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MULTI-CHANNEL GROUPING TECHNIQUES FOR CONDUCTING REACTOR SAFETY STUDIES

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In conducting safety studies for postulated unprotected accidents in an LMFBR system, it is common practice to employ multi-channel coupled neutronics, thermal hydraulics computer programs such as SAS3A or MELT-III. The multichannel feature of such code systems is important if the natural fuel failure incoherencies and the resulting sodium void/fuel motion reactivity feedbacks--which have strong spatial variations--are to be properly modeled. Because of the large amounts of computer time associated with many channel runs, however, there is a strong incentive to conduct parametric studies with as few channels as possible. The present paper is focused on methods successfully employed to accomplish this end for a study of the hypothetical unprotected transient overpower accident conducted for the FFTF.

The procedure chosen was to model the core in as much detail as was computationally possible and then calculate the channel failure sequences with fuel motion following failure purposely suppressed. By observing these failure patterns, systematic lumping into fewer channels could then be effected. An important requirement of this process was to insure that the axial location of failure was well preserved for the few channel cases.

As noted from SLIDE 1, the beginning-of-cycle 4 (BOC-4) core configuration was chosen as the base case for investigating the utility of this technique. At the upper left hand corner, you will note the 91 subassemblies which comprise the physical layout of the core, and on the upper right hand corner, the burnup in thousands of MWd/T associated with each assembly. The lower left corner represents the total power in MW's extracted from each subassembly at full power conditions, and on the lower right hand corner a 20-channel representation of this configuration is given. Of the 91 subassemblies in the FFTF only approximately 74 subassemblies contain driver fuel and these were the only ones considered in this particular lumping process. Although it may be difficult for you to read the numbers contained in the sketches shown here, the main thrust of the slide is to draw your attention to the normal procedure of lumping 74 driver subassemblies into a 20-channel configuration. First we look at the power

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distribution and try to preserve power as closely as possible during the lumping process. Secondly, we look at fuel burnup because fuel failure characteristics are strongly dependent upon whether the fuel is fresh or irradiated. As denoted by the four subassemblies colored red, these constitute what we call channel 3 and are singled out here because that was the first channel computed to fail. The second channel computed to fail is dashed in green. This is channel 11 which contained five subassemblies in the outer enrichment zone of the core.

The next slide (SLIDE 2) also contains a lot of detail but is included to provide an overview of the microstructure which is calculated to occur by the 20 representative pins in the core. The top circles designate the channel number which goes from 1 to 20 in this case. The second number is the peak burnup in thousands of MWd/T and the next line represents the peak power in KW/ft. I would also like to draw your attention to the flow orifice zones which these particular pins represent. You will note the first nine subassemblies are contained in the flow orifice zone number 1, subassemblies 10 - 13 are in orifice zone number 2 (that is physically in ring 5 of the core), and the remaining subassemblies, 14 - 20, are all located in the outer row, namely, in orifice zone number 3. Although it would be difficult to read these numbers, the colors should indicate those pins which reside in the high power areas where columnar fuel extends over a wide axial range of the fuel pins as opposed to those pins which are located in the outer periphery of the core operating at very much lower power levels. The purpose of this slide is to illustrate the general complexity of trying to reduce such a run down to a more manageable size. Nevertheless, because of the computation times involved, there is very strong incentive to attempt such a process.

Before proceeding into the actual reduction process, SLIDE 3 is included to denote the fuel failure sequence that was obtained in the full 20 channel run. To construct this plot, the fuel squirting following failure was purposely suppressed. That is, the intent was not to determine the timing for the failure sequence beyong the first failure but rather to determine the failure order because we thought that this would be useful in trying to reduce the numbers of channels down to a fewer number. Plotted on the ordinate is the number of subassemblies which fail and on the abscissa is the actual time in seconds following, in this case, a 50¢/sec reactivity insertion into the FFTF core. As I indicated earlier, channel 3 was the first channel calculated to fail. This particular channel comprises a total of 4 subassemblies. Next was channel 11, which is physically positioned in flow orifice zone 2, followed by channels 5, 9, 1, etc. The top dashed line represents the integral effect of sequential subassembly failure.

Slide 4 summarizes the channel lumping criteria which was used in order to reduce the 20 channel run to fewer channels. First, we attempt to preserve fuel types, that is, recognizing that power level and exposure are both instrumental in determining the axial position and timing of failure. Secondly, we tried to preserve the coolant orifice zone; that is, to match the power to flow ratios, to the extent practicable.

Slide 5 indicates having done such, several tests were used in looking at the results to see if the lumping procedure was successful. First of all, we wanted to be sure that the failure sequence was reasonbly well preserved. Secondly, the preservation of the axial failure location was important, and third, a check of the net reactivity feedback to see if at least initial phases of the post failure squirting process could be preserved.

Slide 6 shows the results of the reduction process in going from 20 channels to 10 channels and finally to seven channels. Plotted on the ordinate are the total number of subassemblies failed and on the abscissa is the time after the accident was initiated. The top line contains the same set of values as was illustrated in an earlier slide, and from this you will note how the 10 channel case was derived. First, we tried to preserve the initial failure sequence as best possible. That is, channel 3 was retained with four subassemblies, but this was now called channel 2. Channel 11 was also retained as were Channels 5, 9, and 1. From that point on, a more gross lumping procedure was used. In going from a 10 channel to the 7 channel case, the initial channel 3 and 5 subassemblies were lumped together whereas the original channel 11 subassemblies were retained as a separate channel. This was done because 3 and 5 are both near the center of the core in the inner orifice zone whereas channel 11 is in a different orifice zone.

