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EFFECTS OF TRANSIENT POWER HISTORIES ON THE INTRASUBASSEMBLY FAILURE INCOHERENCIES

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EFFECTS OF TRANSIENT POWER HISTORIES ON THE INTRASUBASSEMBLY FAILURE INCOHERENCIES

by

S. C. Yung

In this talk, I will present my findings on the effects of different Transient Power Histories on the intrasubassembly failure incoherencies in an unprotected Transient Overpower (TOP) Hypothetical Core Disruptive Accident (HCDA). In this context, I will first discuss the historical background of this subject; then, I will briefly describe the method, the computational tool and other relevant points of present analysis. The computational results from the analysis will be also discussed, and finally, the summary of the present study will be stated.

A comprehensive analysis of TOP accidents in the Fast Test Reactor (FTR) was released in 1975 from HEDL[1]. Since then, efforts to upgrade the TOP accident assessments have been initiated. One of these efforts is to examine the pattern of fuel pin failure within the FTR subassembly. The reasoning behind this effort is due to following considerations. The computational tool used in the 1975 TOP report was the MELT-IIIA code[2], which is an integrated neutronics thermal-hydraulic safety analysis code. In this code, one single fuel pin and its associated coolant path (its so-called "channel"), was used to model one subassembly or a cluster of subassemblies of the FTR core. This model implies that all 217 pins within a given FTR subassembly behave in an identical manner, or, conversely, that a single average pin can reasonably represent an entire subassembly behavior.

However, it was realized that there are two dominant factors which would cause an inherent fuel pin failure pattern to develop within subassemblies during the course of a postulated accident sequence. The first is the hydraulic effect; i.e., the variation in power to effective-coolant-flow ratio between those pins in the inner region and those in the outer region of the subassembly; and the <u>second</u> is the power skew; i.e., the variation in pinwise power density for pins throughout the subassembly. As a result of these conditions, the failure times and axial failure location of the fuel pins within an FTR subassembly under a postulated TOP transient are anticipated to vary significantly across the subassembly. Thus, the study on intrasubassembly failure incoherency was deemed warranted.

The computer codes available for detail analysis within a subassembly are COBRA series[3,4] and other similar thermal-hydraulic subchannel analyses codes. These codes can be utilized to predict individual fuel pin failure characteristics (failure time, axial location of failure, molten fuel inventory, etc.) if proper modifications and detailed fuel pin models are added to them.

However, these COBRA series codes do not have the integrated neutronic package as do MELT and SAS[5] to simulate the accident transient itself. A decision was thus made to use a two-pronged approach to the intrasubassembly failure incoherency studies:

1) One of the COBRA-IIIM[4] codes would be upgraded to study the problem; and
2) The accident power history needed as an input for the upgraded code COBRA/MELT[6] would be provided by MELT calculations. It was thought at the time that, since MELT used average values for its pin and associated coolant path calculation, the power history generated by MELT would be reasonably representative.

Two papers on the intrasubassembly failure incoherencies[7,8] using this approach, were reported the 1977 and 1978 ANS meetings for the hydraulic effect and power skew cases. The results of the power skew case are illustrated in slides 5 and 6 for pin failure sequences and failure times where the regular 7-channel grouping power history[9] was used. It can be seen that the span of failure times is of the order of hundreds of msecs for a 50¢/sec ramp. This time span is of the same order as the MELT-predicted time span between subsequently failing channels.

It was concluded that the single-pin model, as used in MELT and SAS codes, is not representative, and a subgrouping approach with more than one representative pin is needed for codes like MELT and SAS to simulate the pins in different regions within a subassembly.

The validity of using the MELT-generated power histories has long been a point of contention, because we all realized the intertie between TOP transient power and the fuel motion within the pin, as well as the fuel that is squirted out of the pin after pin failure. In addition, the observation of widespread fuel pin failure times within a subassembly suggested that an examination of the validity and the effect of the transient power histories is warranted. It is to this subject the present paper is addressed.

A tentative subgrouping study with MELT,[10] using two representative pins to simulate the pins in the inner and outer regions of the subassembly, indeed displays a noticeable difference in its calculated transient power history from the one calculated by standard grouping.

Slide 9 shows the two transient power histories from MELT's 7-channel calculations of 50¢/sec ramp for the beginning-of-cycle-4 (BOC-4) core of FTR. The dotted line curve is the regular 7-channel results. The solid curve is the one with subgrouping; the latter is believed to be more representative. These two TOP transient histories will be used to learn how the different transient histories will affect the assessments and the conclusions of intrasubassembly incoherency analyses.

Recently, a non-mechanistic blockage model has been implemented into the COBRA/MELT code for studying the fuel blockage effect on the long-term survivability of peripheral fuel pins.[11] I have taken advantage of this latest version of the code in the present analysis. Considering fuel blockage formation allows us to make prolonged calculations down to the TOP transient of quasi-steady-state. The present analysis will follow the same method of modelling the blockage as the Seattle report.[11] A subassembly belonging to channel 2 of the 7-channel grouping[9], as shown in slides 11 and 12, was used in the present analysis. The reasons and constraints of selecting this subassembly were presented in the 1978 ANS meeting[8] and will not be repeated here.

The fuel pin failure criterion used in the present study is the Failure Potential (FP) model[12], a HEDL empirical correlation of fuel pin TOP failure thresholds. This criterion had been used in previous studies[7,8]. In the present study, however, a prolonged computation for the FP of each fuel pin up to the quasi-steady state of the simulated accident transient is performed. Unfortunately, the validity of FP calculation is quite uncertain in the down-fall of power transient.

It was suggested[12] that the calculation should stop when the thermal damage term in the FP formula, as shown in slide 13, reaches its peak value for survived pins. In the base calculation, the FP correlation was used within its recommended domain of validity. At the time that the recommended domain of validity was exceeded, it appeared that additional fuel pin failures might still be possible. Therefore, a conservative calculation was made using the FP correlation beyond its recommended domain, thus resulting in additional fuel pin failures.

The fuel pin failure patterns for the recommended FP domain are illustrated in slides 14 and 15. In these slides, the fuel pin in the center of the FTR subassembly is designated as ring 1 and the ring number increases as teh ring moves outward. There are nine rings and 217 pins in an FTR subassembly.

Slide 14 shows the results from the subgrouping power history. It is predicted that 32 more fuel pins in rings 1 through 8 will survive in addition to all pins in ring 9 (peripheral fuel pins). However, when the regular power history is used as shown in slide 15, <u>all fuel pins</u> in rings

1 through 8 are predicted to fail, but peripheral pins still survive in this regular transient. The use of the regular transient causes 32 more fuelpins to fail in comparison with the results by using the subgrouping power history. That is the profound effect of using different power histories. The effect overshadows the blockage effect for TOP analysis, because in an earlier report(11), the consideration with and without fuel blockage formation only causes a small increase of the number of pin failures when the subgrouping power history was used.

In both transients, the predicted axial locations of pin failures are at 38 cm above the midplane of the core for pins in rings 1 to 7 and at 23 cm above midplane for pins in ring 8.

