a given design the fin effectiveness does not vary significantly in space or time during a transient. Constant user supplied fin effectiveness data, developed in a separate parametric study, were therefore applied here. Coupled with the axially nodalized heat transfer analysis, the PASCOL code also solves a one-dimensional quasi-steady momentum equation for the RCCS air flow, including ducting losses and stack effects.

RESULTS

Applying the above codes, using best estimate input data, the results of Figures 2 to 5 were obtained. Core and fuel temperatures rise initially reaching a peak fuel temperature of about 1370°C around 60 hr, with a gradual cooldown thereafter. Figure 3 shows that initially the decay heat exceeds the heat removal, with excess energy being stored in the core and reflector solid capacitances. Around 70 hr, the heat absorbed by the RCCS begins to exceed the decay heat resulting in a net cooldown of the reactor.

Peak fuel temperatures of 1400°C and vessel temperatures of 420°C pose no challenge to either component and are no reason for any concern. However, the above evaluation was a best estimate transient and an important safety question still remains, i.e., whether within the uncertainty bands for some of the input parameters, significantly different results could be expected.

Therefore, a parametric study was conducted to identify those parameters that do affect performance significantly, and to establish the safety margins available in these parameters. Some of these variations are summarized in Table 1, showing the effects of in-core gaps between fuel elements, reflector irradiation, graphite annealing, as well as ambient air inlet temperature and vessel and RCCS panel thermal emmissivity. Variation of none of these parameters had any significant effect on the transient, except that Case 6 (i.e., reduced thermal emmissivity), showed the importance of maintaining a reasonably high emmissivity on the vessel and RCCS panels to avoid hot spots. The results of Case 4 point out that inclusion of a complete graphite annealing process in the model did affect the results significantly.

However, the two parameters which were found to be of major concern are the decay heat function and the core effective thermal conductivity. Both of these can significantly affect the peak fuel temperatures. Current fuel failure data indicate that there is virtually no fission product release due to core heatup up to 1600°C peak fuel temperature, with very little increase in the range of 1600 to 1800°C. At about 2200°C, massive fuel failures would be expected to occur. By varying the best estimate decay heat function it was found that a 30% increase in decay heat would cause peak fuel temperatures to reach 1600°C, and a 110% increase would be required to reach peak fuel temperatures of 2200°C. Similarly, by arbitrarily varying the core thermal conductivities, it was found that a reduction to 63% of best estimate values raised peak fuel temperatures to 1600°C, and a reduction to 30% resulted in 2200°C peak fuel temperatures.

While a reduction of core conductivities affected the vessel temperatures only very little, increased decay heat also raised the peak vessel temperatures, and a 32% increase in decay heat was required to reach the peak vessel temperature to 480°C, a value beyond which restart capability might be compromised.

Conclusions

The above investigations have shown that typical expected depressurized core heatup transients do not result in excessive core and vessel temperatures, and that there are at least 30 to 40% margins in the decay heat function and core thermal conductivities, before temperature levels of concern are being reached. However, the evaluations also indicate the necessity to establish a high degree of confidence in the best estimate decay heat and thermal conductivity data.

REFERENCES

1. Bechtel National, Inc. et al., "HTGR Concept Descriptive Report," DOE-HTGR-86-118, October 1986.

Table 1 - Parametric Comparison of Several Depressurized Core Heatup Transients with Operating RCCS

Case No.	Description	Peak Fuel Temperature			Peak Vessel Temperature			Vessel Cross Over Time* hr
		Value °C	At Time hr	Variation From Base Case °C	Value °C	At Time hr	Variation From Base Case °C	
1	Base Case	1320	58	----	425	89	----	73
2a	Without Any In-Core Gaps	1272	56	-48	433	82	+8	66
2b	In-Core Gap Widths Doubled	1339	59	+19	423	92	-2	76
3a	All Reflector Graphite Unirradiated	1261	54	-59	421	83	-4	68
3b	Replaceable Side Reflectors Plus One Row Each of Top and Bottom Reflectors Irradiated to Saturation	1354	63	+34	427	95	+2	78
4	Suppress Graphite Annealing	1405	67	+85	423	92	-2	74
5	RCCS Air Inlet Temperature 43°C	1321	59	+1	436	90	+11	75
6	RCCS and Vessel Emmissivity 0.6	1324	61	+4	474	97	+49	82

*Time at which heat leaving vessel exceeds decay heat, i.e., net cooldown of reactor vessel and internals begins.