The following slide (Slide 7) is a continuation of the reduction process, normally from a seven channel case to a four channel case and finally to a two channel case. The top line here corresponds to the bottom line on the previous slide. As you will note from these cases, the failure sequence was well preserved in the four channel case, but of course in the two channel case only one subassembly can fail because the remaining subassembly has to represent the bulk of the core in order to get appropriate Doppler feedback, etc. Hence, the early channels had to be lumped together and in fact were lumped into one channel representing a total of 16 subassemblies.

The following slide (Slide 8), although quite busy, represents a summary of the entire reduction process. Basically, this puts together the results of the two previous VU-GRAPHS, and in addition to that contains on the top side a summary of the total number of subassemblies failed as a function of time for all of the channel lumping procedures used. Without going into detail, the essence of this summary is that during the initial 100 msec following failure, all of the lumping processes are shown to produce approximately the same results. Later in time, of course, there is somewhat of a divergence because some of the peripheral channels which did not get involved in the early failure sequence ultimately do not fail, and this, of course, can only be represented by more channels. This accounts for the fact that, with time, the 10 and particularly the 20 channel case tends to diverge from the more simple 7, 4, and 2 channel cases.

Having noted that the failure sequences are preserved reasonably well, at least during the early sequence, the next test was to determine whether the axial failure level was preserved. The following slide (Slide 9), was contained to illustrate the results obtained in this regard. I would first like to draw your attention to the illustration at the bottom of this slide which shows the axial structure used in the pins going from axial node 1, the pin bottom, to axial pin 18 at the pin top. These physically were two inch nodes representing a 36" fuel column. I have contained the actual channel number designations for each of the 20, 10, 7, 4, and 2 representations on the left. But what I would like to draw your prime attention to is the bold letters contained under the heading of axial failure level in each case and basically note that whereas the failure sequences for the first 5 subassemblies to fail on the 20 channel ases varied from axial level 14 to 17, these were quite well preserved, in fact, all the way through the channel reduction process. This, of course, is very important from the standpoint of the reactivity feedback which ensues following failure. We feel that this process did preserve this critical criterion quite well.

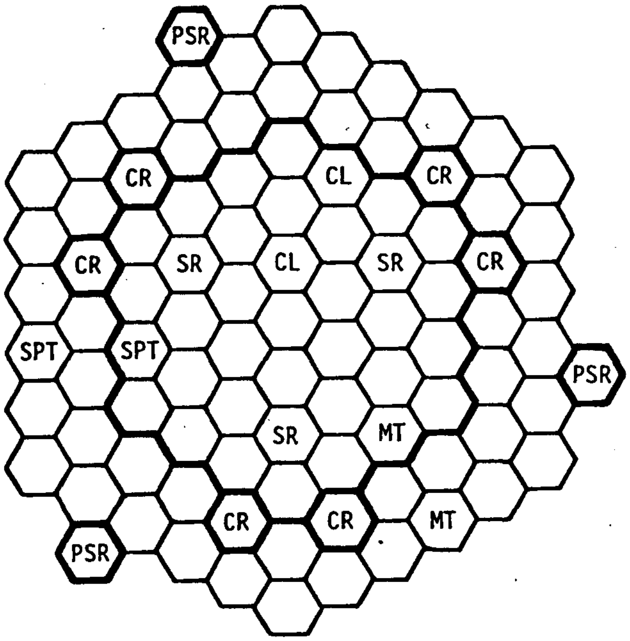
The final test, however, is to look at the net reactivity and power resulting from these various reduction processes. The following slide (Slide 10) is an intercomparison of the reactivity, which is plotted as reactivity in cents vs. time. You will note that there is a change in the time scale at 2.5 sec after initiation of the accident. All cases are noted to agree very well up through the time of failure and, in fact, the time at which the reactor reaches subcriticality is preserved reasonably well in all cases. The agreement is even fairly good up to approximately 200 msec after failure. Beyond that time, however, there is divergence in the sense that the 10 and particularly the 20 channel case contains pins which are now beginning to fail and add more negative reactivity feedback which, of course, cannot be preserved by the few channel configurations.

The following slide (Slide 11) is a similar comparison of power. This contains the same change in the time scale and you will note that the power agrees well up to the time of failure. In fact, it agrees quite well within the first 100 msec following failure and then begins to diverge somewhat for the same reasons described to earlier.

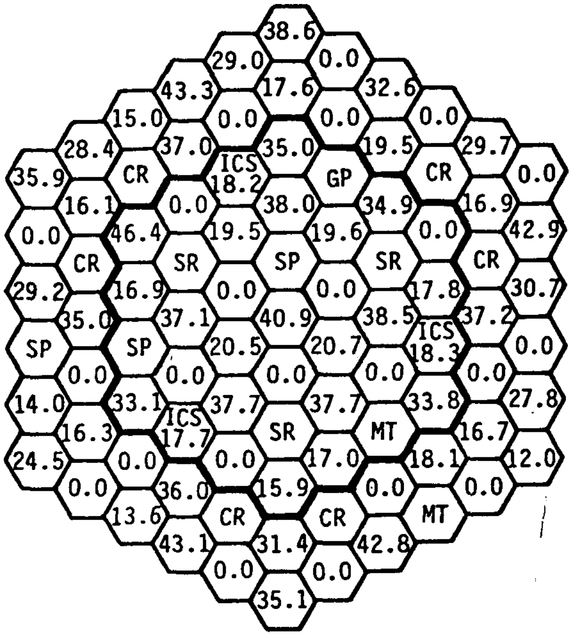
Finally, I have contained an intercomparison (Slide 12) of the computer time involved for these cases, since this was the motivating reason for attempting this reduction process in the first place. Listed at the left are the numbers of channels representing from 20 down to 2, and at the right computer run time up to failure in seconds. It is noted that the 20 channel case required approximately 100 sec up to failure, and this was reduced in an essentially linear process down to 10 seconds for the 2 channel case. A considerable reduction in computer time is obvious for what we belive to be quite comparable results during the early failure and fuel squirting time scale. I should point out, however, that such savings in computer time is not so dramatic if one looks at the accident all the way through fuel squirting because the way the MELT-III code is configured. The small time steps required after failure are confined only to the channels that fail. Therefore, fairly long time steps can be used for the remaining channels.

