FOR UN[illegible] DISTRI[illegible]

DATE ______________________________ [illegible]

1105 103

8

WCAP-9587

STUDY OF TWO-PHASE NATURAL CIRCULATION FOLLOWING A SMALL LOCA USING THE NOTRUMP CODE

by

K. Kesavan

P. E. Meyer

R. Muench

August, 1979

Approved: T. M. Anderson, Manager
Nuclear Safety Department
Westinghouse Electric Corporation

1105 104

WESTINGHOUSE ELECTRIC CORPORATION
Nuclear Energy Systems
P. O. Box 355
Pittsburgh, Pennsylvania 15230

SUMMARY

An analysis of the small break loss of coolant accident (LOCA) using the more advanced thermal-hydraulic code NOTRUMP has been conducted for the first time. The case analyzed related to a postulated 2 inch diameter, cold leg break in a RESAR-3, 4-loop plant. The NOTRUMP code was used in the "time-window" mode, i.e., the initial part of the transient, just prior to the start of steam generator tube drainage, was simulated using WFLASH and the conditions were then fed to NOTRUMP.

The NOTRUMP analysis simulates the natural circulation behavior of the reactor coolant system well. Using [ ] in the vertical regions of the system such as the steam generator U-tubes, and [ ] in the cold and hot leg piping, the code models the draining back of substantial amounts of liquid from the up-hill side of the U-tubes to the reactor vessel. a,c a,c

The above special capabilities of the NOTRUMP code lead to results of the transient strikingly different from those predicted by the current small break LOCA evaluation model using WFLASH. For the case analyzed, the WFLASH model, without the drain back capability in the up-hill side of the U-tubes and the hot legs, shows an early uncovering of the core at about 1700 seconds to a depth of 6 feet. Replenished by the drain back and further aided by the reduced static head resistance to steam relief resulting from it, the vessel mixture shows no uncovering of the core in the NOTRUMP case.

Another interesting observation from the NOTRUMP analysis results is the tendency of the system to seek the broken and the intact loops for steam relief in an alternating fashion. The flow from the reactor vessel is

1105 105

seen to initially favor the less resistive broken loop. This causes the loop-seal in the broken loop to clear first. The subsequent condensation of the enhanced steam flow in this loop leads to a re-plugging of the broken loop loop-seal. The increasing resistance in the broken loop now causes the steam flow to switch to the intact loops, leading to clearing of the loop-seals there. This switching of the steam flow between the broken and intact loops may be expected to go on for an extended duration with decreasing amplitude and increasing period as the reactor decay heat level falls off.

The analysis contained herein demonstrates the conservatism of the Westinghouse Small Break Evaluation Model. It also provides an independent calculation of two phase natural circulation with a new computer code. It is shown that WFLASH can perform a reasonable simulation of two-phase natural circulation.

1105 106

TABLE OF CONTENTS

1105 107

SMALL BREAK LOCA ANALYSIS

WFLASH-NOTRUMP STUDY

1.0 INTRODUCTION

The concerns(1) relating to the decay heat removal under natural circulation in a pressurized water reactor (PWR) plant, employing U-tube type steam generators, following a steam generator-dependent small break loss of coolant accident (LOCA), have prompted an advanced analysis of this type of event.

The simulation of the process occurring during a small break LOCA using the current evaluation model and the WFLASH code(2), although predicting conservative results in terms of the maximum cladding temperatures reached and core uncovery, does not describe all of the flow phenomena accurately. For example, the current analysis tool does not attempt to model the draining back into the reactor vessel of the liquid contained initially in the up-hill side of the steam generator U-tubes or that subsequently formed in them by condensation of steam. Under a low steam flow situation in the hot legs and in the U-tubes, this liquid may be expected to drain back towards the reactor vessel against the steam flow. Although the up-hill side of the U-tubes is represented as a unique control volume in the WFLASH model (see Figure 1 - nodes 3 and 5), nodes 3 and 5 are treated as homogeneous fluid nodes, with the result that the emptying of these nodes is essentially due to forward transport into the down-hill side nodes 9 and 10 in the form of a two-phase mixture. In order for the liquid in nodes 3 and 5 to drain back into the reactor vessel, the pressure gradient between nodes 3 and 5, and the reactor vessel node 1 has to undergo a favorable direction change. As a result of this restrictive feature in the current WFLASH model, the liquid contained in the up-hill side of the U-tubes causes the following: 1) the benefit from the possible draining into the reactor vessel is lost 2) the prolonged presence of the liquid in the up-hill side of the U-tubes offers additional resistance to hot leg flow from the vessel, and 3) the loop-seals in the cold legs have to pass additional amounts of liquid, carried forward from the up-hill side of

1105 108

the U-tubes, before they can void. These characteristics of the analysis based on the WFLASH model generally result in conservative behavior of the steam-water mixture in the reactor vessel, often leading to substantial uncovering of the core.

The more advanced thermal-hydraulic computer program NOTRUMP[3] is a new tool with special capability to analyze situations involving co-current and counter-current flows of steam and water in horizontal and vertical flow fields. The present study using the NOTRUMP code is an attempt at introducing more realism into the analysis of small break LOCA. This also constitutes the first time use of the NOTRUMP code in such an analysis.

2.0 WFLASH-NOTRUMP ANALYSIS

Due to the present lack of a reactor coolant pump model in NOTRUMP, this first time application of the code to the total nuclear steam supply system (NSSS) had to rely on input of dynamic conditions from WFLASH by "patching". The choice of "space-window" mode of using NOTRUMP, modeling only the steam generators and the hot legs with forcing functions derived from WFLASH, was rejected early in the effort for reasons of the absence of overall system feedback effects. It was decided to perform the analysis in the "time-window" mode instead, modeling the total system but with initial conditions corresponding to a time following reactor scram and stoppage of the reactor coolant pumps as indicated by WFLASH.

For the purpose of the current study, a NOTRUMP model consisting of [ ] a,c nodes to represent the NSSS was used. The model is shown in Figure 2. The diagram is mostly self-explanatory. Using the NOTRUMP terminology, the "fluid nodes" (marked by uncircled numbers) represent segments of the system volume and contain fluid mass. The "flow links" (denoted by circled numbers) serve as connections between specified fluid nodes and carry fluid.

The [ ] model contains sufficient detail in representing the system a,c
for analysis of small break LOCA. Fluid nodes [ ] are arranged a,c
serially to represent the reactor core. The vessel upper plenum is
represented by [ ] and the lower plenum by [ ]. The a,c
volume of the downcomer is [ ]. The a,c
piping and the primary side volumes of the steam generators in the
broken and intact loops are represented [ ] as can be seen from a,c
the diagram. The U-tube volume of each of the two loops is [a,c
]. The hot leg in each loop is represented by [a,c
] and the loop-seals by [ ]. The volumes of the primary coolant pumps a,c
are included in [ ]. The cold leg volume of the a,c
intact loop is [
] a,c

[a,c

] The accumulators are represented by [ ] and a,c
the steam generator shell-sides by [ ]. a,c

[ ] a,c

Using the foregoing NOTRUMP model a postulated small break LOCA event in a RESAR-3 4-loop plant was analyzed. The break was assumed to be a 2 inch diameter hole in the cold leg of one of the loops. This break size was chosen since it is the largest size which requires energy removal through the steam generators for a substantial period of time. A corresponding WFLASH run, with the standard small break LOCA assumptions of loss of off-site power at the instant of reactor scram, minimum safety injection and minimum auxiliary feedwater, formed the basis for the NOTRUMP analysis.

1105 111

NOTRUMP INPUT DATA:

The starting time of the NOTRUMP analysis was 240 seconds from the initiation of the event. This time point was chosen from the WFLASH basis run since the reactor coolant pumps had coasted down, and forced pumping of the primary coolant had ceased. Also at this time the liquid in the steam generator U-tubes had not yet begun to drain. The primary and secondary system fluid conditions such as pressure, mass, and enthalpy corresponding to this time in WFLASH transient were input to the NOTRUMP code. Also the heat stored in the system metals was considered likewise. Salient features of the input to NOTRUMP are summarized below:

- Core decay heat history as in WFLASH.

- Core power shape, skewed to the top, as in WFLASH.

- Decay energy deposited into individual fuel and cladding mass lumps associated with core fluid nodes.

- Pumped safety injection pressure-flow characteristics as in WFLASH.

[-] a,c

- Break located [ ] at the bottom of the cold leg pipe. a,c

[ ] a,c

- Break fluid discharge model as in WFLASH - modified Zaloudek in the subcooled regime and Moody in the two-phase regime.

1105 112

- Steam generator safety valve characteristics as in WFLASH.

[-] a,c

- Auxiliary feed flowrate as in WFLASH.

1105 113

3.0 RESULTS

Using the NOTRUMP code, the 2 inch diameter small break LOCA event was analyzed, as outlined in Section 2.0.

A comparison of the NOTRUMP and the WFLASH results reveals interesting differences in the dynamic behaviors as predicted by the two codes. (Plots are available in Reference 4, Section 3.1, Case E for the WFLASH Case). Some of these differences are attributable to the specific modeling capabilities of the respective computer codes, [a,c

]; some of the differences noticed early in the NOTRUMP transient can be explained by the starting of the NOTRUMP run from an unsteady state as obtained from WFLASH ("patching" mis-match).

Following a brief rise in the reactor coolant system (RCS) pressure, believed to result from the "patching" mis-match, the NOTRUMP case (Figure 3) does not exhibit as long of a plateau at the steam generator safety setpoint level as seen in the WFLASH case. The RCS pressure plot for Case E, Section 3.1 of WCAP-9600 shows that the pressure stays around 1200 psia until about 1800 seconds. The pressure in the NOTRUMP case is seen to fall below this level early, at about 1450 seconds. The difference in the behaviors of the cold leg loop-seals in the two simulations is traced to be the major cause of this.

In the case of the WFLASH analysis, the loop-seal in the broken loop cold leg is found to clear at about 1800 seconds which brings about an effective relief of system pressure by steam discharge through the break. The NOTRUMP analysis shows a much earlier clearing of the loop-seal at 1450 seconds. This early clearing of the loop-seal is a direct consequence of draining back into the reactor vessel a significant part of the liquid in the up-hill side of the U-tubes initially present and formed by condensation later. From Figures 77 and 39 it can be seen that this flow reversal and steam condensation begin as early as 600 seconds. This draining back of the liquid, as portrayed by NOTRUMP, would have otherwise continued to feed the loop-seal causing an extended resistance to steam relief as normally simulated by WFLASH.

1105 114

The more rapid depressurization of the NOTRUMP case is also influenced to a smaller extent by higher break mass and energy discharge rates and enhanced condensation of steam in the U-tubes.

A comparison of the break flowrates as calculated by NOTRUMP (Figure 101) and WFLASH (Reference 4, Section 3.1) shows substantially higher values for the former. For example, prior to the clearing of the loop-seal, at 1400 seconds, the NOTRUMP case yields a subcooled break discharge flowrate of nearly 300 lb/sec. The corresponding figure for the WFLASH case is 200 lb/sec. a,c

Furthermore, following clearing of the loop-seal, when the break fluid node becomes saturated, substantially higher break mass and energy flowrates are calculated by NOTRUMP. Whereas WFLASH predicts saturated steam discharge during this time regime, NOTRUMP shows substantial liquid discharge along with steam. This is due to the way the break is represented in the NOTRUMP analysis.

The enhanced condensation in the NOTRUMP case also contributes to the more rapid depressurization. The NOTRUMP case shows (see Figures 39 and 61) development of steam space in the U-tube nodes [ ] as early as 600 seconds. a,c With the condensation heat transfer coefficient [ ] applied in the steam region, more effective heat transfer from the primary takes place. a,c In the WFLASH model, recall that the up-hill side tube volumes (nodes 3 and 5 in Figure 1) are treated as homogeneous fluid nodes and consequently these do not develop explicit steam spaces in them. [ ] a,c

Figures 5 through 76 show plots of mixture heights and mixture void fraction in various locations of interest. Although these plots are of use in understanding the behavior of the system, the table on page 3-9 makes this understanding easier.

A significant contribution to resistance to natural circulation in the loops arises from the amounts of liquid trapped in the steam generator tubes and the loop-seals. The tabulated values of the liquid mass in various locations of the broken and intact loops at various times during the transient demonstrate how the loops void and become replenished with liquid from condensation. In the table, the data corresponding to fluid nodes in the intact loop are shown within parentheses.

At the start of the NOTRUMP run at 240 seconds the liquid mass distribution in the broken and intact loops is seen to be symmetric. This is due to the fact that the asymmetric effect of the break in the broken loop has not begun to be felt yet, dominated by the forced circulation of the coolant. As natural circulation takes over from this stage, the broken loop, with its less resistive path, is preferred by the flow leaving the reactor vessel. As the flows in the hot legs of both loops decay as shown by Figures 77, 78, 89 and 90, the hot legs and steam generator fluid nodes begin to drain.

1105 116

The table shows that during this time, the hot side of the intact loop has drained more than that of the broken loop. At about 600 seconds (see Figures 77 and 89) the hot legs of both loops begin to drain liquid into the reactor vessel for the first time. Due to safety injection in the intact loop (see Figure 97 for liquid flow reversal into intact loop loop-seal) and the asymmetric preference of the loop flows, the loop-seal in the broken loop clears first at about 1450 seconds. This is also seen in the table (t = 1500 seconds, Fluid Node 26).

Figure 103 shows the hot leg mass flowrate for Case E of WCAP-9600, Section 3.1. This plot can be compared to Figure 77. Note that Case E of WCAP-9600 overpredicts the time at which natural circulation terminates (800 seconds rather than 600 seconds) due to the homogeneous modeling in the up-hill side of the steam generator. This overprediction is not consequential since the core remains covered. Between the time of steam generator drain initiation (340 seconds) and 600 seconds, WFLASH and NOTRUMP flows agree rather well. The WFLASH flow oscillates more than NOTRUMP [ ] a,c

The clearing of the loop-seal in the broken loop at about 1450 seconds causes a sudden surge of flow in the broken loop, and a corresponding reduction in the intact loop (see Figures 78 and 90). The RCS pressure responds to this first clearing of a loop by a rapid fall (see Figure 3). The increased steam flow through the broken loop steam generator leads to enhanced liquid build-up in the loop due to condensation. The increasing resistance caused by this forces more steam flow now through the intact loop. Eventually this leads to a clearing of the intact loop loop-seal at around 2600 seconds as shown in the table of liquid mass distribution. A sudden rise in the intact loop hot leg steam flow may be noticed in Figures 90.

A crucial part of all small break LOCA analyses is the behavior of the core mixture height. The WFLASH run shows uncovering of the core by the mixture to a depth of 6 ft. at around 1700 seconds, prior to voiding of the loop-seal. Following loop-seal voiding, the core is quickly recovered by a two-phase mixture. In contrast, this new study using the NOTRUMP code shows that the core remains covered throughout the transient.

MICHELSON'S NATURAL CIRCULATION MODES

The NOTRUMP analysis of the 2 inch cold leg break for a typical 4-Loop Plant allows a clearer analytical picture of the various modes of natural circulation following a small LOCA as described by Michelson(1). All of the modes discussed by Michelson are observed in this analysis except Mode 6, "Re-established Natural Circulation With the Reactor Vessel Pressure Controlling." This mode does not occur because the 2 inch break is large enough that system refill above the vessel nozzle elevations will not occur.

Mode 1, "Natural Circulation With Pressurizer Pressure Controlling", actually occurs during the WFLASH part of this analysis. It terminates where the pressurizer empties at $\sim$120 seconds. This can be seen from the pressurizer level plot for Case E, Section 3.1 of WCAP-9600.

Mode 2, "Natural Circulation With Reactor Vessel Pressure Controlling", begins at 120 seconds. This can be seen from the core (vessel) mixture level plot for Case E, Section 3.1 of WCAP-9600. This plot depicts the growth of the steam space at the top of the vessel as the mixture level decreases. This mode of natural circulation continues as the NOTRUMP portion of the analysis begins at 240 seconds. Figure 23 shows the upper plenum mixture level still decreasing. After this time, the densities of the fluid in the core, hot legs and steam generator up-hill side are decreasing due to flashing and boiling. This can be seen in Figures 10, 12, 14, 16, 18, 20, 22, 34, 38 and 40. On the other hand, the fluid inventories in the steam generator down-hill side and reactor vessel downcomer remain subcooled until at least 600 seconds. This can be seen in Figures 42, 44, 26, 28 30 and 32. Thus, an improved density gradient for natural circulation develops and loop flow increases. This is seen in Figure 77 between 250 seconds and 340 seconds.

Mode 3, "Transition From Natural Circulation to Core Boiling Mode", begins at 340 seconds when the steam generator starts to drain. The steam generator initially begins to drain on the down-hill side. If a snapshot was taken of the systems at this time the "hot half" of the natural circulation loop (bottom of core to the top of the steam generator) is full of a two-phase mixture. The cold half of the system is saturated or subcooled liquid. Thus, there is a driving force for natural circulation which will continue to push a two-phase mixture over the top of the steam generator tube (Note: The effect of multiple tubes in parallel is under investigation in a separate study) for a short period of time. As the down-hill side of the steam generator drains, this flow diminishes until at around 600 seconds the loop flow drops fairly abruptly and begins to oscillate (see Figure 78). A schematic of the system at this stage is shown in Figure 104. It is expected that with several tubes of various bend radii modeled, this stoppage of natural circulation will happen at different times for different tubes. Also, oscillations will probably occur amongst the various tubes. Multiple tube modeling is now being performed. At any rate, when the flow stops, the up-hill side of the steam generator also begins to drain. This can be seen on Figure 39.

It should be pointed out that while reactor coolant loop flow has stopped, local flow loops are developing between the core and the steam generator allowing steam to flow from the core to the steam generator and condensate to flow in the reverse direction. This is a form of natural circulation: reflux boiling.

Mode 4, "Core Boiling", begins at 600 seconds with core steam bubbling through liquid in the up-hill side of the steam generator. Some of this steam is condensed on both the up-hill and down-hill side of the steam generator. This is the beginning of the "reflux boil" mode. However, steam is being stored in the steam generator as indicated by the falling liquid levels. The system pressure will "seek" a value which will condense the difference between the steam entering the steam generator from the core and that being stored as the break drains the system. The counter-current flow models in NOTRUMP indicates that the water condensed on the up-hill side of the steam generator drains back to the vessel along the bottom of the hot leg. This is indicated as negative flow in Figures 77 and 79. This occurs as the core steam continues to flow into the steam generator along the top of the hot leg as indicated as positive flow on Figure 78.

Some thought has been given to how the steam generator begins to drain. It must be first realized that the vertical U-tube Steam Generator has a tremendous amount of heat removal capacity which allows for rapid condensation of steam even with very small temperature driving force. When two-phase mixture is first introduced into the inlet of the steam generator, there is still a driving force for condensation and the primary side of the steam generator is still above saturation pressure. The initial steam flow is condensed quickly. At some time in the transient the tubes on the up-hill side of the steam generator reach saturation pressure (slightly above secondary pressure). At this point simultaneous condensation and flashing is occurring and soon steam reaches the down-hill side of the steam generator. Several phenomena are also occurring on the down-hill side of the steam generator. First, it is still above saturation pressure and the secondary pressure. Therefore, voids are being collapsed. The steam bubbles acquire a drift velocity which is opposite to the direction of the main flow. The steam bubbles are originally still being carried with the flow but they decelerate. For a while void collapse prevents coalescence of these bubbles.

Mode 4 continues as the system continues to drain. By about 1300 seconds, the steam generators are completely drained (see Figures 35 and 45). Reflux is still occurring on both sides of the steam generator as evidenced by the presence of both liquid and steam discharging from the outlet of the steam generator and falling by gravity into the loop-seal (see Figures 81 and 82). Shortly thereafter, the loop-seal has drained to the point where steam can be vented directly to the break. This causes an increase in the broken loop steam flow (see Figures 78, 80, 84, 86 and 101). The ensuing phenomena during Mode 4 were discussed in detail earlier. That is, condensation on the up-hill side of the broken loop steam generator leads to a build-up of water, which causes the steam flow to diminish and eventually to switch over to the intact loops. At about 3500 seconds, safety injection flow exceeds break flow and the vessel level begins to recover.

Mode 5, "Transition From Core Boiling to Natural Circulation", is an incomplete mode for this size break in the sense intended by Michelson. The system does not refill for this size break so continuous two-phase natural circulation does not occur again. However, the reflux boiler form of natural circulation continues indefinitely. Decay heat is being removed predominantly by the break as seen by Figure 102. The condition of alternating steam venting through the intact and broken loops may continue during this mode.

Some time later the down-hill side of the steam generator reaches saturation pressure and the steam bubbles begin to coalesce. Drain of the down-hill side of the steam generator begins. It consists of a growing upper region of water film on the tube surface surrounding a steam core with a level of saturated liquid below that is "draining out" of the steam generator.

a,c

1105 122

4.0 CONCLUSIONS

The use of the NOTRUMP code with its special capability to model steam and liquid movement under natural circulation conditions in the reactor coolant system brings the analysis of the small break LOCA a step closer to reality. The new analysis [ ] shows results strikingly different from those conservatively predicted by the current WFLASH evaluation model. a,c

This analysis demonstrates that uncovering of the core does not occur during a small LOCA if the drainage of the steam generator is modeled more correctly. It also demonstrates that WFLASH adequately predicts two-phase natural circulation.

1105 123

5.0 REFERENCES

1. Michelson, C., "Decay Heat Removal Problem Associated With Recovery From a Very Small Break LOCA for CE System 80 PWR," TVA Internal Document, May 1977 (Made available by US NRC).

2. Esposito, V. J., Kesavan, K. and Maul, B. A., "WFLASH: A FORTRAN-IV Computer Program for Simulation of Transients in a Multi-Loop PWR," WCAP-8200, July 1973.

3. Meyer, P. E. and Frick, G. K., "NOTRUMP, A Nodal Transient Model Boiler, Steam Generator, and General Network Code," WCAP-8913, Revision 2, to be released.

4. "Report on Small Break Accidents for Westinghouse NSSS System," WCAP-9600, Volume 1, June 1979.

5. Kesavan, K., "WFLASH Steam Generator Primary-side Liquid Heat Transfer Coefficient," Calc. Note: PDC-SEC-SAI-917-CO, June 15, 1979.

