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**The High Flux Isotope Reactor
Accident Analysis**

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Operations Division

THE HIGH FLUX ISOTOPE REACTOR
ACCIDENT ANALYSIS

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CONTENTS

	<u>Page</u>
INTRODUCTION	1
DESCRIPTION OF CHANGE	2
SAFETY IMPLICATIONS	3
DISTRIBUTION	9

INTRODUCTION

In the original design of the HFIR safety system, power rate trips were incorporated in operating Modes 2 and 3. The original safety analysis document (The High Flux Isotope Reactor Accident Analysis, ORO-3573, dated April, 1967) specified inclusion of rate trips in Modes 2 and 3 (page 74) and included consideration of rate trips in these operating modes in the analyses of various reactivity transients (pages 78 and 80).

In 1968 the ion chambers in the safety system were repositioned (moved further from the core) in order to extend chamber lifetime and increase system reliability. As a result, chamber lifetime has increased five-fold. Repositioning of the chambers required an increase in the gain (by a factor of 15) of the safety system flux amplifiers. In 1973 new flux signal conditioners were installed to replace obsolete components. However, in operation, these units were more sensitive to noise than anticipated. As a result of these two modifications, the system has become more sensitive to noise to the extent that operation in Modes 2 and 3 has been precluded. Efforts to eliminate the noise at the source met with little or no success. Since a requirement for operation in these modes is anticipated, particularly in connection with satisfying certain requirements of the Technical Specifications, remedial changes described herein have been evaluated. Specifically, these changes include placing feedback smoothing capacitors in the ion chamber flux amplifiers and removing the rate trip in Modes 2 and 3.

It is the purpose of this supplement to update the original safety analysis document, to describe the changes, and to provide a summary of the performed analyses which show that the safety implications of the changes are acceptable. These changes fall within the scope of the original safety analysis document and this supplement substantiates that the changes described herein do not involve a safety question not reviewed in the original safety analysis document.

DESCRIPTION OF CHANGE

In the original design of the HFIR, provisions were made to permit the reactor to be operated in any one of three modes: Mode 1--normal operating mode, full pressurization, full flow, operation to 100 MW; Mode 2--with or without pressurization, at least 10 percent of full rated flow, operation to 2.5 MW; Mode 3--no pressurization, no coolant flow, operation to 100 kW.

Inclusion of the previously referred to smoothing capacitors prevented the noise from producing level trips in Modes 2 and 3, although it was still sufficient to cause rate trips in these modes, even in the shutdown condition. The rate protection was provided originally as a means of providing faster safety action against very short period transients which might be caused by optimum void insertion when operating in Mode 1. The rate trip was originally included in Modes 2 and 3 operation, not because it was required, but because additional circuits would be necessary to disable the trips and no operational difficulties were anticipated from leaving the trips in the active state. However, as noted above, modifications made the system more sensitive to noise and precluded operation in Modes 2 and 3. In order to realistically reflect the divergent requirements of the various operating modes, rate protection is provided for Mode 1 operation only and is disabled when operating in Mode 2 or Mode 3. Further, in Modes 2 and 3 the flux signals are smoothed with capacitors as stated above.

For each mode, the gain of the safety flux amplifier is automatically set by the position of the Mode Selector Switch so that the full operating power level always corresponds to 100 percent on the linear flux recorder. When compared to Mode 1, this requires a gain increase of ~ 40 for Mode 2 and $\sim 1,000$ for Mode 3. The gain, or sensitivity, of the flux amplifier in Modes 2 or 3 is such that electrical noise causes flux level trips and flux rate trips even if the reactor is in a shutdown condition. The most significant noise contribution has been found to be at a frequency of 60 Hz. Efforts to eliminate the noise at the source have been unsuccessful.

It has been demonstrated that the effect of this noise on the safety flux signals is reduced by placing feedback smoothing capacitors in the safety flux amplifier for Modes 2 and 3. The addition of these capacitors introduces a first-order delay in the response of the flux amplifier, by the following approximate amounts: Mode 3, 40.5 msec; Mode 2, 35 msec; Mode 1, 27 msec (which is insignificant).

