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BREACHED FUEL LOCATION IN FFTF

BY DELAYED NEUTRON MONITOR TRIANGULATION

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NOTICE

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INTRODUCTION

The Fast Flux Test Facility (FFTF) features a three-loop, sodium-cooled 400 MWt mixed oxide fueled reactor designed for the irradiation testing of fuels and materials for use in liquid metal cooled fast reactors. To establish the ultimate capability of a particular fuel design and thereby generate information that will lead to improvements, many of the fuel irradiations are continued until a loss of cladding integrity (failure) occurs. When the cladding fails, fission gas escapes from the fuel pin and enters the reactor cover gas system. If the cladding failure permits the primary sodium to come in contact with the fuel, recoil fission products can enter the sodium. The presence of recoil fission products in the sodium can be detected by monitoring for the presence of delayed neutrons in the coolant. It is the present philosophy to not operate FFTF when a failure has occurred that permits fission fragments to enter the sodium. Thus, it is important that the identity and location of the fuel assembly that contains the failed cladding be established in order that it might be removed from the core.

Location of failed fuel in FFTF is presently accomplished through the use of a tag gas system. Each of the fuel pins in an assembly is pre-loaded with a unique isotopic composition of the noble gases xenon and krypton. When a cladding breach occurs, this tag gas is released along with the fission product gas. The presence of the radioactive fission gas triggers an alarm and a sample of the cover gas is taken and analyzed by a mass spectrometer to determine the composition of the tag that is present. This system has worked perfectly in FFTF to date; however, at times more than one assembly in the core contain the same tag and an alternate or backup method has some value. The purpose of this work was to evaluate the use of the delayed neutron monitor (DNM) system signals as a method of locating the failed fuel in the core.

SYSTEM DESCRIPTION

The DNM system for FFTF includes three independent counting systems, one for each of the three primary heat transport system loops as illustrated in Figure 1. Each monitor consists of a boron trifluoride counter inside a thimble within a graphite moderator block placed adjacent to the hot leg pipe containing primary sodium. In the absence of delayed neutron precursors in the sodium, a background count rate in the range 10-20 counts per second is measured. This background is associated with photoneutrons ejected from the deuterium contained in the water associated with the concrete walls of the cells. The background provides a valuable function in that it establishes that the system is operating satisfactorily.

The count rate of a particular DNM counter is dependent on a number of factors: the number of delayed neutron precursors entering the sodium, the fraction of these that enter a particular loop, the transit time from the time of the fission event until the precursors reach the vicinity of the counter, and geometric factors relating to the probability of obtaining a count for each delayed neutron emitted.

$$C_{jk} = F_k P_{jk} K_j T_{jk}$$

where the subscript j is for a loop and k for a core position, C is in counts per second when F is in fission events per second whose fragments enter the sodium, P is the partition fraction, K is the geometric factor, and T is the radiation transfer function, which depends on the transit time. For the purpose of locating the failed assembly, P_{jk} is the key parameter.

In spite of the turbulence and mixing that takes place in the reactor pool above the core, data obtained from a scale model water mockup of the FFTF hydraulic system indicate a relatively stable flow split exists from each core position to each loop. Using the limited hydraulic mockup information that was available, including data from a mockup of the Clinch River Breeder Reactor (CRBR) system, a complete empirical partition matrix was generated for FFTF. Key assumptions in generating this matrix were: the central core position would divide equally among the three loops, the sum of the three loop partition fractions was exactly unity, and each of the three 120° was identical with respect to the loop that it faced. Table 1 illustrates the range of partition factors that were generated by this method.

The domain of proximity method is employed to locate a failed assembly. To use this method, the relative count rate for each loop is obtained by dividing its net delayed neutron signal by the sum of the net delayed neutron signals from all three counters. As in the case of the partition fractions, these relative rates satisfy the relation:

$$\sum_{1}^{3} R_j = 1$$

For each core location k of interest, the quantity d_k is generated, where

$$d_k = \left[\sum_{1}^{3} (R_j - P_{jk})^2 \right]^{\frac{1}{2}}$$

is a measure of the agreement between the two sets of ratios. The smaller the value of d_k, the better the agreement and the more likely the failure is in that core location.

EXPERIENCE TO DATE

During the first six operating cycles, only two cladding failures in experimental fuel assemblies occurred that permitted the release of detectable quantities of delayed neutron precursors. The first of these occurred on August 19, 1984 and was associated with an oxide test assembly located in core position 1201. For about 50 minutes, very low delayed neutron count rates (less than 10 counts per second) were measured on each of the three DNM systems. When normalized, these gave count rate ratios of 0.30:0.48:0.22 for loops 1, 2 and 3. At the end of that time period, the count rates on all three monitors began to increase rapidly, exceeding the arbitrary operational limit requiring the reactor to be manually scrammed. During this transient time, the ratios changed dramatically, with R_2 becoming quite large, as shown in Table 2. This systematic variation is attributed to the difference in transit times from the particular core position to the three counters. The higher count rate ratios stabilized after about thirty seconds, yielding 0.32:0.45:0.23, in quite good agreement with the low count rate ratios.

Table 3 illustrates the results of domain of proximity calculations for the low count rate data. It can be seen that the best agreement is achieved for core position 1201; however, adjacent core positions also have a relatively small value of d_k. A code has now been written that does a d_k calculation for each of the 91 core positions and then lists the results in ascending order to provide a sequential ranking.