1105 124

a,c

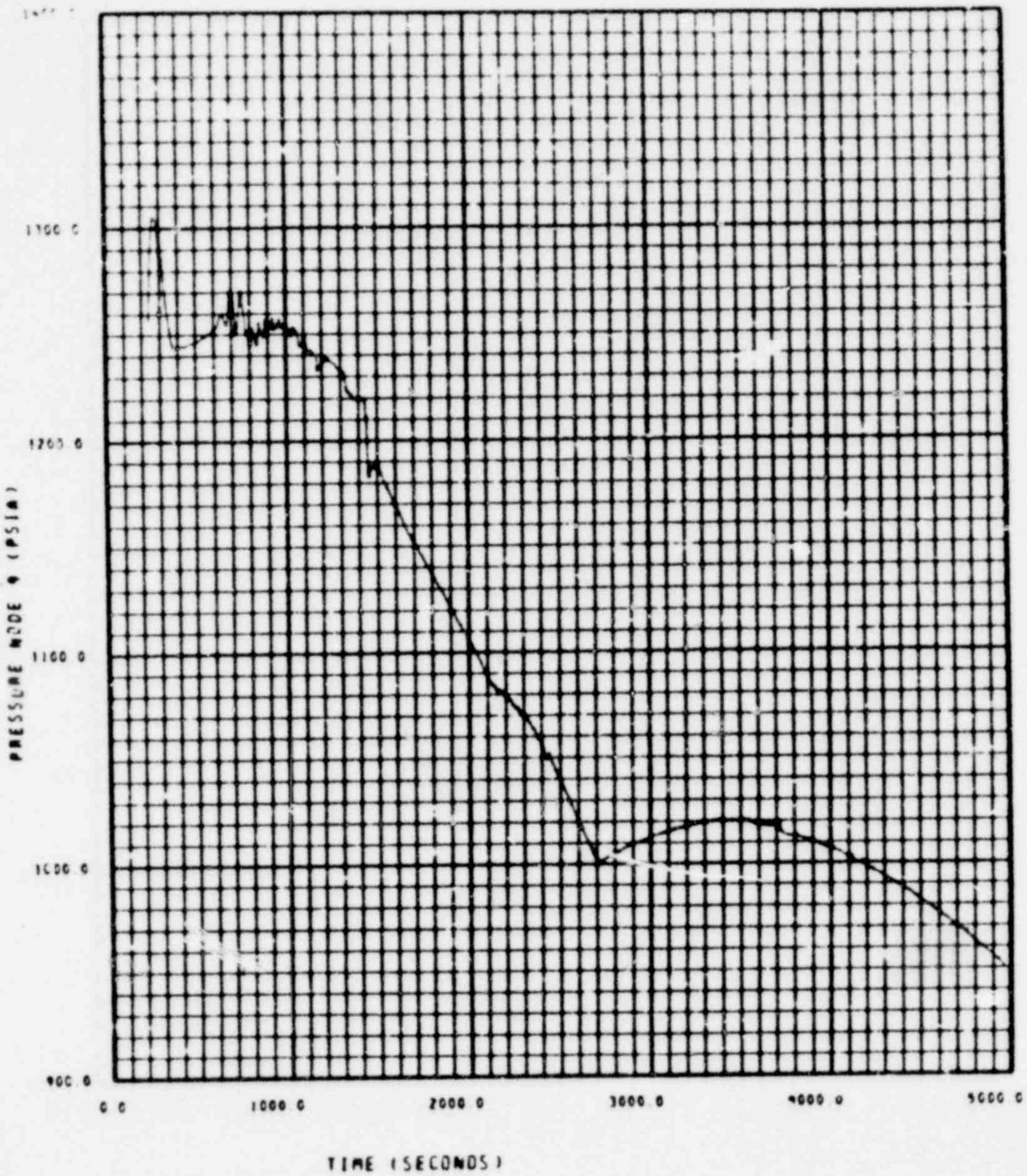
1105 125

Figure 1 WFLASH Model for a (W) PWR

a,c

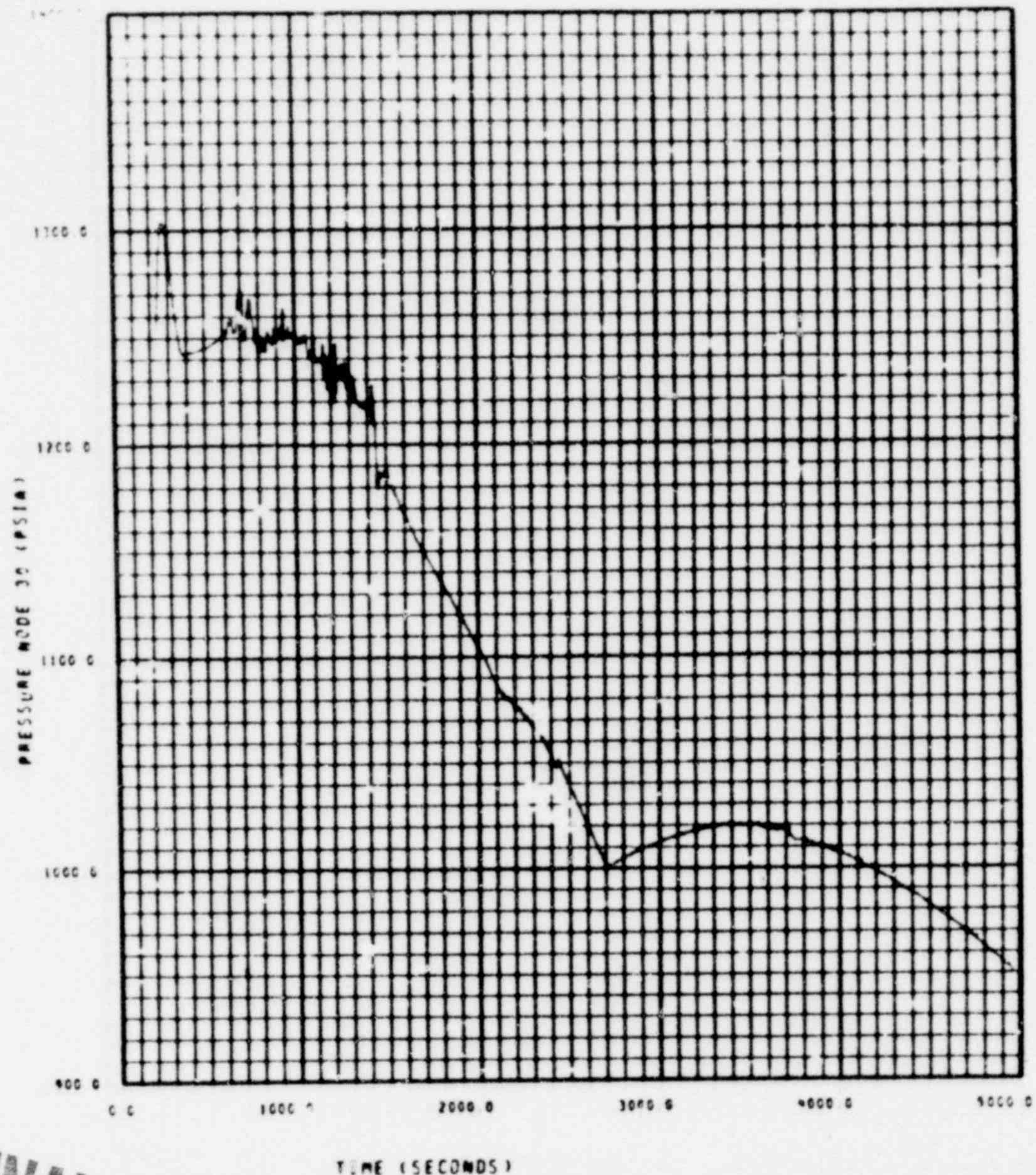
FIGURE 2.

1105 126



RESAR3 2 IN CL WFLASH-NOTRUFP

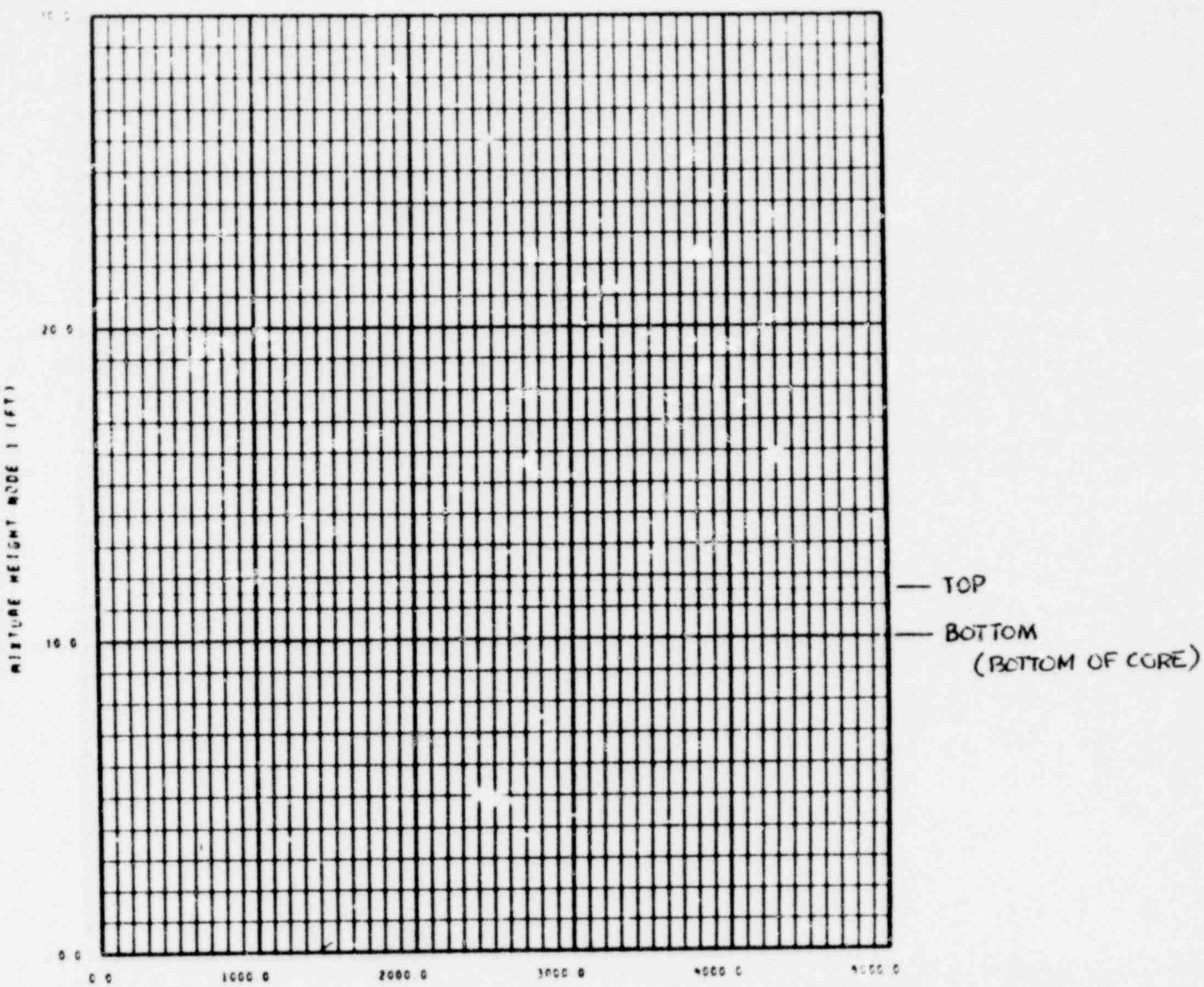
FIGURE 3



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 4

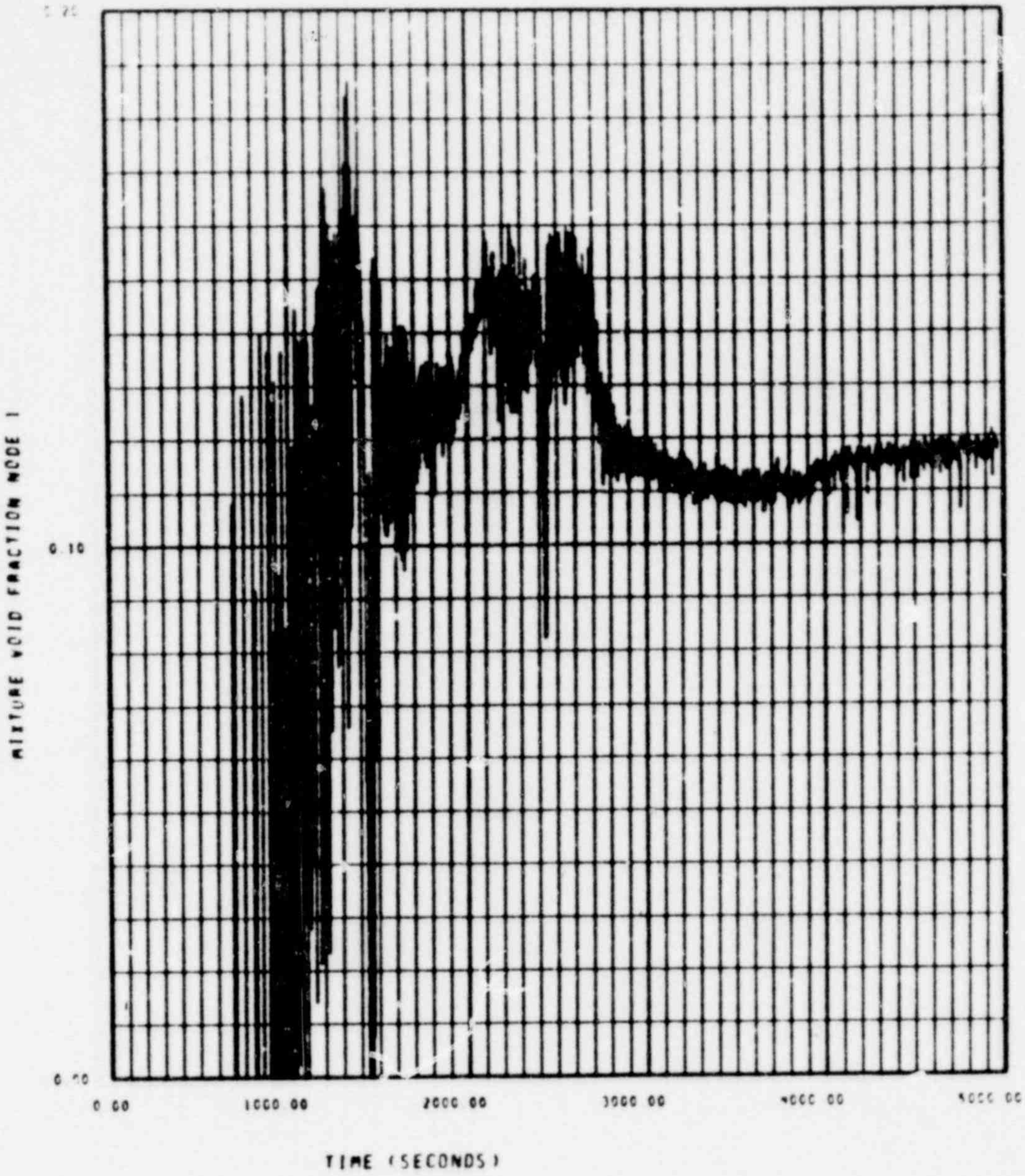
1105 128



TIME (SECONDS)

RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 5



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 6

1105 130

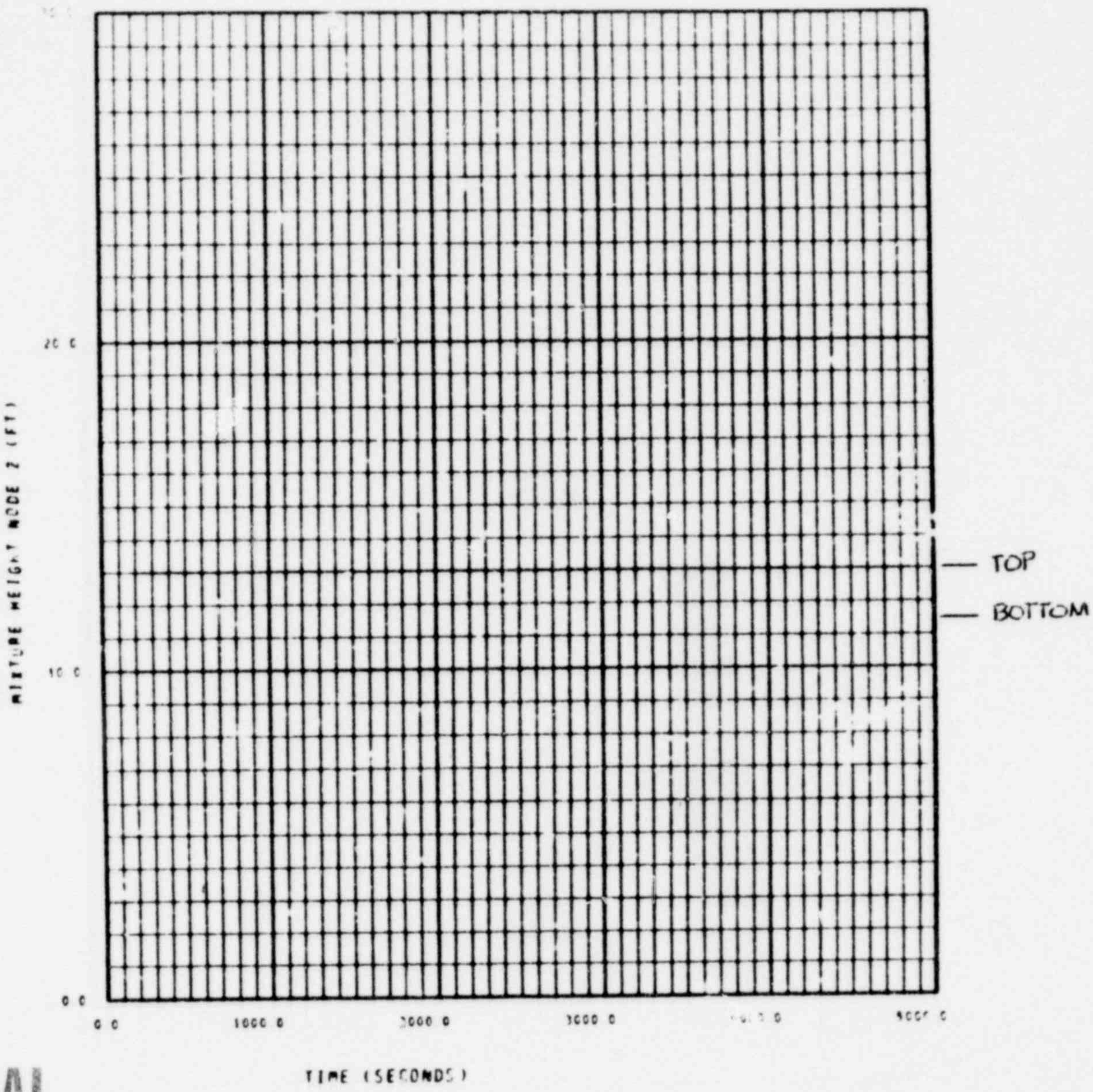


FIGURE 7

1105 131

POOR ORIGINAL

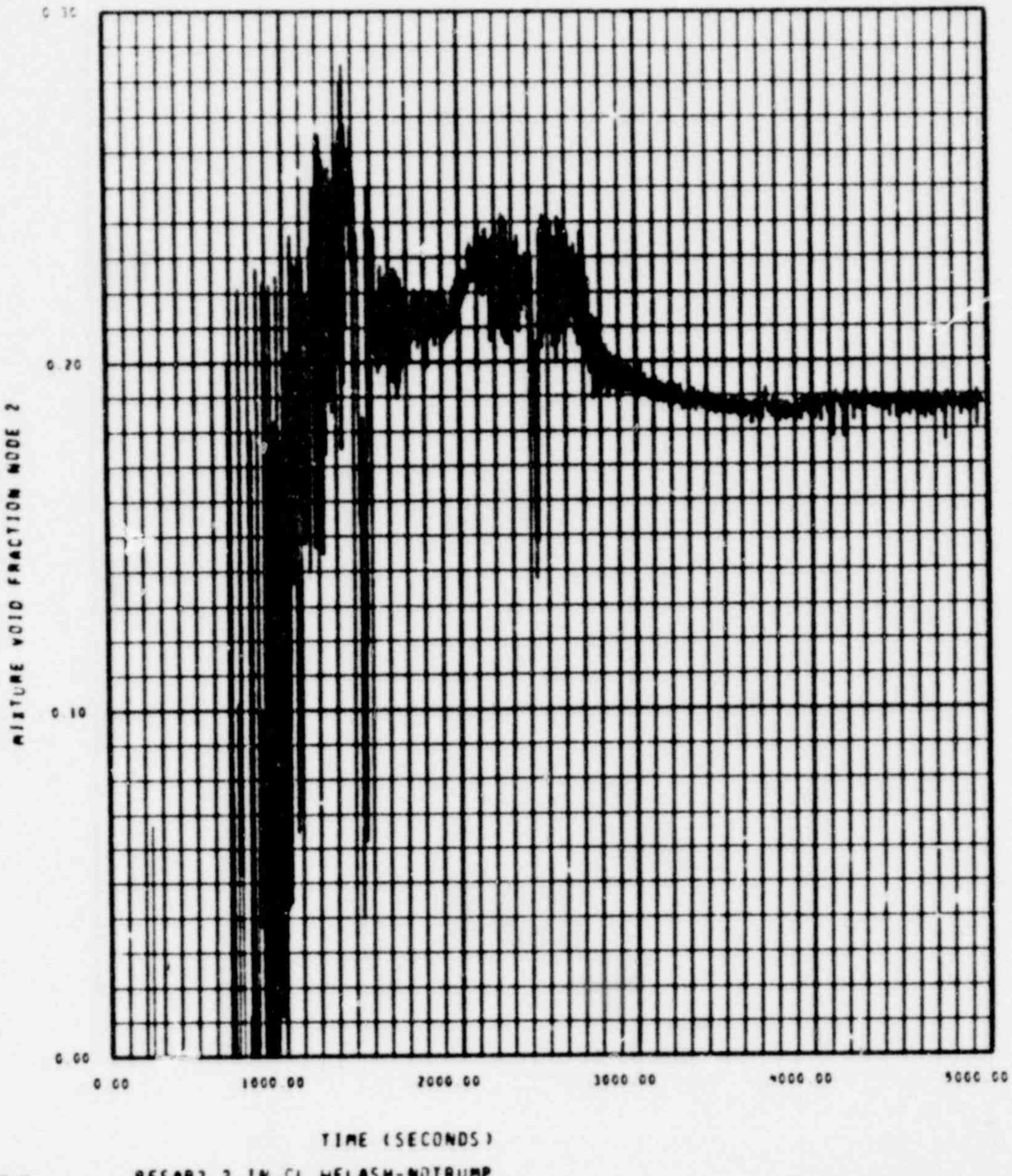
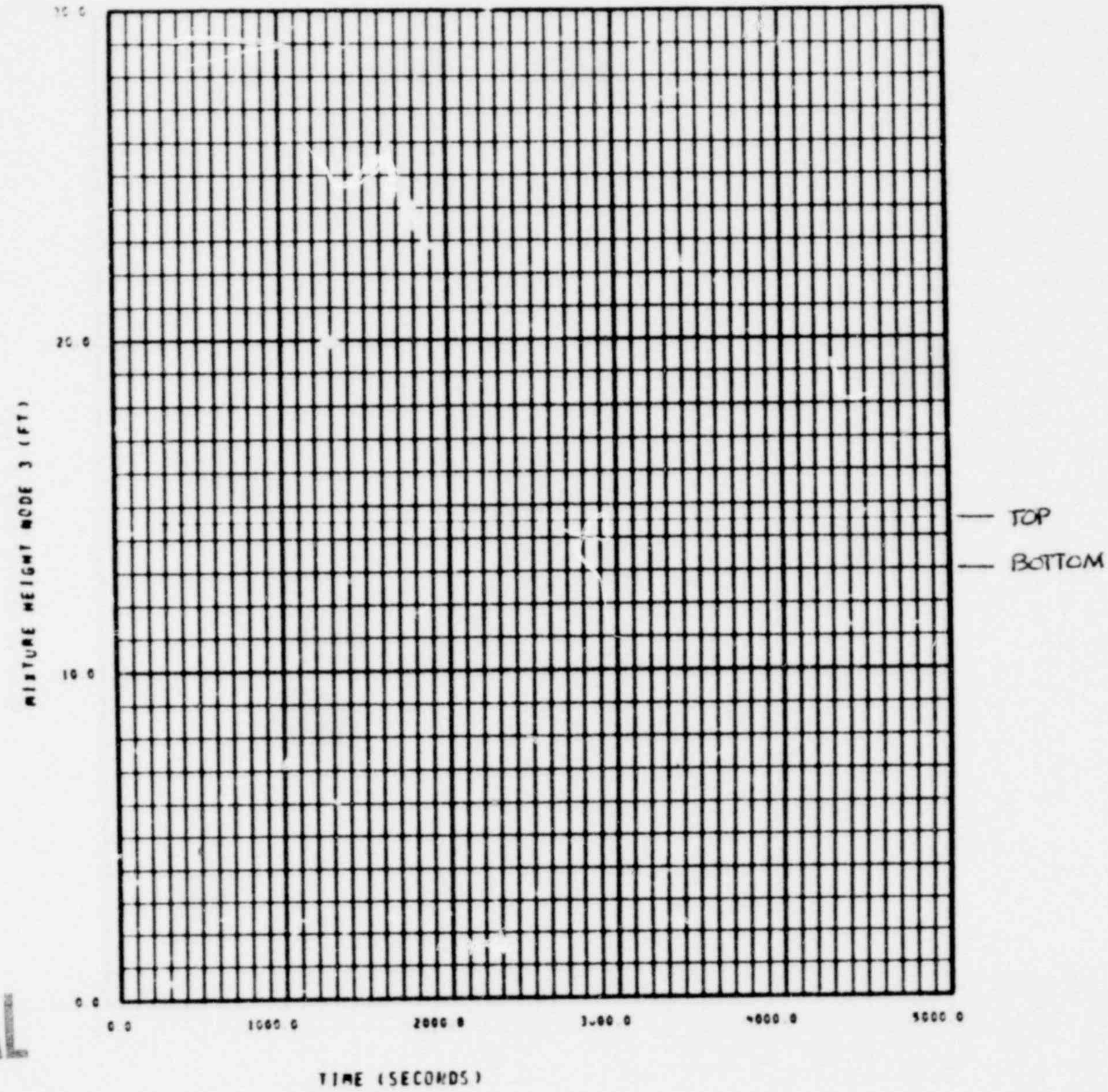

0.30
0.20
0.10
0.00
MIXTURE VOID FRACTION NODE 2
0.00
1000.00
2000.00
3000.00
4000.00
5000.00
TIME (SECONDS)
RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 8

