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SURVIVAL OF PERIPHERAL PINS DURING A TOP-HCDA

MASTER

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ABSTRACT

This study addresses the survival of peripheral pins within an LMFBR subassembly during an unprotected Transient Overpower (TOP) Hypothetical Core Disruptive Accident (HCDA) by consideration of intrasubassembly incoherencies. A continuous analysis was made vs. time from the initiation of the accident up to the point where the power decreases to a quasi-steady state for a Beginning-of-Cycle-4 (BOC-4) core of Fast Test Reactor (FTR), 0.5$/sec ramp case. Blockage was assumed to be formed after fuel pin's failure and effects due to blockages were examined. The study concludes that most peripheral pins within an LMFBR subassembly indeed will survive.

INTRODUCTION

There are two dominant intrasubassembly incoherencies in the current designed Liquid Metal Fast Breeder Reactors, namely: 1) hydraulic effect, i.e. the variation in pin-power to effective-coolant-flow ratio between pins in the inner region and those in the outer region of the subassembly; and 2) the power skew, i.e. the variation in pinwise power density for pins throughout the subassembly. Both effects have been studied [1,2] for an unprotected Transient Overpower (TOP) Hypothetical Core Disruptive Accident (HCDA). It was concluded from these analyses that:

a) The one-pin presentation as used in SAS3A [3] and MELT-IIIA [4], integrated multi-channel LMFBR safety analysis codes, represents neither the fuel pin failure characteristic in the central nor in the peripheral region, but only the failure characteristic of some "average" pin. A subgrouping with the use of more than one representative pin is needed for codes like MELT to simulate the pins in different regions within a subassembly.

b) Fuel pins did not fail simultaneously in all transient studies. When power skew was considered, the times of failure among failed pins were scattered even wider, which alleviates Molten Fuel/Coolant Interaction (MFCI) by not squirting molten fuel into all coolant subchannels simultaneously.

c) The azimuthal failure direction of all fuel pins is preferentially toward the hottest subchannel surrounding the fuel pin which is usually facing the inner region of the subassembly.

d) The location of pins' failures may exist at different axial levels within a subassembly.

e) The pins in the outermost ring do not fail up to the peak of power transient for the flat power case where the intrasubassembly incoherency is due to hydraulic effect alone. For the power skew case there are even more initially surviving pins than in the flat power case.

Thus, if the formation of blockage occurs after pin's failure, it will be in the inner region, centrally or eccentrically located dependent on the intensity of power skew, and the coolant flow may still occur through the peripheral region and remove the heat being generated. If the peripheral fuel pins can continue to survive intact during the TOP accident after a fuel blockage is formed, the probability of long-term coolability of an LMFBR subassembly becomes quite high. This report addresses the long-term survivability of the peripheral pins by consideration of intrasubassembly incoherencies.

COMPUTATIONAL TOOL

In order to make the present analysis consistent with the previous analysis [1,2], the COBRA/MELT code [5] was upgraded to analyze the survivability of the peripheral fuel pins within an FTR subassembly. A semi-empirical model for simulating the formation fuel blockage and concurrent coolant flow reduction has been implemented into this code. The rationale of adapting the semi-empirical approach is that:

a) Once the original pin geometry is lost, the complexity of the interacting phenomena in a pin bundle with coolant subchannels interrelated in mass, momentum and energy exchanges even if not impossible, is probably beyond present computational capabilities.

b) Most mechanisms involved in the post-failure phenomena are not yet fully understood. The justification of the common post-failure mechanistic model is usually based on the global calculation results instead of any phenomenologically experimental evidences.

For these reasons, at the present stage a semi-empirical model would better serve the purpose than the mechanistic model.

In the model, the user of the code provides the following empirical or semi-empirical correlations as input:

- a correlation on the flow reduction vs. blockage area
- blockage size, shape, location and physical properties vs. molten fuel inventory and other factors; and
- time span for the blockage formation.

The calculation result certainly relies heavily on the skillful selection of the correlations and numbers which are input to the program.

The flexibility of the present model is illustrated in Figure 1, where Δt designates the time interval after a pin's failure. The flow area change as a function of time can be specified at will by the user. The blockage may form abruptly immediately after the pin's failure or slowly pile up as specified. Also, the blockage may start to form below, at the same location, or above the rupture site, and may occupy one or more axial nodes.

BACKGROUND AND ASSUMPTIONS

Briefs on the reasons of choosing the case for the study, uncertainties of the fuel pin failure criterion and other assumptions will be given here in order to provide a background of analysis and interpretating the computational results.

The objective of this study is to examine the intrasubassembly incoherency effect on peripheral fuel pins' long-term survivability within an FTR subassembly. Furthermore, since this is a part of the subsequent efforts to answer the long-term coolability question for the TOP accident, the case chosen for present study and all related conditions have borne the continuity and consistency in mind with regard to previous studies [1,2].