For cases in which the FP calculations were allowed to continue beyond their recommended domain, the results were significantly different and are illustrated in slides 16 and 17. Inherent in the FP formulation was an over-estimation of pin failure severity after peak in power down-fall of a prolonged transient. Even in this extremely conservative approach, when the subgrouping power history was used, as shown in slide 16, failure was predicted for all pins from rings 1 to 8; however, all the peripheral pins survived intact. On the other hand, the results shown in slide 17, using the regular transient history, show that the failure pattern was much more severe. Almost all but 6 peripheral pins failed. Nevertheless, the axial locations of failure for peripheral pins were moved further down either at 8 cm or at 13 cm above midplane.

To illustrate the pin failure events clearly, the pin failure data were plotted in time coordinates vs. ring number and are shown in slides 18 and 19. In these slides, the fuel pin failure events for the recommended FP domain are identified by small solid circles, while the failure events calculated by using the FP correlation beyond its recommended domain are identified by small empty circles.

The data calculated from subgrouping power histories are shown in slide 18. The two vertical dotted lines at 3.109 sec and 3.346 sec in this slide are the failure times of the inner and of the outer representative pins of channel 2 from MELT simulation. The subgrouping transient power history is also plotted in the slide. The curve is normalized to the steady-state power.

Almost all failure times represented by solid circles (events calculated within FP valid domain) occurred later that the predicted failure time of the inner representative pin of the MELT calculation. For physical reasoning, it was anticipated that the MELT failure time of inner representative pins would fall somewhere in the neighborhood of time average of the failure pins in the inner rings (rings 1 to 8) of the subassembly. Therefore, it is felt that the power history for the tentative subgrouping was slightly underestimated.

The majority of fuel pins have failed within one hundred msec after the initial failure. For most pins that failed after 3.22 sec (events calculated beyond the FP valid domain and represented by empty circles), their fuel and cladding temperature actually began to decrease before their calculated failure time. The occurrence of fuel pin failures decreases substantially after 3.24 sec. Although the possibility of these failure events cannot be ruled out completely, they would be expected to decrease substantially as the transient power is reduced far below the steady-state power level. In the present study, the calculation was continued up to six seconds into the transient when FP values of all non-failed pins were decreasing, and no fuel pin in ring 9 was predicted to fail.

Now let's look at slide 19 where the results were calculated by use of the regular transient power history. The vertical dotted line in this slide is at 3.213 sec. Since the regular power history was used, there was one single pin to represent a subassembly, therefore there is only one failure time for channel 2. All the pins, without exception, in rings 1 through 8 were predicted to fail and almost all failed earlier than MELT calculated failure time for the channel. It is quite clear that the regular grouping overestimated the power level of the TOP transient. After a relatively long time lapse of about 300 msec from the failures of inner group, most of the peripheral fuel pins in the ninth ring were predicted to fail. Since these peripheral fuel pin failures were predicted to occur at a much lower axial level, moreover, they failed much later and contained less molten fuel inventory. Therefore, it is expected that a total flow blockage would not occur.

The difference in results obtained by using the two different power transients in the present study led to quite different failure sequences; this would have a significant impact on the probability of retaining long-term coolability for TOP accident.

In summary, the correct power history is one of the key factors in assessing intrasubassembly failure incoherencies in a TOP accident. In order to obtain a reliable TOP accident power history, it is felt that refinements in the Code are needed in the following areas:

- Subgrouping technique
- Neutronic integration
- Internal fuel movement model
- Fuel squirted model and blockage simulation

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CONTENTS

- BACKGROUND
- PRESENT ANALYSIS
- SUMMARY

SLIDE 2.

BACKGROUND

- INTEGRATED LMFBR SAFETY CODES: SAS, MELT
- SUBCHANNEL THERMAL-HYDRAULIC CODES: COBRA, SABRE

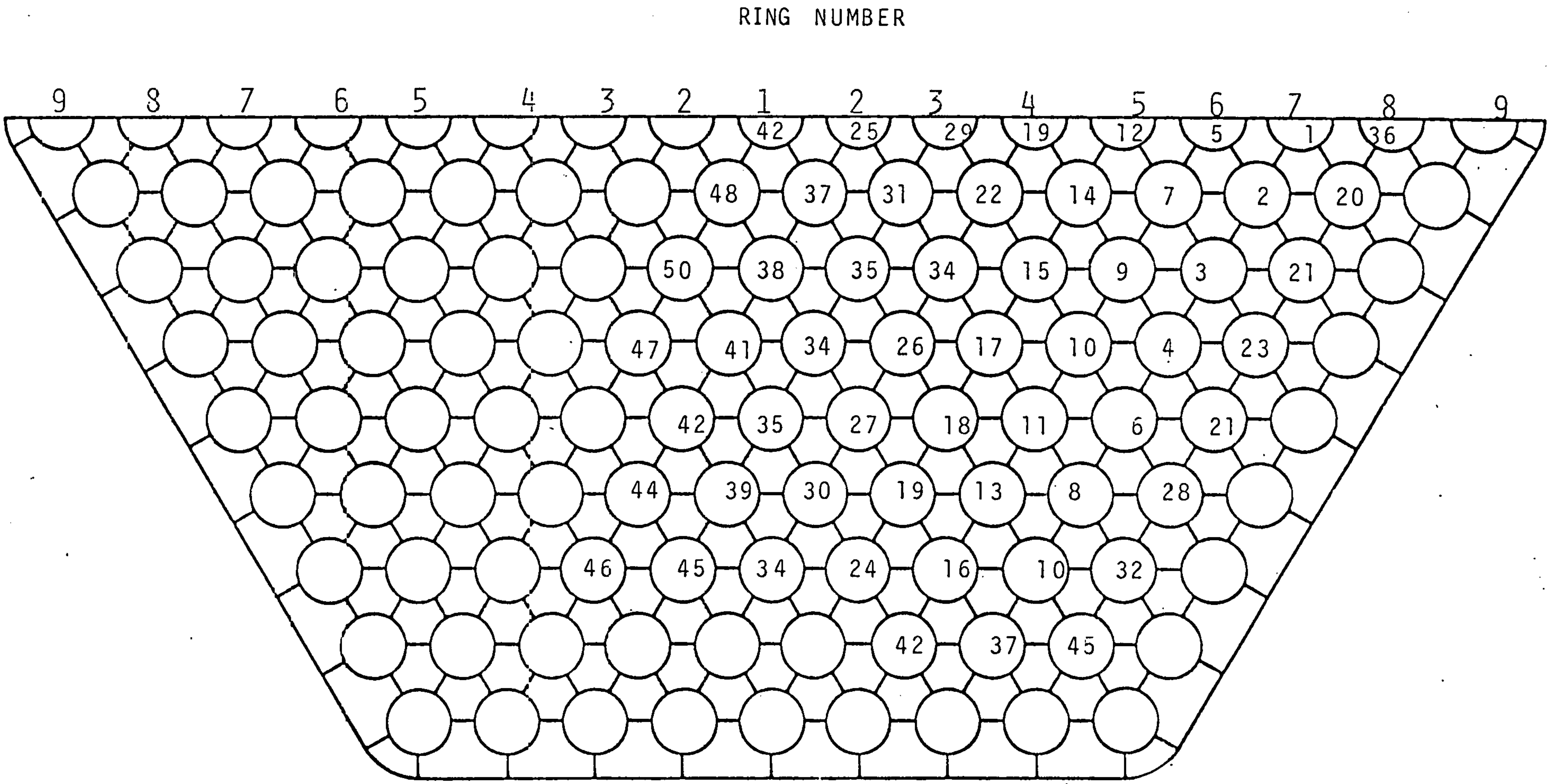
SLIDE 3.