SAFETY IMPLICATIONS

The performance of the safety system with the delayed response and with the rate trip disabled for Modes 2 and 3 is set forth in OBNL-TM-5783 (to be published). These changes directly affect the safety system by: (1) disabling the rate trip for Modes 2 and 3 operation; and (2) installing signal smoothing capacitors in the safety flux signal conditioner modules, thereby increasing the response times of the flux amplifiers. In assessing the safety implications of these changes, it is necessary to analyze two classes of reactivity insertion accidents--the "startup accident" and the "optimum void accident", taking into account the effect of the changes.

Mode 3 is intended to be run at no flow (vessel head open) and at very low power. Under normal Mode 3 conditions (vessel head open) pressurization of the primary system is impossible. Under this condition (no pressurization) operation of the primary coolant pump main motors is prevented by interlock. Operation in Mode 3 with pony motor flow (an abnormal operating condition) is equivalent to operation in Mode 2 except with a lower level scram setpoint. (A discussion of the optimum void accident under normal Mode 2 operation is given later in this document.) Hence, under normal Mode 3 conditions there is no mechanism for high speed void transport into the core. Therefore, the design basis accident for normal Mode 3 operation is the "startup accident". The very improbable Mode 3 situation of operation with the vessel head closed, full system pressure, and full coolant flow is considered in connection with the optimum void accident later in this document.

The Mode 3 "startup accident" is initiated by a postulated uncontrolled withdrawal of all shims. The entire withdrawal is assumed to take

place with the regulating cylinder at full speed, though this rate is available for only a 1-in. stroke. The three shim-safety rods assumed scrammable are positioned in their region of least worth. The fourth shim-safety rod and the regulating cylinder are initially positioned for the 1 percent subcriticality, and then continuously withdrawn until the resulting excursion initiates a scram. The level trip scram setting is nominally 100 kW; for purposes of this analysis a conservative value of 130 kW was used. In the analysis no rate trip was considered, and a 50 msec smoothing time constant (vs. 40.5 msec actual) was imposed between the power sensor and the trip actuation. No credit for the negative temperature coefficient was taken, and core cooling by the surrounding water was set at zero (adiabatic core). With these uniformly conservative conditions the analysis in OBNL-TM-5783 indicates no significant core temperature rise. The analysis indicates a peak power of only 2 MW and a peak mean fuel temperature rise of only 3.45°F. Thus, the consequences of the Mode 3 startup accident are clearly trivial.

In Mode 2 operation, i.e., low power operation with the vessel head on or off and only pony motor coolant flow (~15 percent of full system coolant flow), the possibility of an optimum void insertion at this reduced flow rate must be taken into consideration. Even at this reduced flow, reactivity from potential void insertion comes in at a far higher insertion rate than the startup accident, and therefore the optimum void accident is the design basis accident for Mode 2.

Since the HFIR flux trap is overmoderated, it has a positive void coefficient. The limiting value of the possible reactivity insertion associated with the optimum void is 1.5% $\Delta k/k$ with the target installed. Technical Specifications requirements preclude operation of the reactor without the target or its equivalent installed in the flux trap. Of the possible 1.5% $\Delta k/k$ void associated reactivity in the flux trap, only 1.3% $\Delta k/k$ is in a region which can be filled at high velocity.

When coolant is flowing in the system, water sweeps through the flux trap at high velocity. It is not clear how ~2 liters of void could get into this system and be directed preferentially to the flux trap; but if this combination of events did occur, a 1.3% $\Delta k/k$ void could go into the island in a time dependent on the coolant flow (about 200 msec at pony

motor flow, 30 msec at full system flow). It is this highly improbable, but mechanistically possible maximum occurrence which is addressed as the "optimum void accident".