In this failure the results of the delayed neutron monitor triangulation was of great value because there were two assemblies in the core that contained the same tag gas. Thus, in the absence of the DNM analysis it might have been necessary to remove both assemblies from the core or to attempt other methods of identification. Actually, gas was released from the assembly when it was raised from the core, further confirmation that it contained the failed pin.

A second cladding failure occurred on April 14, 1985 that permitted delayed neutron precursors to enter the primary sodium. The first release of delayed neutron precursors lasted for about five hours, after which the count rates of the DNM sensors returned to background. Similar events occurred again on April 16, 1985 and April 18, 1985, lasting each time for a few hours at rates just a few counts per second above background. On April 22, 1985, the count rate increased rapidly over about a 30 second time period, requiring a manual scram of the reactor when the arbitrary operating limit was reached.

Results of domain of proximity analyses for the four events are summarized in Table 4. It can be seen that almost identical rankings are obtained for all events except that on April 18, 1985, when the reactor was operating at 75% power for unrelated testing. This indicates that the operating partition fractions for the reactor loading were constant, within the experimental uncertainty over this eight day time period. That is an important result in confirming the applicability of triangulation, minimizing the concern that random variations in the flow would give inconsistent results. The non-consistent results at 75% power (100% flow) indicate that the partition functions are influenced by sodium temperatures and temperature gradients as well as flow rates.

Unfortunately, the April 1985 cladding failure was associated with an assembly located in core position 3304 and was correctly identified by the tag gas system. This core position is about 60° from the positions indicated by DNM triangulation and about three rows closer to the center of the core. This shows that the actual partition function for the particular core loading was extremely different than the empirical matrix derived from hydraulic core mockup data.

CONCLUSIONS

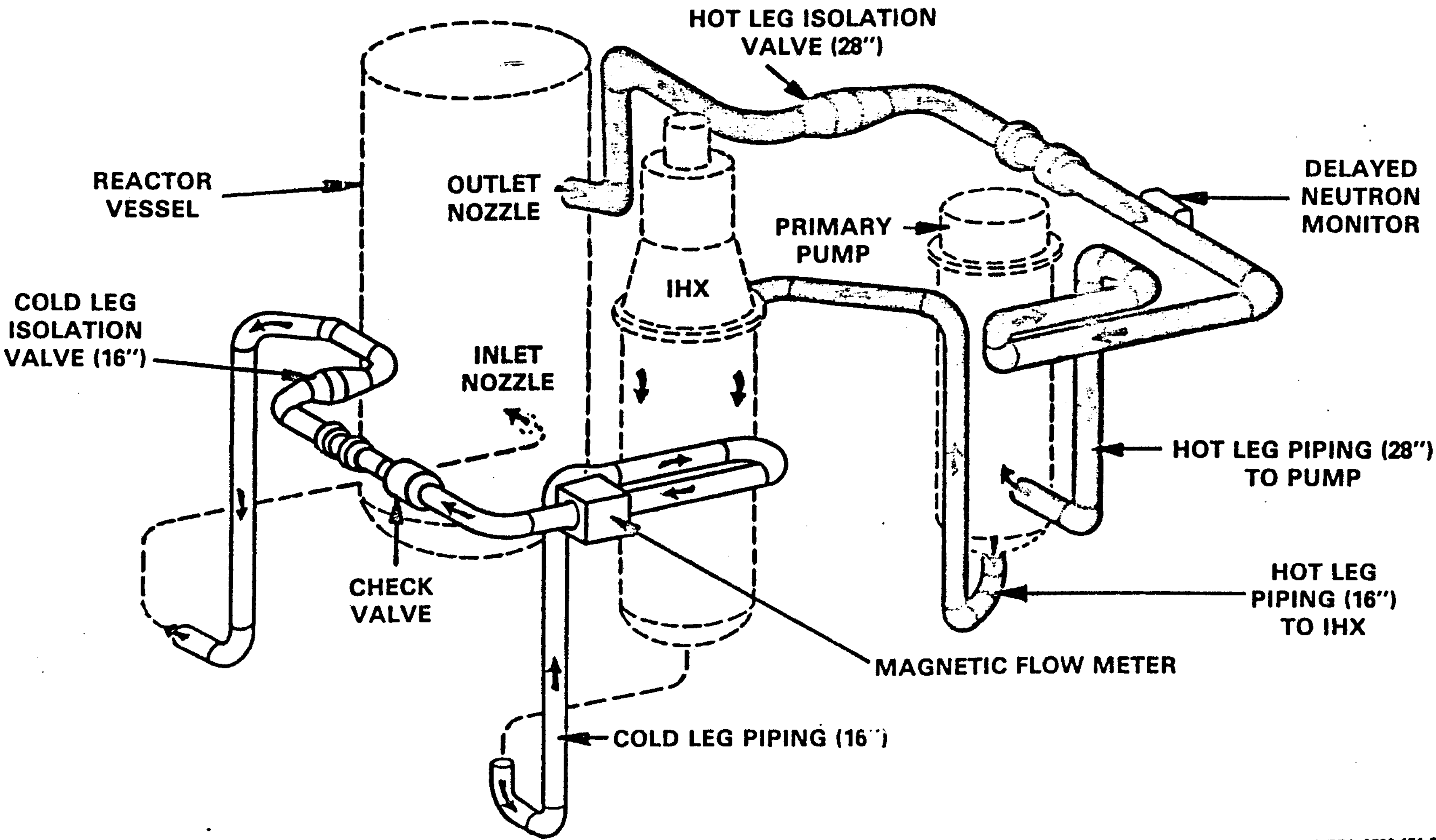
The limited experience gained from triangulation of DNM signals from two events in FFTF has both positive and negative aspects. On the positive side is the fact that the partition matrix for a given loading was constant over a long period of time and returned to the same matrix following intervening power perturbations. A second positive finding is that consistent results can be realized with quite low net count rates (less than 10 counts per second). With continuous on-line monitoring and analysis, early identification of the failure would be possible. A third positive result was the correct location of one of the two failures using the empirical matrix.