ASSUMPTION OF PREVIOUS STUDIES

THE POWER HISTORY CALCULATED FROM MELT IS VALID.

SLIDE 4.

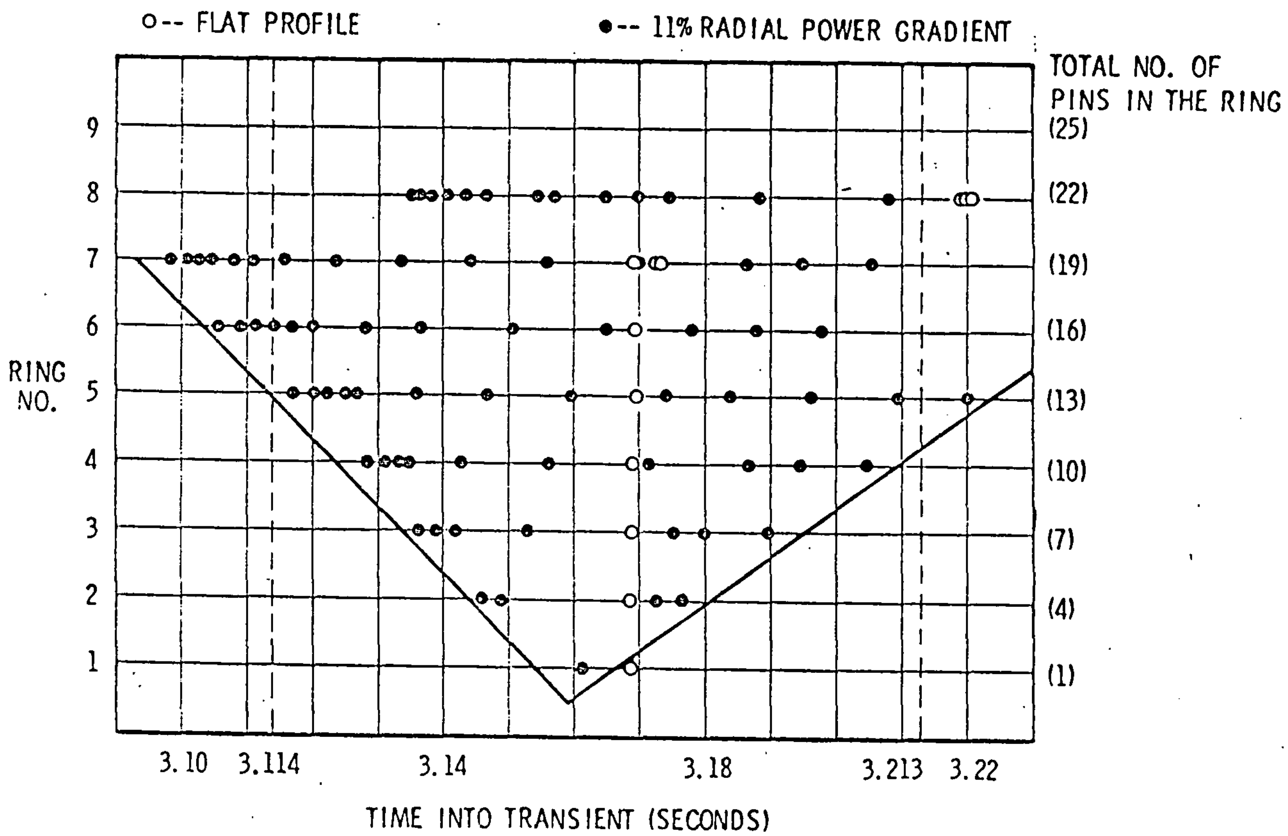
FAILURE PATTERN - PREVIOUS ANALYSIS



(Number inside the fuel pin indicates the failure sequence)

SLIDE 5. Fuel Pin Failure Pattern for a .5$/sec Ramp in an FTR Subassembly with Power Skew for BOC-4 Core.

FAILURE TIME - PREVIOUS ANALYSIS



SLIDE 6. Failure Times for Fuel Pins in an FTR Subassembly During 0.5$/sec Ramp: Channel 2 of a 7-Channel Grouping of FTR BOC-4 Core.

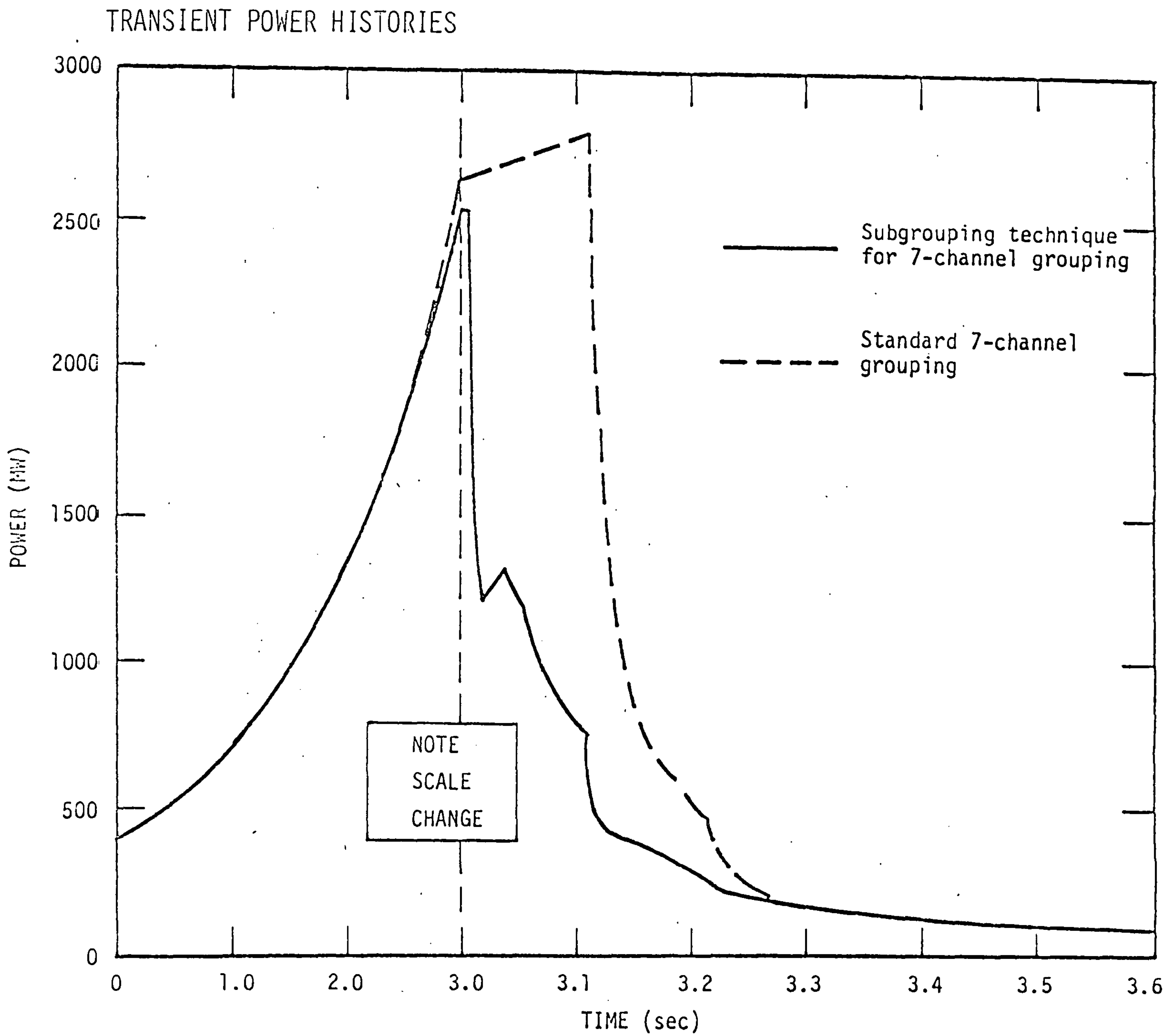
TIME SPAN OF FAILURE EVENTS = 0 (100 MSEC)