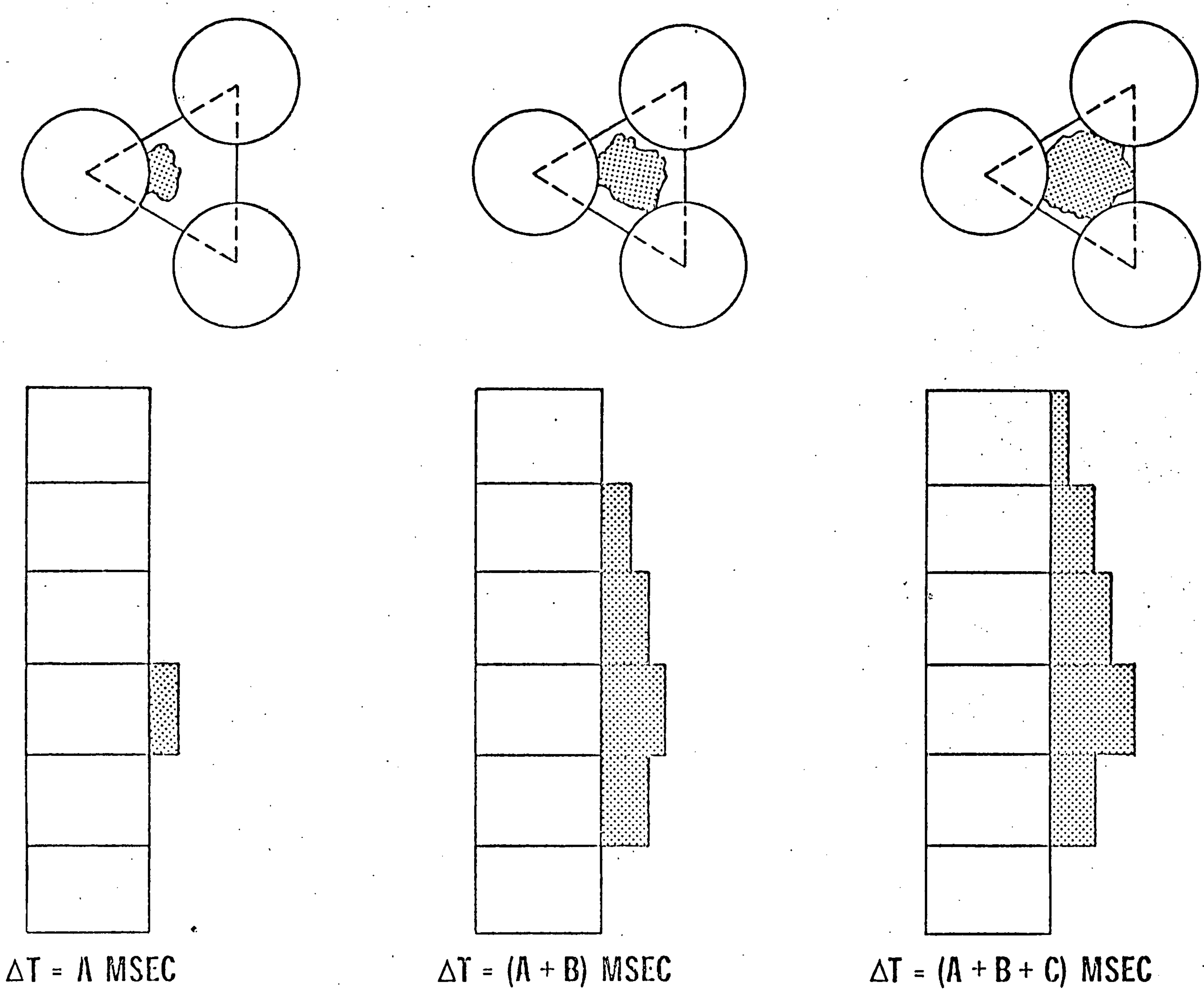

FIGURE 1. The available specifications of blockage after pin's failure both in time and space.

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The BOC-4 FTR core, was selected for this study. Not only was BOC-4 the case for previous investigations, but the Cycle-4 closely approximates core configurations expected during a major portion of the FTR lifetime. Presently, a particular 7-Channel grouping is used as the benchmark case in FTR TOP studies[6]. A subassembly belonging to Channel 2 of 7-Channel grouping [6] as described in detail in Reference 2 was used in present analysis. The reasons and constraints of selecting this subassembly were also provided in this reference.

COBRA/MELT is a thermohydraulic code only and does not have the capability to generate the accident power history itself. The power history needed for COBRA/MELT present calculation as an input are provided by MELT calculations for 7-Channel grouping[6]. The intertie between TOP transient power and the fuel motion within the pin as well as squirted out of the pin after pins' failure and the observation [2] of wide spread failure times within a subassembly (an order of hundred msecs), suggest that a subgrouping approach may alter the TOP's calculated transient power profile considerably. A tentative subgrouping study [7] by use of two representative pins to simulate the pins in the inner and outer regions of the subassembly confirmed this anticipation. This power transient history by subgrouping for MELT 7-Channel analysis was plotted in Figure 2. The history is believed to be better representative than that without subgrouping and is used for present analysis.