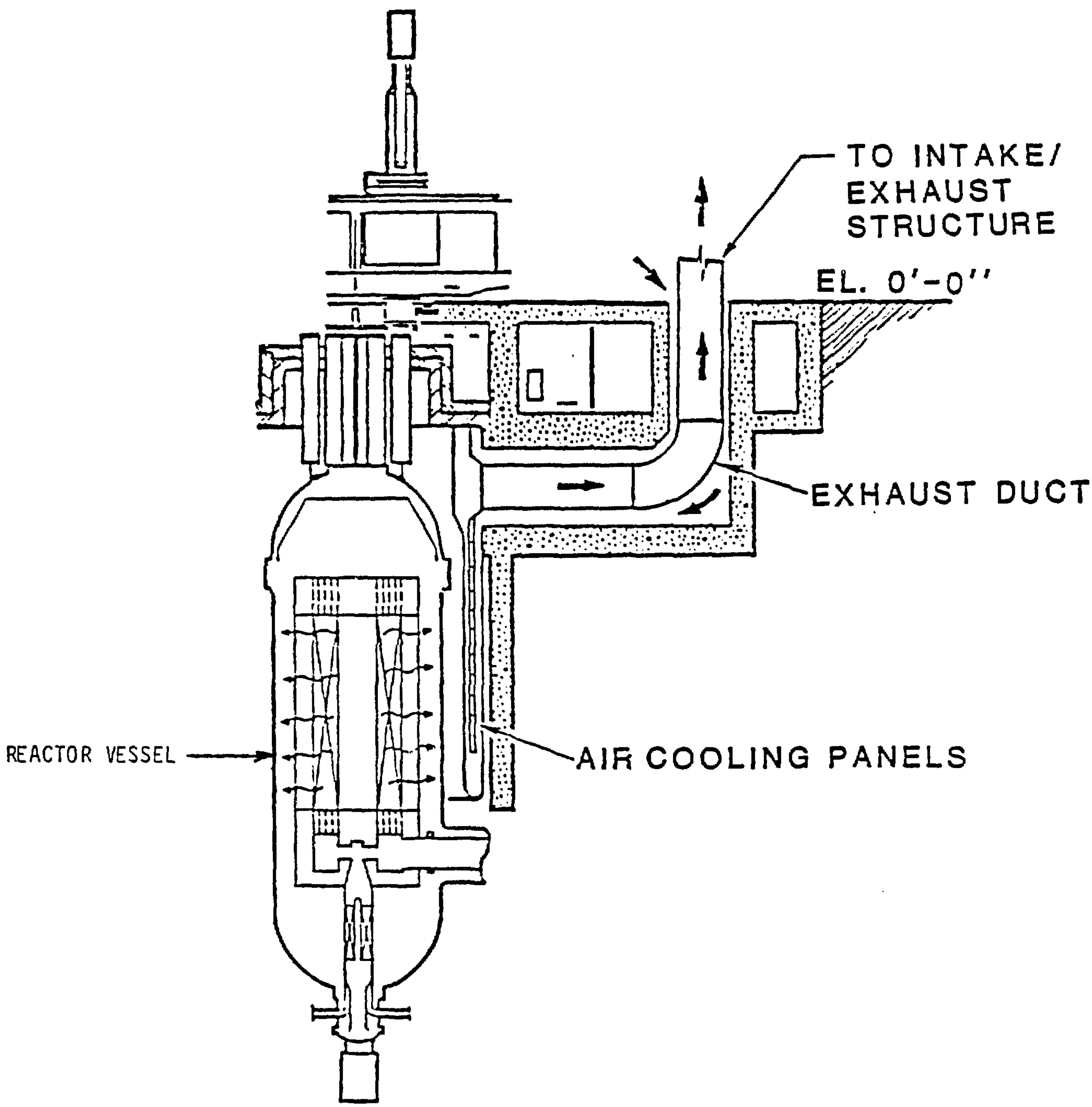

Figure 1: Schematic of Reactor Vessel and Reactor Cavity Cooling System (Ref. 1)