In conclusion, therefore, (Slide 13) we believe that the lumping procedure developed for this study does work quite well for at least the initial squirt cycles, that is up to the time of initial neutronic shutdown. If one is interested in these short time scales as, for example, when concluding numerous parametric studies using different fuel motion models, FCI models, etc., a considerable amount can be saved. In fact, this study shows that fairly accurate results can be obtained from even a two channel run--with approximately an order of magnitude savings of computer time. Such a process is invalid if very long time scales are required in order to assess long term problems such as post-accident heat removal, etc. However, for the purposes of this study, which was to investigate the validity of such reduction process in order to perform numerous parametric studies, we have found the process to work very well.

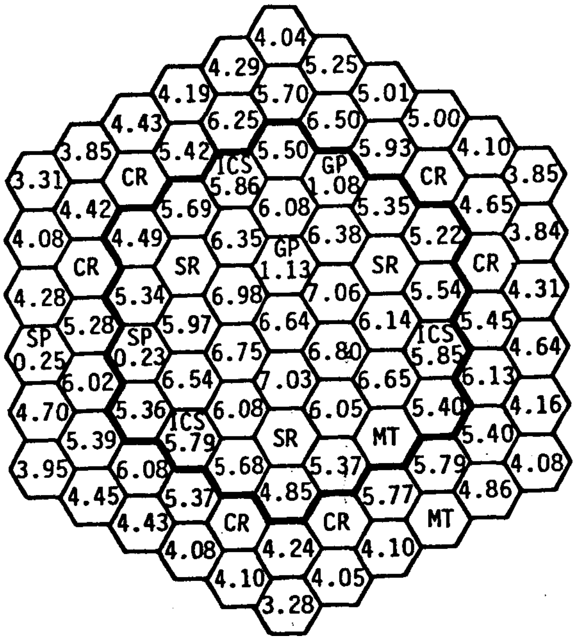
20 CHANNEL BOC-4 REPRESENTATION



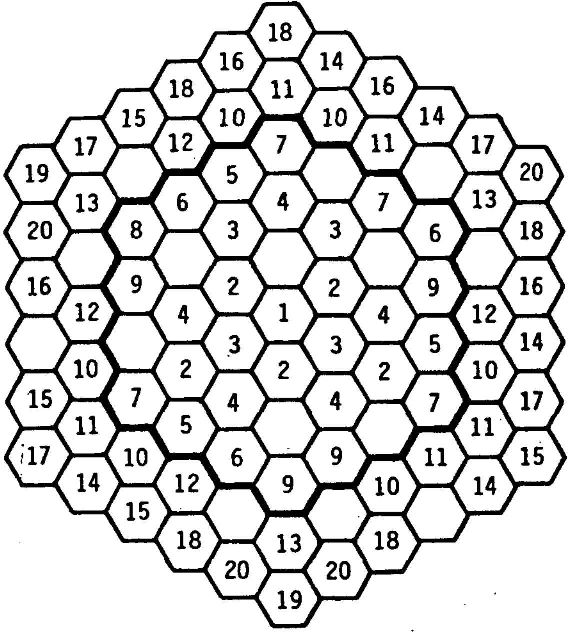
PHYSICAL LAYOUT



BURNUP (THOUSAND MWT/T)



POWER PER SUBASSEMBLY (MW)