On the negative side is the finding that the empirical matrix was significantly in error for the second event, with a translation and rotation magnitude that is outside the expected realm of uncertainty. The relatively large perturbation in the matrix caused by lowering the reactor power (outlet temperature) at a constant flow rate is a second negative finding, indicating that a single partition is not appropriate, severely limiting the practical application of the method.

A large amount of reactor testing time will be required to establish definitively the ultimate applicability of DNM triangulation for location of failed fuel. This would include use of a fission product source at a number of core locations to establish whether or not loading changes influence the partition function, the effect of power changes, the magnitude of either short- or long-term variations associated with random walk of the flow distribution, and the effect of transit time differences. Such testing is not planned at the present time because of obvious impact to on-going programs; therefore, future knowledge will only be gained as the result of future failures that occur. Any support that triangulation calculations give in confirming tag gas identifications of failed assemblies will be of great value because of the large impact on plant capacity factor that can occur if failures are not promptly identified and removed.

Figure 1

LOCATION OF DNM MODERATOR BLOCK



HEDL 8608-151.2

Table 1

SELECTED PARTITION FRACTIONS

CORE POSITION	FLUID PARTITION		
	LOOP 1	LOOP 2	LOOP 3
2101	0.33	0.33	0.33
2201	0.26	0.28	0.46
2301	0.10	0.42	0.48
2401	0.08	0.44	0.48
2501	0.06	0.44	0.50
2601	0.02	0.44	0.54
2603	0.04	0.19	0.77
2605	0.06	0.08	0.86
2607	0.16	0.04	0.80
2610	0.44	0.02	0.54

HEDL 8508-151.9

Table 2

AUGUST 19, 1984 DNM DATA

	RELATIVE COUNT RATES		
TIME	R_1	R_2	R_3
07:33:0	0.19	0.72	0.09
07:33:10	0.24	0.61	0.15
07:33:20	0.26	0.51	0.23
07:33:30	0.33	0.44	0.23

HEDL 8508-151.12

Table 3

AUGUST 19, 1984 DOMAIN OF PROXIMITY RESULTS

j	R_j	P_{jk} k = 1201	k = 1202	k = 1303	k = 1301
LOW COUNT RATE					
1	0.30	0.28	0.26	0.23	0.42
2	0.48	0.46	0.46	0.55	0.47
3	0.22	0.26	0.28	0.22	0.11
	d_k	0.0484	0.0745	0.1004	0.1698
POST SCRAM DATA					
1	0.320	0.28	0.26	0.23	0.42
2	0.452	0.46	0.46	0.55	0.47
3	0.228	0.26	0.28	0.22	0.11
	d_k	0.0518	0.0800	0.1333	0.1634

HEDL 8508-151.13

Table 4

APRIL 1985 FAILURE
DNM TRIANGULATION

DATE	RELATIVE COUNT RATES LOOP 1	LOOP 2	LOOP 3	POWER (%)	LOCATION (d_k RANK) 1	2	3
04/14/85	0.597	0.070	0.333	100	3602	3601	3501
04/16/85	0.597	0.068	0.335	100	3602	3601	3501
04/18/85	0.486	0.132	0.382	74	3301	3401	3501
04/22/85	0.605	0.039	0.356	100	3602	3601	3501