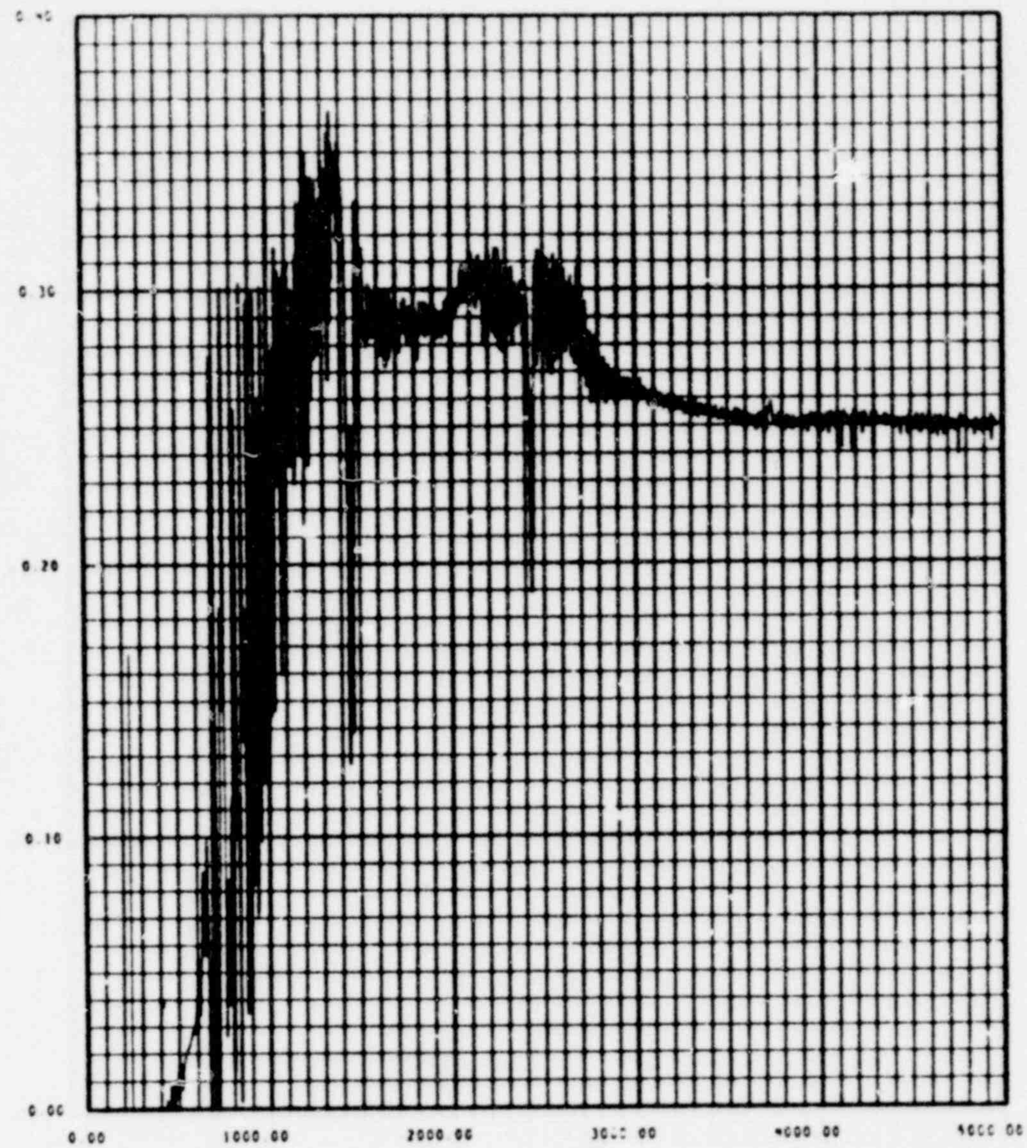


RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 9

POOR ORIGINAL

1105 133



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 10

1105 134

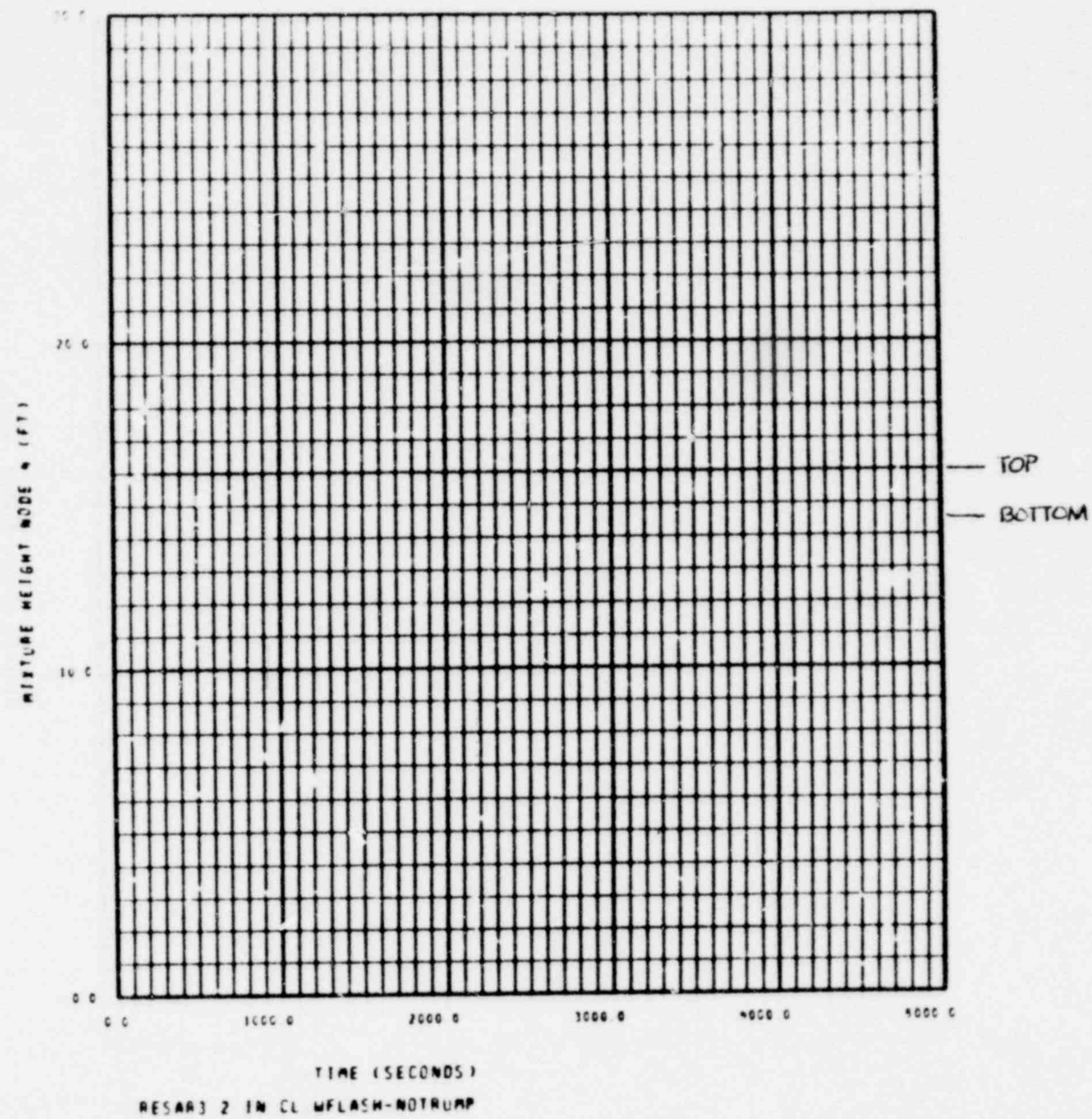
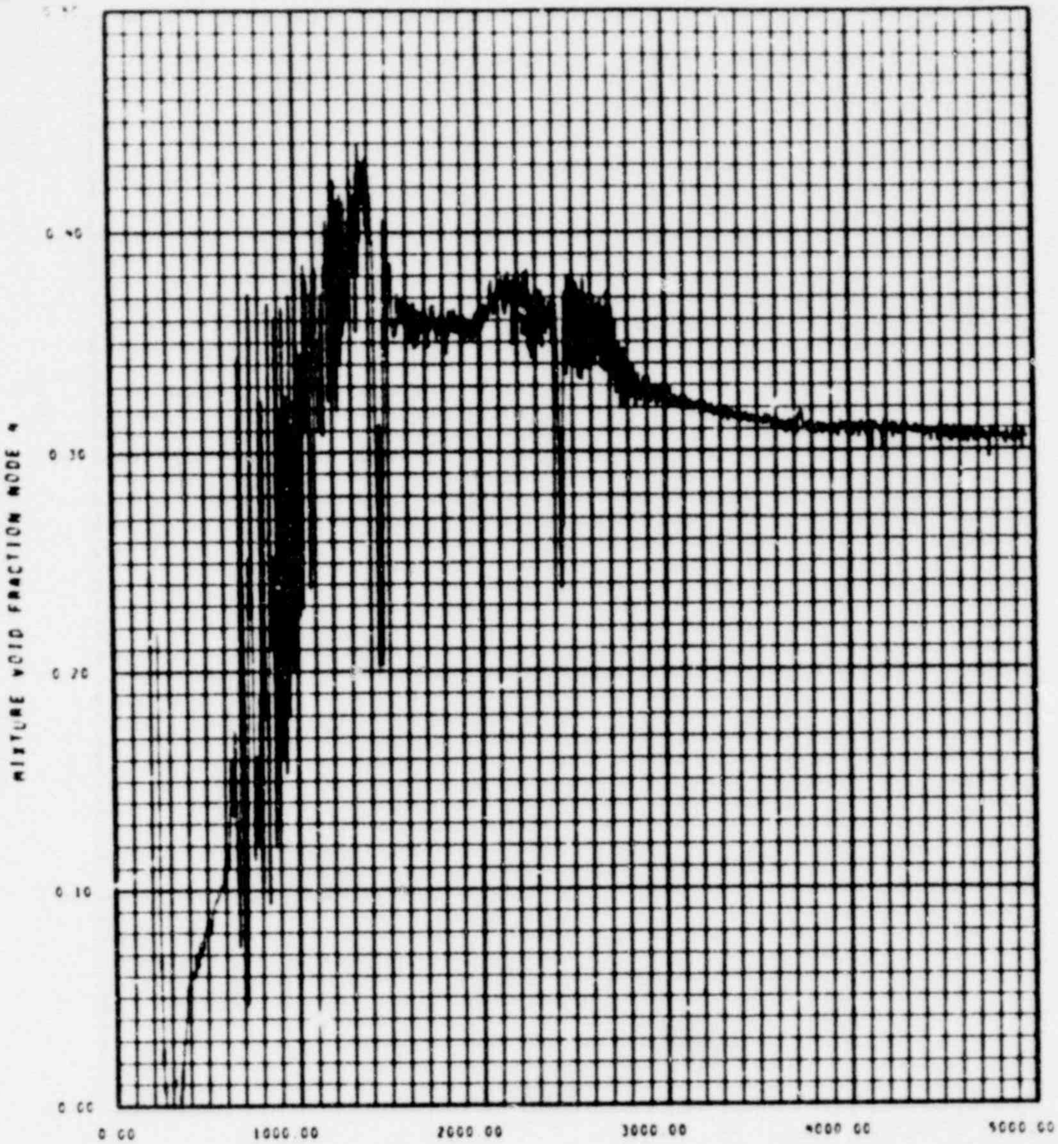


FIGURE 11

POOR ORIGINAL

1105 135



REGAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 12

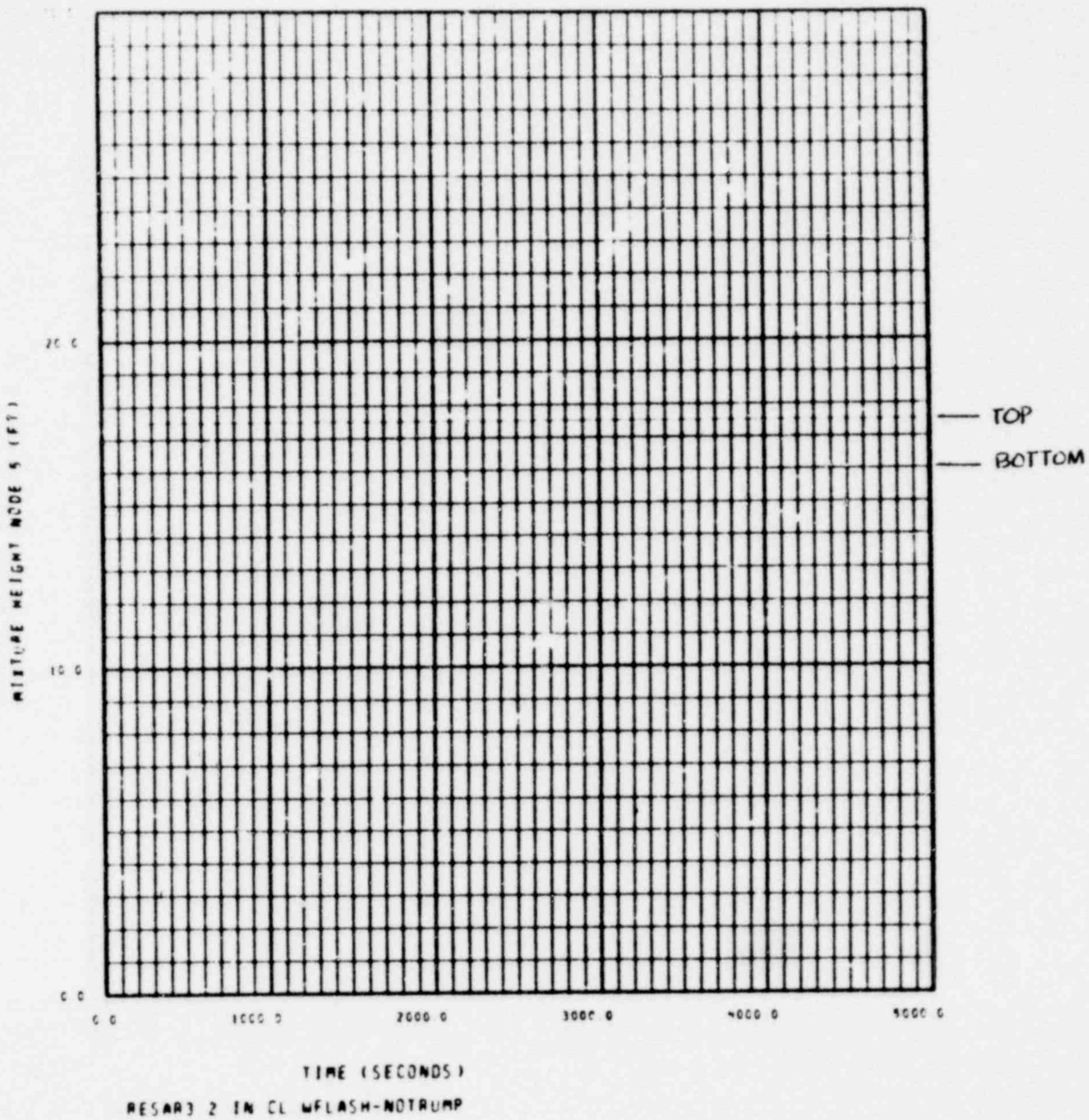
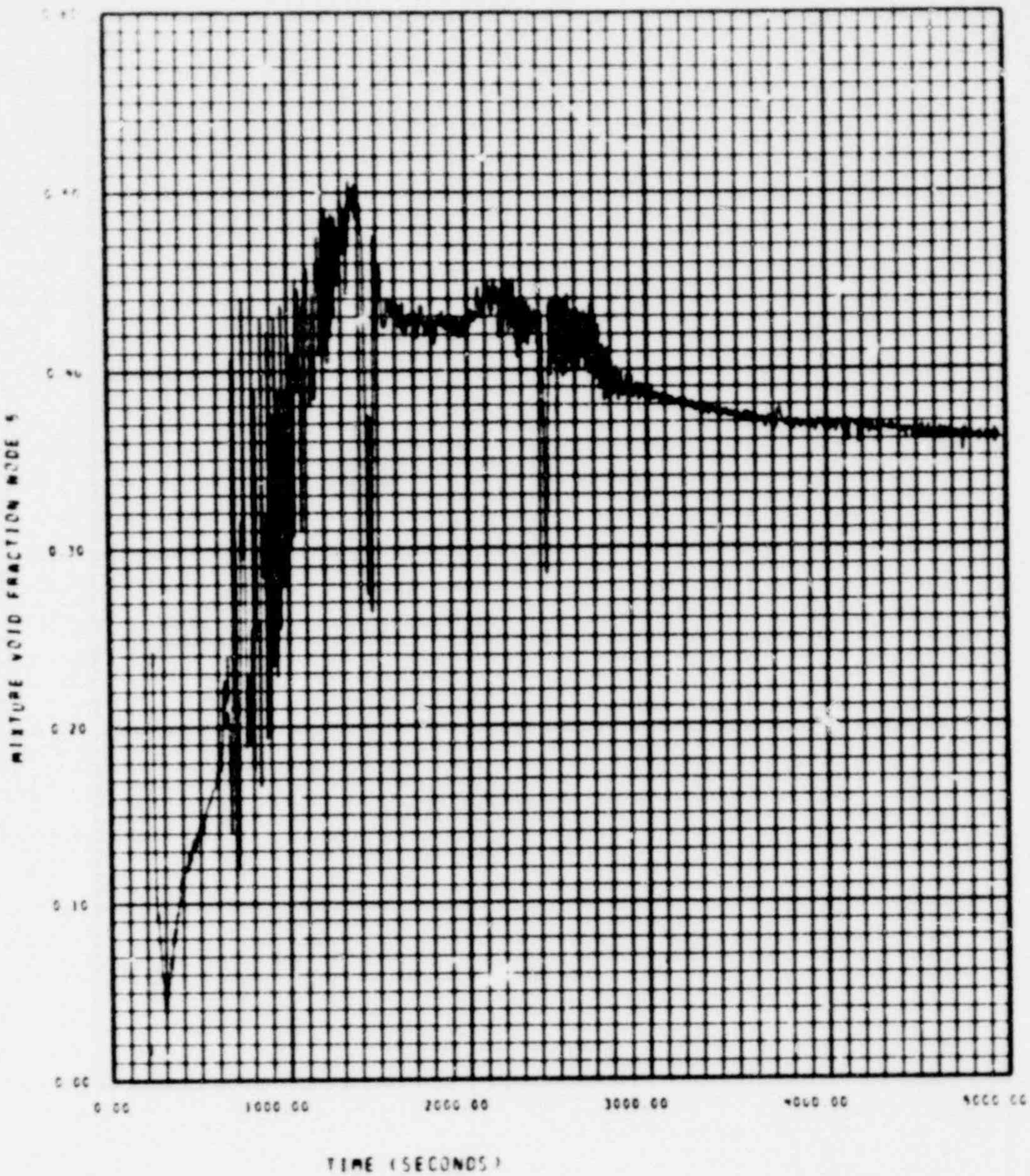