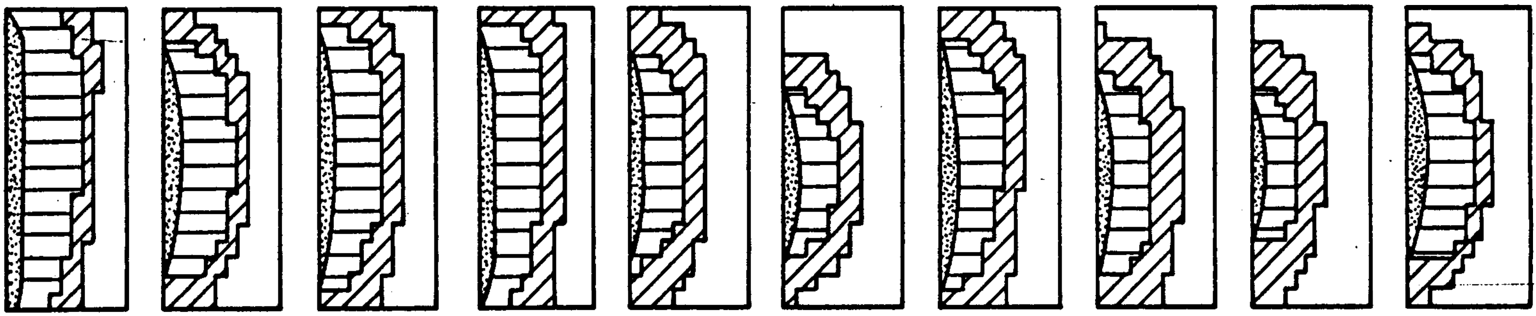


20 CHANNEL REPRESENTATION

HEDL 7505-138.100

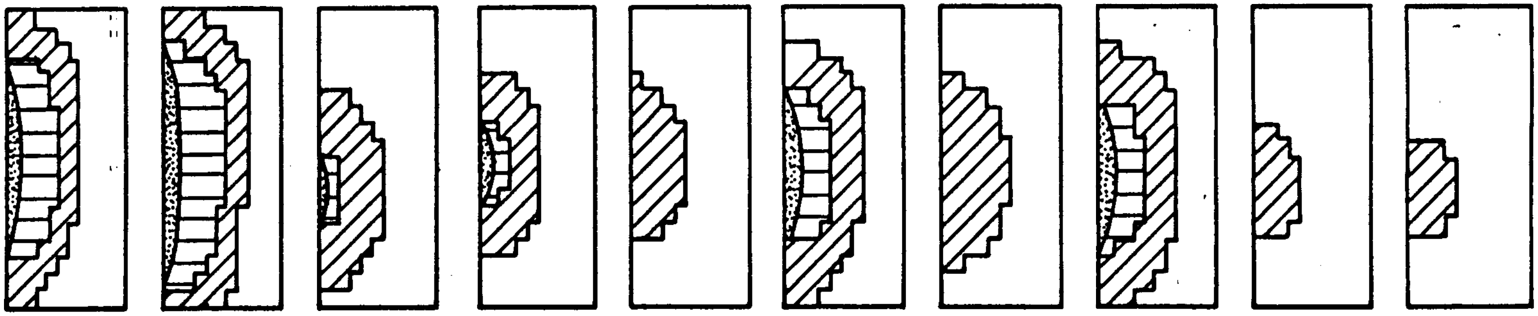
20 CHANNEL BOC-4 MICROSTRUCTURE

CHANNEL	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
PEAK B.U.	41	0	20	38	18	0.	34	46	17	0
KW/FT	11.9	12.3	11.8	10.9	10.6	10.2	9.8	8.3	9.7	11.1
SUB/CHANNEL	1	5	4	5	3	3	4	1	4	6



ORIFICE ZONE 1

CHANNEL	⑪	⑫	⑬	⑭	⑮	⑯	⑰	⑱	⑲	⑳
PEAK B.U.	18	36	22	0	14	30	28	42	35	0
KW/FT	10.2	9.9	8.6	8.8	8.0	8.2	7.4	7.5	6.2	7.7
SUB/CHANNEL	5	4	3	5	4	4	4	5	2	4



ORIFICE ZONE 2

ORIFICE ZONE 3

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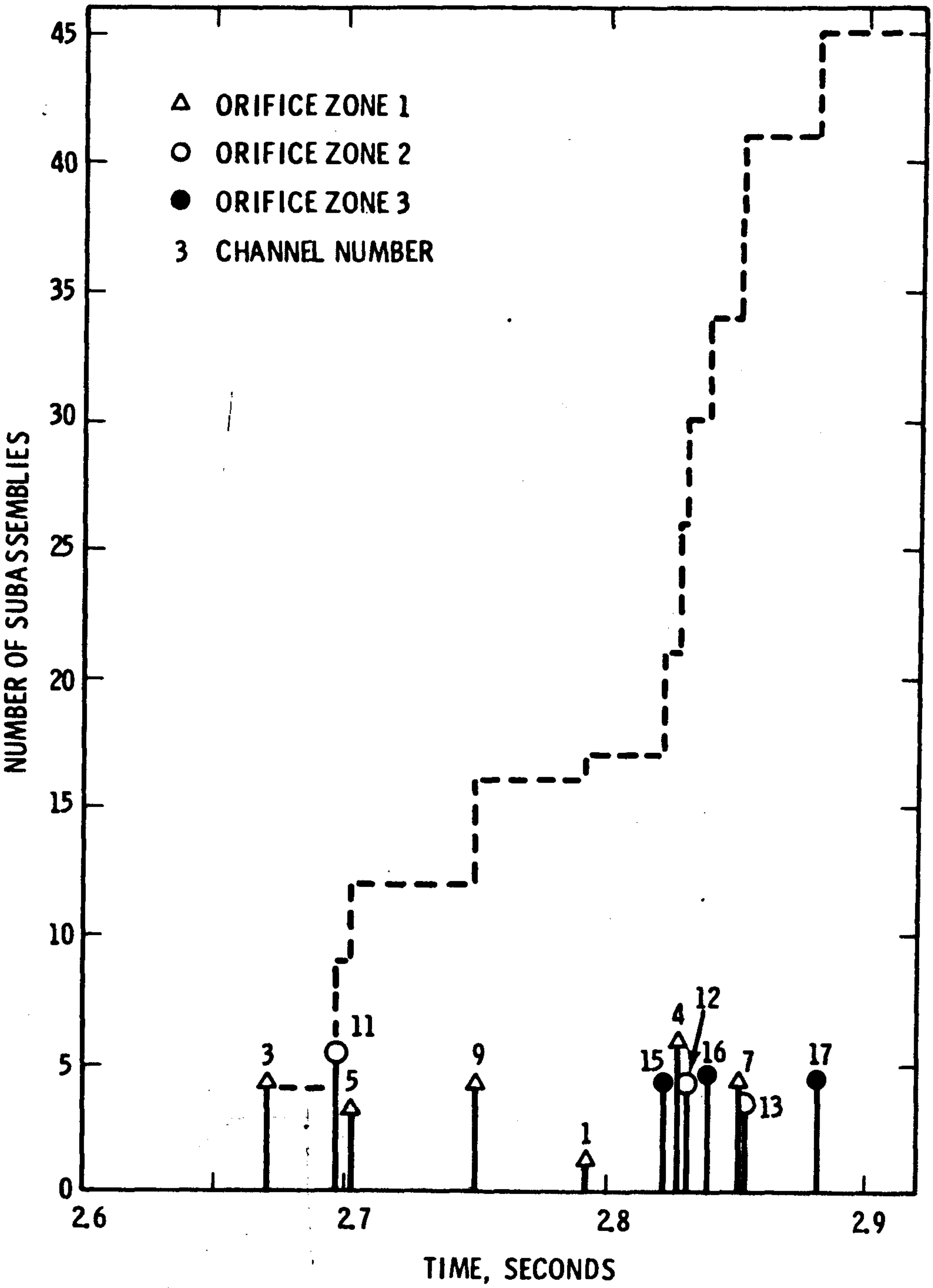
20 CHANNEL BOC-4 FAILURE SEQUENCE