HEDL 8508-151.15

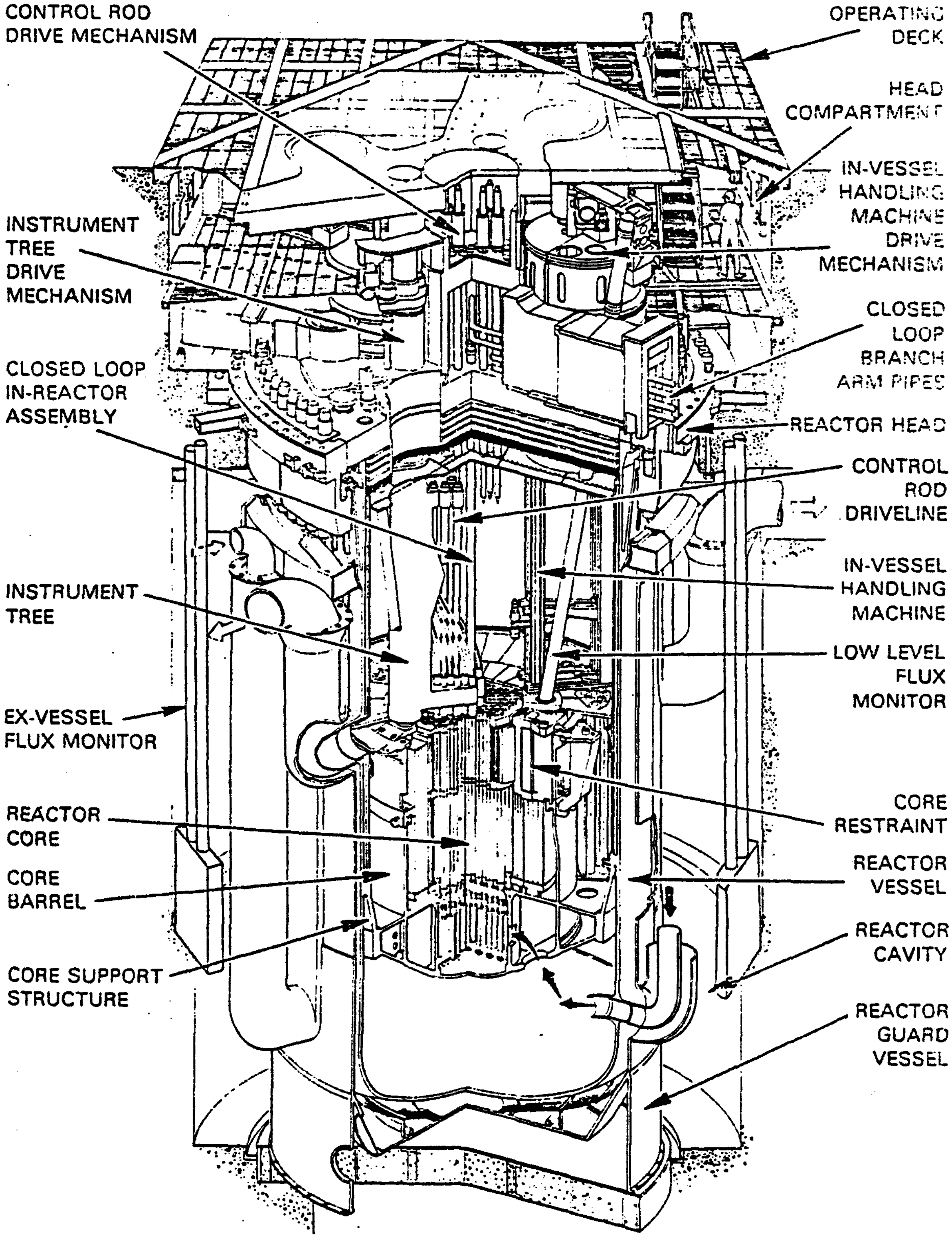
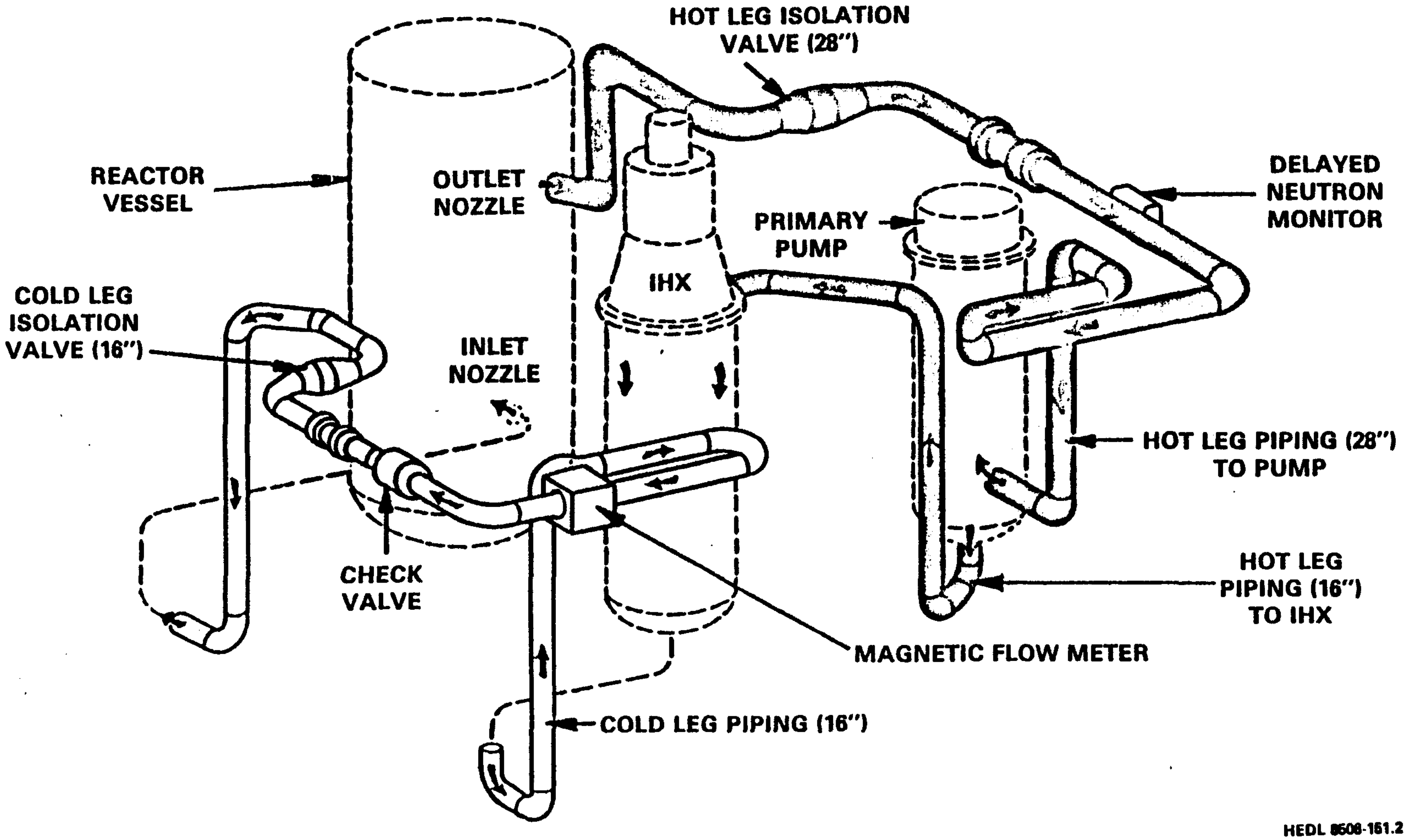