Fuel pin's failure criterion used in present study is the Failure Potential (FP) model, a HEDL's empirical correlation of fuel pin TOP failure thresholds [8]. This criterion had been used in previous studies[1,2]. In this long-term survivabilities study, however, a prolonged computation for fuel pin's FP value up to the quasi-steady-state of the accident transient is needed. The validity of FP calculation is uncertain in this domain. It

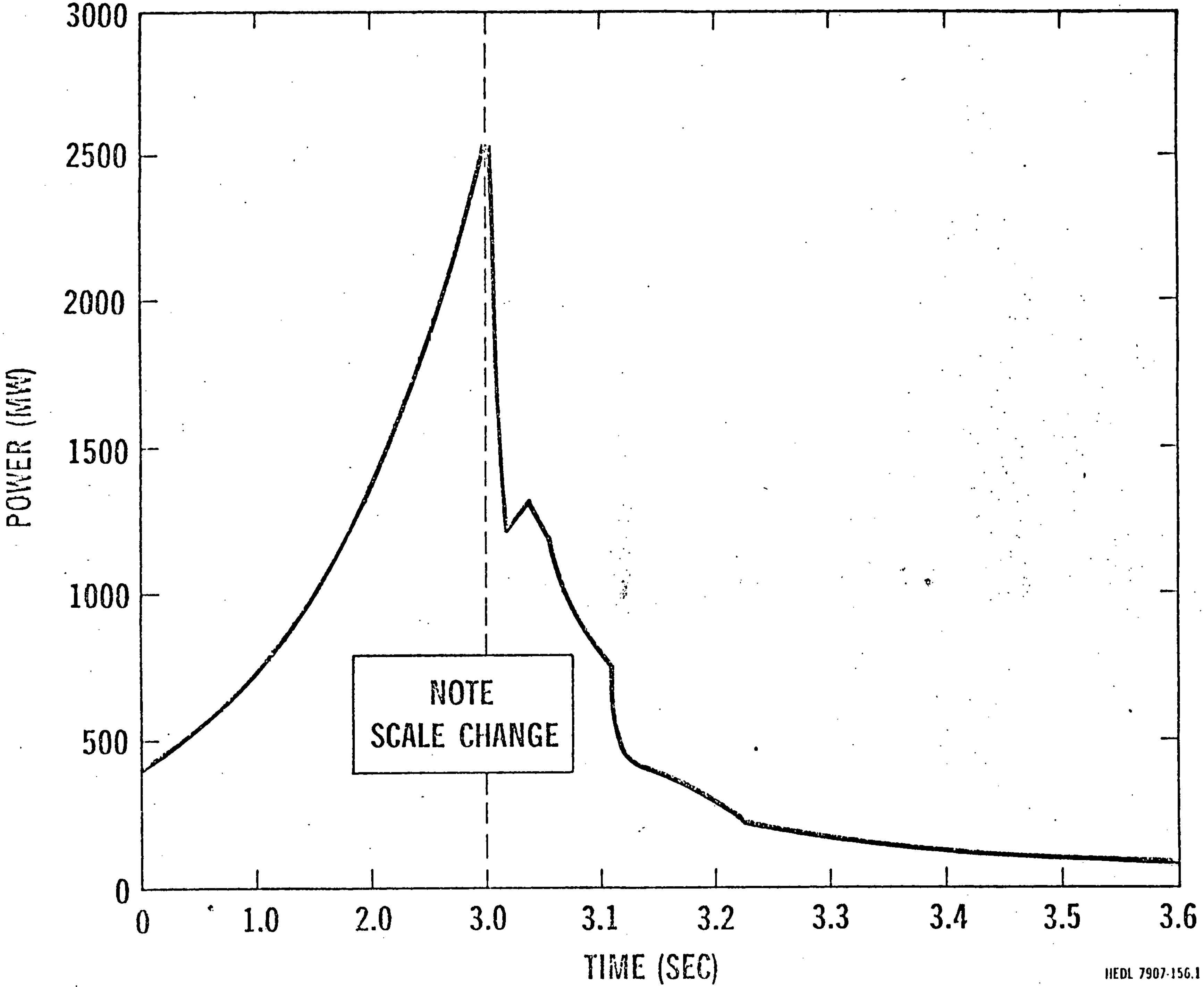

FIGURE 2. BOC-4 Power vs. Time (0.5$/sec TOP)

was suggested [8] that the calculation should stop when the thermal damage term in the FP formula reaches its peak value for initially survived pins. In this study, this suggested guideline was adopted. However, a continuous calculation of FP, until the FP value begin to decrease, also obtained to examine the most conservative assessment on the survival of peripheral pins.