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20-Channel BOC-4 Failure Sequence (no squirting)

CHANNEL LUMPING CRITERIA

- PRESERVE FUEL TYPES
  (POWER LEVEL, EXPOSURE)

- PRESERVE COOLANT ORIFICE ZONES

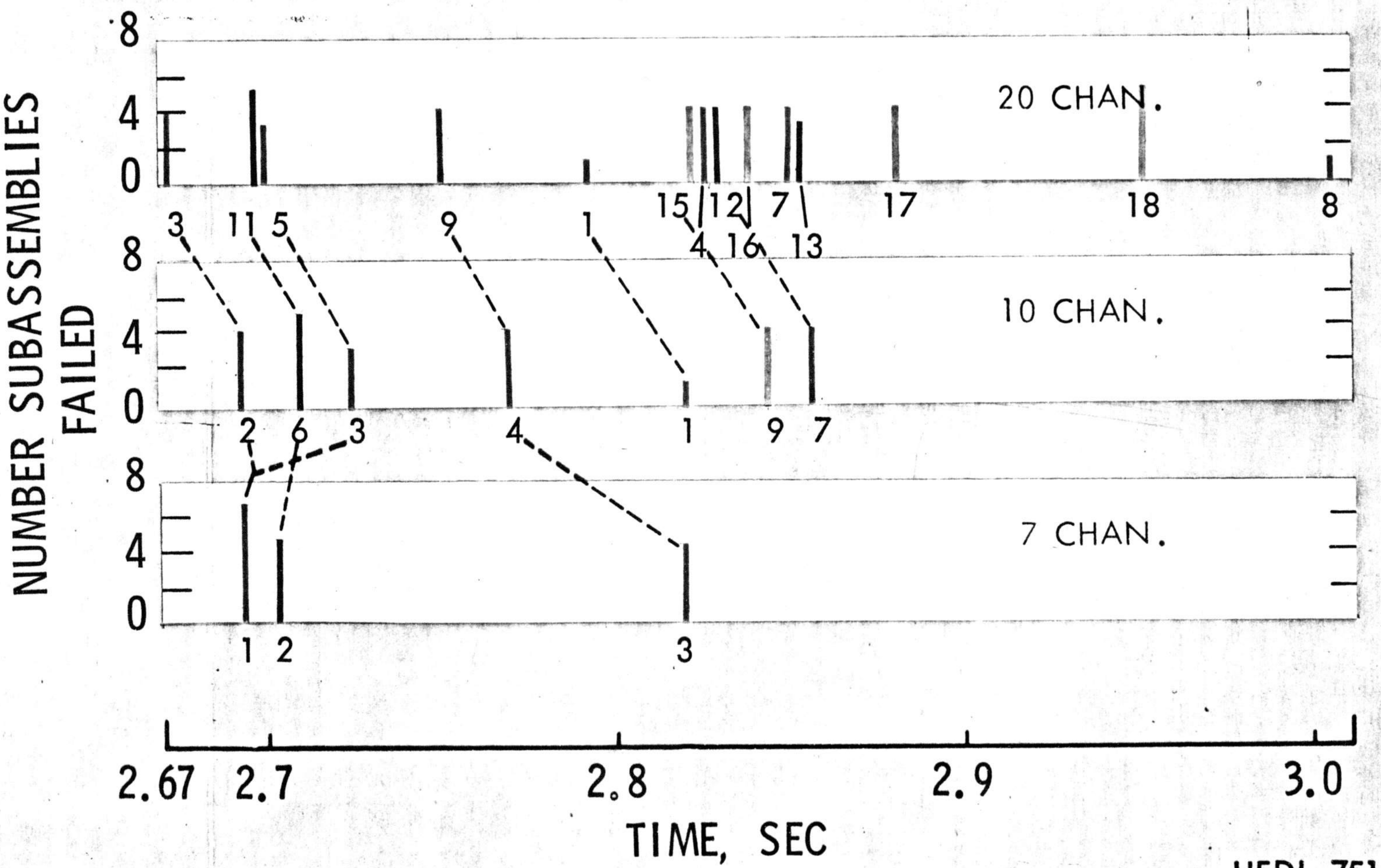
HEDL 7510-181.5

TEST OF RESULTS

- FAILURE SEQUENCE
- AXIAL FAILURE LOCATION