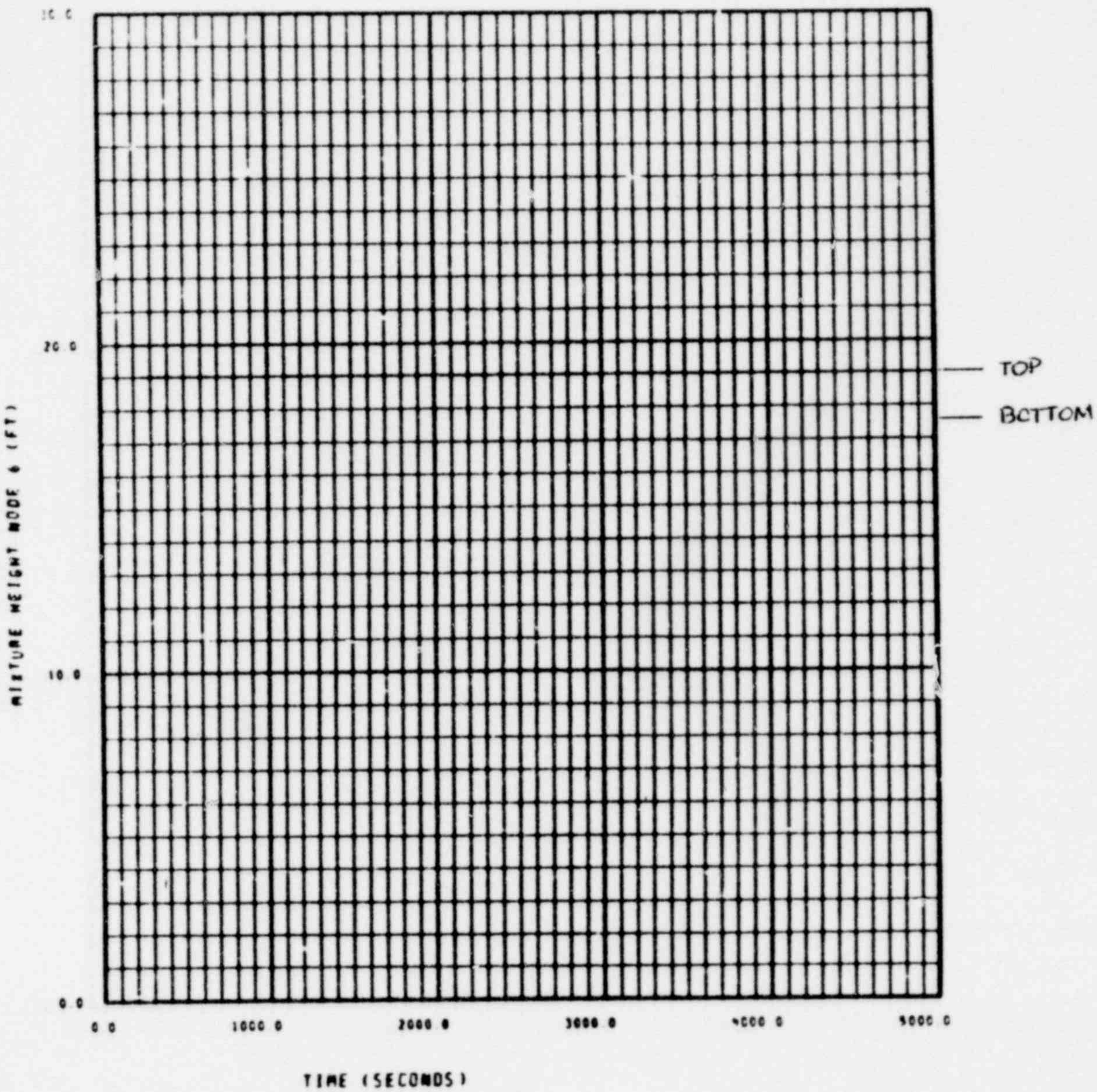
FIGURE 13

1105 137



RESAR3 2 IN CL WFLASH-NOTRUMP

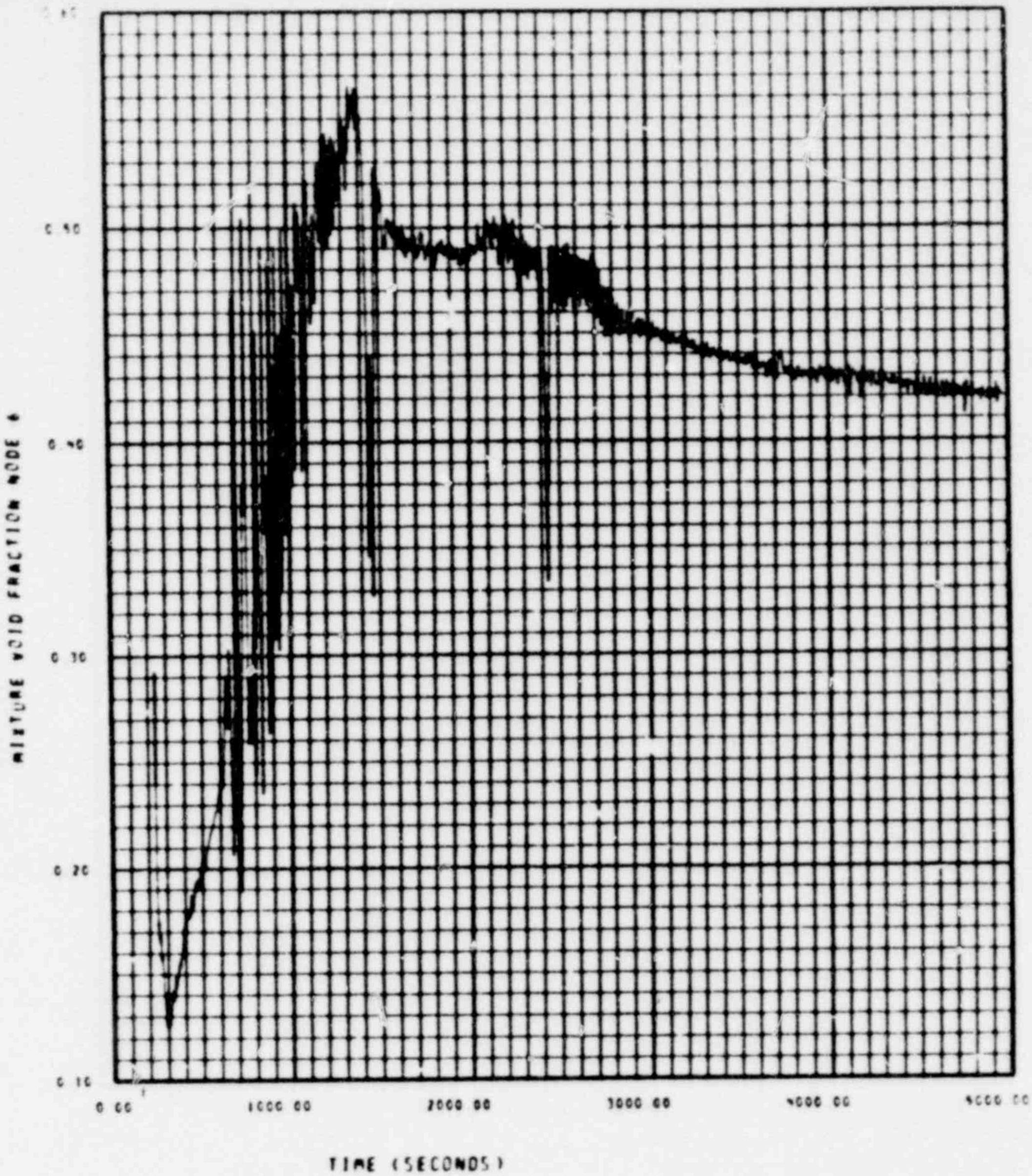
FIGURE 14



RESAR3 2 IN CL .FLASH-NOTRUMP

FIGURE 15

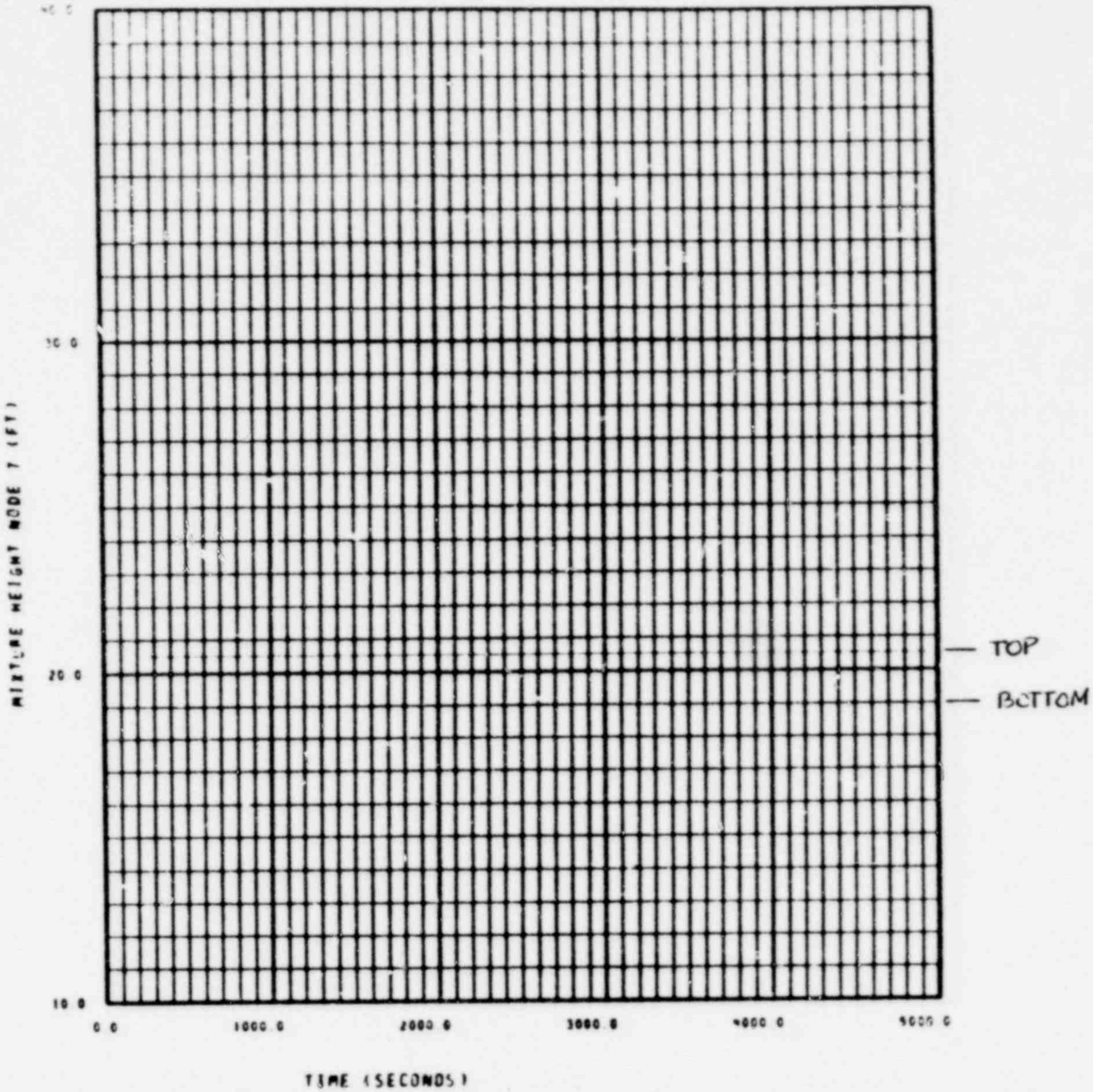
1105 139



RESAR3 2 IN CL WFLCSH-NOTRUMP

FIGURE 16

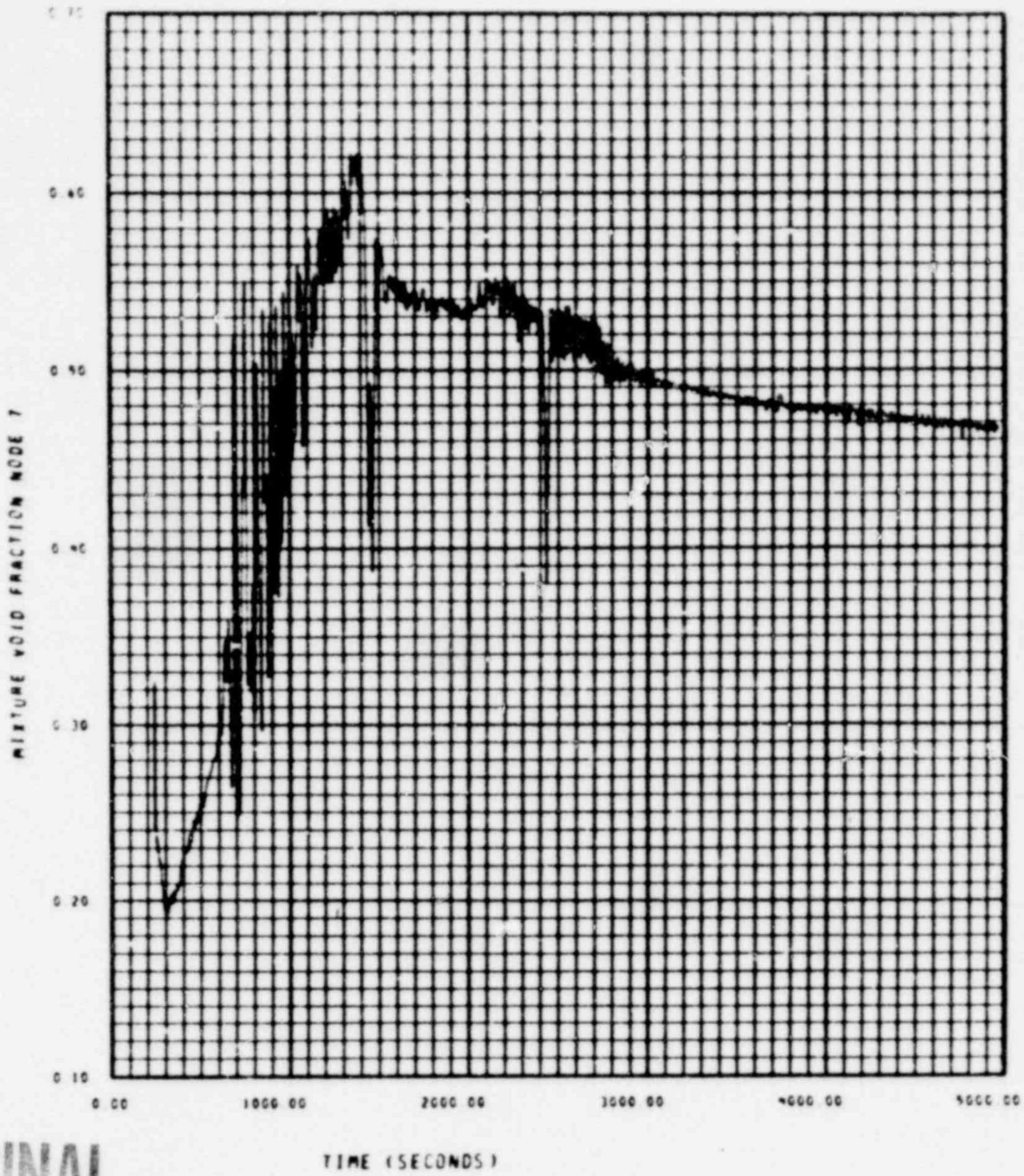
1105 140



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 17

1105 141



RESAR3 2 IN CL WFLASH NOTRUMP

FIGURE 18

1105 1

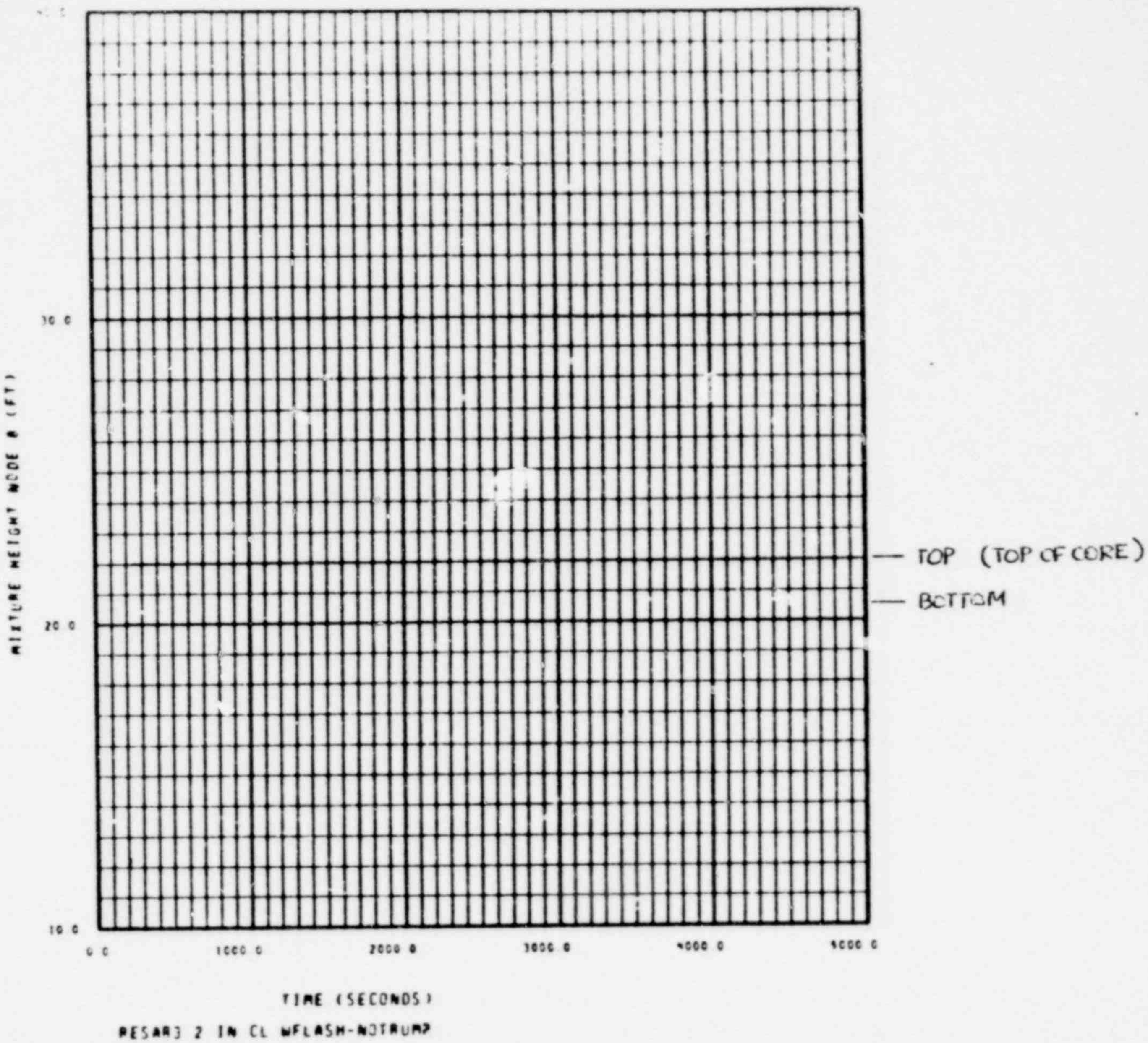
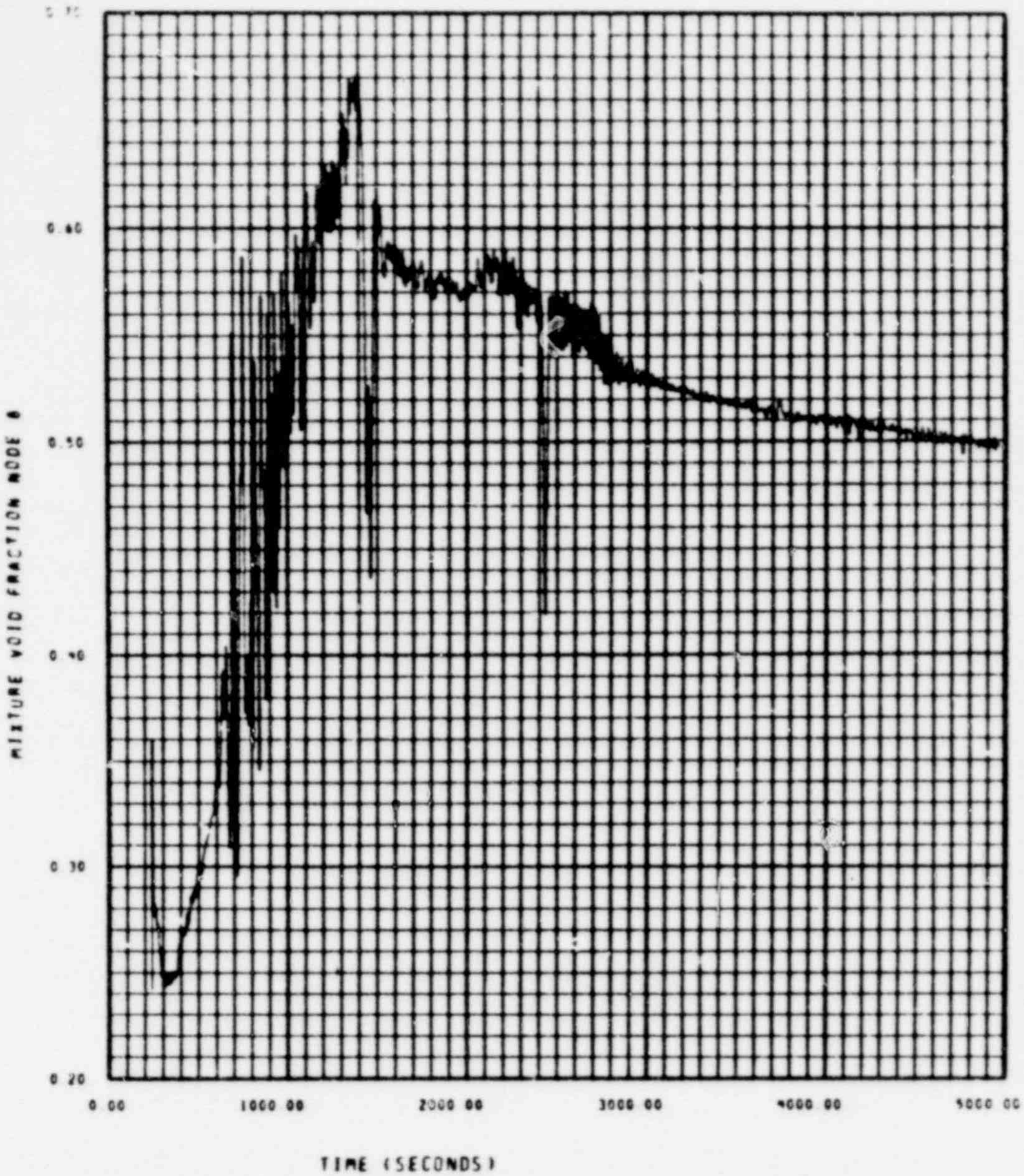