In this first attempt to access the survival of peripheral pins, no MFCI after fuel pin's failure is assumed due to the restrictions of the computational tool that is used here. However, from both in-reactor and out-of-reactor experimental evidences [9,10], it is believed that the no MFCI assumption will not alter any basic scenario and conclusions of the survival on peripheral pins study from the one where MFCI is considered. The flowrate-reduction-curve vs blockage sizes is taken from PSAR of CRBR [11]. To be conservative, a safety factor is used to force a large flowrate reduction to area blocked than the data provided. The original curve and the curve used here which is with a safety factor are plotted in Figure 3.

RESULTS AND DISCUSSIONS

The results of fuel pin's failure patterns with the consideration of fuel blockage within an FTR subassembly are illustrated in Figure 4. The blockage is assumed to be formed immediately after pin's failure instead of gradually piling out by the molten fuel. This assumption is conservative because that the blockage formed abruptly causes most severe flow disturbance than any other assumptions. In Figure 4, pins with dots represent the failure events according to FP calculation guideline [8] whereas the pins with crossline represent the failure events where FP calculation is beyond its credible domain.

Consider the results according to FP calculation guideline first. There are 32 more pins in the ring 1 through ring 8 permanently survived besides all peripheral pins. The pins in ring 1 to 7 failed at the axial level 38.10 cm above the midplane of the core and pins in the ring 8 failed at axial level 22.86 cm above the midplane. This result indicates that

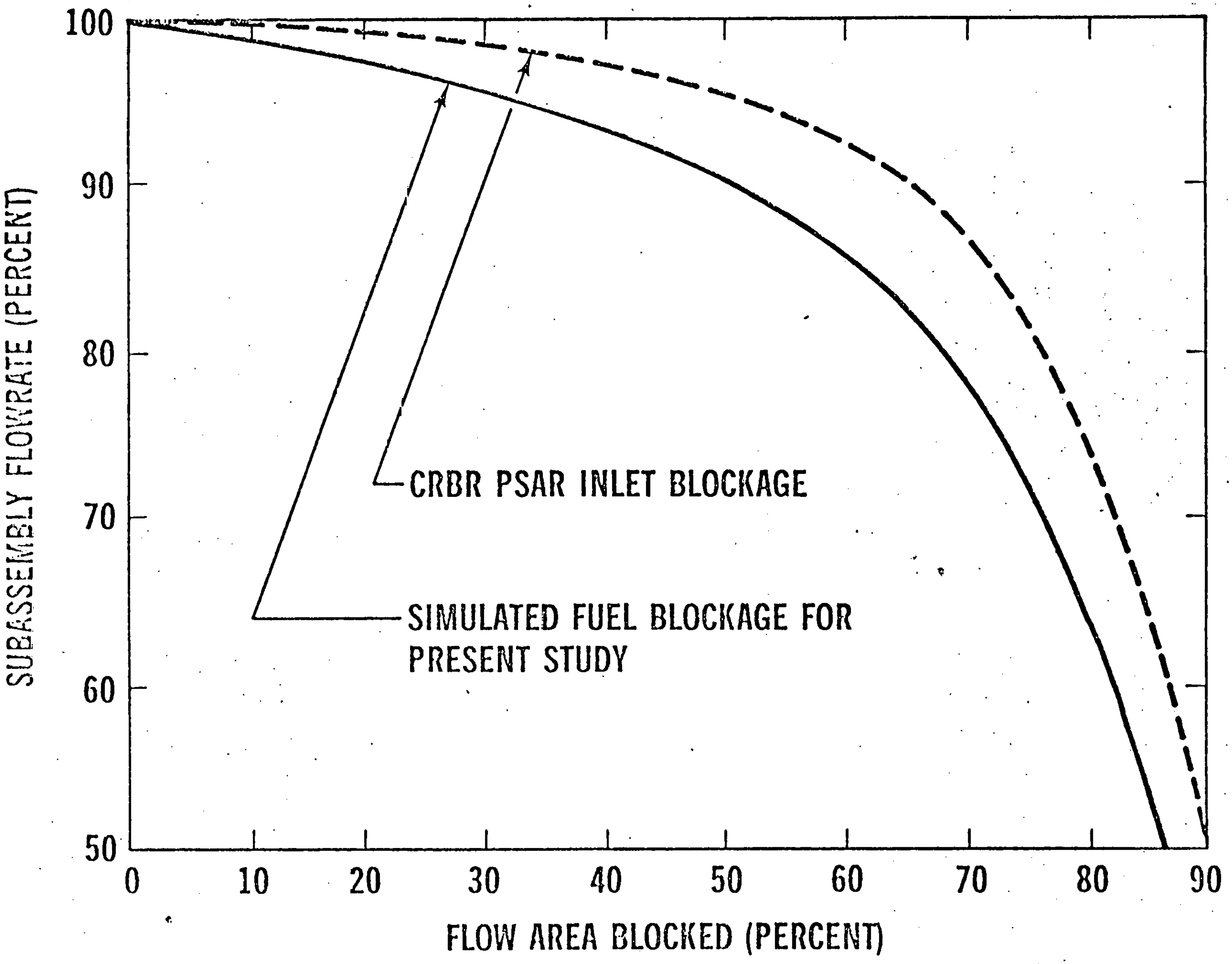

FIGURE 3. Subassembly Flow Rate Reduction vs. Flow Area Blocked.