- REACTIVITY FEEDBACK

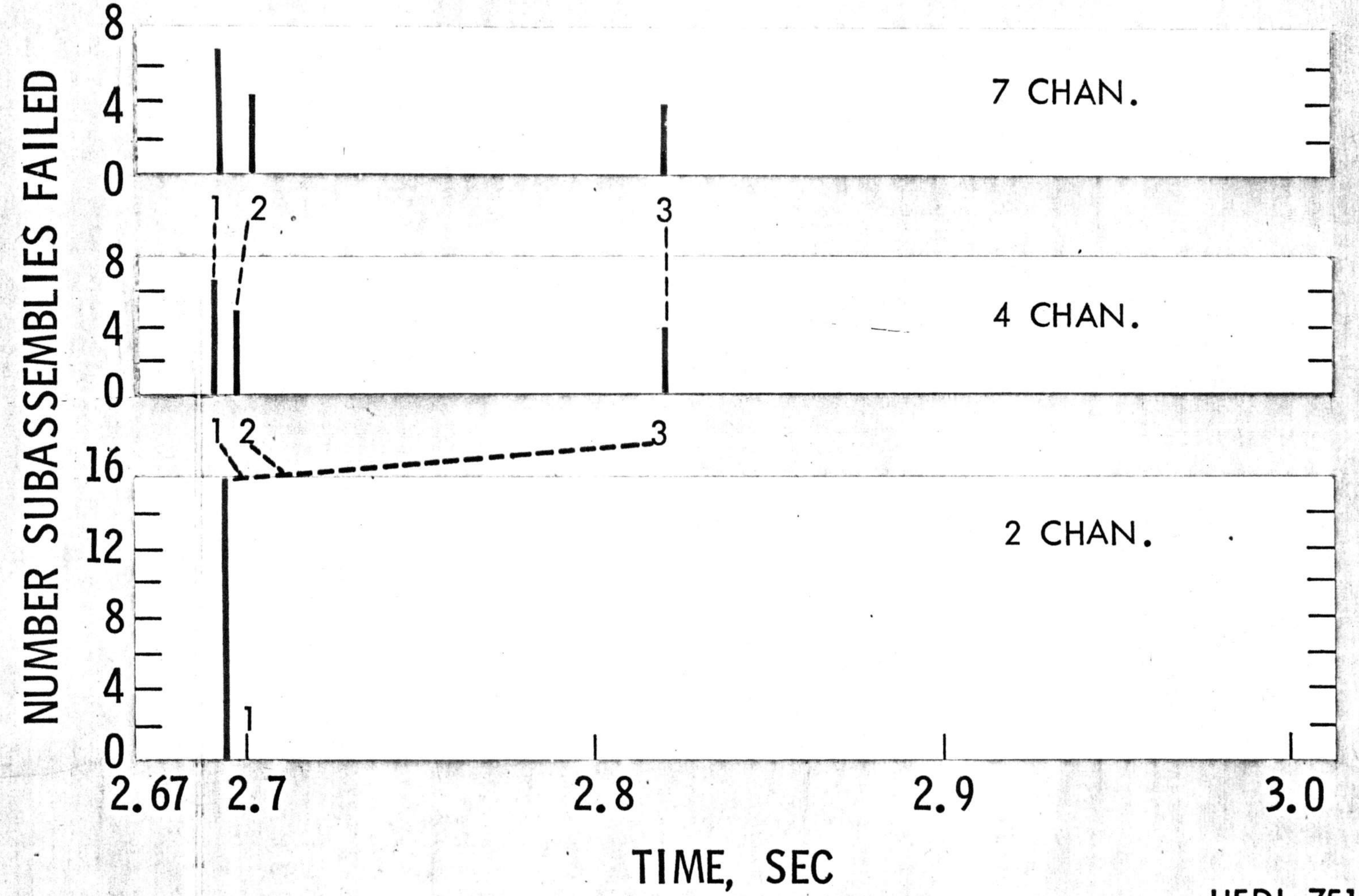
HEDL 7510-181.8

REDUCTION FROM 20→10→7 CHANNELS



HEDL 7510-181.4

REDUCTION FROM 7→4→2 CHANNELS



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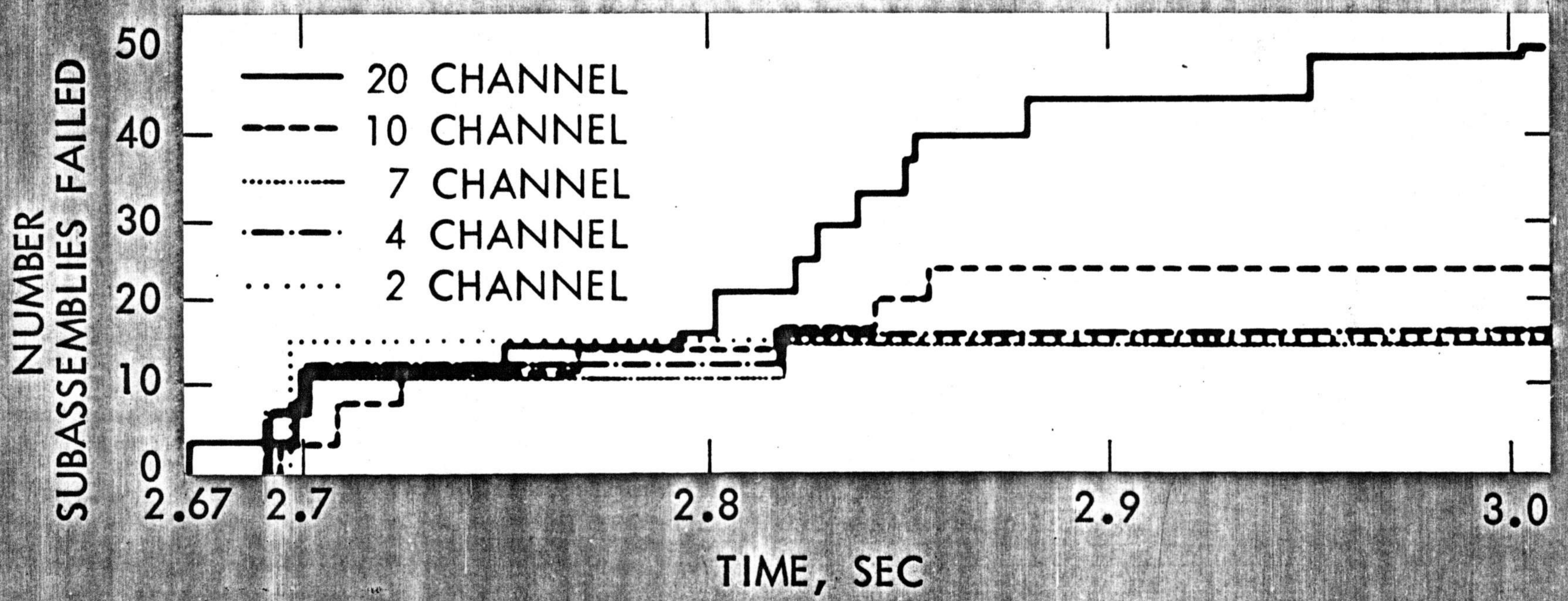
SUMMARY OF REDUCTION PROCESS



HEDL 7510-181.12