SLIDE 7

TOP POWER HISTORY

- FUEL MOTION
  - WITHIN THE PIN
  - SQUIRTED OUT OF THE PIN
- WIDE SPREAD OF FAILURE EVENT

SLIDE 8



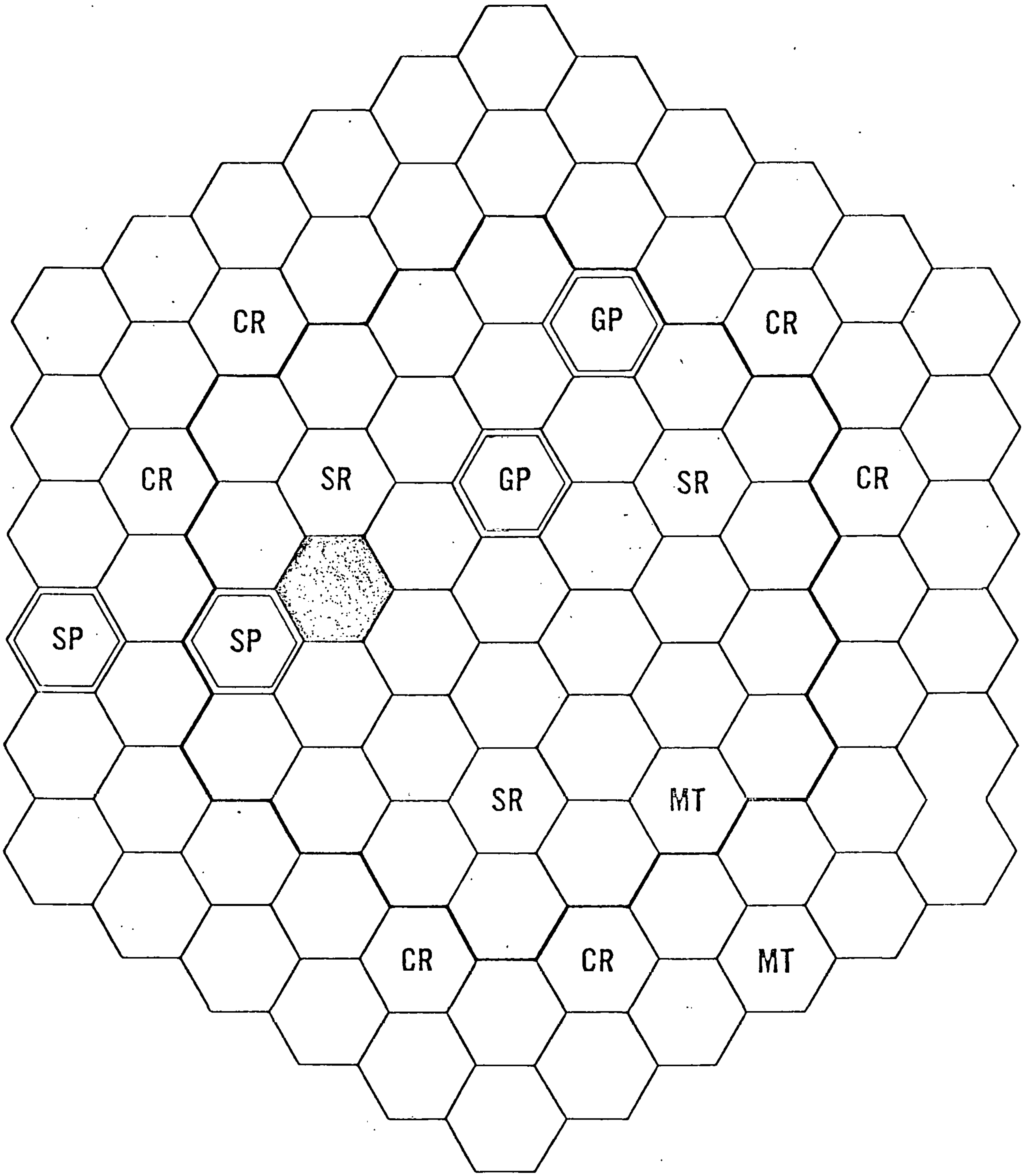
SLIDE 9. BOC-4 Power vs. Time (0.5$/sec TOP)