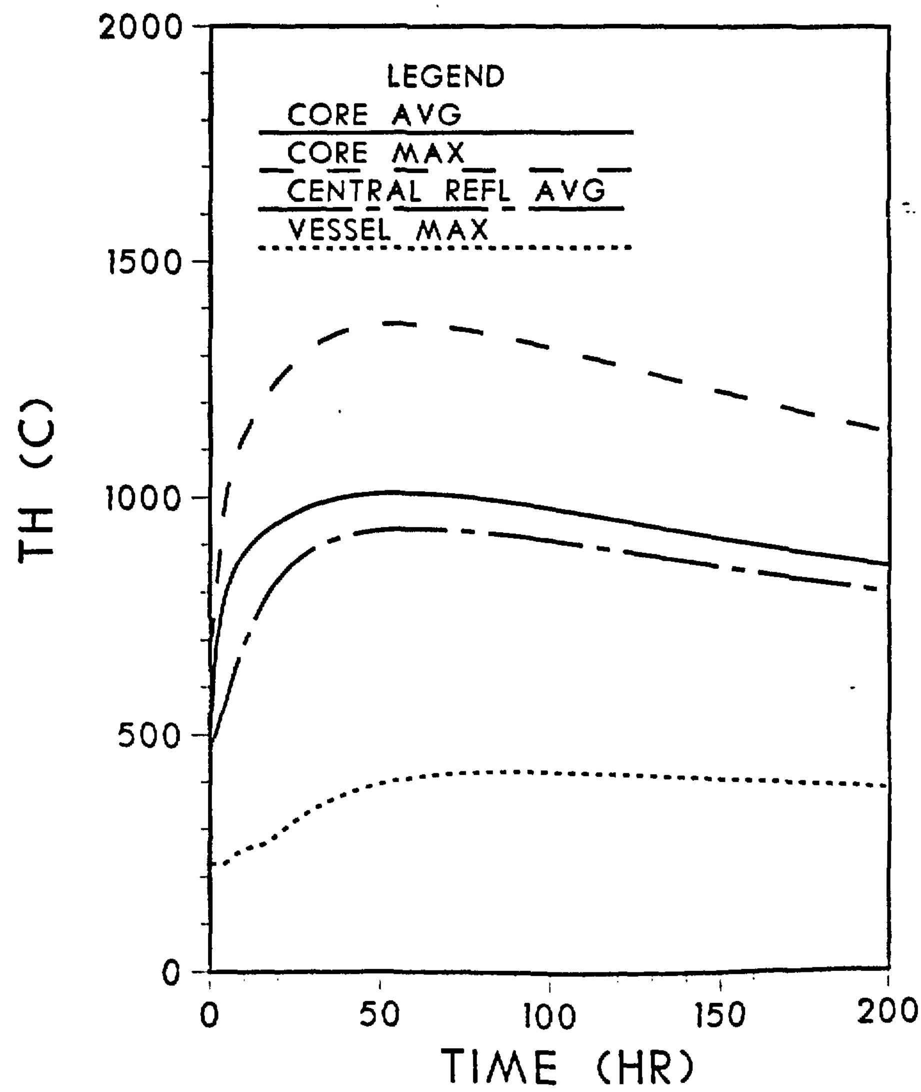

Figure 2: Best Estimate Core and Reactor Vessel Temperatures During Depressurized Core Heatup Accident Conditions