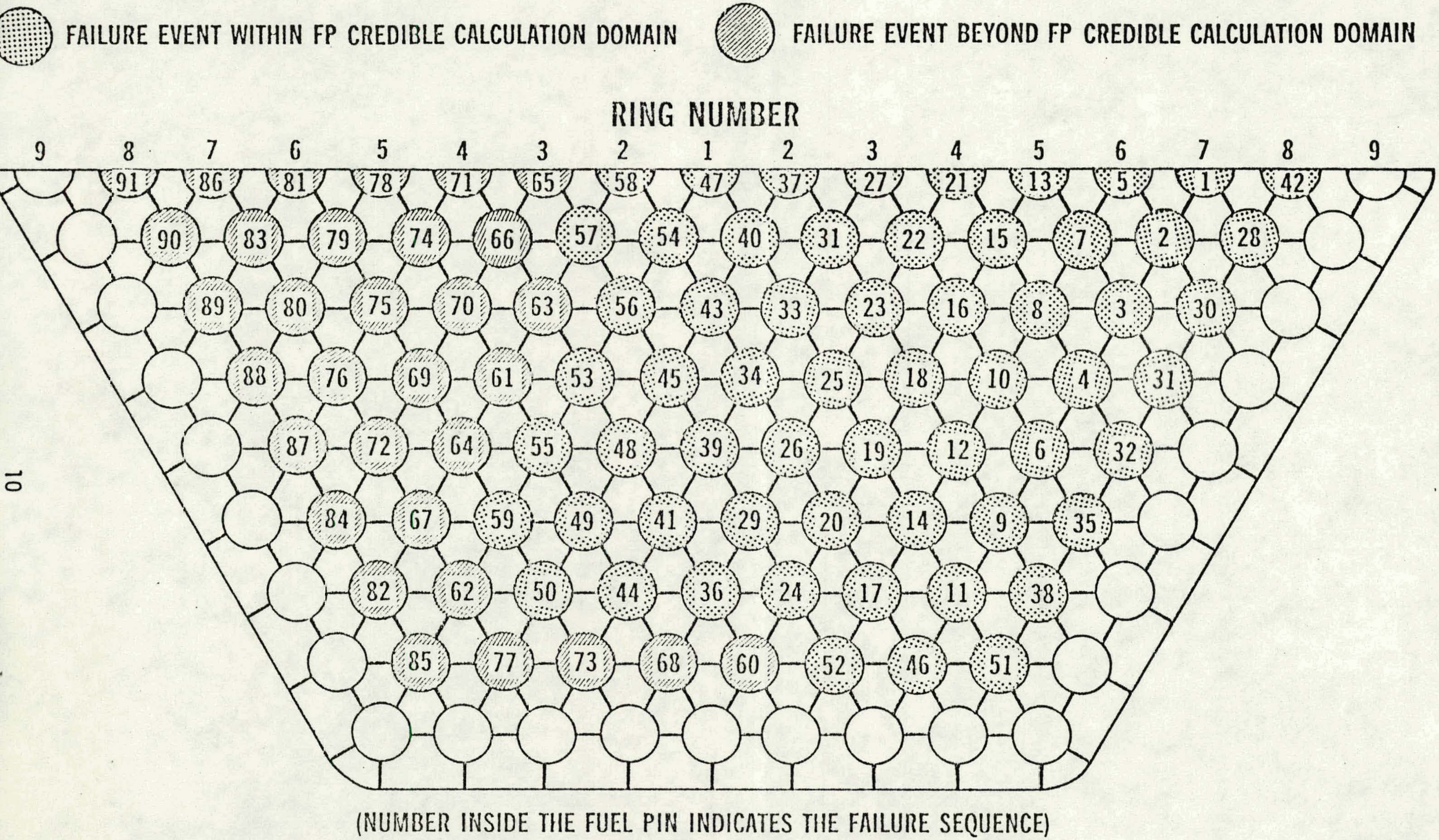

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FIGURE 4. Fuel Pins Failure Pattern with consideration of Fuel Blockage.

peripheral fuel pin indeed survive after fuel blockages formed and concurrent flow rate reduced. Turn to the results with continuing calculation of FP. Due to the very nature of the FP formulation, the calculated value of FP will over-estimate the severity of pin's failure in the down-fall of prolonged transient. In this extremely conservative approach, all pins from ring 1 to ring 8 fail but peripheral pins do survive.

The blockage pattern is illustrated in Figure 5. The input parameter for the flow area blocked per pins' failure are based on the following assumptions: 1) if all pins of the subassembly failed at the same axial level, the entire subassembly will be blocked; and 2) each failed fuel pin will block the same flow area. The first assumption is assured that there will be absolutely no flow if all pins failed at the same axial level. The second assumption adopted here is for simplicity in computation, however, is somewhat over simplified the physical reality.