EFFECT OF DIFFERENT POWER HISTORIES

- FAILURE PATTERN
- LONG-TERM COOLABILITY ASSESSMENT

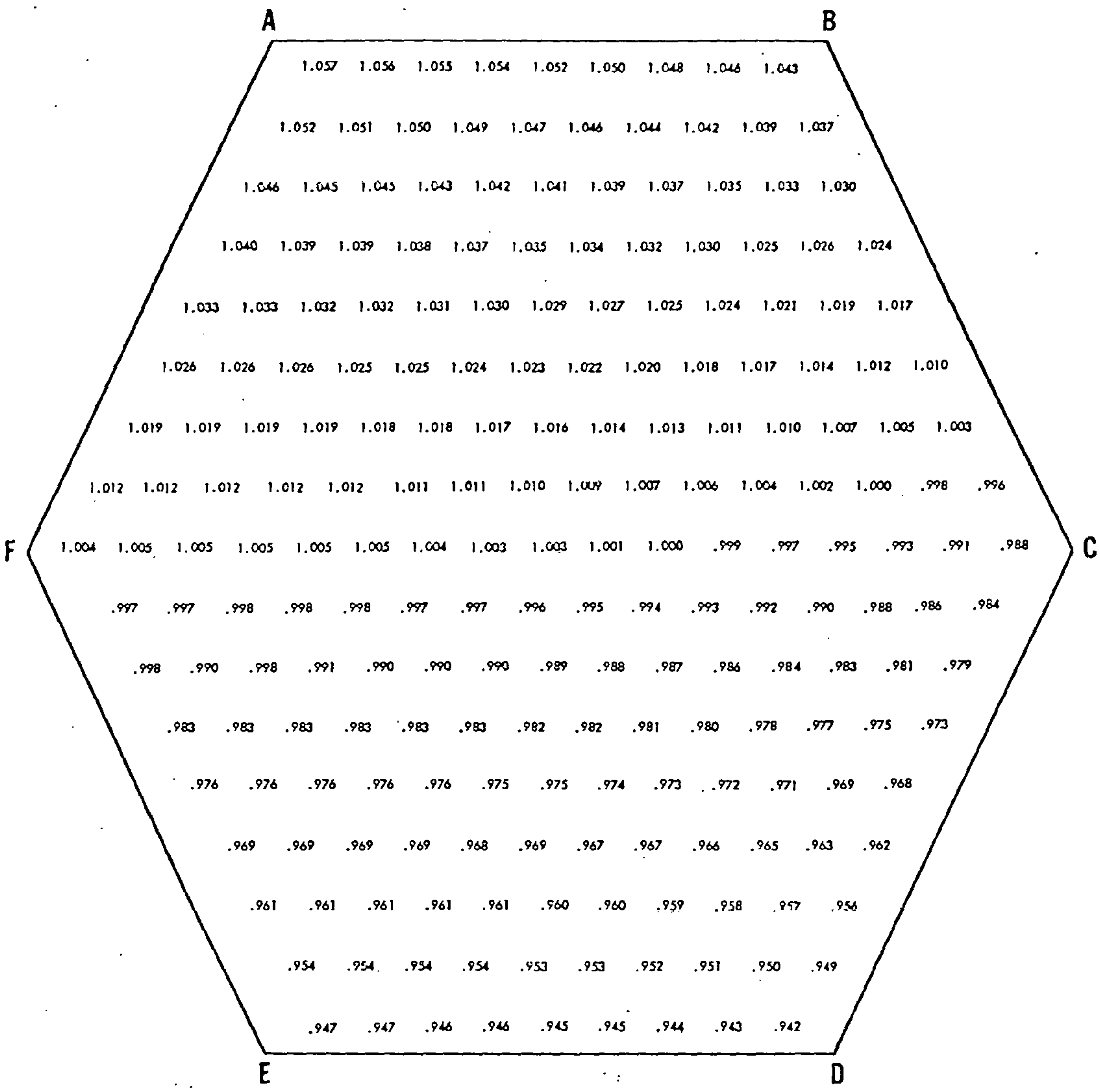
SLIDE 10.

FTR BOC-4 CORE



SLIDE 11.

PINWISE POWER DENSITY



SLIDE 12. Pinwise Power Densities of FTR Subassembly Belonging to Channel 2 Normalized by Subassembly Average at Mid-Core Layer.

FAILURE CRITERION - FAILURE POTENTIAL

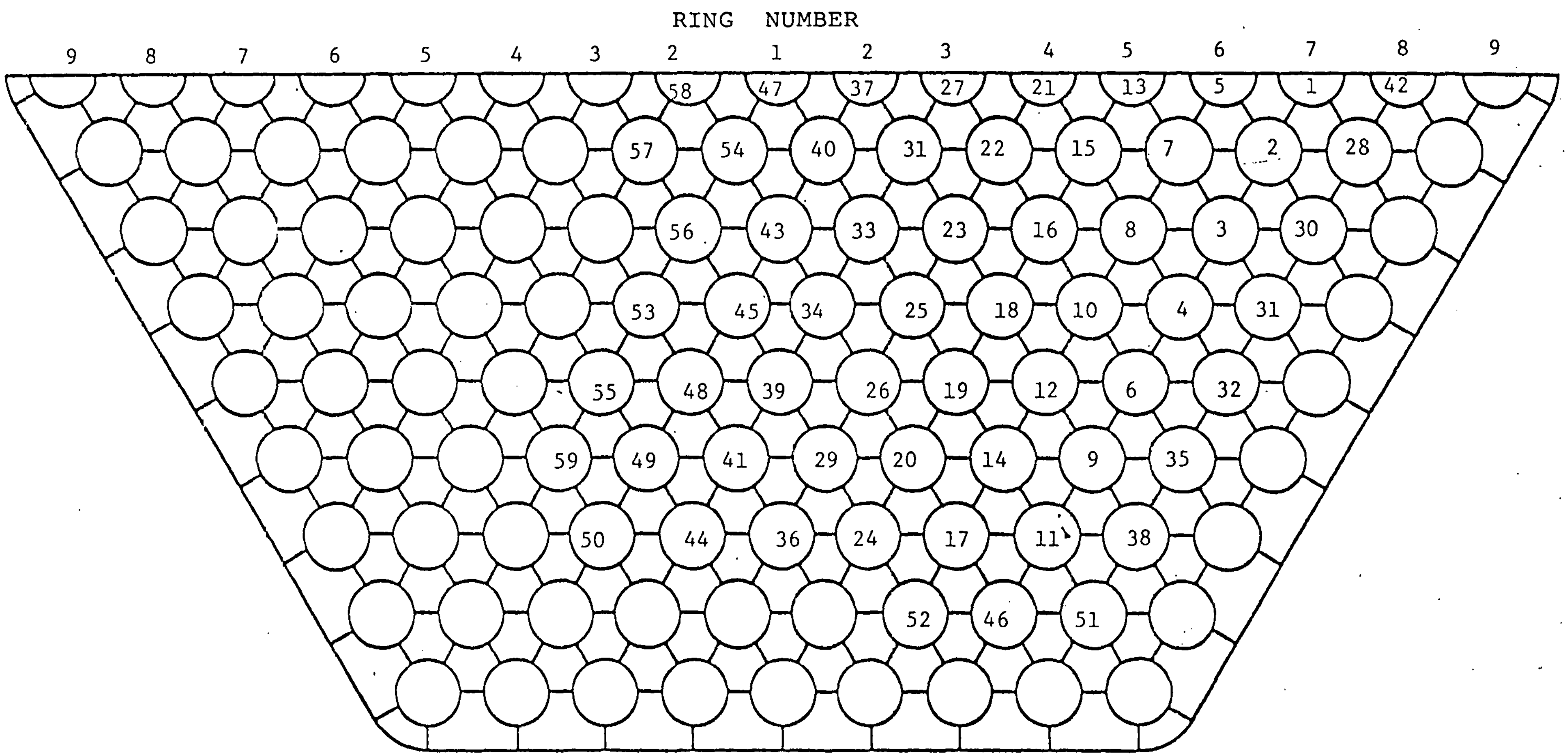
$$FP = \left(\begin{array}{l}\text{Fuel Pin}\\ \text{Microstructure}\end{array}\right) \cdot \left(\begin{array}{l}\text{Thermal}\\ \text{Damage}\end{array}\right) \cdot \left(\begin{array}{l}\text{Time Into}\\ \text{Transient}\end{array}\right)$$

$$= A \exp(cs)\, D^{D} \left(\frac{\Delta H}{Y}\right) t^{B}$$

- STOP AFTER $(\Delta H/Y)$ REACHES ITS PEAK VALUE
- CONTINUE BEYOND $(\Delta H/Y)$ REACHES ITS PEAK VALUE

SLIDE 13.