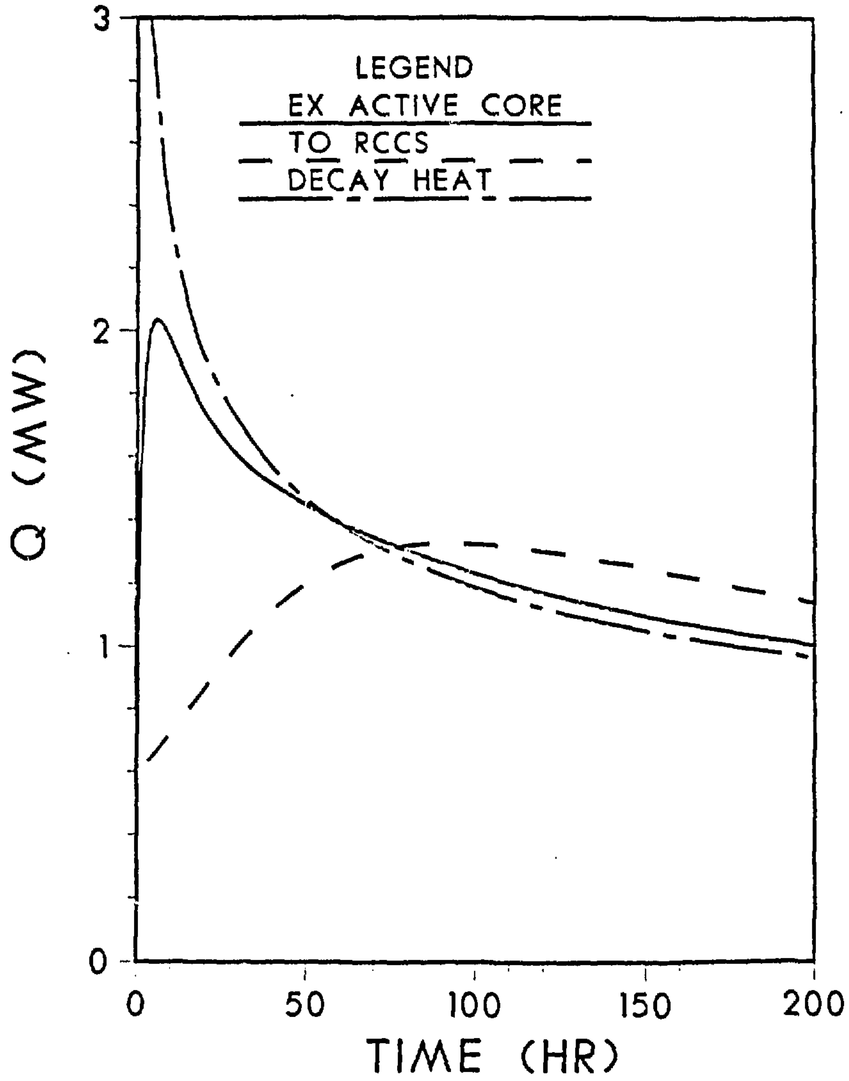

Figure 3: Best Estimate Heat Flows During Depressurized Core Heatup Accident Conditions