AXIAL FAILURE LEVEL

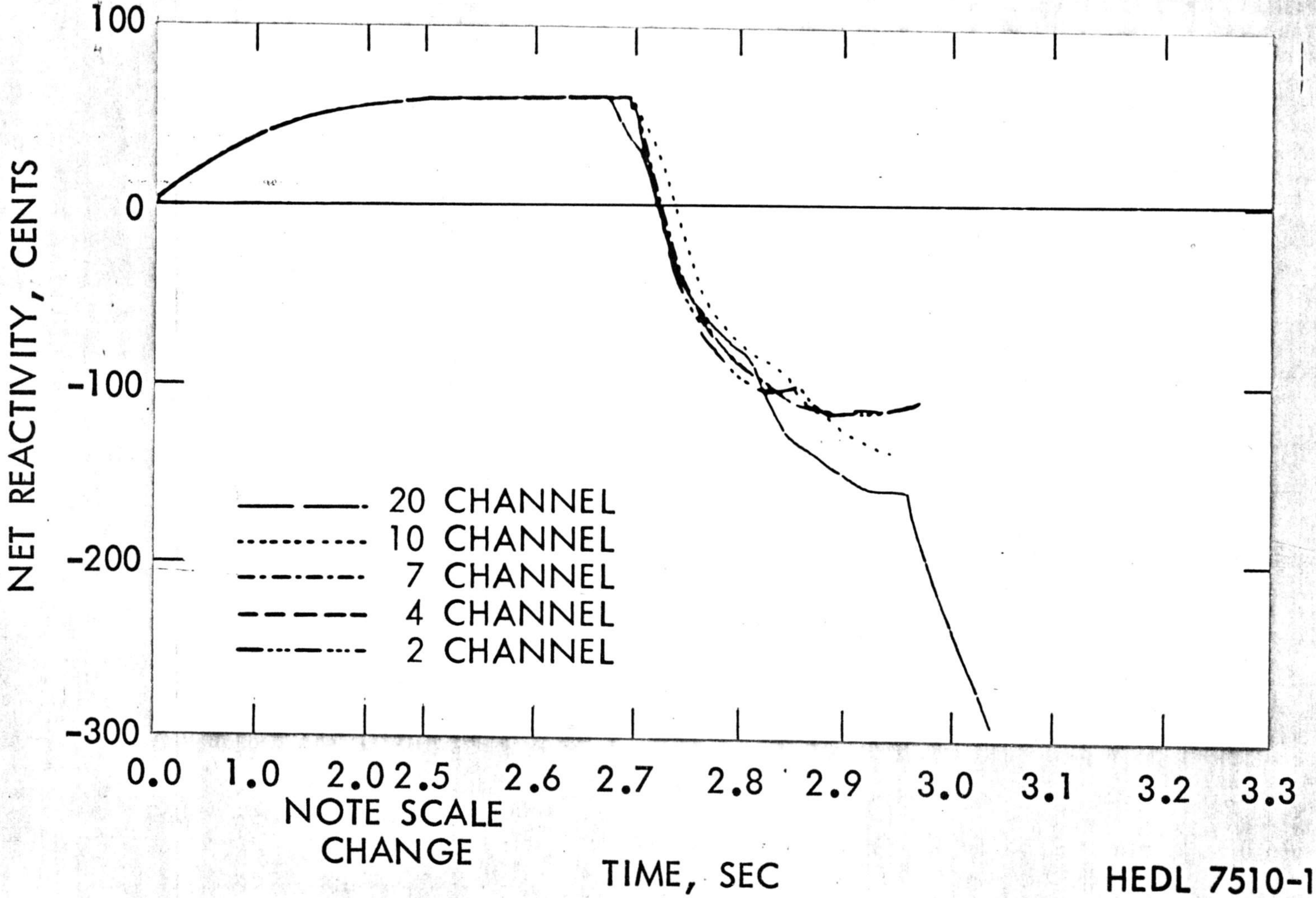
20 CHAN		10 CHAN		7 CHAN		4 CHAN		2 CHAN	
#	LEVEL	#	LEVEL	#	LEVEL	#	LEVEL	#	LEVEL
3	**16**	2	**16**	2	**15**	1	**16**	1	**15**
11	**15**	6	**15**	1	**16**	2	**15**		
5	**15**	3	**15**	3	**13**	3	**13**		
9	**14**	4	**14**						
1	**17**	1	**17**						