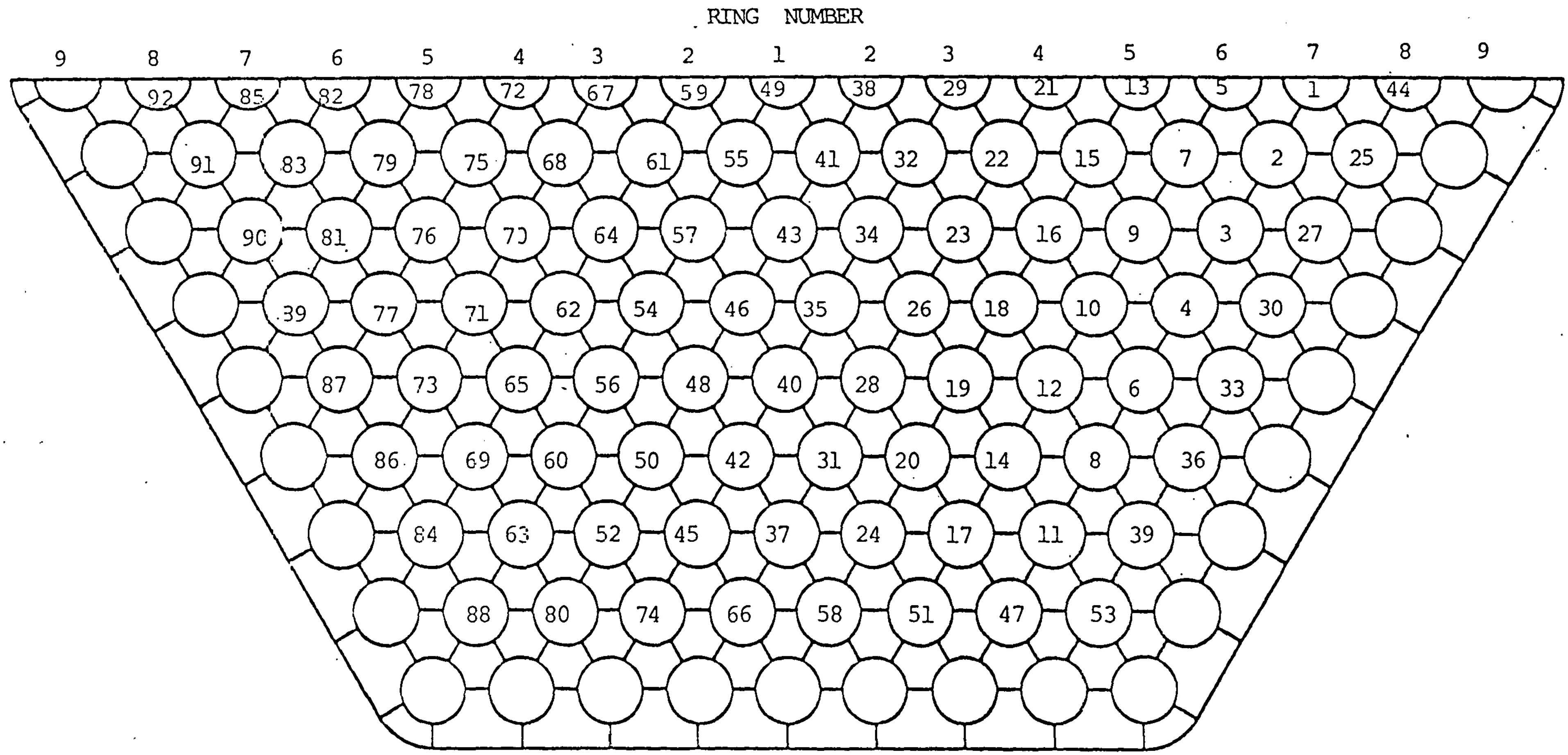
FAILURE PATTERN



(number inside the pin indicates the Failure Sequence)

SLIDE 14, Fuel Pins Failure Pattern with Consideration of Fuel Blockages by Using Subgrouping Power History (FP calculations Stop According to Guideline)

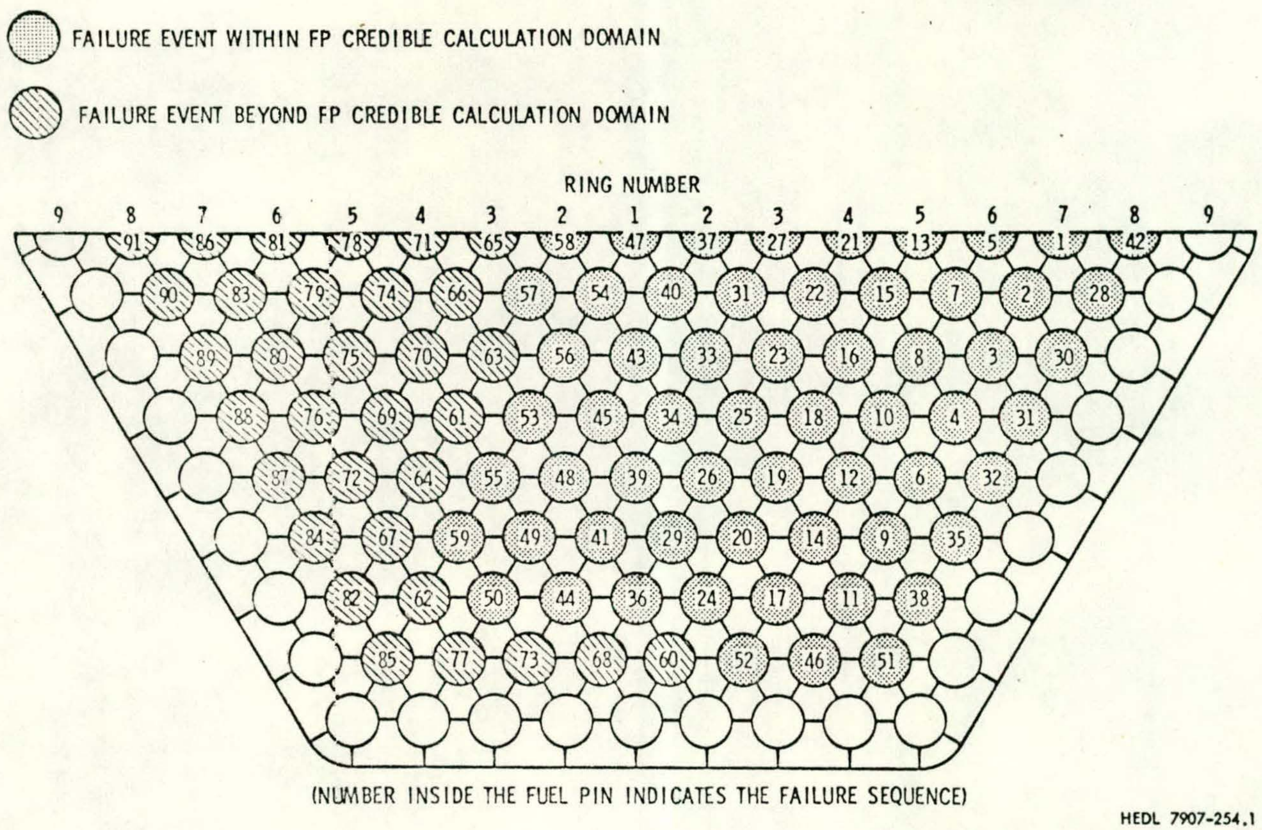
FAILURE PATTERN



(number inside the pin indicates the Failure Sequence)