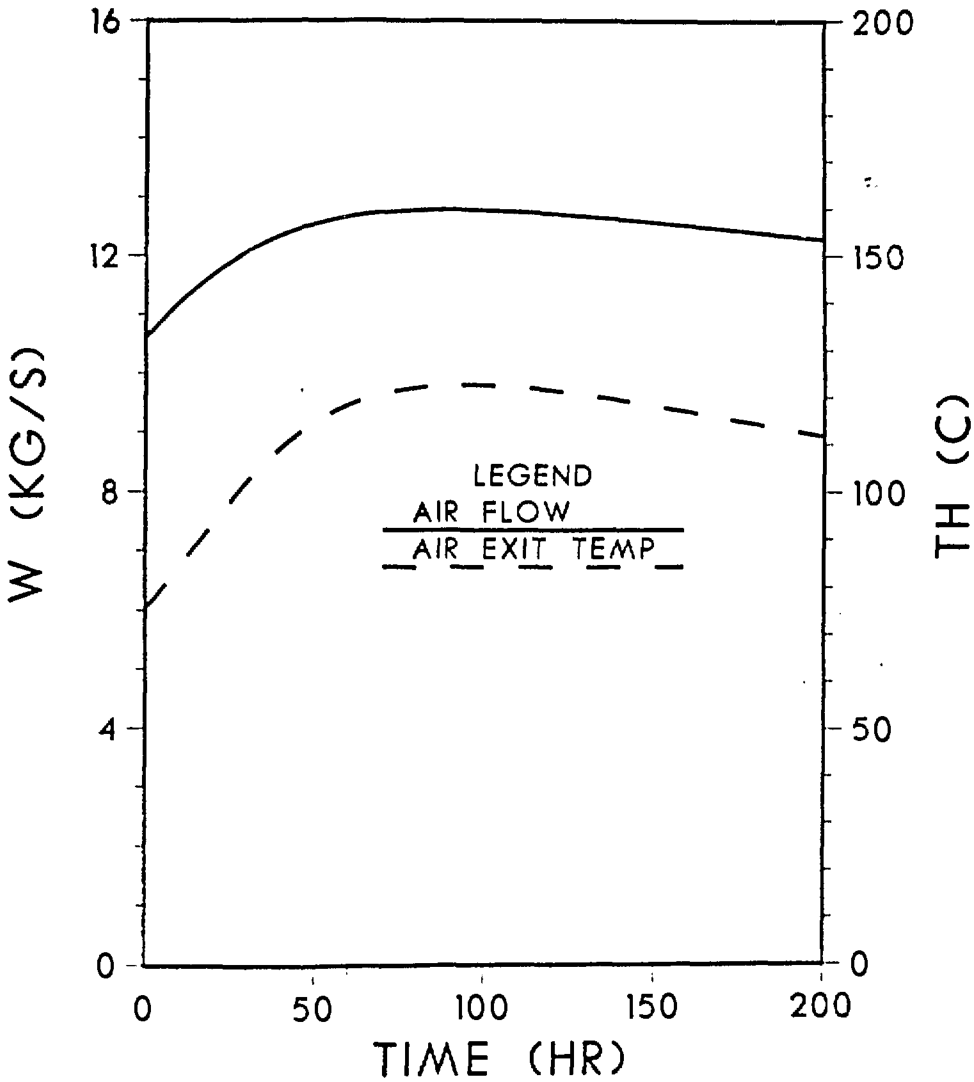

Figure 4: Best Estimate RCCS Performance During Depressurized Core Heatup Accident Conditions

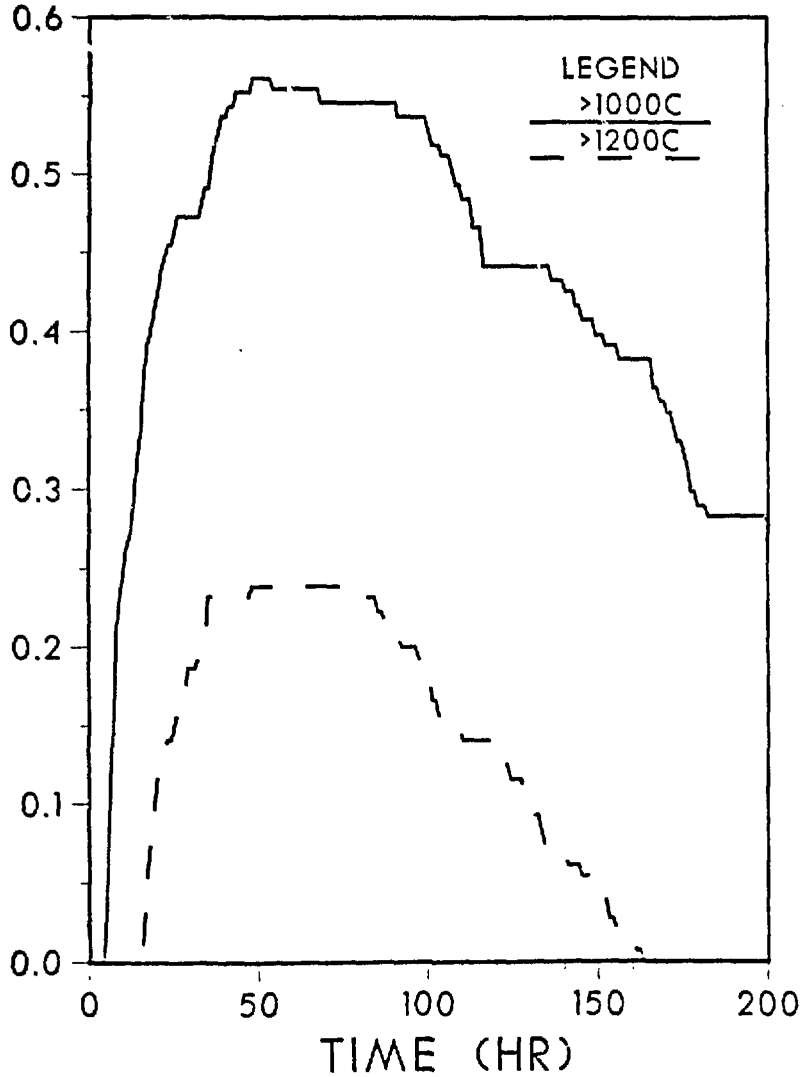

Figure 5: Fractions of Active Core Exceeding Specified Temperature During Depressurized Core Heatup Accident Conditions