1								9						**15**			18

PIN BOTTOM ——— AXIAL LEVEL ———→ PIN TOP

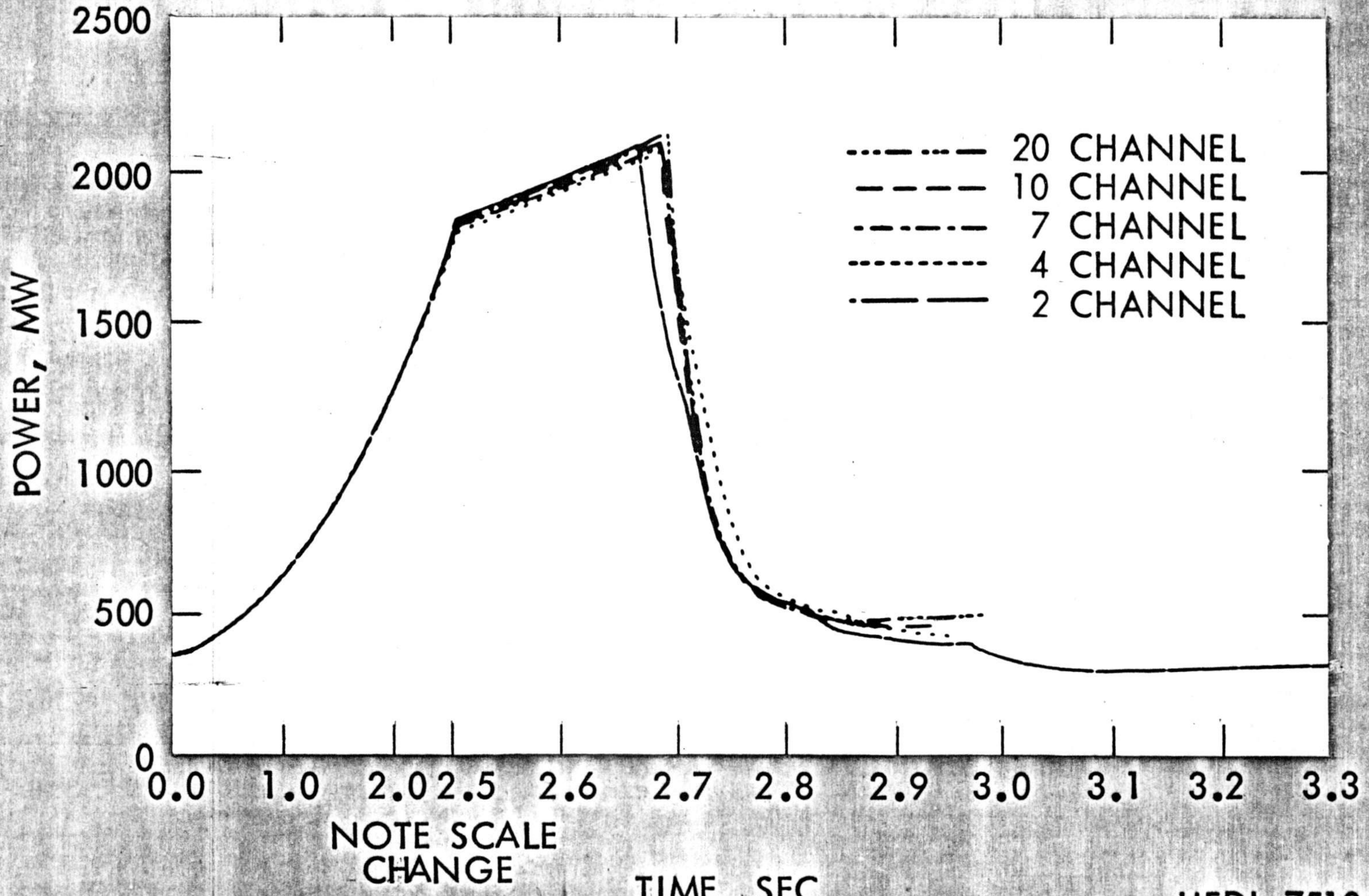
HEDL 7510-181.13

INTERCOMPARISON OF NET REACTIVITY



HEDL 7510-181.11

INTERCOMPARISON OF POWER



HEDL 7510-181.10

INTERCOMPARISION OF COMPUTER TIME

CHANNELS	RUN TIME TO FAILURE (SECONDS)
20	102
10	50
7	36
4	21
2	10

HEDL 7510-181.6

CONCLUSIONS

- LUMPING PROCEDURE WORKS WELL FOR INITIAL FUEL SQUIRT CYCLE
- CONSIDERABLE COMPUTER TIME SAVED
- NOT VALID FOR LONG-TIME SCALES

HEDL 7510-181.7