Two half subassemblies with subchannel flow paths blocked as shown in Figure 5 are the fuel blockage patterns at the indicated axial levels of the reactor core. Fuel blockages are assumed to be formed immediately upon pin's failure at its ruptured site and extended 5.08 cm (i.e., one computational node) upstream as well as downstream in the coolant flow paths. The axial level of the upper blockage located only 5.08 cm below the end of fuel zone (i.e., occupied the axial interval from 35.56-40.64 cm above mid-plane) and is formed by the molten fuel from pins in the ring 1 through ring 7 which failed earlier. The lower blockage is about 15.24 cm relatively lower than the upper blockage and is formed by pins in the ring 8 which failed later. The upper blockage is like a disk and the lower blockage is like a donut. If FP calculation stops as suggested by the guideline, the disk and the donut shape of blockage would be a broken one instead a full and consequently allowing more coolant passing through.

The peripheral pin (ring 9) have entirely survived after the blockage formation up to the time when power diminished to the quasi-steady state

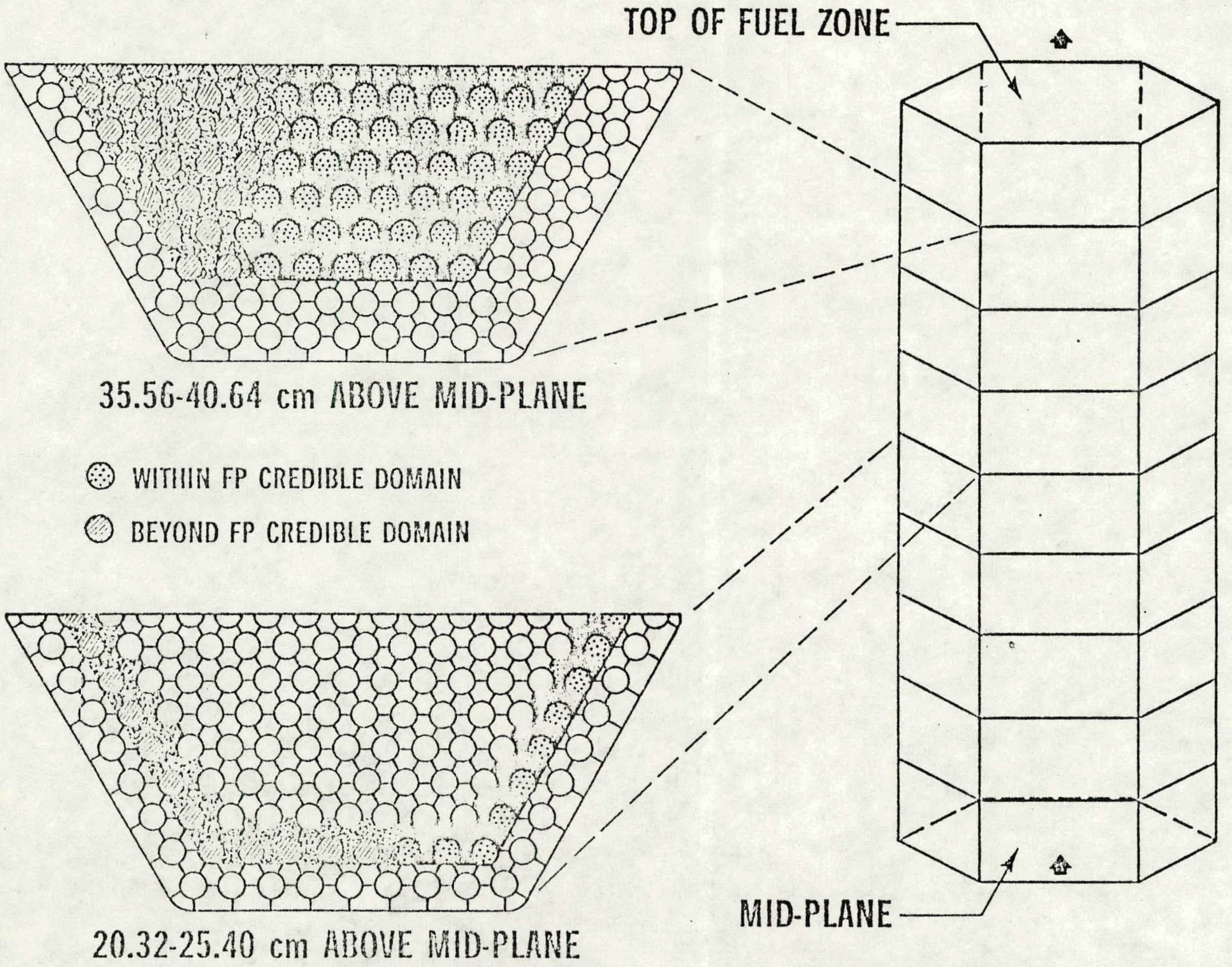

FIGURE 5.' Subassembly Fuel Blockage Pattern of a 0.5$/sec Ramp.