FIGURE 19

1105 143

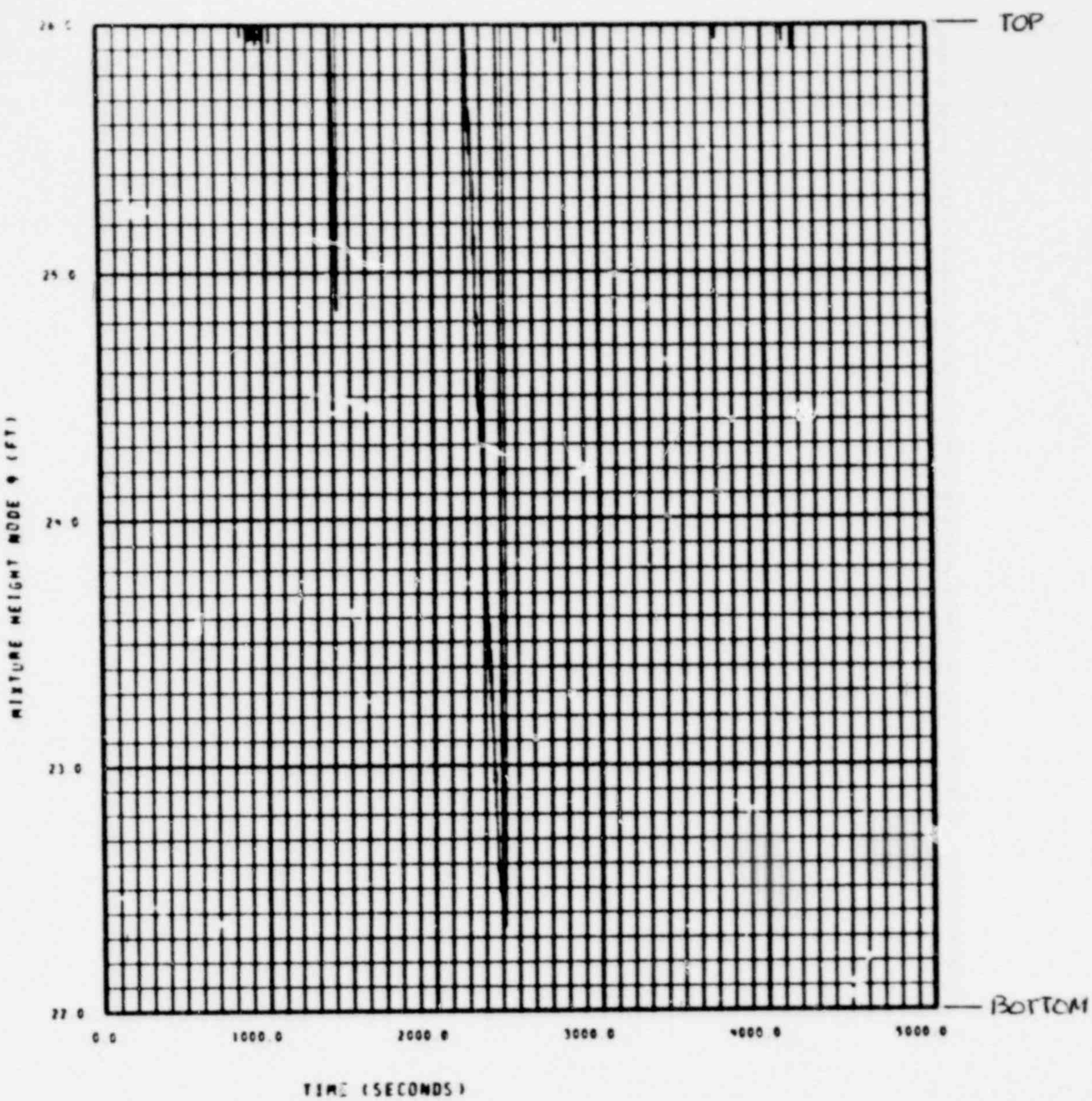
POOR ORIGINAL



RESAR? 2 IN CL WFLASH-NOTRUMP

FIGURE 20

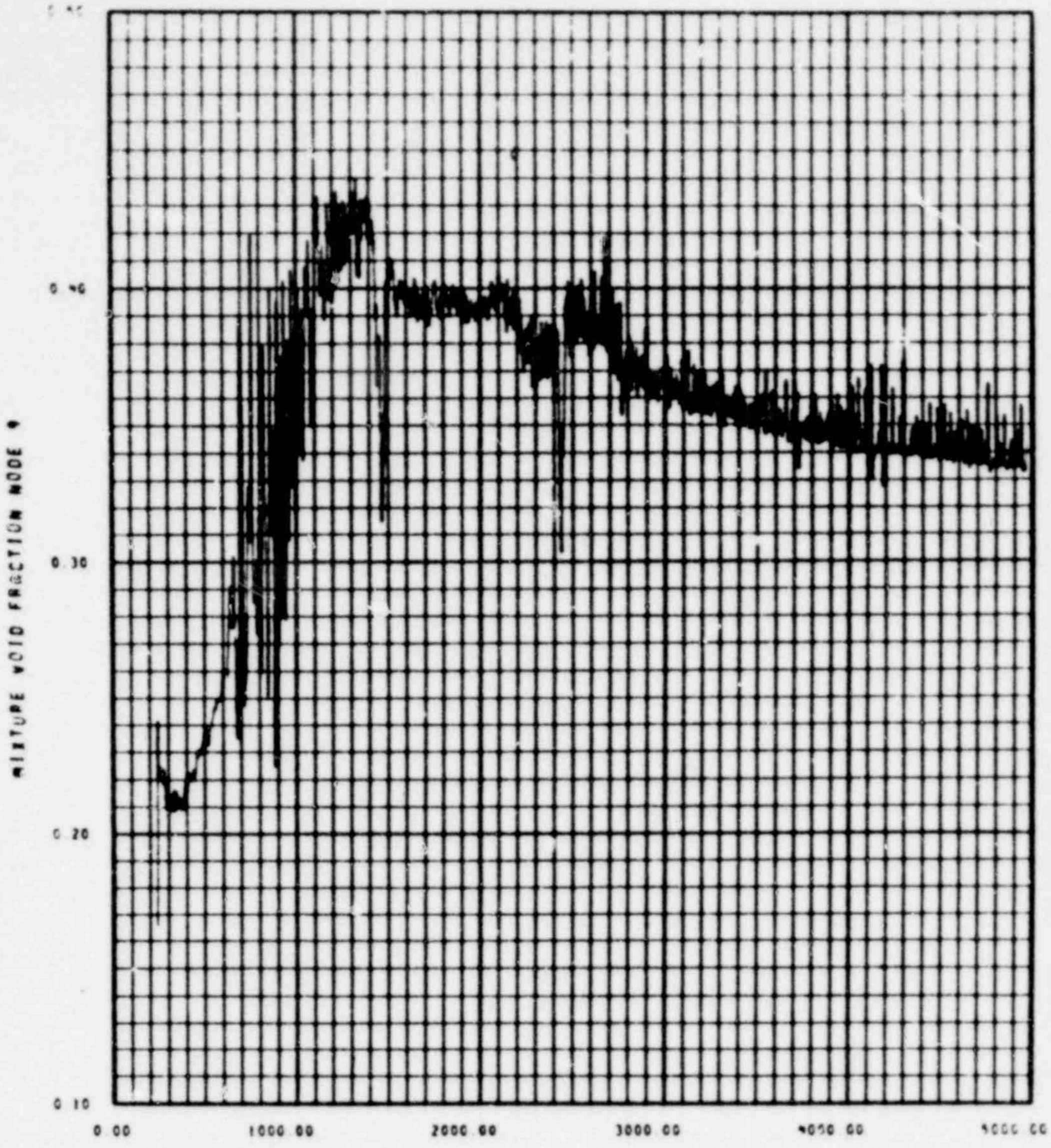
1105 144



RES?R3 2 IN CL WFLASH-NOTRUMP

FIGURE 21

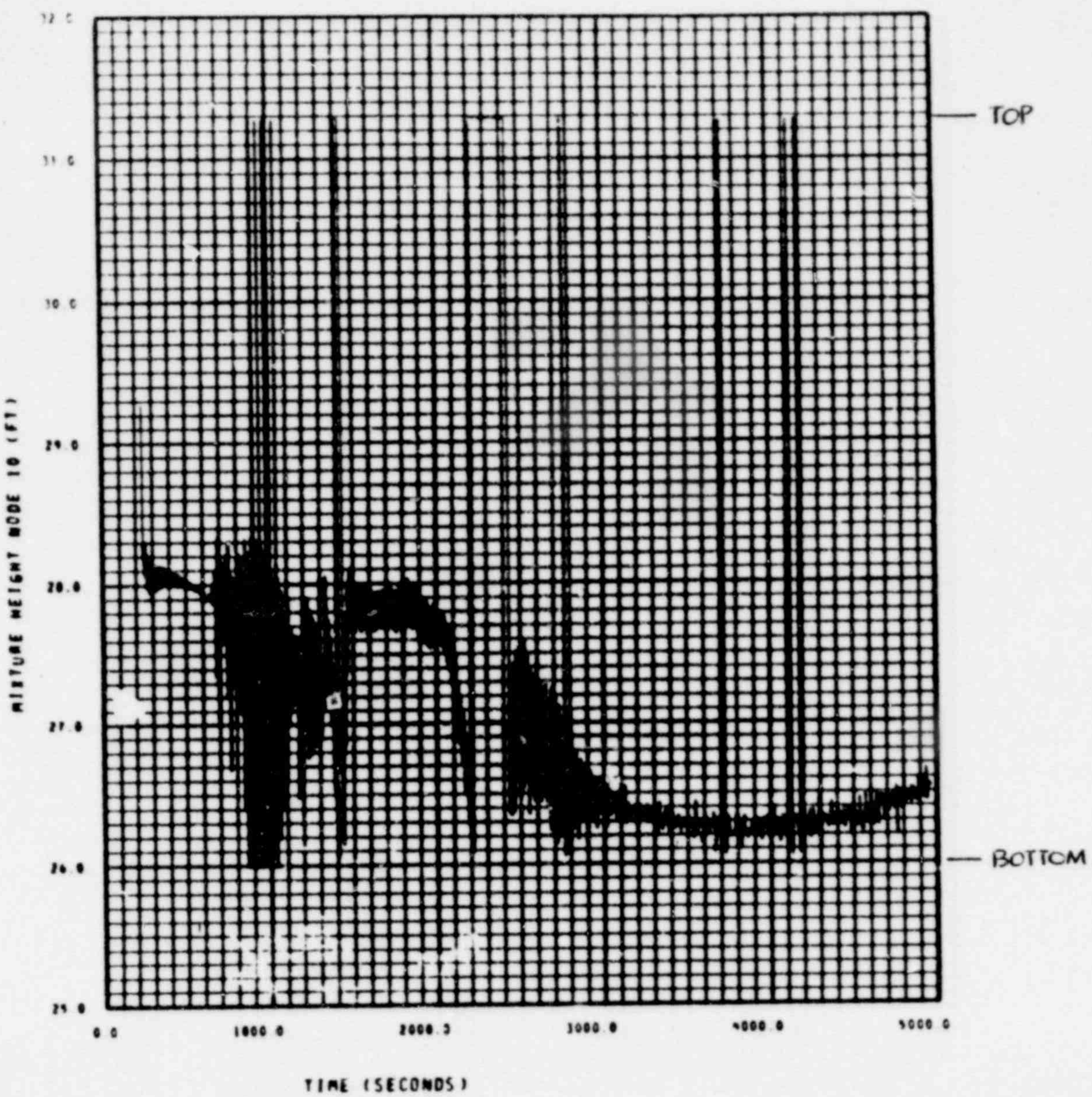
1105 145



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 22

1105 146



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 23

1105 147

POOR ORIGINAL

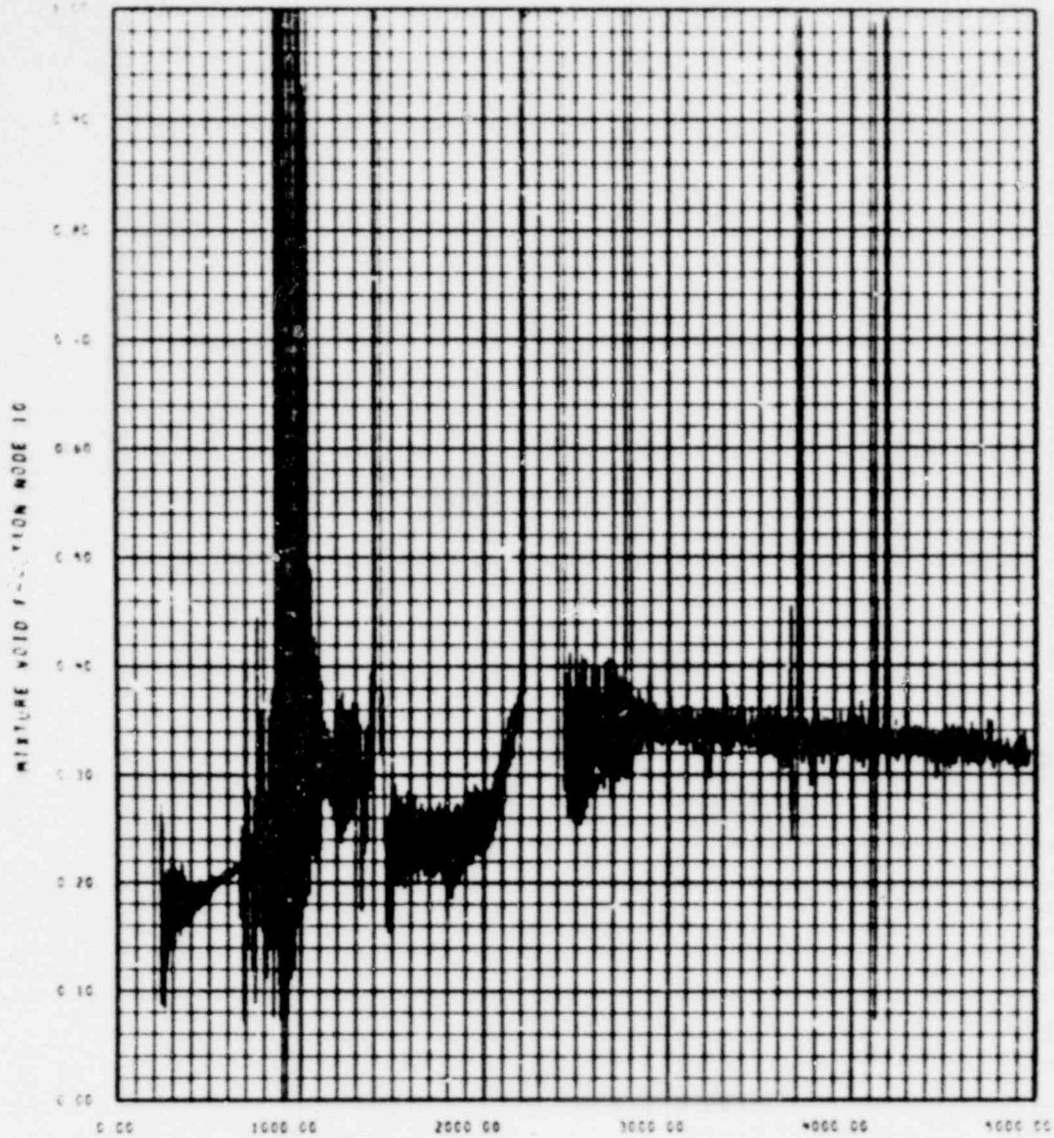
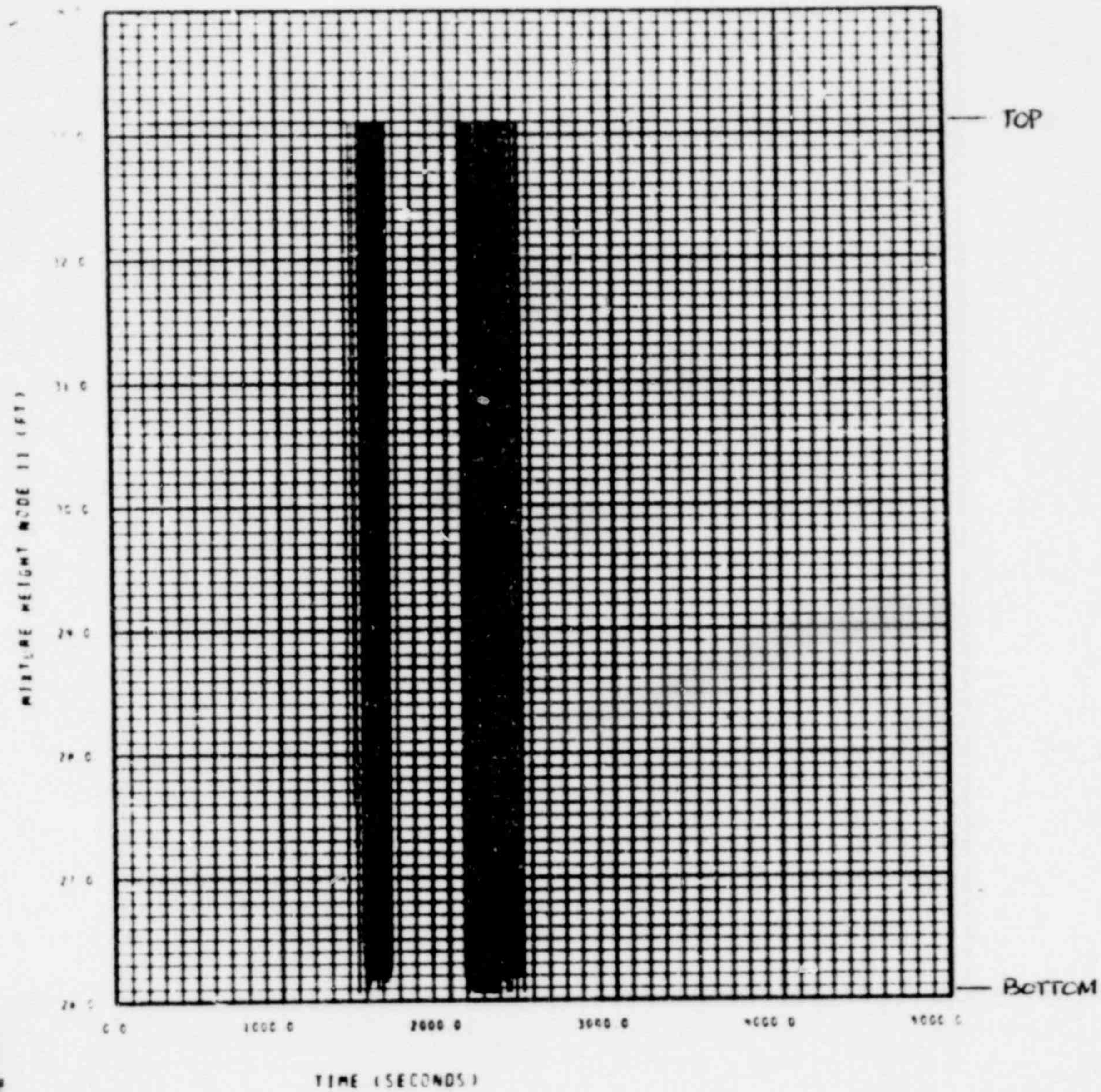