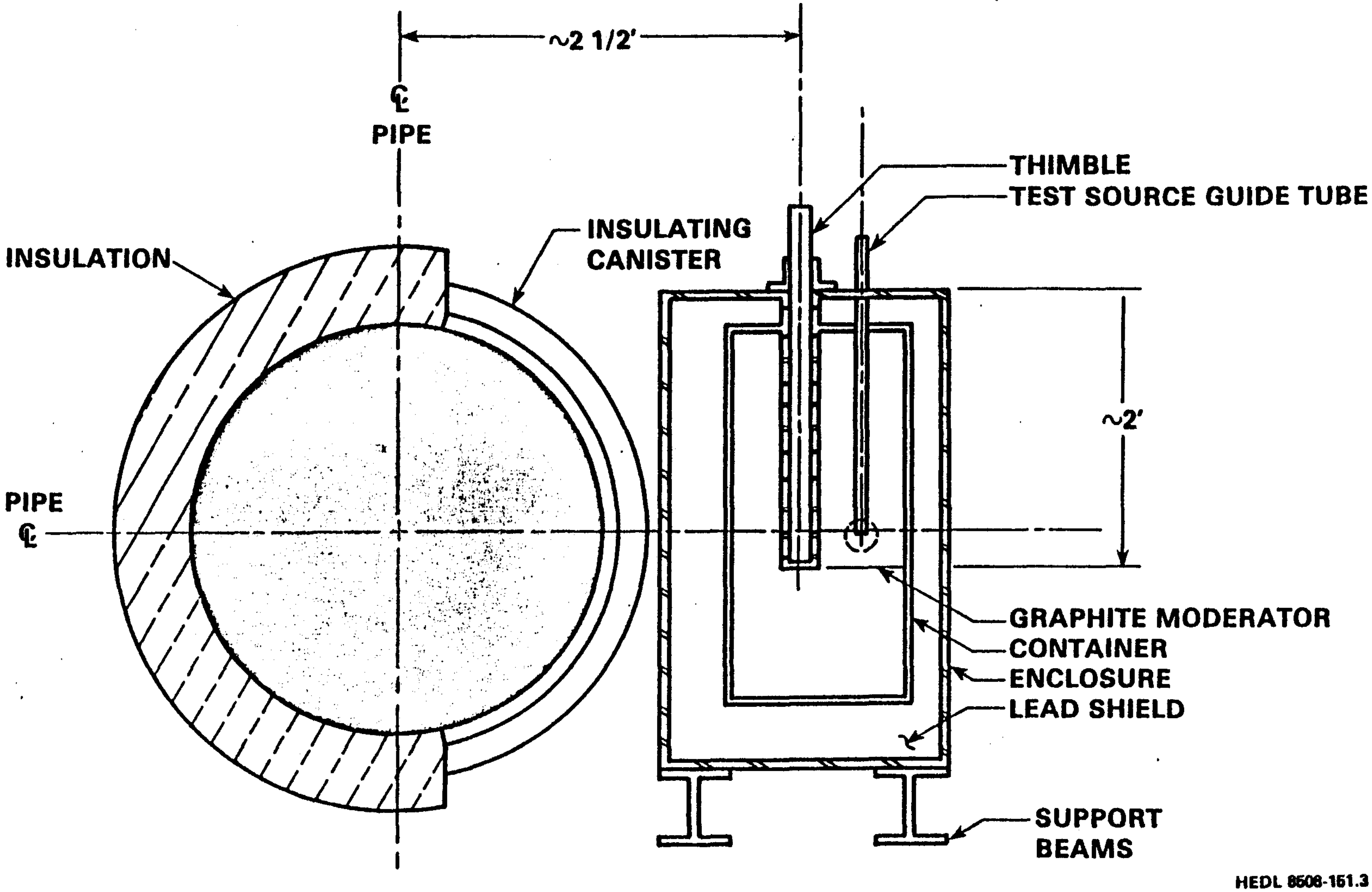
FIGURE 2-5. Reactor Cutaway.