value, and even more, 32 inner pins also survived when FP calculation guideline is used. This is somewhat not as expected, because it is anticipated that the much hotter coolant in the inner subchannels would be diverted into the outer subchannels after fuel blockage is formed. The hotter coolant is thought to weaken the pin's cladding which would lead to the peripheral pins' failure. A scrutiny of flow diversion from the inner region to outer, the flow rate reduction and axial location of the blockage convinces one that the results are justified. Most crucial character of protecting the outer pins' survival is that the central blockage formed at the top of the active core zone, so that when the hotter coolant reaches the outer subchannel it is either at the end of the fuel zone or is beyond the fuel zone. This situation limits the damage potential carried by the hotter coolant. The nominal pressure drop in an FTR subassembly inlet to outlet is more than 100 psi. Under this condition, the flow rate is not substantially reduced by the presence of blockage as experimental indicated [11,12]. A moderate flow reduction accompanied with transient power decreasing simultaneously, makes a favorable condition for the peripheral pins' survival.

When fuel blockage is considered, the fuel blockage build up as pins failed subsequently and the coolant flow rate decreases, accordingly. Hence the temperatures of the coolant and fuel/cladding of early-survival-pins increase more with blockage than that without blockage which force more early survival pins to fail and to fail sooner. A comparison of the pins failure pattern within a subassembly with and without blockage by the FP calculation guideline reveals that: for no fuel blockage there are 36 survival pins instead of 32 with blockage and time span is 132 msec for failure event instead of 106 msec as with blockage.

To illustrate the pins failure events clearly, the failure sequential data were plotted in time coordinate vs. ring numbers in Figure 6. The small solid circles in both figures represent the pin's failure time where FP calculation stops according to the guideline. While the empty circles represents the pin's failure time by continuing calculation FP values beyond their credible domain. The dotted lines is the Channel 2's failure time