Analysis was made (ORNL-TM-5783) of the excursion resulting from optimum void insertion under normal Mode 2 flow conditions (~15 percent of full coolant flow, 200 msec void insertion time), with safety system action. Safety system conditions were: (1) no rate trip; (2) a 50 msec smoothing time constant; and (3) a level trip setting of 3.25 MW. Water cooling was simulated at the low flow rate. Under these conditions the results were:

Peak power	= 18 MW
Peak bulk water temp.	= 128°F
Peak mean fuel temp.	= 148°F
Peak hot streak temp.	= 176°F
Peak hot spot fuel temp.	= 200°F

As can be seen, the consequences are completely inconsequential. Further, the results of analyses reported in the original safety analysis document (ORNL-3573, page 78, Case 24) for normal Mode 2 flow rates indicate no safety action is required to prevent hot spot melting for the Mode 2 optimum void accident occurring at the start of the fuel cycle, even with the very conservative assumption of a step insertion of the optimum void.

As indicated above, Modes 2 and 3 are not intended for use at full flow. Indeed, their whole purpose is to permit operation at low flow and no flow, respectively. However, as long as the system is pressurized, it would be possible to turn on full flow in Modes 2 and 3, thereby providing the flow rate needed for high velocity insertion of the optimum void. For this reason, the results of optimum void insertion at full flow were examined with the reactor in Modes 2 and 3 (ORNL-TM-5783), incorporating safety system modifications (i.e., signal smoothing and no rate trip). Scram conditions were the same as described for the startup accident (three-out-of-four plates coming in from their region of smallest worth per inch). Lifetime and heat transfer coefficients are those for a new core, a conservative choice as determined by making runs at both the beginning and end of core life. For these optimum void runs the simulation included water cooling of the core. For comparison, a Mode 1 run was also made.

The Mode 1 run of course includes rate scram and has essentially no signal smoothing (27 usec), since the subject modifications do not apply to Mode 1. The results of these analyses of the optimum void insertion at full flow condition for Modes 2 and 3 are shown in Table 1. Also shown, for the purpose of comparison, are the results of the optimum void insertion in Mode 1.

The main points to be made are that mean fuel temperature goes up only modestly in any of these cases, and that the Modes 2 and 3 cases with smoothed signals and no rate trip have less heating in the hot spot than does the normal Mode 1 case with rate trip and undelayed signals, the consequences of which have been previously deemed acceptable. Interpretation of the physical consequences of calculated temperatures in excess of the melting point in terms of the fraction of the heat of fusion added is discussed in ORNL-3573 (page 73).

It should be pointed out that the very existence of the hot spot (and hot streak) conditions simulated requires the juxtaposition of the maximum credible fuel segregation with the maximum credible coolant channel narrowing and clad separation, all at the highest flux region of the core. To this has been added full coolant flow in modes which do not normally have full coolant flow, the production of an exactly optimum void from an unknown source, the sweeping of this void into the flux trap (with none of it entering the fuel) at full speed, and the maintenance of it in the optimum location until the transient terminates. With all of these conditions occurring simultaneously, only extremely localized melting is indicated, and comparison with SPERT data (ORNL-3573, page 83) provides further substantiation that the model used in these analyses is quite conservative. Finally, should one of these barely credible excursions be realized, the HFIR is designed to safely and adequately contain, shield, and clean up the fission product releases from any consequent localized melting.

Table 1. Results of Optimum Void Insertion at Full Flow Conditions

Mode	Initial Power	Level Trip Point	Peak Power (MW)	Peak Bulk Water Temp. (°F)	Peak Mean Fuel Temp. (°F)	Peak Hot Streak Response (Melting Point in 1080°F)	Peak Hot Spot Response (Melting Point in 1080°F)
3	100 kW	130 kW	950	170	410	920°F	1550°F (Reaches melting point and adds 95% of heat and fusion)
2	2.5 MW	3.25 MW	1200	190	490	1180°F (Reaches melting point and adds 20% of heat of fusion)	1960°F (Reaches melting point and adds 179% of heat of fusion)
1	100 MW	130 MW	1100	230	525	1520°F (Reaches melting point and adds 89% of heat of fusion)	2720°F (Reaches melting point and adds 333% of heat of fusion)