LOCATION OF DNM MODERATOR BLOCK



HEDL 8508-161.2

DNM GEOMETRY



DNM RESPONSE

$$C_{jk} = F_k P_{jk} K_j T_{jk}$$

WHERE:

F_k	=	FISSIONS/sec
P_{jk}	=	PARTITION FRACTION
K_j	=	GEOMETRY FACTOR
T_{jk}	=	TIME DEPENDENCE

HEDL 8508-151.4

$$K_j = \frac{A \varrho \Phi D_j}{G_j}$$

WHERE: A = PIPE AREA, cm^2

ϱ = SODIUM DENSITY, g/cm^2

G_j = FLOW RATE, g/sec

Φ = NEUTRONS/cm^2 sec AT DETECTOR PER DELAYED NEUTRON/cm BORN IN PIPE

D_j = COUNTS PER n/cm^2

HEDL 8508-151.5

$$T_{jk} = \sum_{i} Y_i \lambda_i e^{-\lambda_i t_{jk}}$$

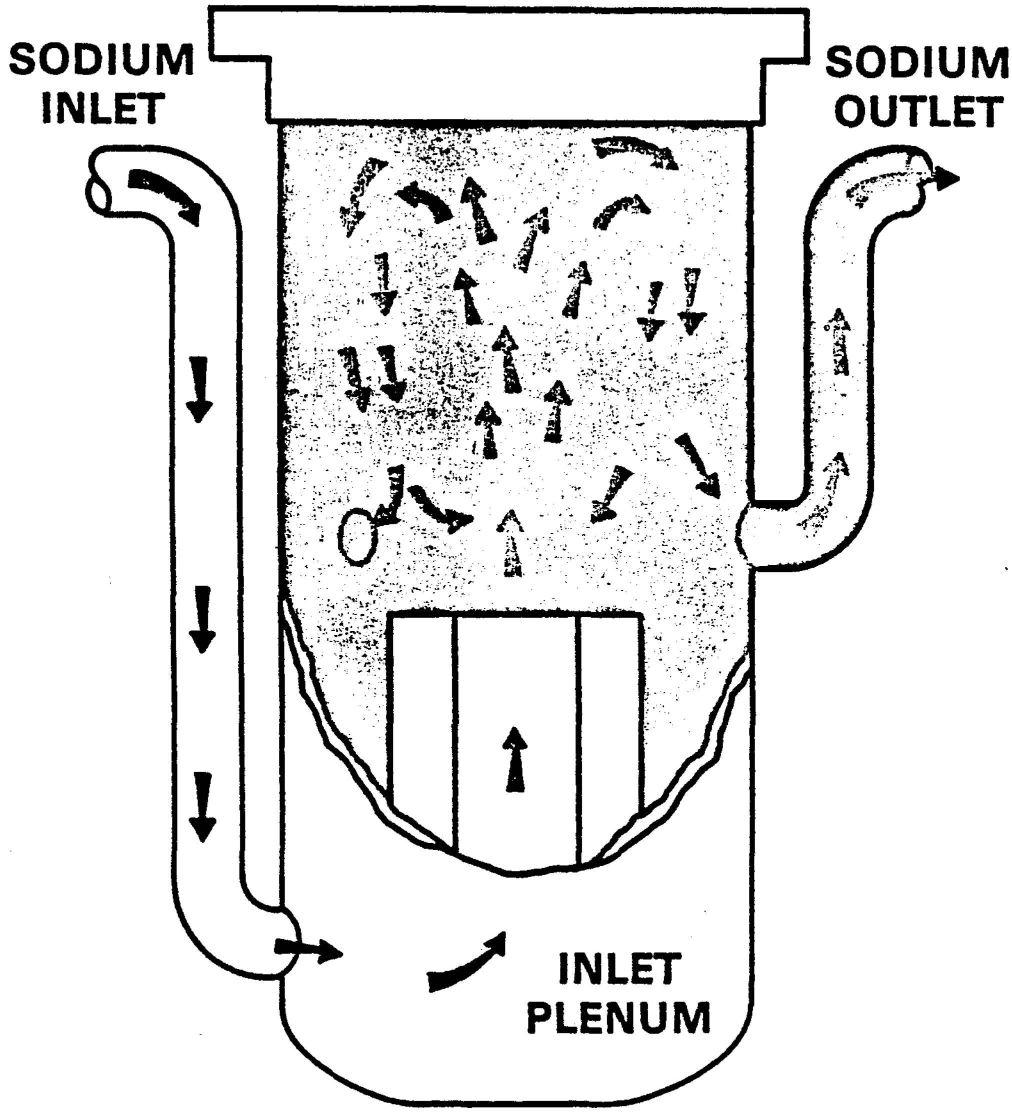
WHERE: Y_i = YIELD OF DELAYED NEUTRON PRECURSOR i