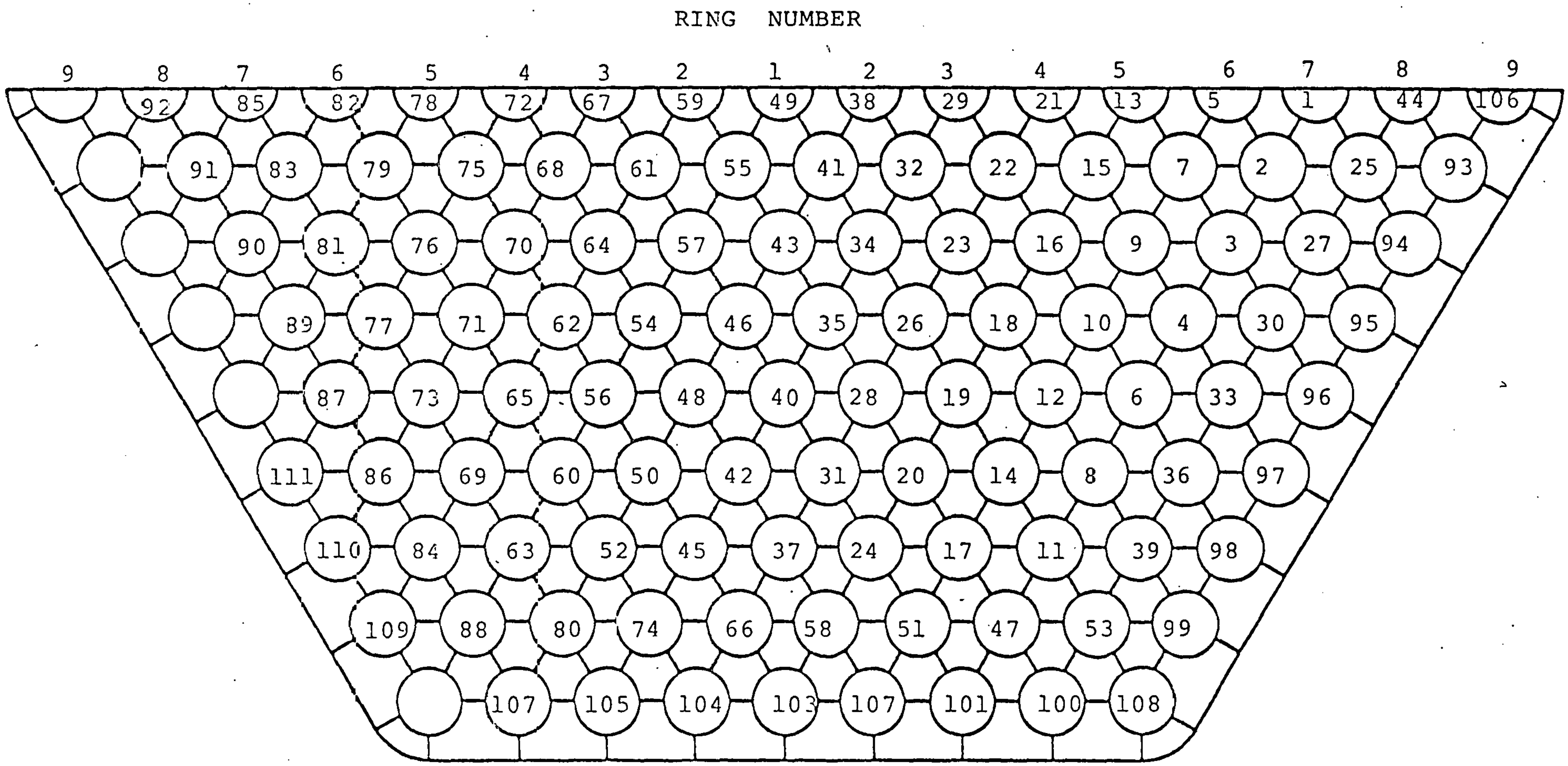
SLIDE 15. Fuel Pins Failure Pattern with Consideration of Fuel Blockages by using Standard Power History (FP calculations Stop according to Guidelines)

FAILURE PATTERN



SLIDE 16. Fuel Pins Failure Pattern with consideration of Fuel Blockage by using Subgrouping Power History (FP Calculation Continued until FP value decreased).