FIGURE 24

1105 148

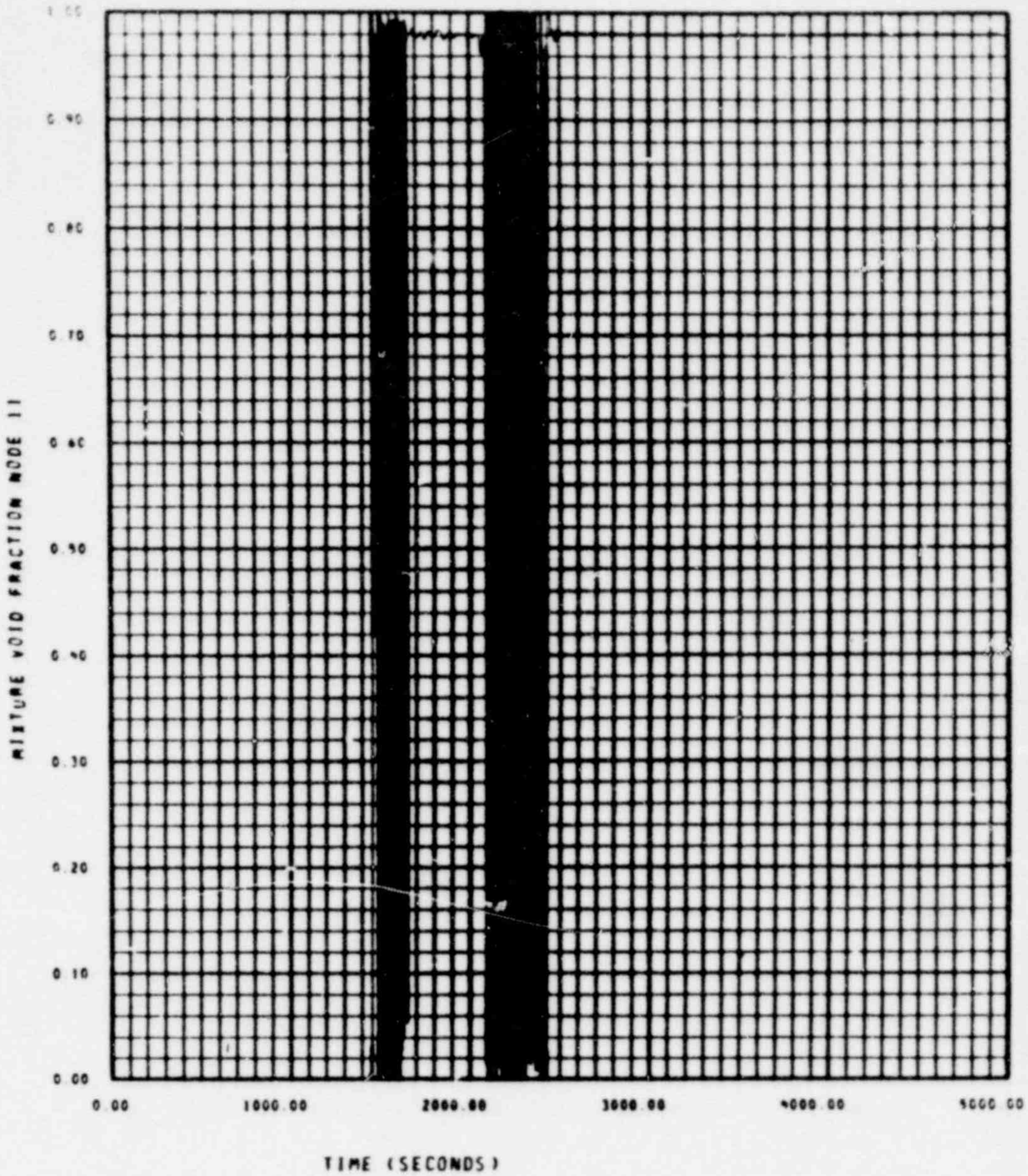


RESART 2 IN CL WFLASH-NOTRUMP

FIGURE 25

1105 149

POOR ORIGINAL

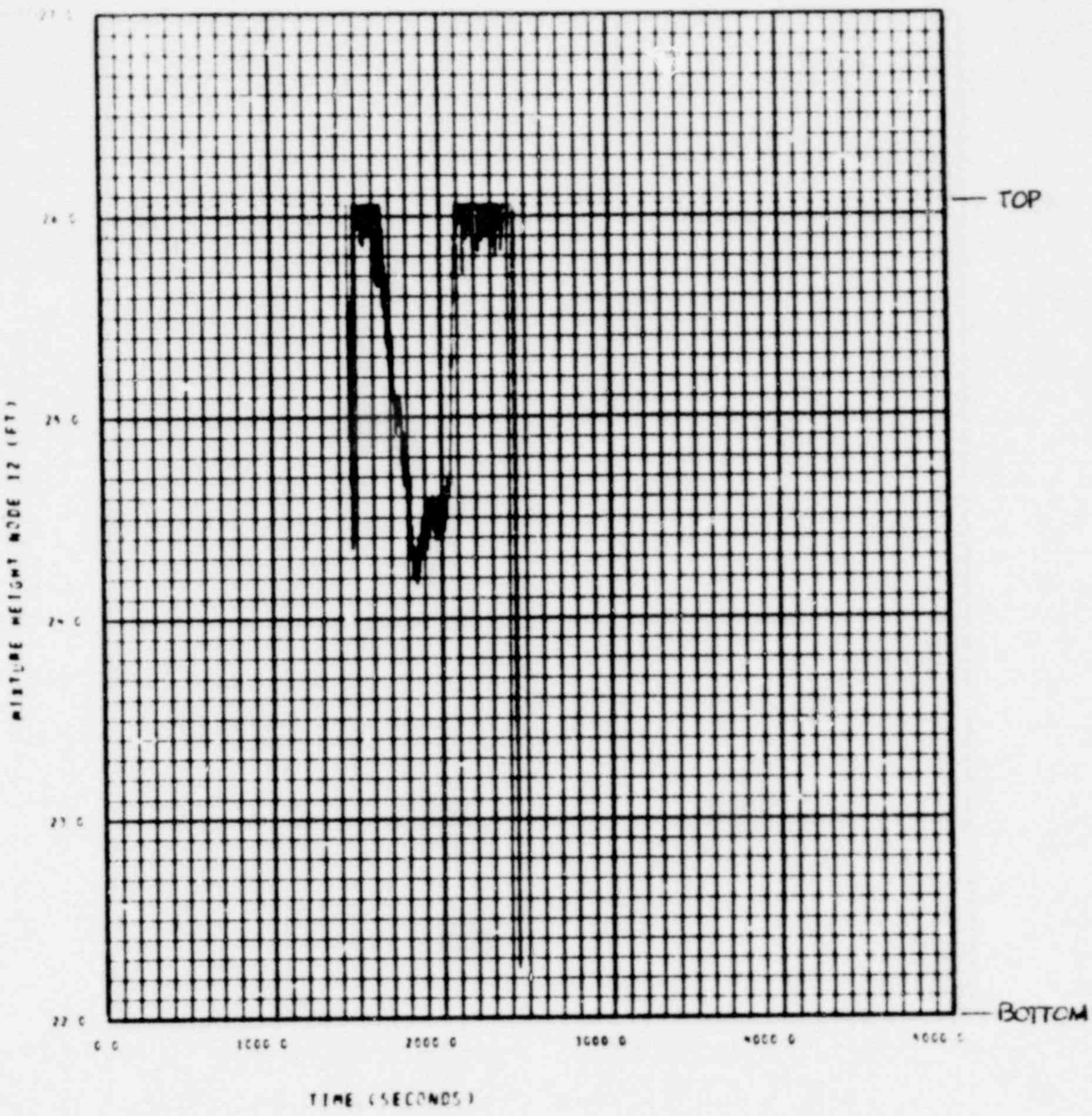


RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 26

POOR ORIGINAL

1105 150

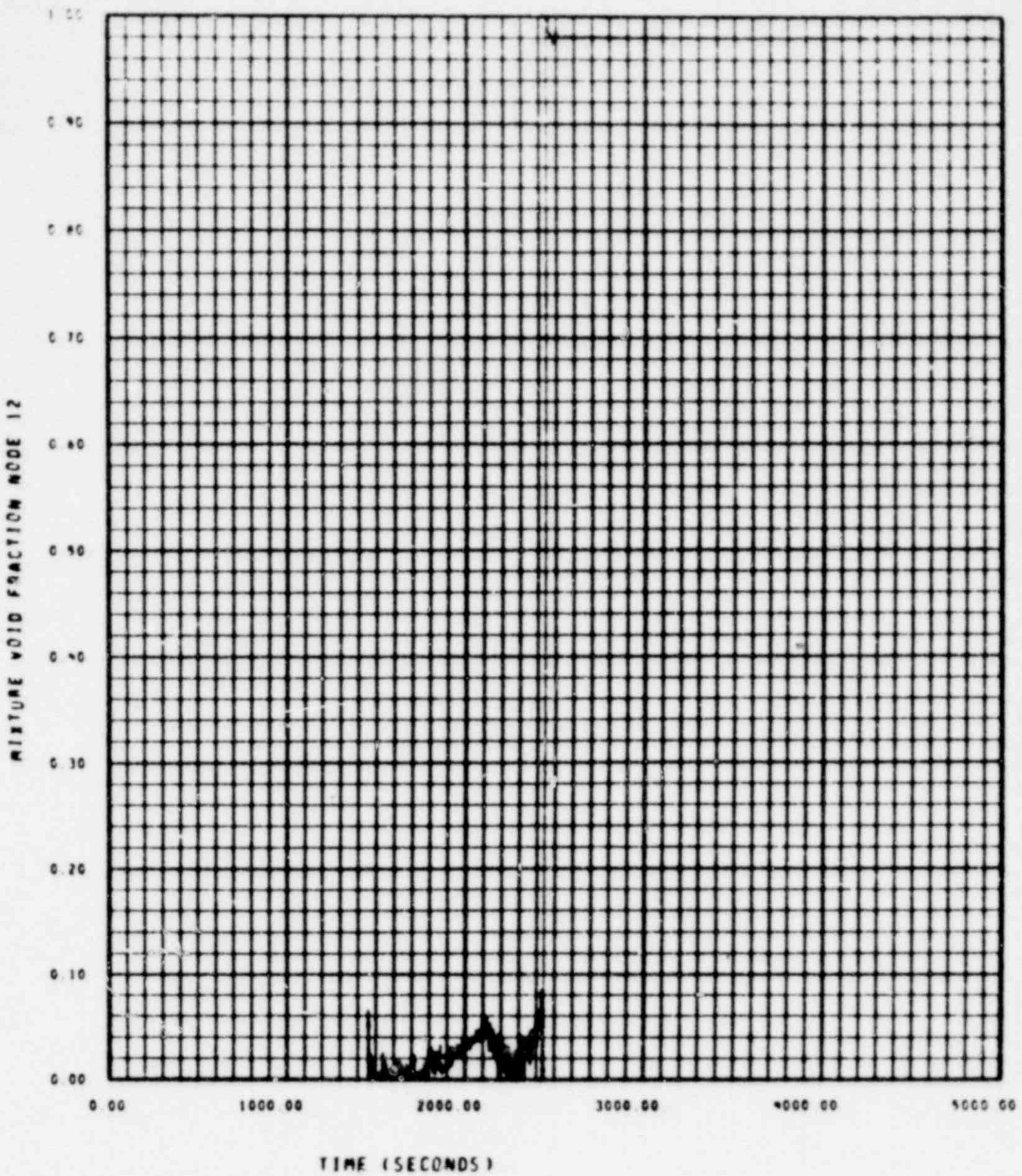


RESAR3 2 IN CL UFLASH-NOTRUMP

FIGURE 27

POOR ORIGINAL

1105 151



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 28

1105 152

POOR ORIGINAL

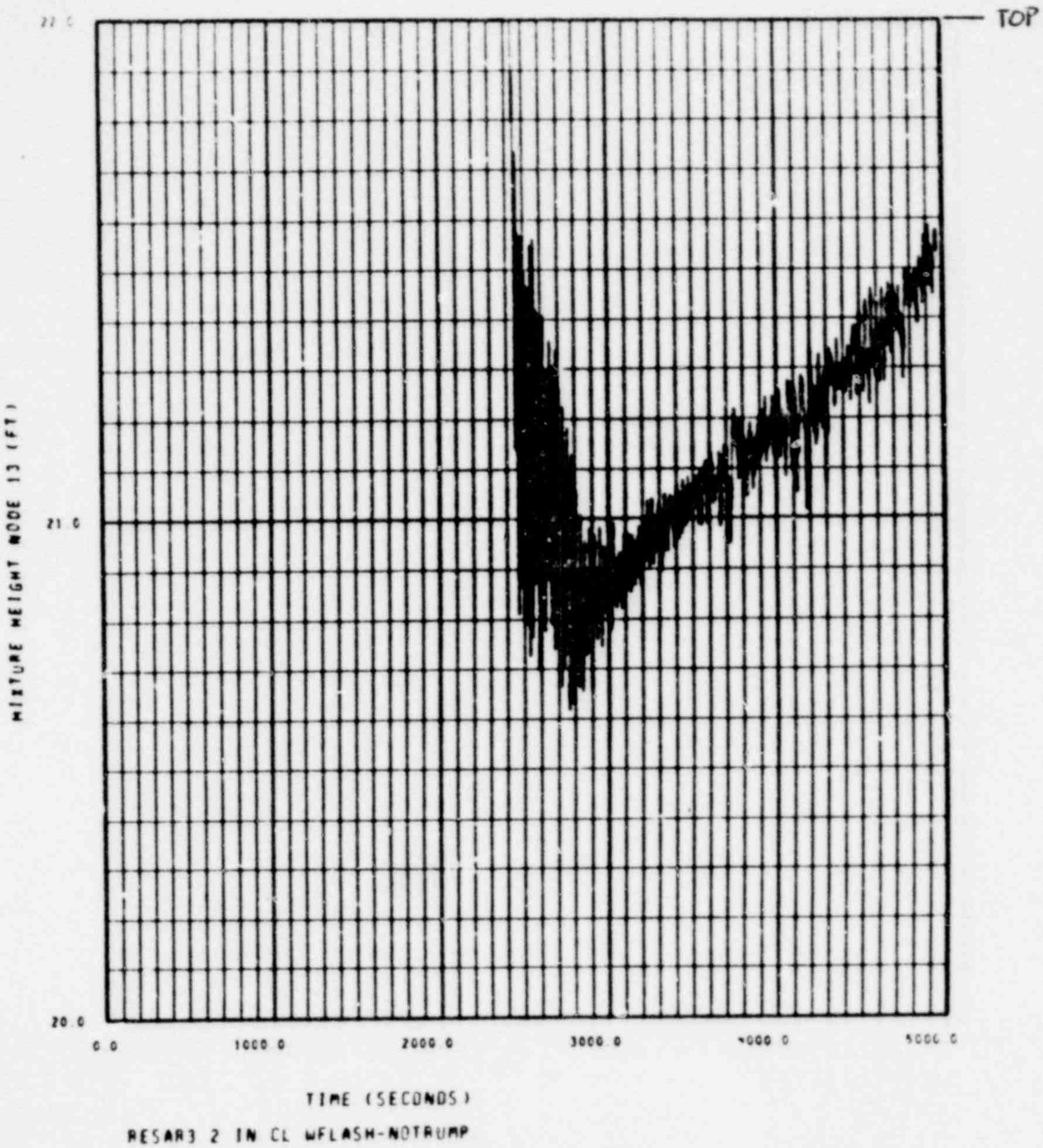
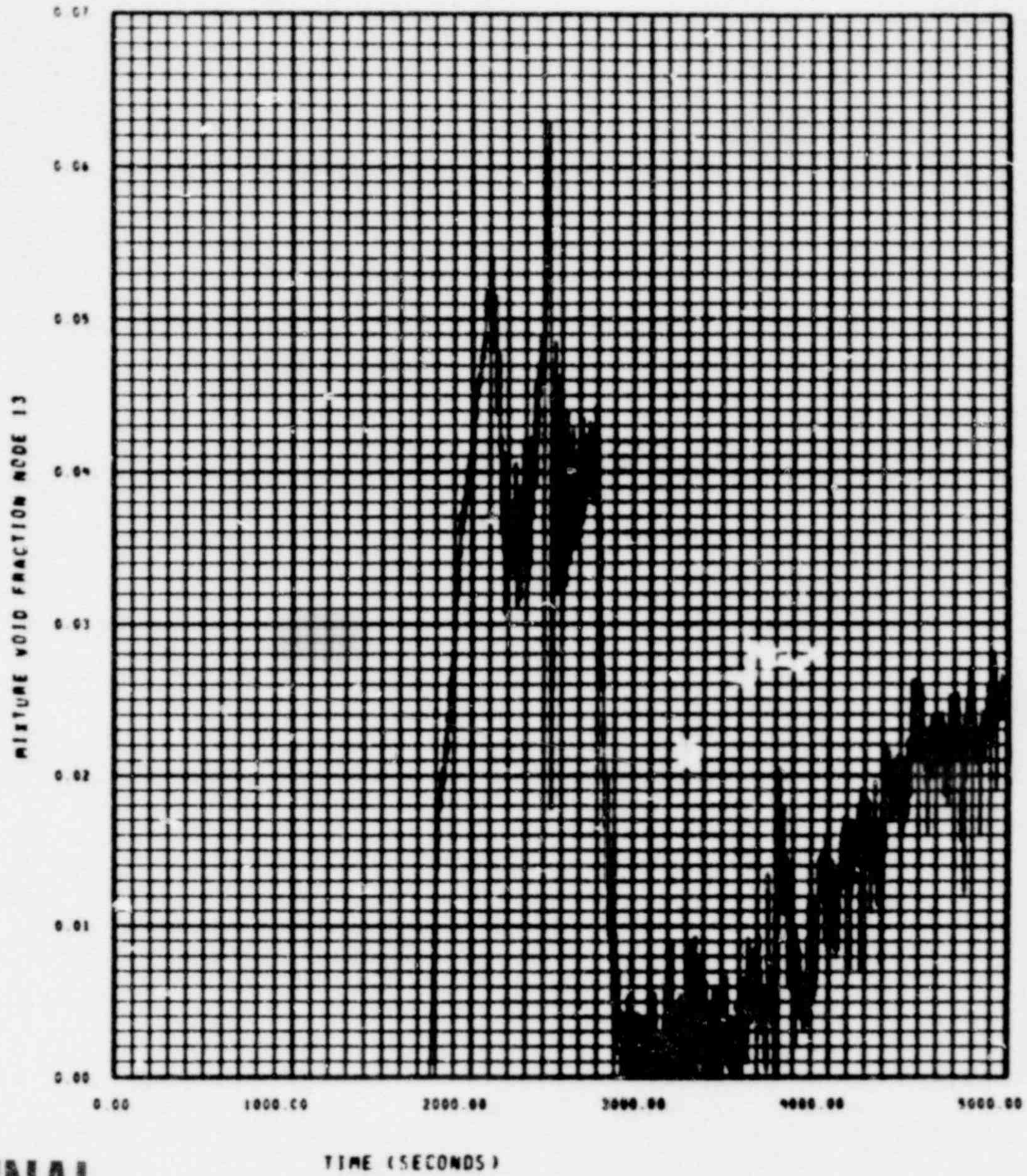
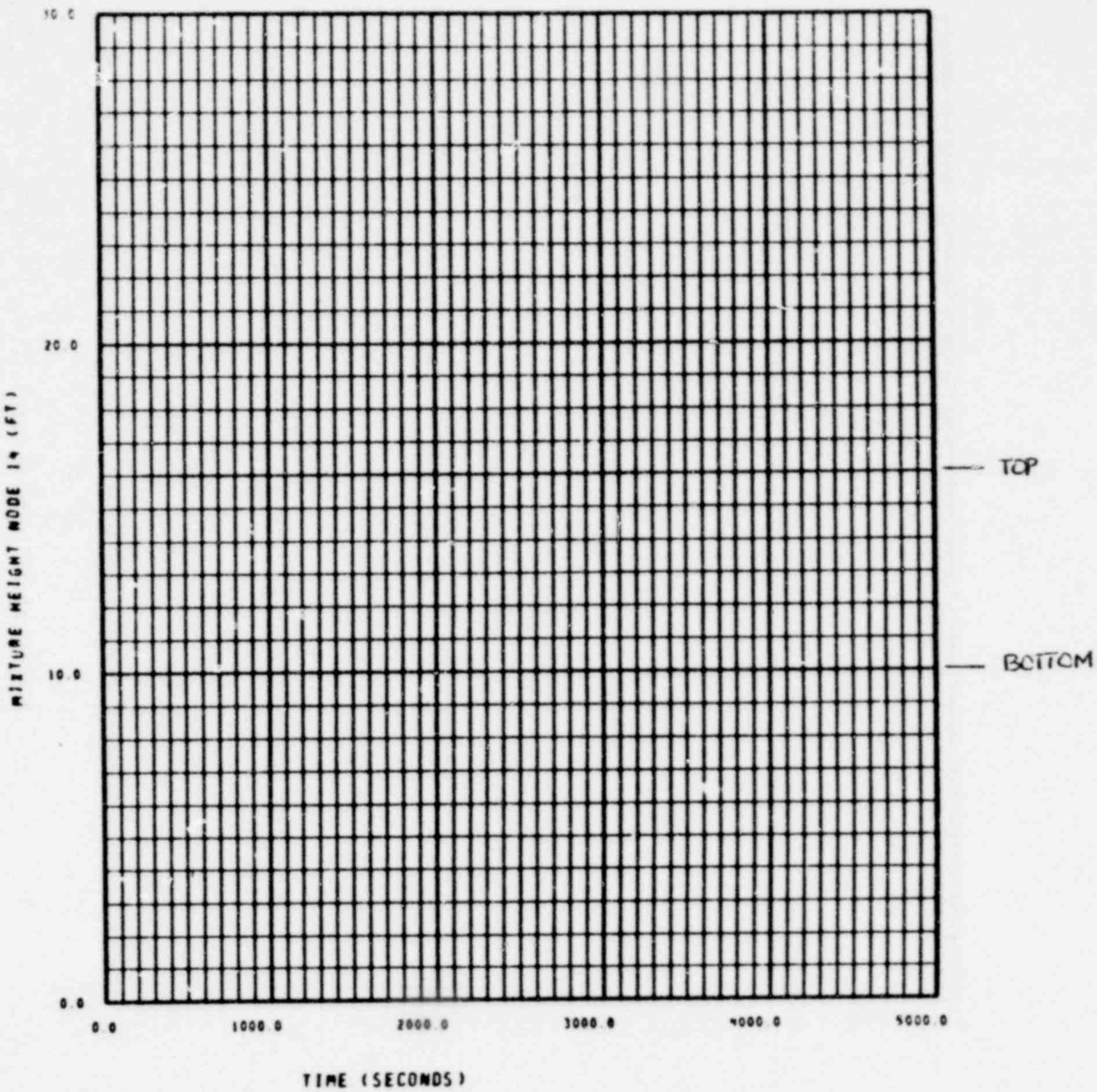

TOP
22.0
21.0
20.0
MIXTURE HEIGHT NODE 13 (FT)
0.0
1000.0
2000.0
3000.0
4000.0
5000.0
TIME (SECONDS)
RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 29



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 30

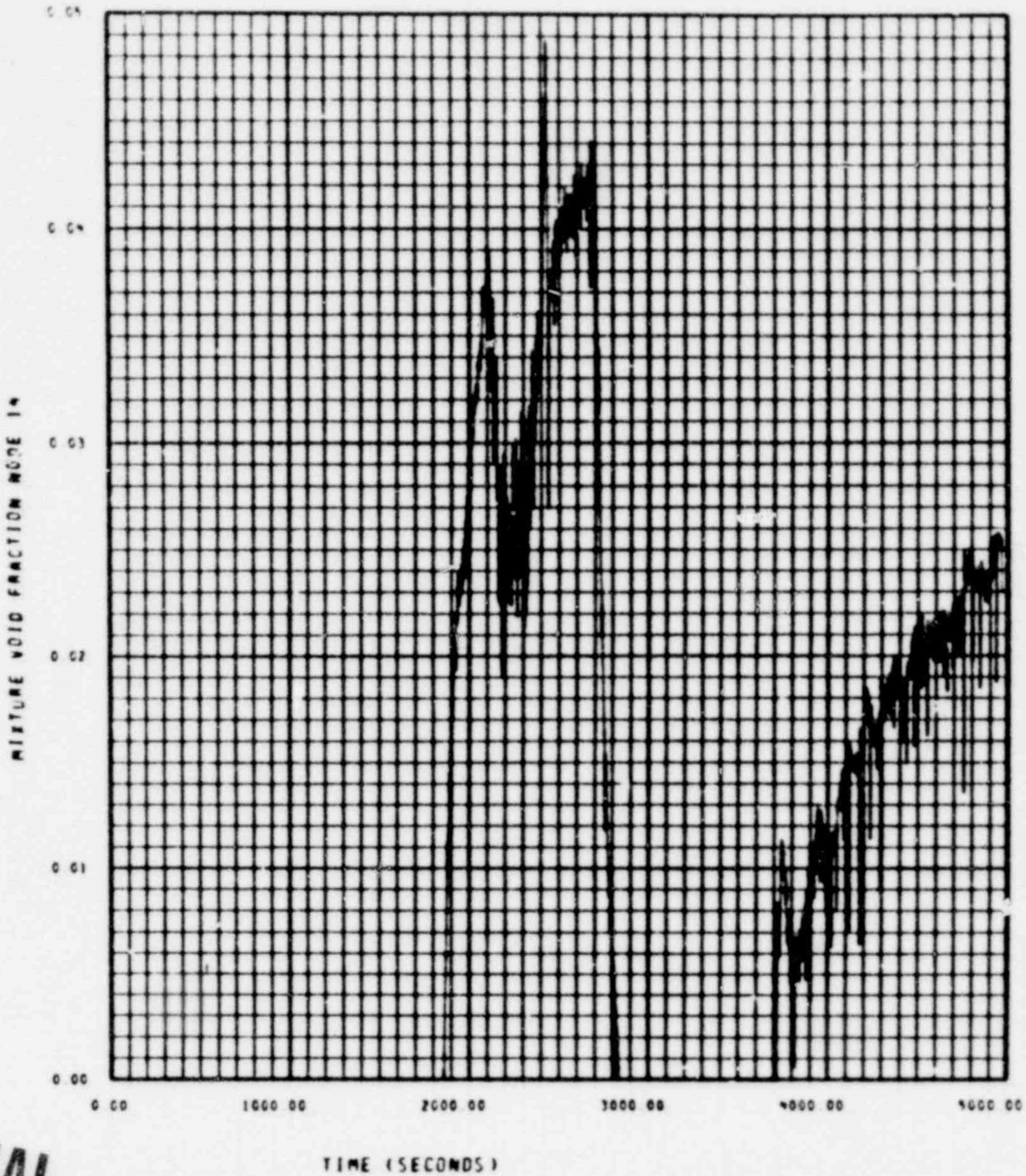


RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 31

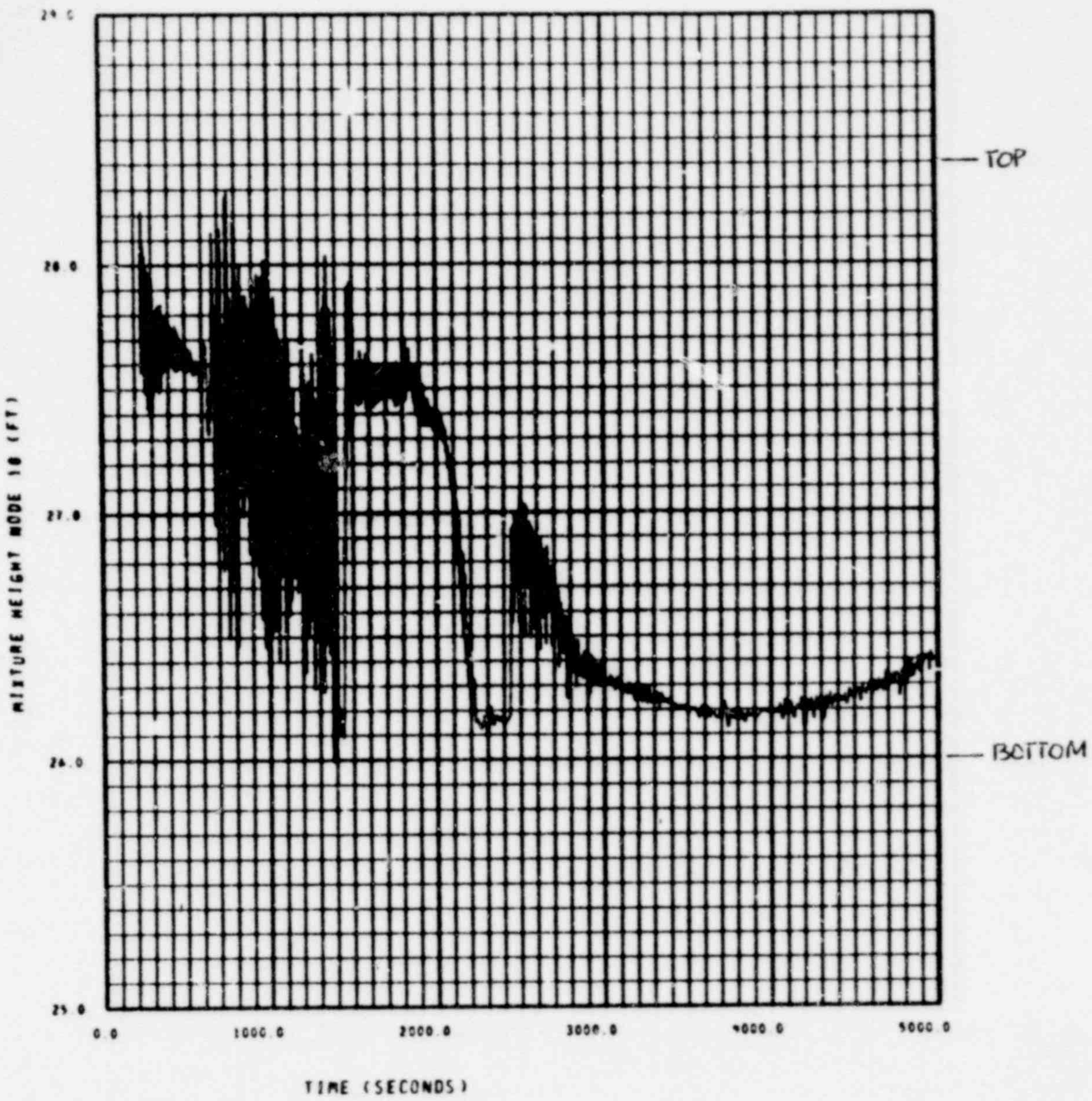
POOR ORIGINAL

1105 155



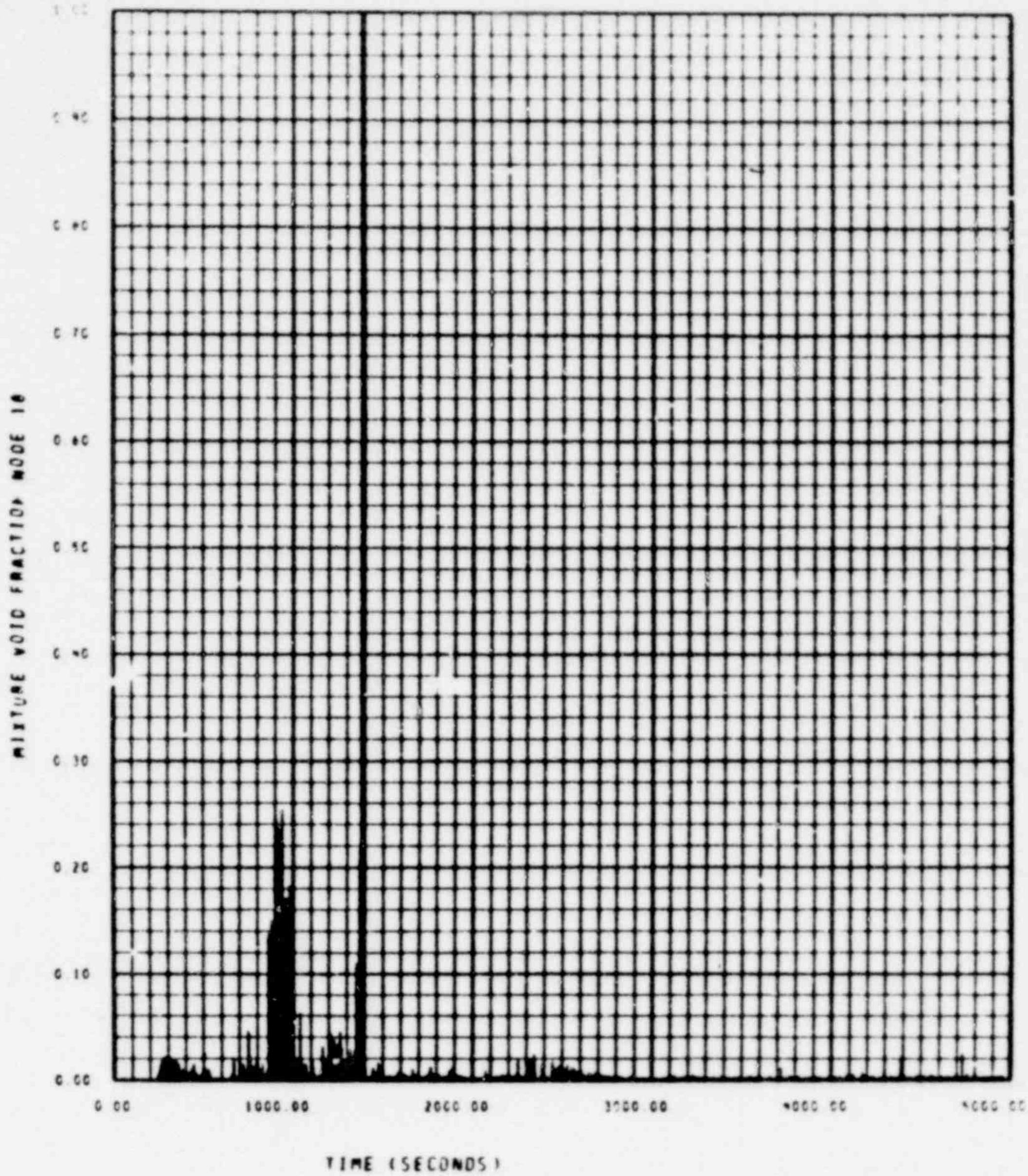
RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 32



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 33



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 34

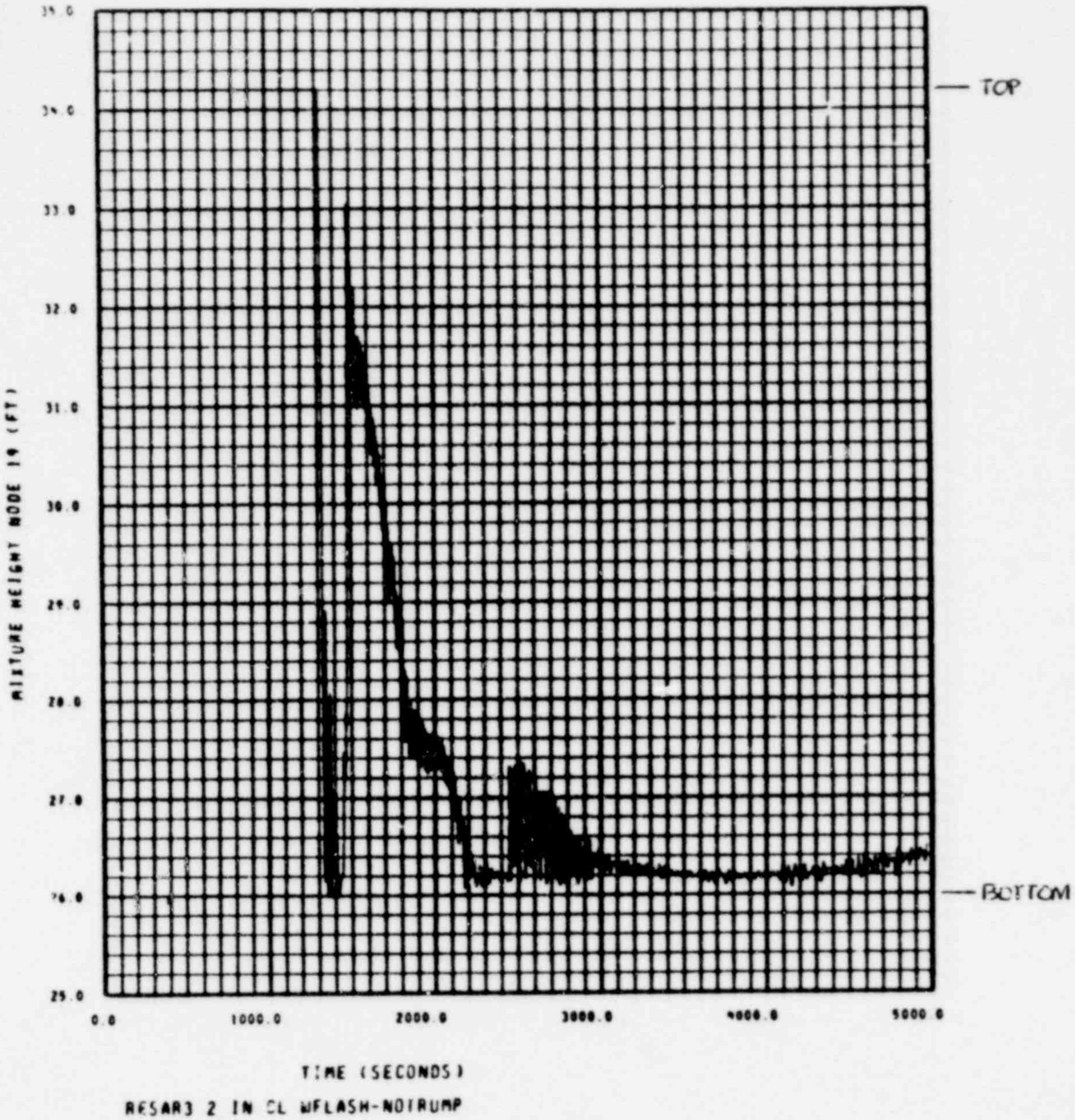
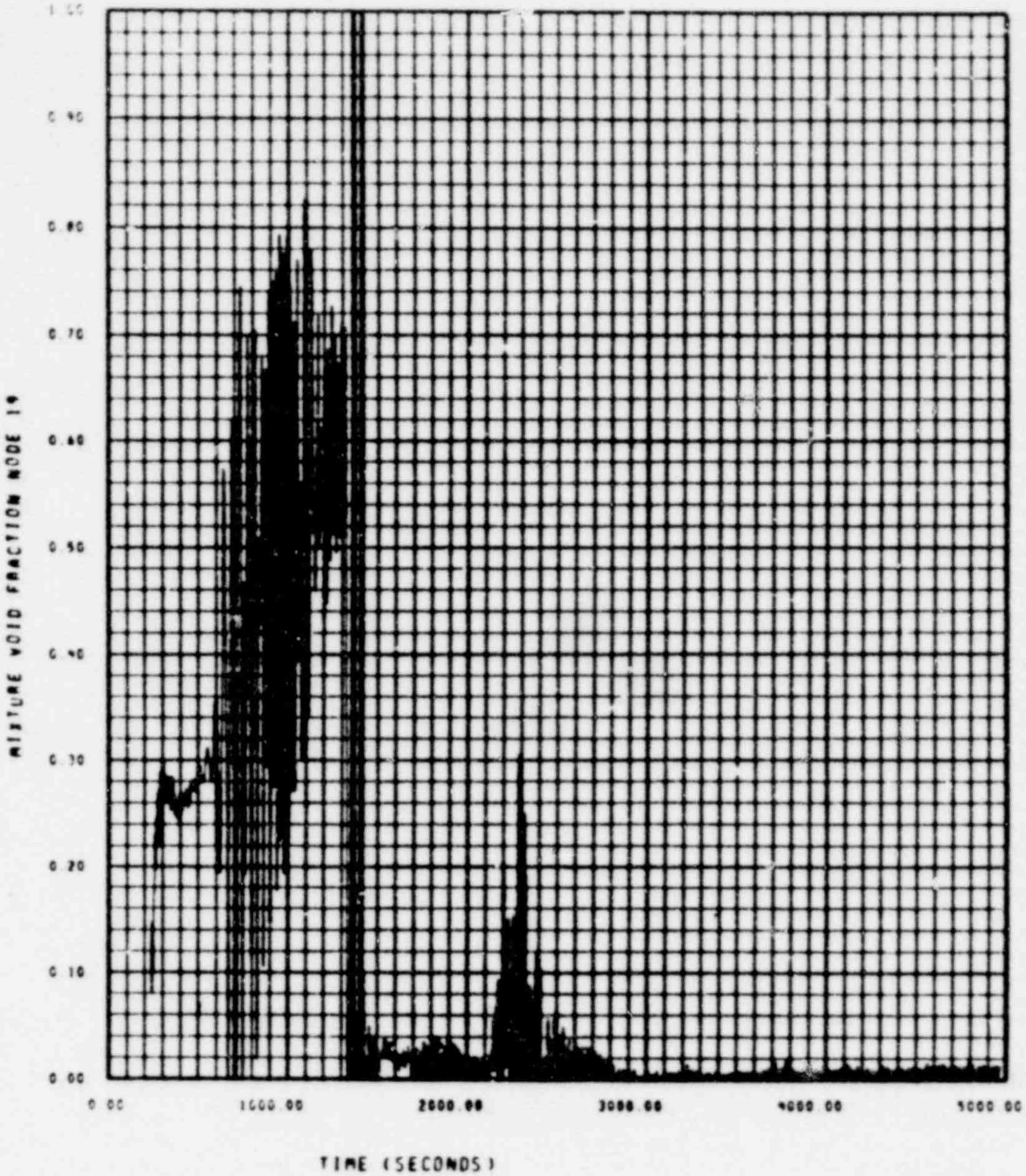