λ_i = DECAY CONSTANT, sec^{-1}

t_{jk} = TRANSIT TIME FROM CORE LOCATION k TO DNM SENSOR j

HEDL 8508-151.6

SODIUM FLOW THROUGH FFTF REACTOR VESSEL



HEDL 8508-151.7

PARTITION ASSUMPTIONS

1. CENTER POSITION EQUAL 0.333:0.333:0.333

2. $\sum_{j} P_{jk} = 1$

3. EACH 120° SECTOR HAS SAME SYMMETRY

HEDL 8508-151.8

SELECTED PARTITION FRACTIONS

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HEDL 8508-151.9

COUNT RATE NORMALIZATION

$$R_j = \frac{C_j}{\sum_j C_j}$$

WHERE: R_j = RELATIVE COUNT RATE, LOOP j

C_j = DELAYED NEUTRON COUNT RATE, LOOP j

$$\sum_{1}^{3} R_i = 1$$

HEDL 8508-161.10

DOMAIN OF PROXIMITY

$$d_k = \left[\sum_{1}^{3} (R_j - P_{jk})^2 \right]^{1/2}$$

WHERE: R_j = RELATIVE COUNT RATE, LOOP j

P_{jk} = PARTITION FRACTION FOR CORE POSITION k, LOOP j

HEDL 8508-151.11

AUGUST 19, 1984 DOMAIN OF PROXIMITY RESULTS

j	R_j	P_{jk} k = 1201	k = 1202	k = 1303	k = 1301
LOW COUNT RATE					
1	0.30	0.28	0.26	0.23	0.42
2	0.48	0.46	0.46	0.55	0.47
3	0.22	0.26	0.28	0.22	0.11
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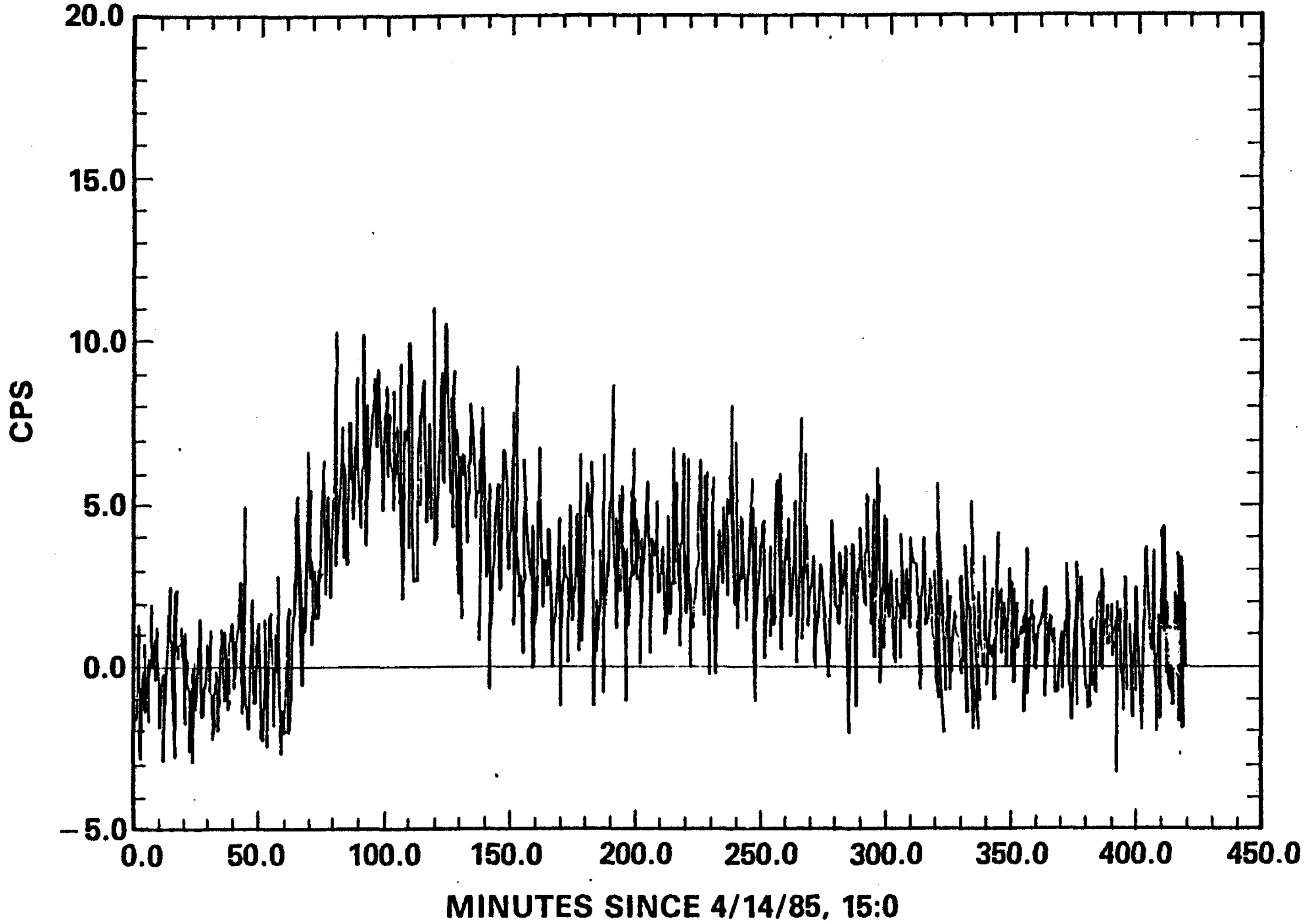
07:33:20	0.26	0.51	0.23
07:33:30	0.33	0.44	0.23