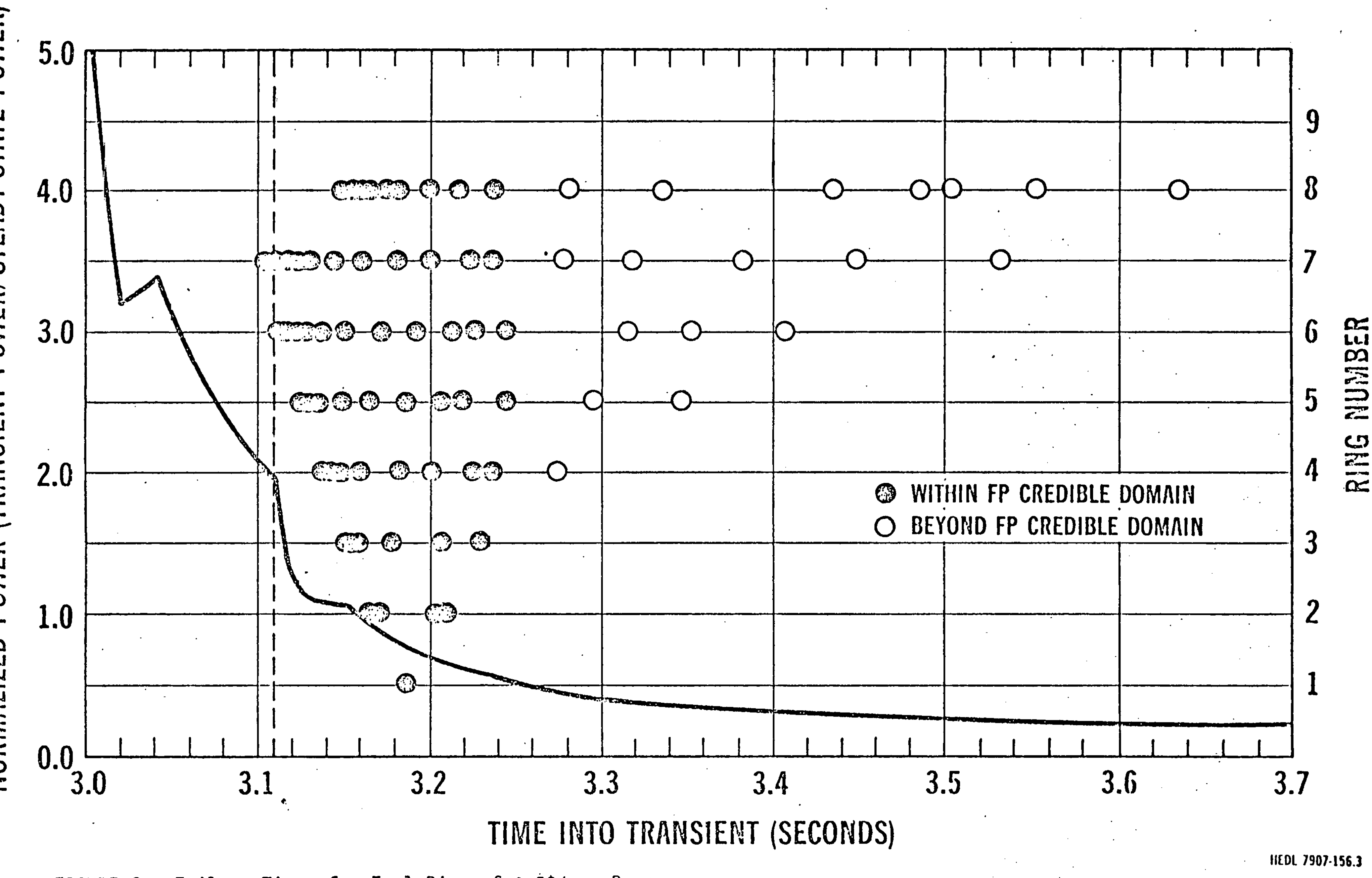

FIGURE 6. Failure Times for Fuel Pins of 0.5$/sec Ramp.

from MELT's calculations. The accident power history is also plotted in the Figure. The curve is plotted in terms of the ratio of the transient power level to steady-state power. Only two pins failed slightly before the MELT's Channel failure time at 3.104 sec and 3.107 sec into the transient. The majority of pins failed within one hundred msec after 3.104 sec. For most pins that have not yet failed, their temperatures of fuel and cladding begin to decrease uniformly somewhere after 3.220 sec. The frequency of pin's failing event decreases substantially after 3.240 second of the transient. It is believed that the possibility of these failing events which can not be ruled out completely may decrease substantially as transient progresses into later time since after 3.240 sec the transient power is far below the steady-state power level. The calculation of present study had been actually carried on up to six seconds when all the FP values of non-failed pins had been decreased and yet no single pin in ring 9 failed.

CONCLUSION

It is concluded that, based on present analysis with the consideration of blockage formed after pins failure, the peripheral pins within an FTR subassembly indeed survive permanently for a .5$/sec ramp. A limited damage to the outer pins, especially the peripheral pins, due to the presence of fuel blockage has been observed in this study. This is because the earlier blockage is formed at a favorable axial location (near the end of fuel zone) and at a down-fall of the power level simultaneously. There are several road-blocks remained, such as MFCI model added after fuel pin's failure, etc. that should be overcome before a confident prediction on the long-term coolability can be stated for a TOP accident. However, it is believed that the conclusion drawn here will be held without basic changes.

REFERENCES

1. S. C. Yung and N. P. Wilburn, "Failure Pattern Within an FTR Subassembly under a TOP Accident," Trans. Am. Nucl. Soc., 27, 536 (1977).

2. S. C. Yung and N. P. Wilburn, "Effect of Power Skew on the FTR TOP Accident," Trans. Am. Nucl. Soc., 28, 475 (1978). Also HEDL-SA-1463FP Hanford Engineering Development Laboratory, Richland, WA, June 1978.

3. F. E. Dunn, et al., The SAS3A LMFBR Accident Analysis Computer Code, ANL/RAS 75-17, Argonne National Laboratory, Argonne, IL, April 1975.

4. A. E. Waltar, et al., MELT-III: A Neutronics, Thermaal-Hydraulics Computer Program for Fast Reactor Safety Analysis, HEDL-TME 74-47, Hanford Engineering Development Laboratory, Richland, WA, December 1974.

5. S. C. Yung, COBRA-III/MELT: A Computer Code for Analyzing Thermal-Hydraulic Behavior in Large LMFBR Pin Bundles, HEDL-TC-653, Hanford Engineering Development Laboratory, Richland, WA, October 1976.

6. N. P. Wilburn, Improved Subassembly Grouping for Multi-channel TOP-HCDA Safety Analysis, HEDL-TME 77-25, Hanford Engineering Development Laboratory, Richland, WA, August 1977.

7. N. P. Wilburn, et al., An Update Assessment of the Unprotected Transient Overpower Accident in the FTR, HEDL-TI-75285, Hanford Engineering Development Laboratory, Richland, WA, October 1977.

8. R. E. Baars, et al., "HEDL Empirical Correlation of Fuel Pin TOP Failure Thresholds - Status 1976," ANS Proc. International Meeting on Fast Reactor Safety and Related Physics; October 1976, Vol. IV, p. 1673-1678.

9. L. W. Deitrich et al., "Summary and Evaluation of Fuel Dynamic Transient Overpower Experiment," ANL-77-44, Argonne National Laboratory, Argonne, IL, June 1977.

10. B. W. Spencer et al., "CAMEL Seven-Pin Fuel Sweepout Tests," Trans. Am. Nucl. Soc., 29, 443 (1978).

11. CRBR PSAR April 1975, Appendix F.

12. M. H. Fontana, et al., "Thermal-Hydraulic Effects of Partial Blockages in Simulated LMFBR Fuel Assemblies with Applications to the CRBP," ORNL-TM-4779, (1975).