FIGURE 35

POOR ORIGINAL

1105 159



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 36

1105 160

POOR ORIGINAL

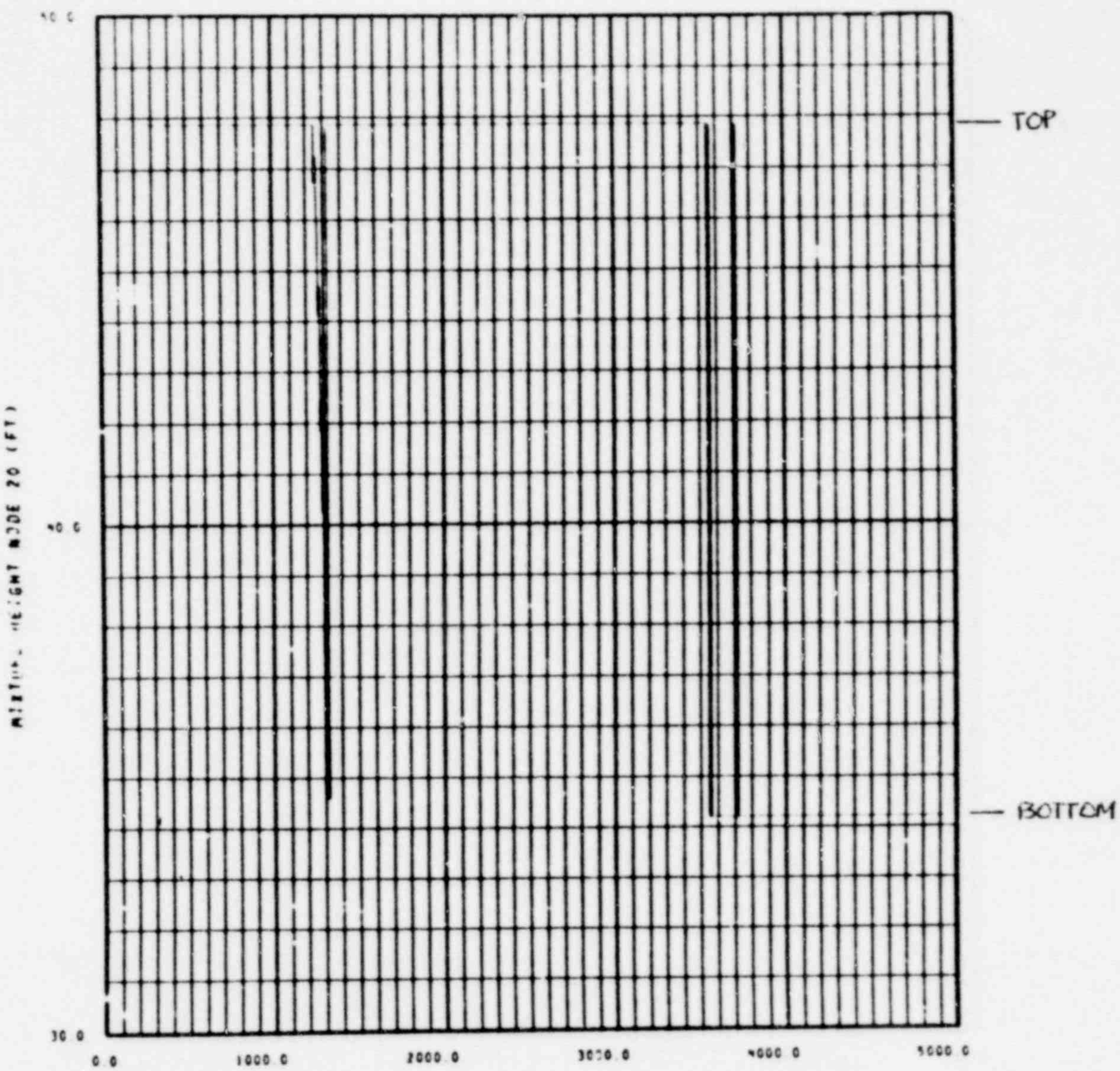


FIGURE 37

1105 161

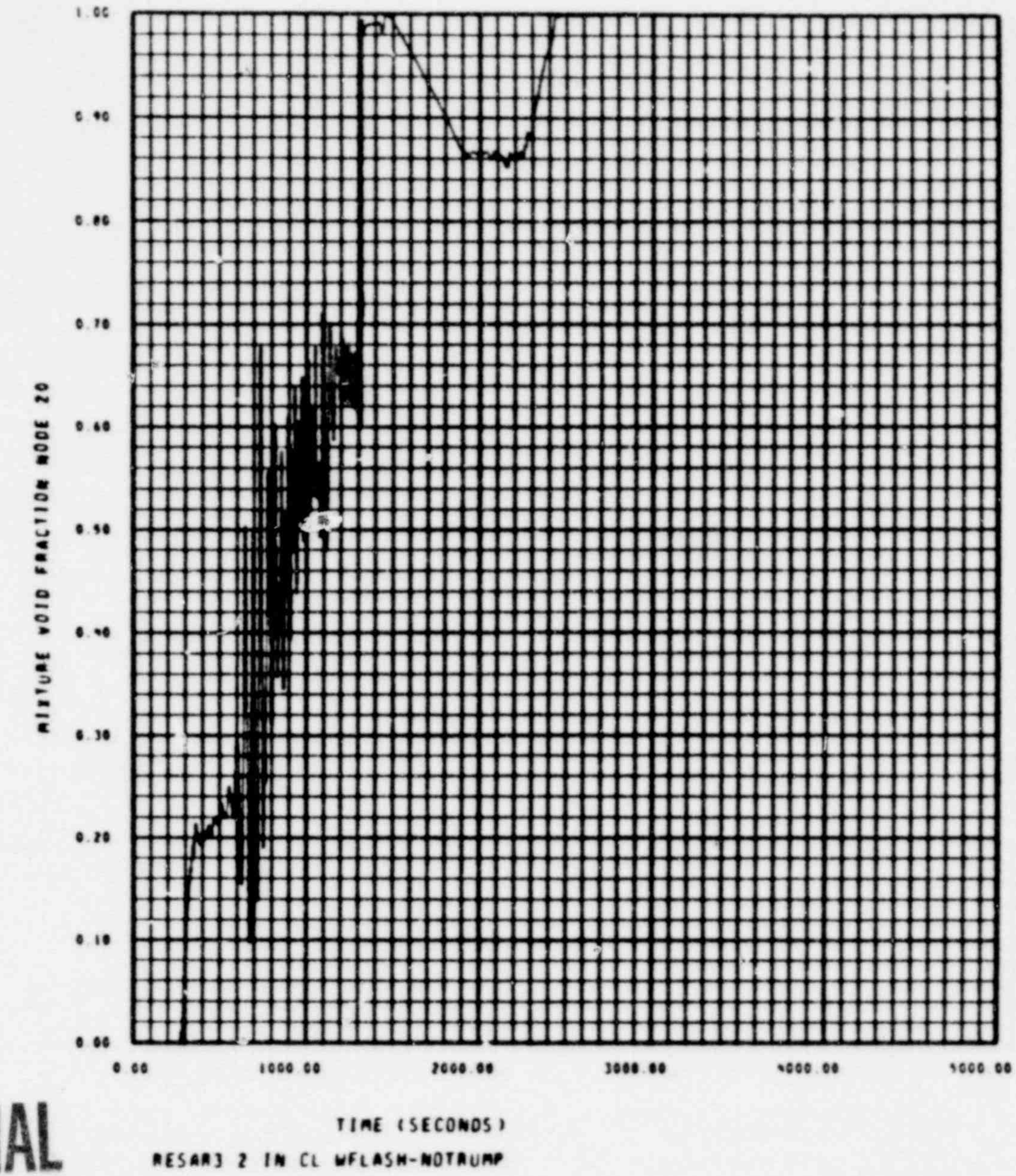
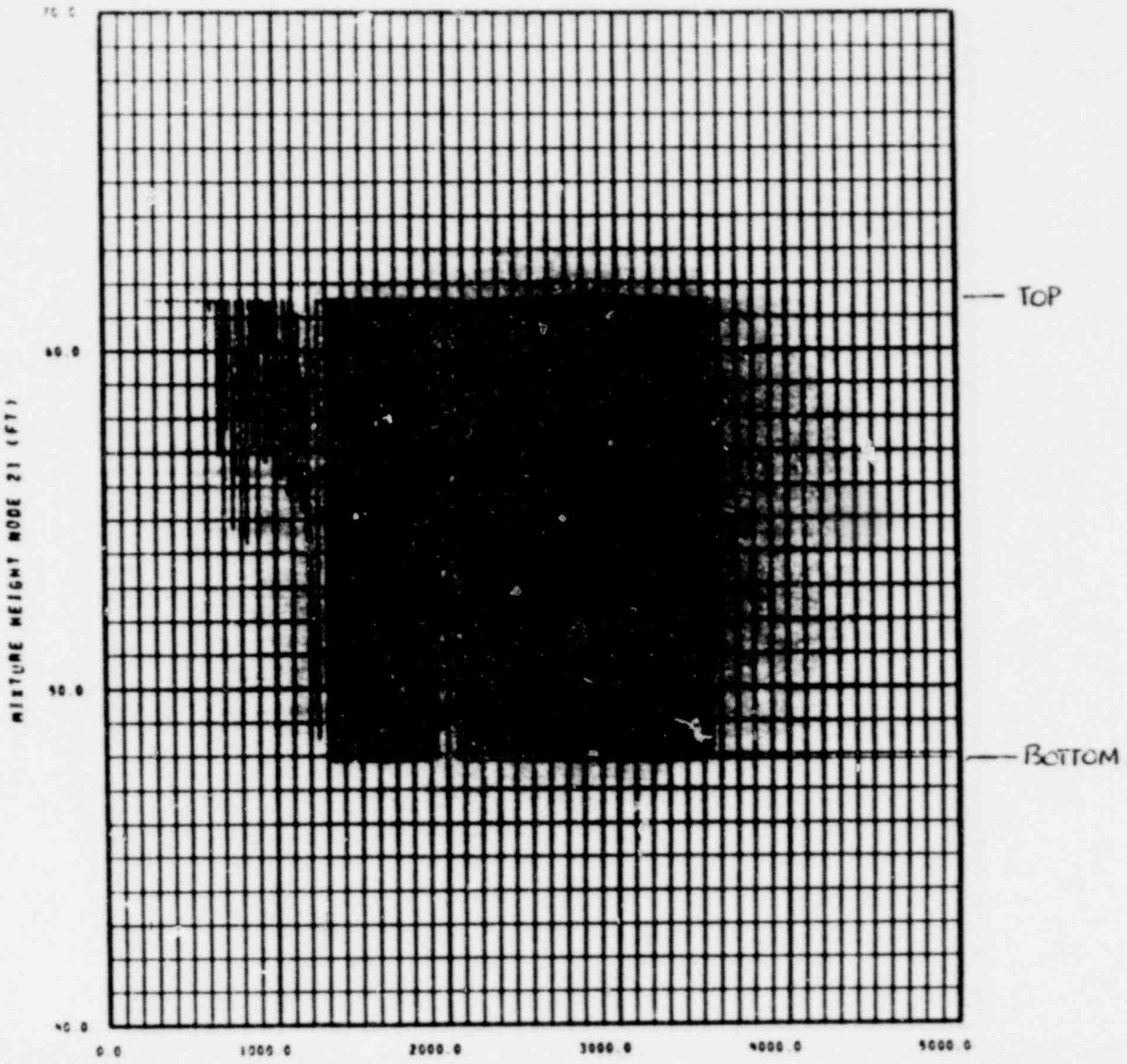


FIGURE 38

1105 162

POOR ORIGINAL



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 39

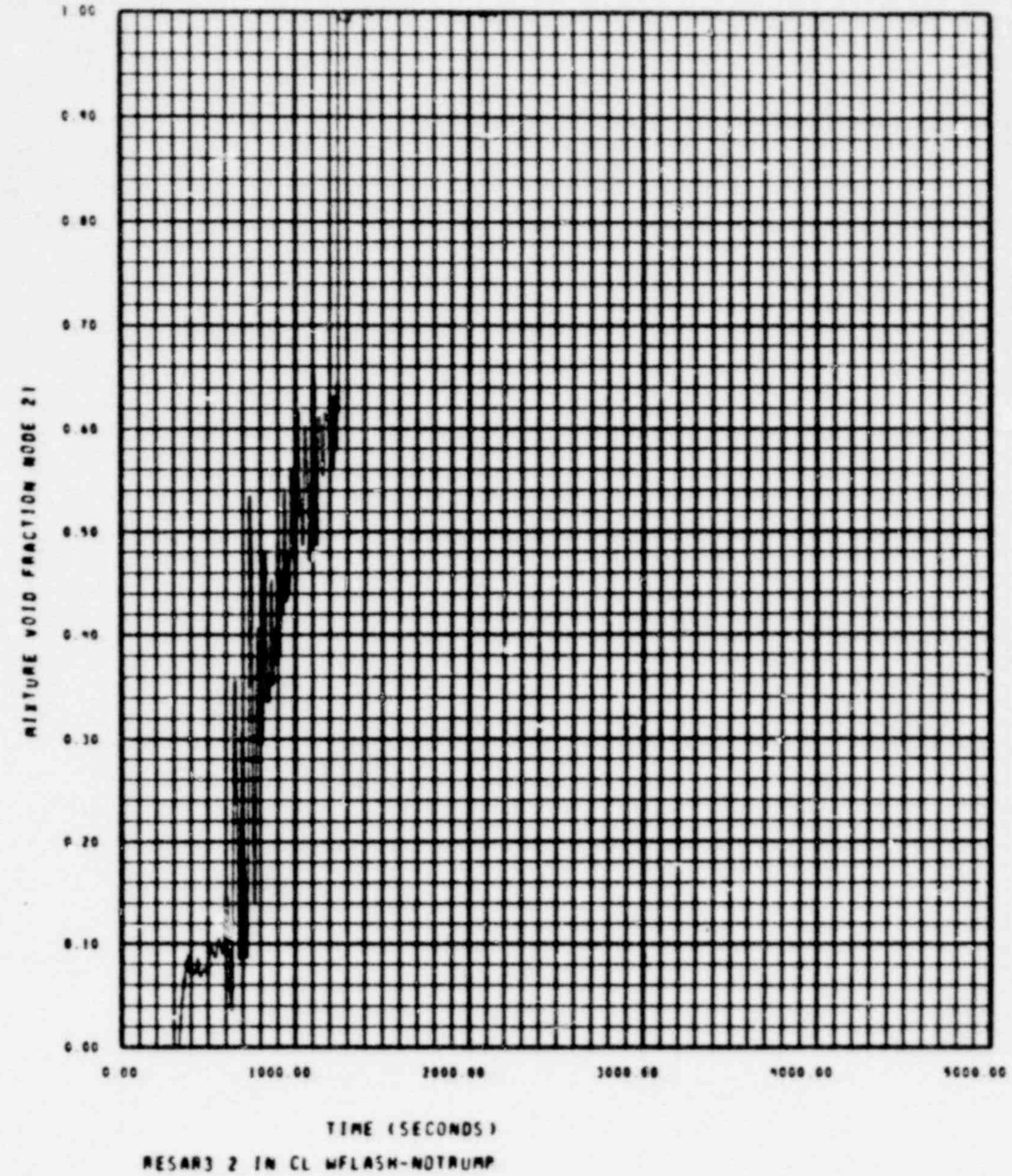
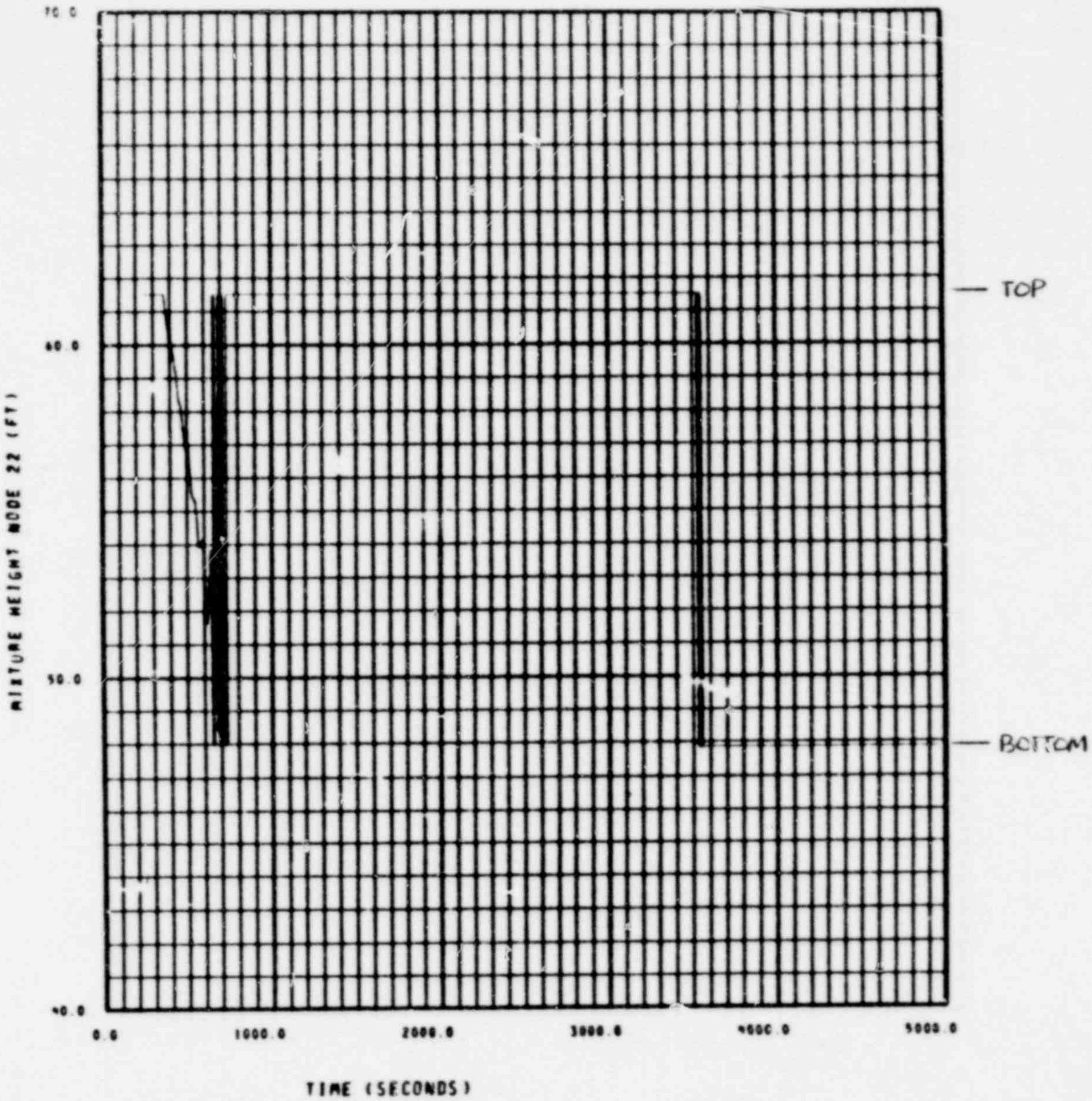


FIGURE 40

1105 164



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 4)