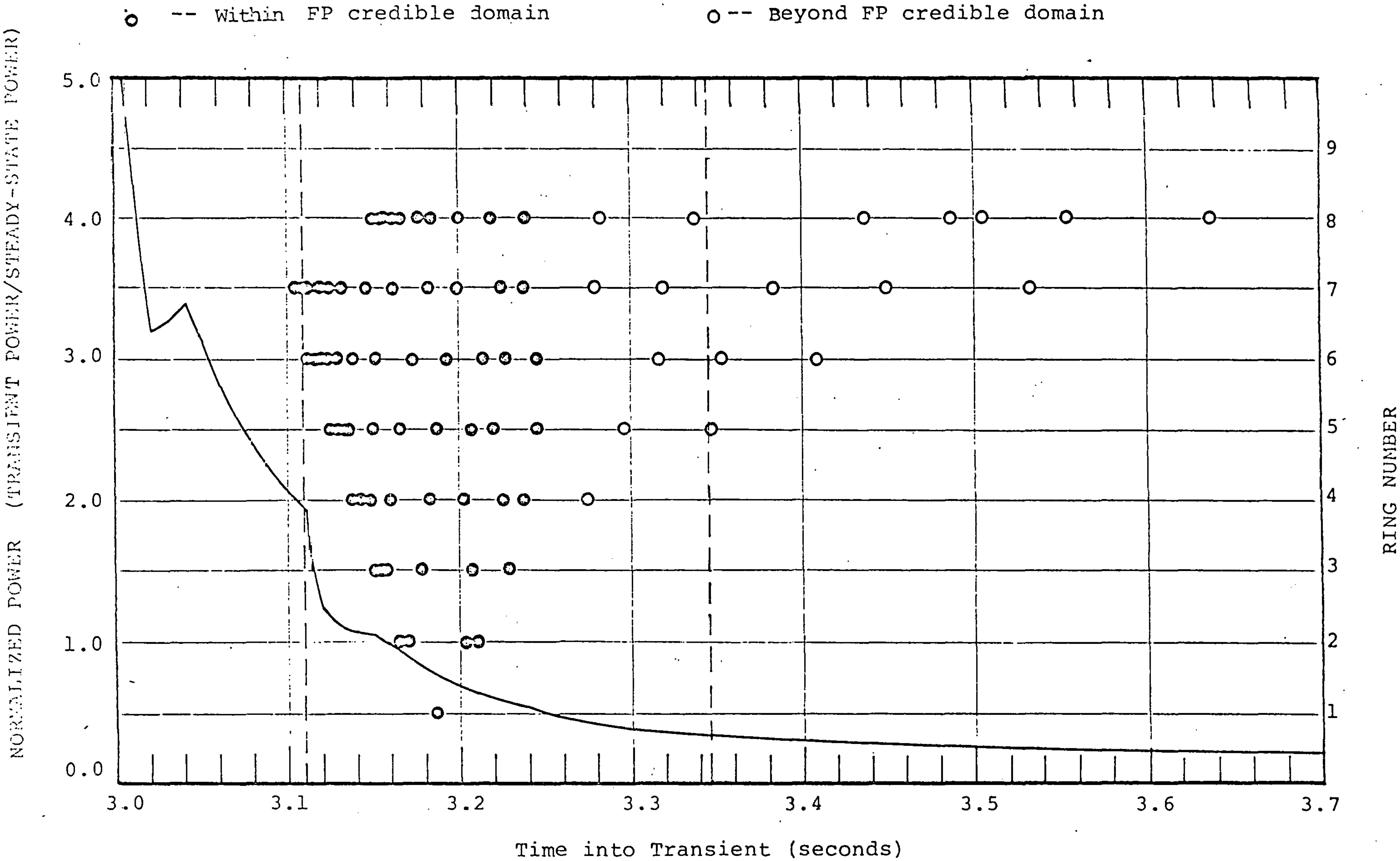
FAILURE PATTERN



(Number Inside the Fuel Pin indicates the failure Sequence)

SLIDE 17. Fuel Pins Failure Pattern with consideration of Fuel Blockage by using standard Power History (FP Calculation Continued Until FP Value Decreased)

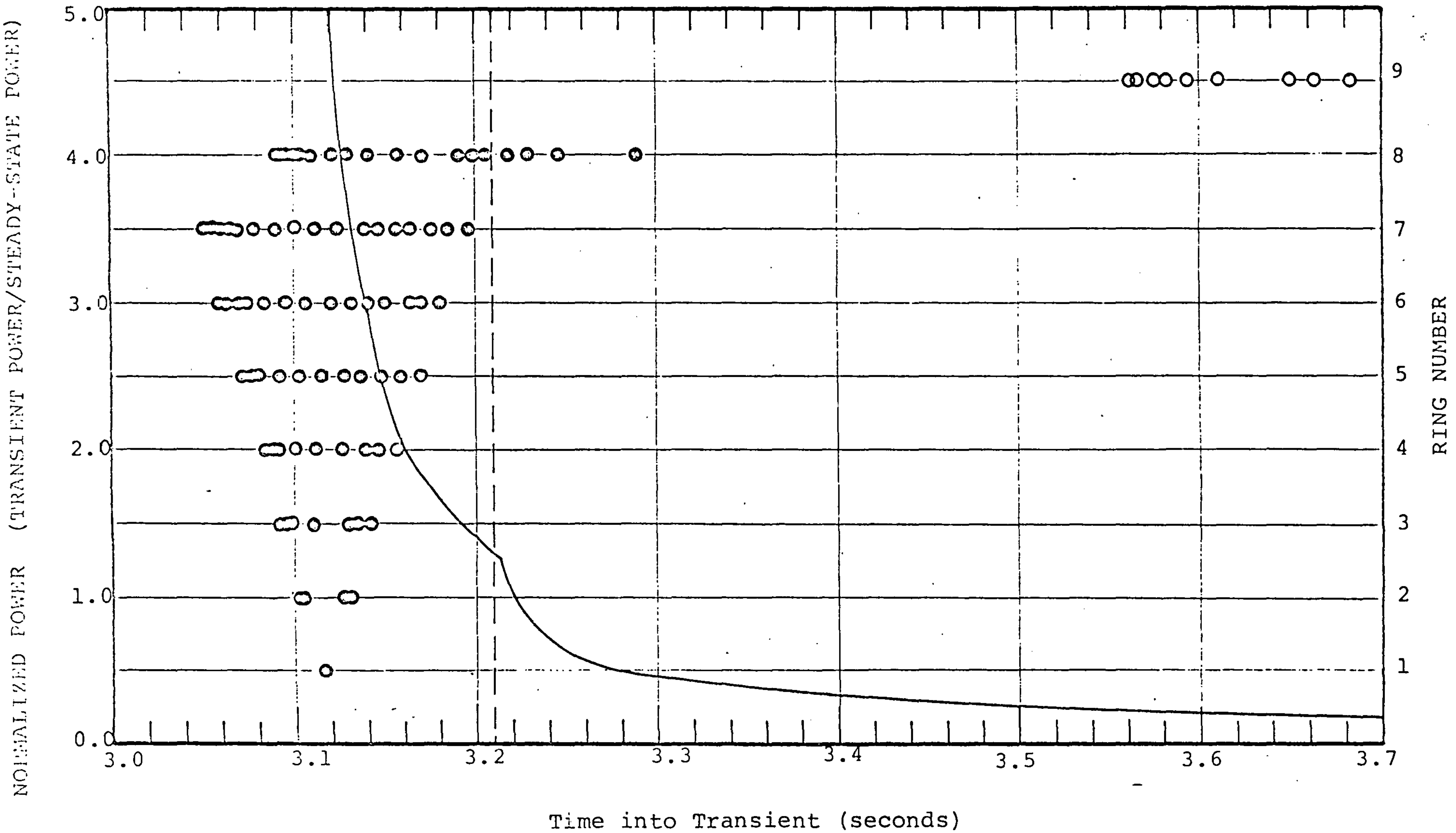
FAILURE TIME - SUBGROUPING POWER HISTORY



SLIDE 18. Failure Times for Fuel Pins by use of Subgrouping Power History at .5$/sec Ramp.

FAILURE TIME _ REGULAR POWER HISTORY

o - Within FP credible domain   o -- Beyond FP credible domain



SLIDE 19. Failure Times for Fuel Pins by Use of Standard Power History at .5$/sec Ramp.

SUMMARY

- INTEGRATED NEUTRONICS
- SUBGROUPING TECHNIQUE
- INTERNAL FUE MOVEMENT
- FUEL SQUIRTED OUT AND BLOCKAGE

SLIDE 21.

EFFECT OF DIFFERENT POWER HISTORIES

- FAILURE PATTERN
  (NOTICEABLY DIFFERENT)
- LONG-TERM COOLABILITY ASSESSMENT
  (SIGNIFICANT)

SLIDE 20.