HEDL 8508-151.12

DNM COUNT RATE CYCLE 6A



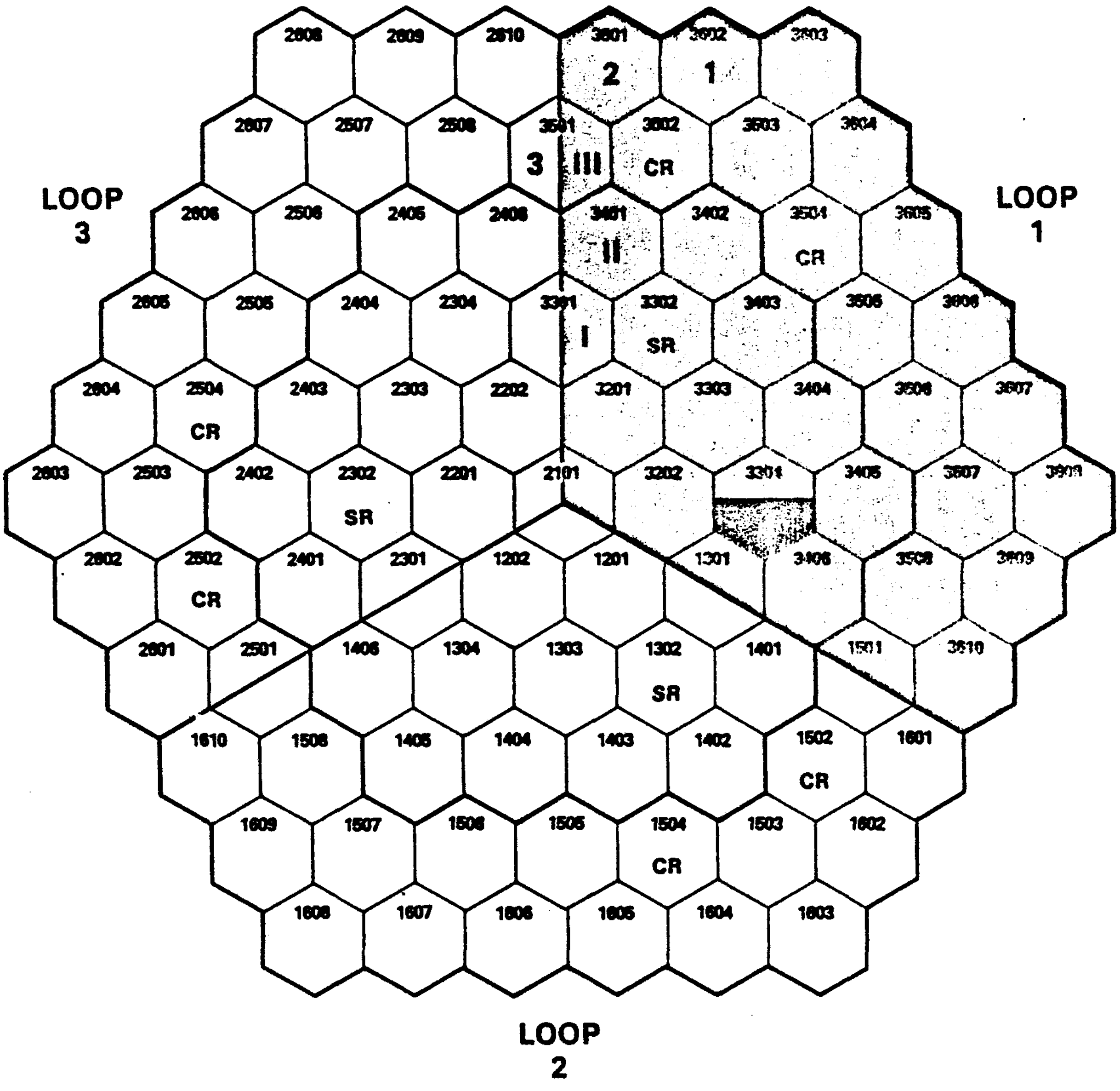
HEDL 8508-151.14

APRIL 1985 FAILURE
DNM TRIANGULATION

DATE	RELATIVE COUNT RATES			POWER (%)	LOCATION (d_k RANK)		
	LOOP 1	LOOP 2	LOOP 3		1	2	3
04/14/85	0.597	0.070	0.333	100	3602	3601	3501
04/16/85	0.597	0.068	0.335	100	3602	3601	3501
04/18/85	0.486	0.132	0.382	74	3301	3401	3501
04/22/85	0.605	0.039	0.356	100	3602	3601	3501

HEDL 8508-151.15

DNM TRIANGULATION
APRIL 1985 FAILURE



1,2,3 — 100% POWER
I, II, III — 74% POWER

HEDL 8508-151.16

DNM TRIANGULATION

IDENTIFIED PROBLEMS:

- EMPIRICAL PARTITION MATRIX DOES NOT AGREE WITH EXPERIENCE
- CHANGES IN POWER (CONSTANT FLOW) AFFECT MATRIX

UNKNOWNS:

- IMPACT OF LOADING CHANGES, EFFECT OF RE-SEATING IT'S, IVHM'S ON PARTITION MATRIX
- MAGNITUDE AND PERIOD OF ANY RANDOM FLUCTUATIONS IN PARTITION MATRIX
- IMPACT OF TRANSIT TIME AND "SPREAD" IN DNM SIGNAL

HEDL 8508-151.17

DNM TRIANGULATION

1. SUCCESSFULLY LOCATED FIRST FAILURE
2. GAVE CONSISTENT RESULTS OVER EIGHT-DAY SPAN
3. RETURNED TO "SAME" PATTERN AFTER POWER REDUCTION
4. LOW COUNT RATES PROVIDE ADEQUATE DATA

HEDL 8508-151.18