1105 165

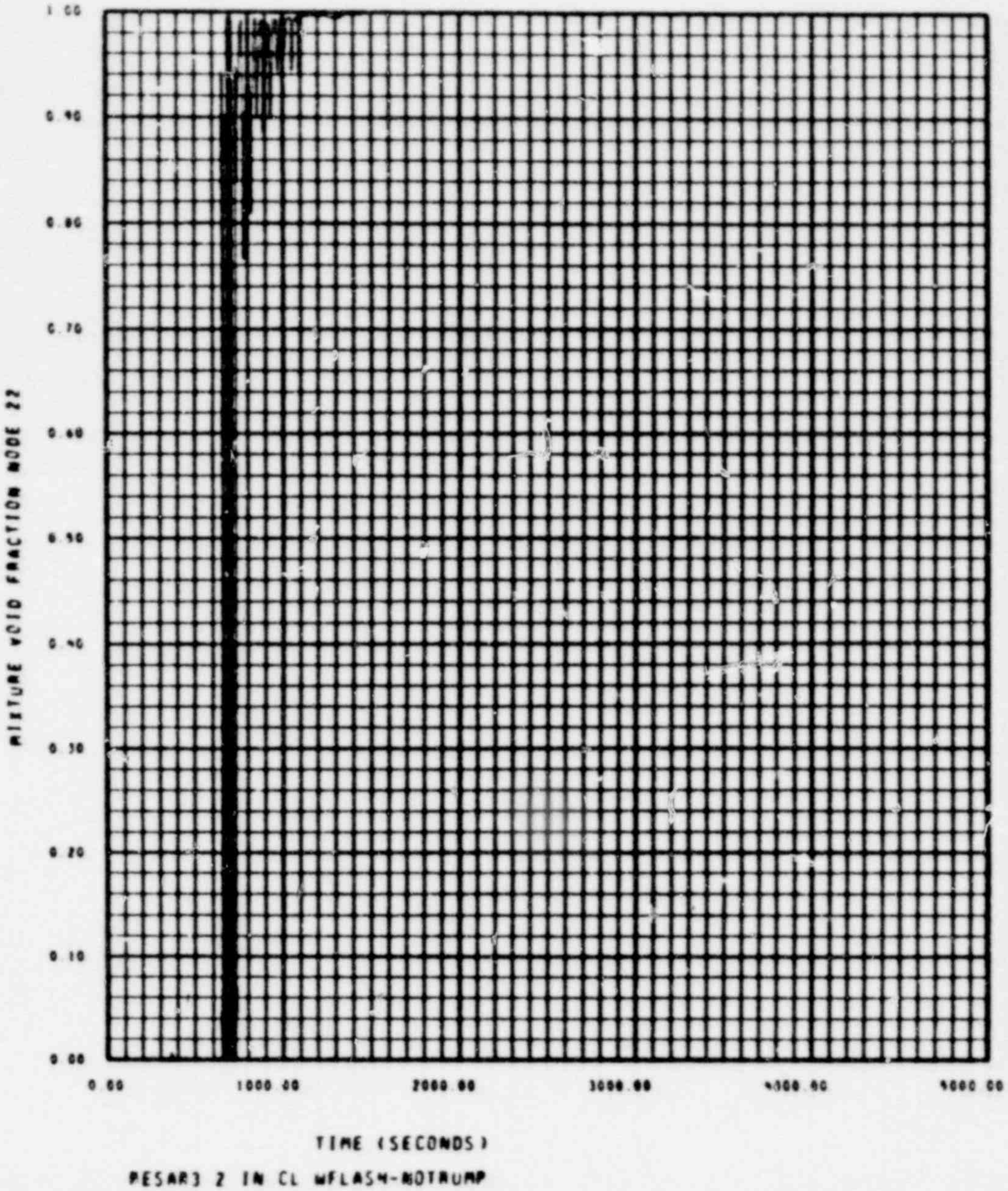
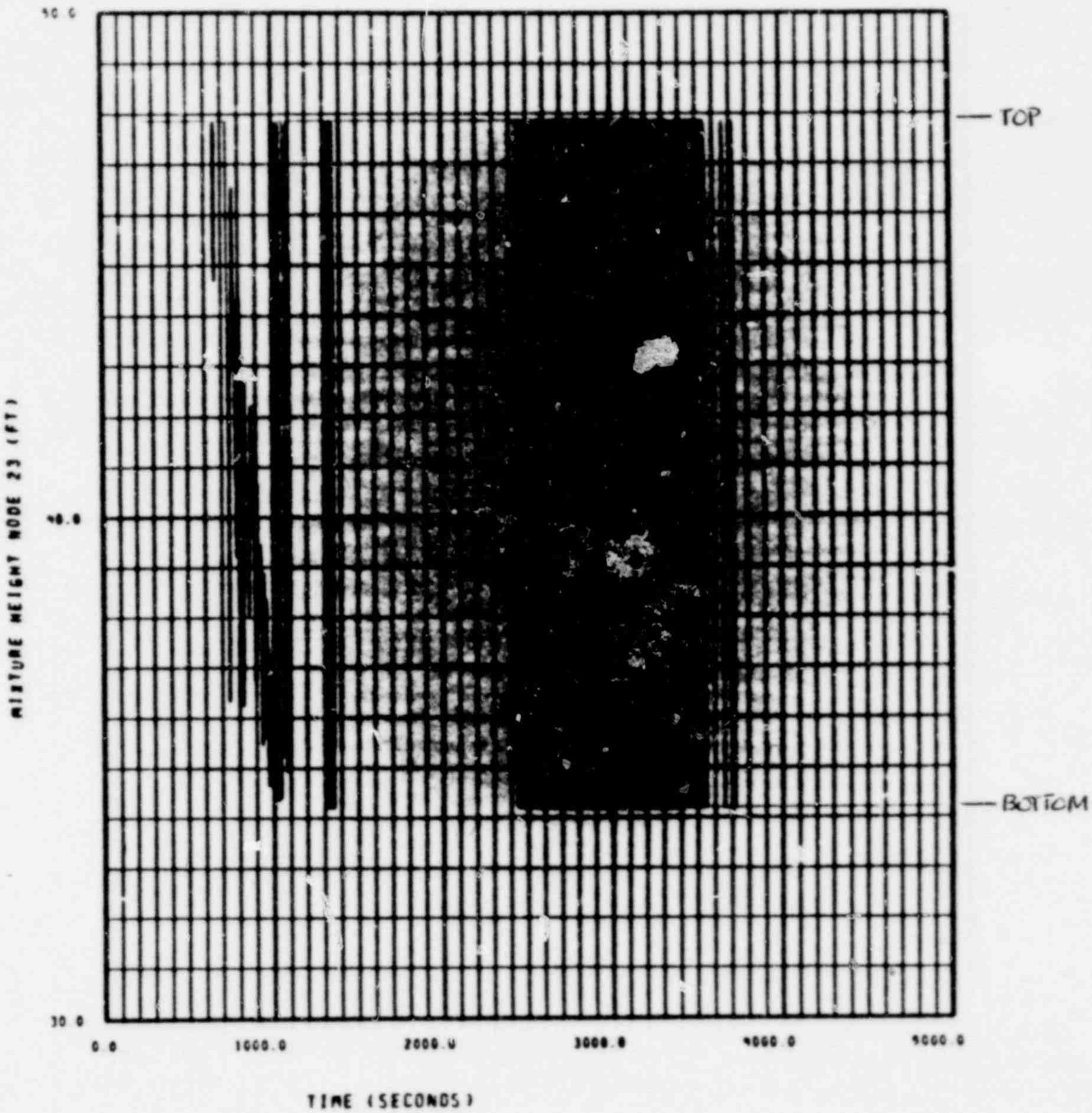


FIGURE 42

1105 166

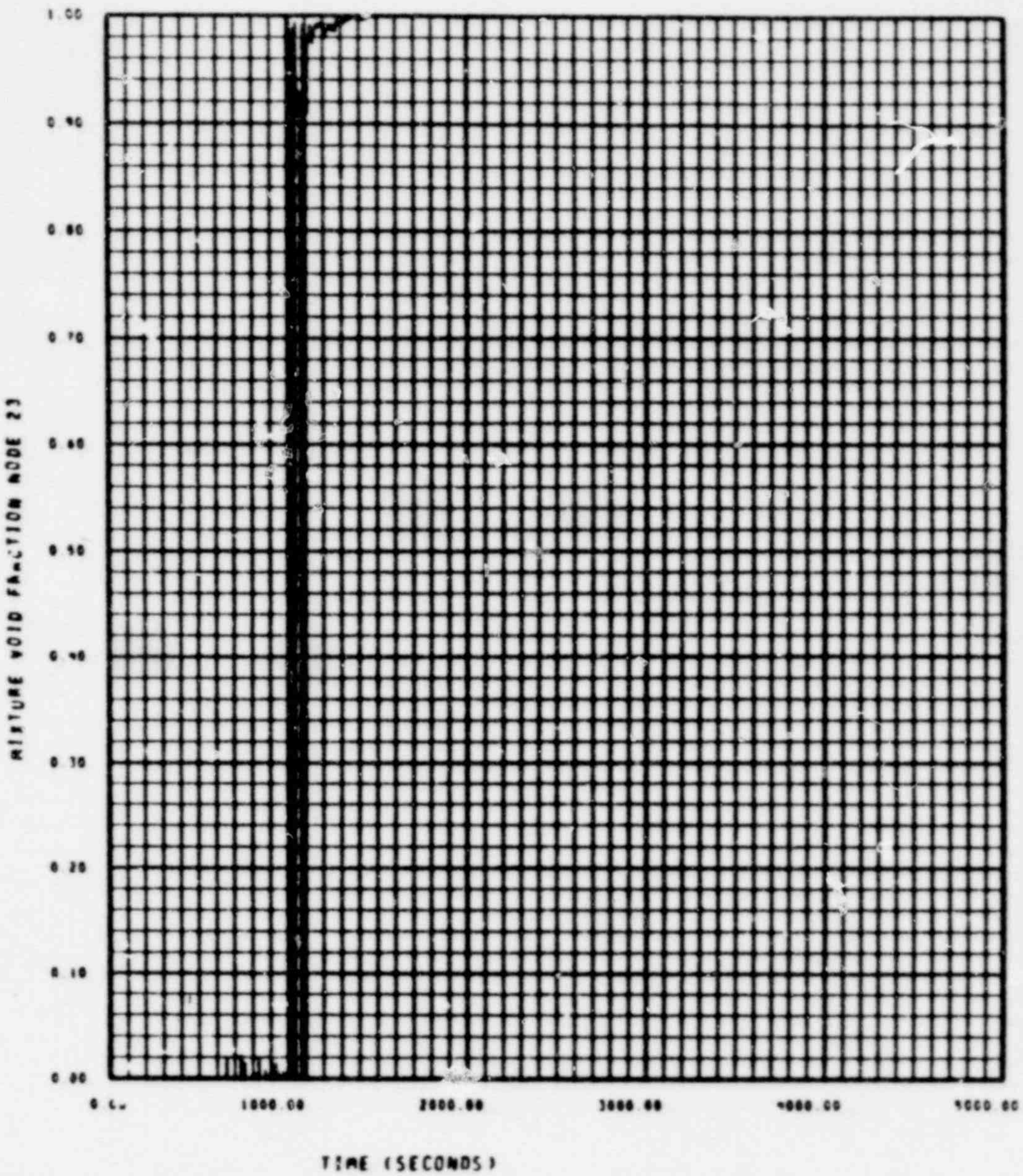
POOR ORIGINAL



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 43

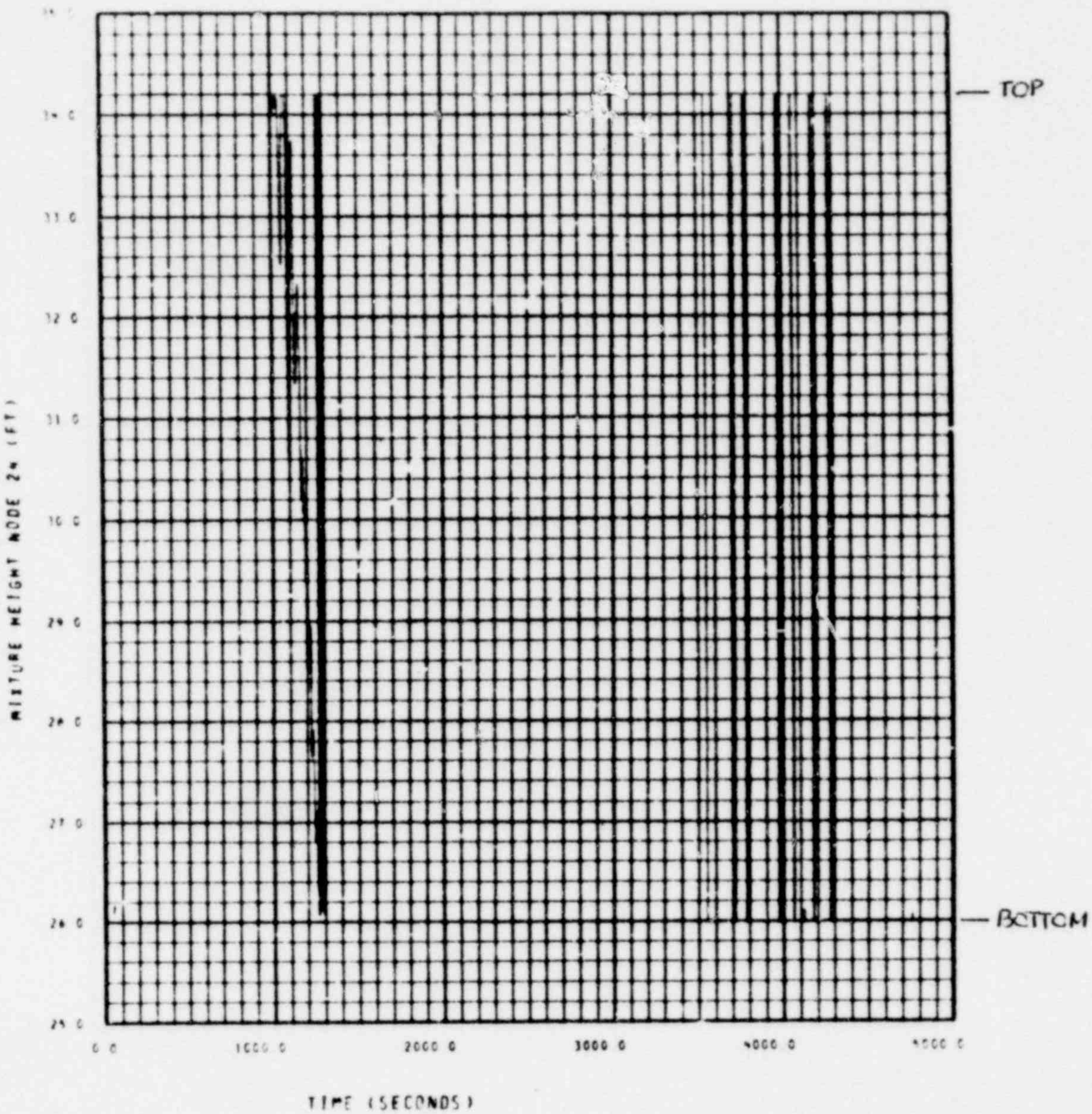
1105 167



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 44

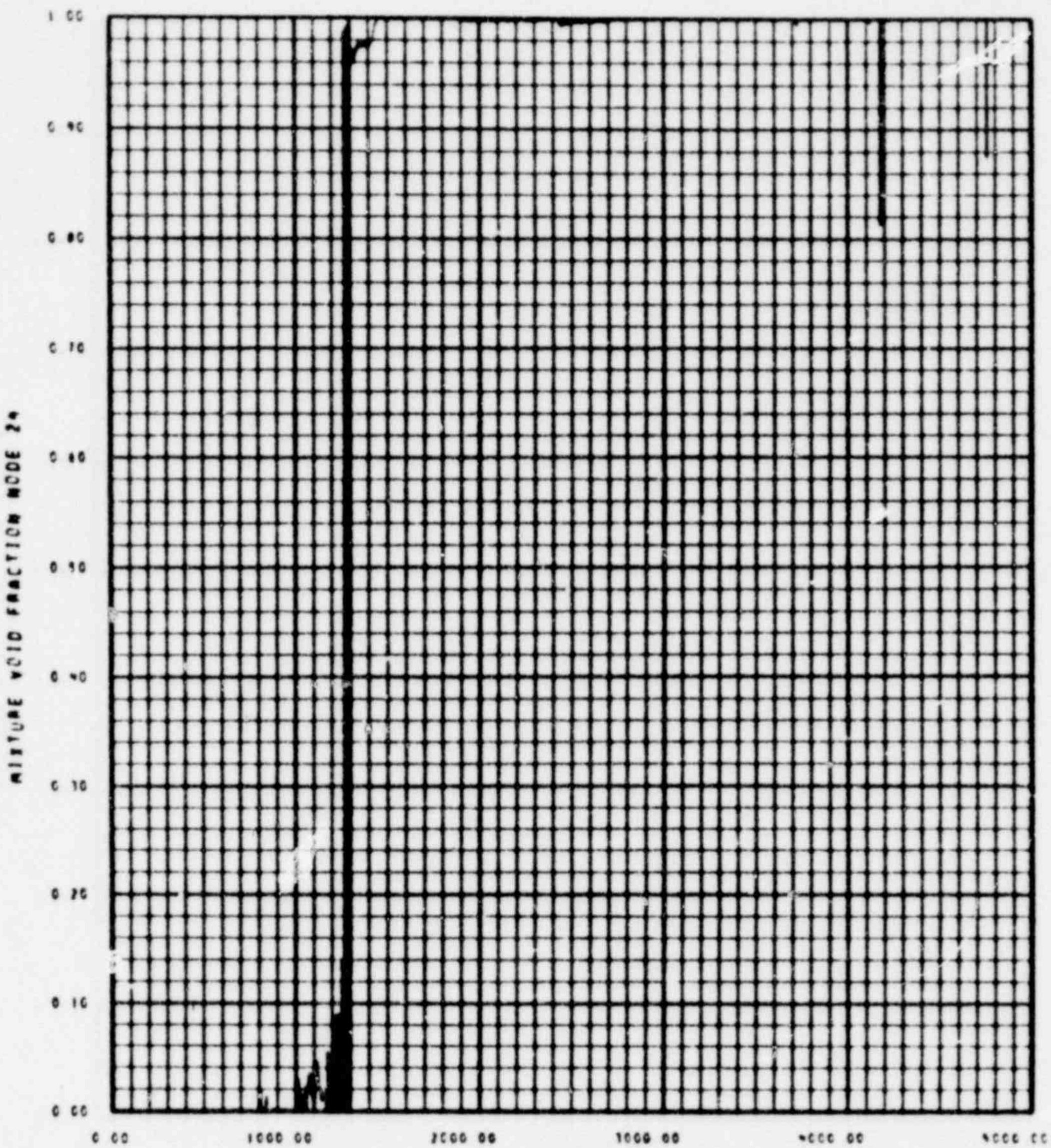
1105 168



RESAR3 2 IN CL WFLASH-NOTRUMP

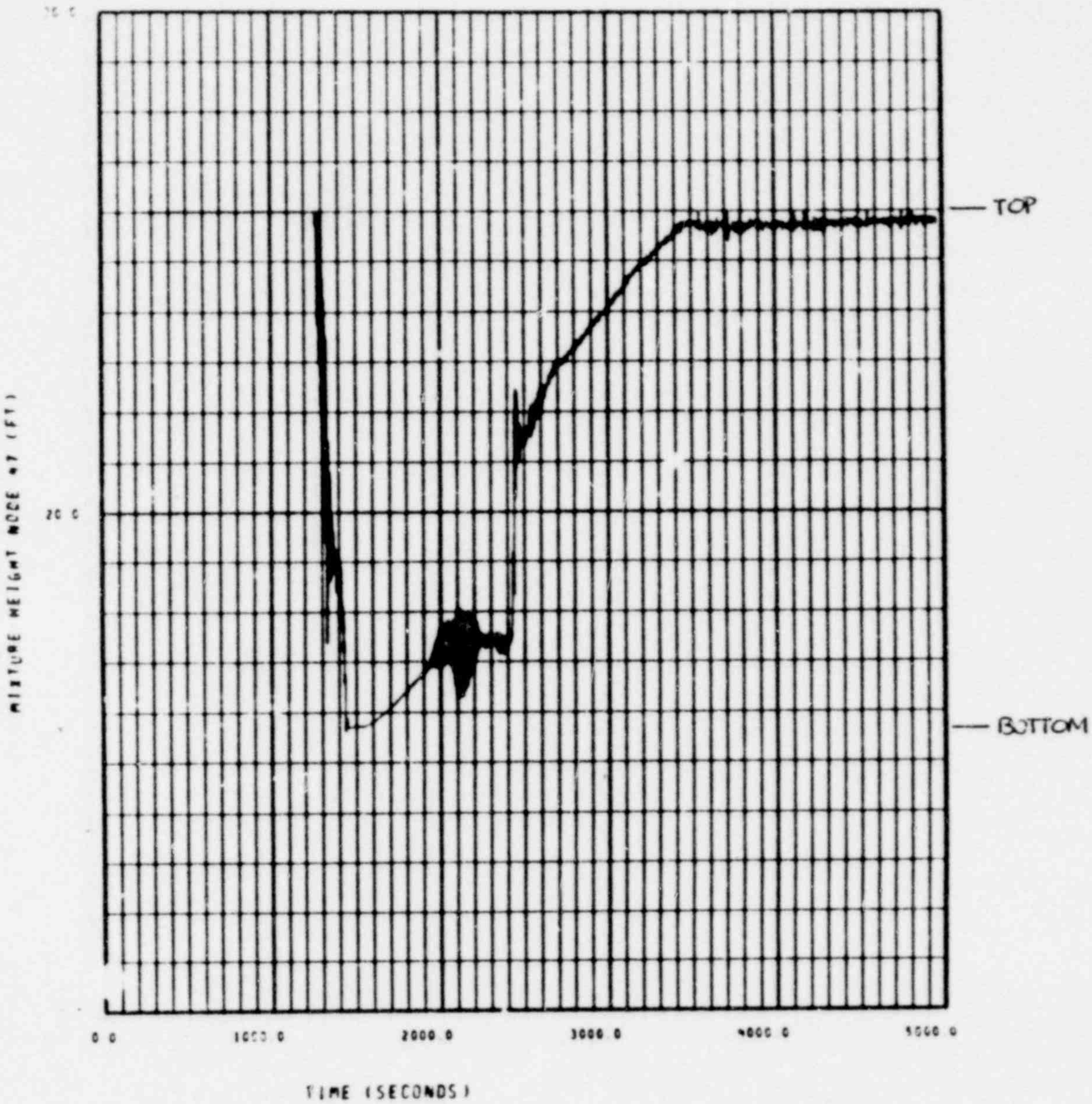
FIGURE 45

1105 169



RESAR3 2 IN CL WFLASH-NOTRUMP

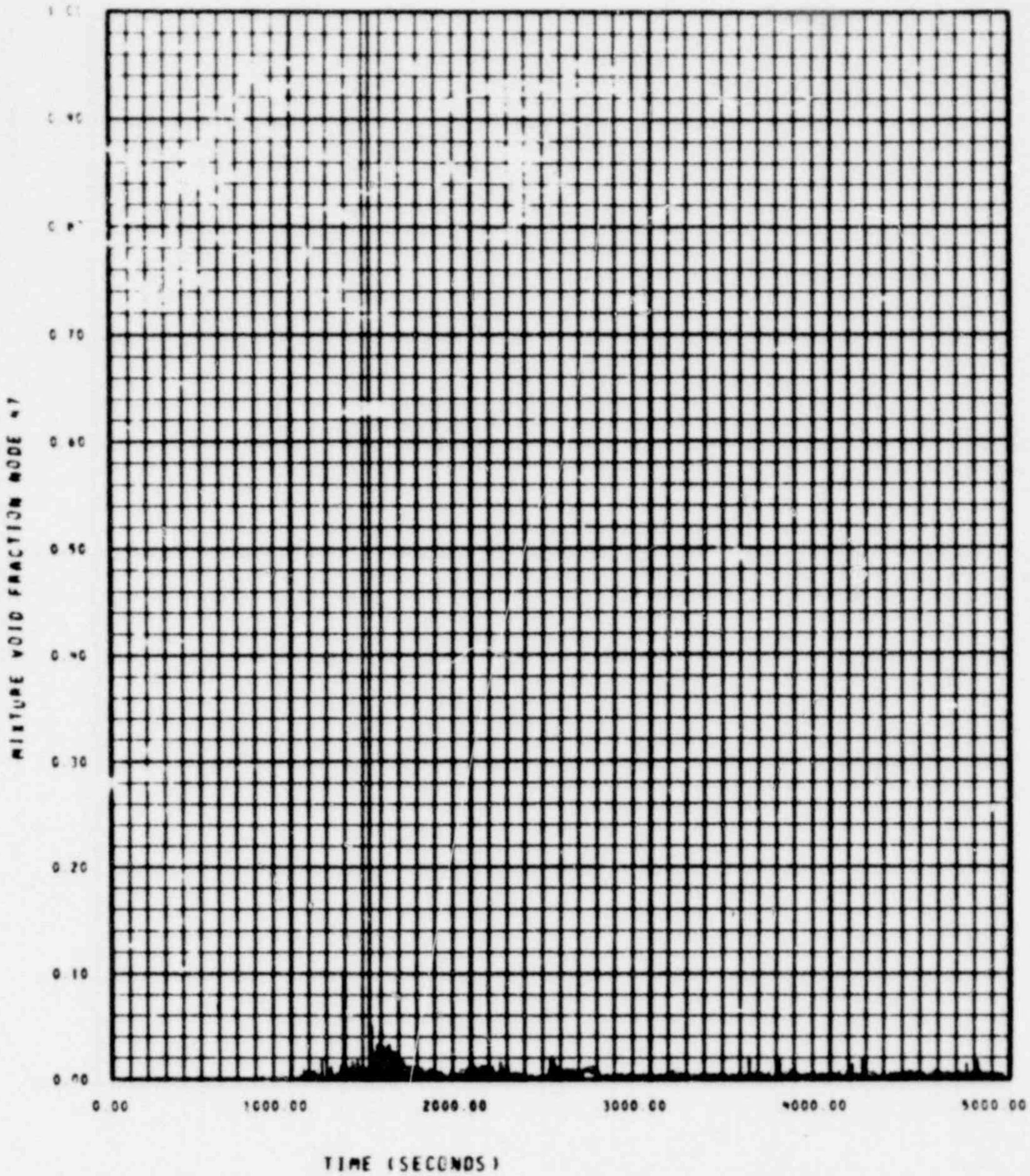
FIGURE 46



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 47

1105 171

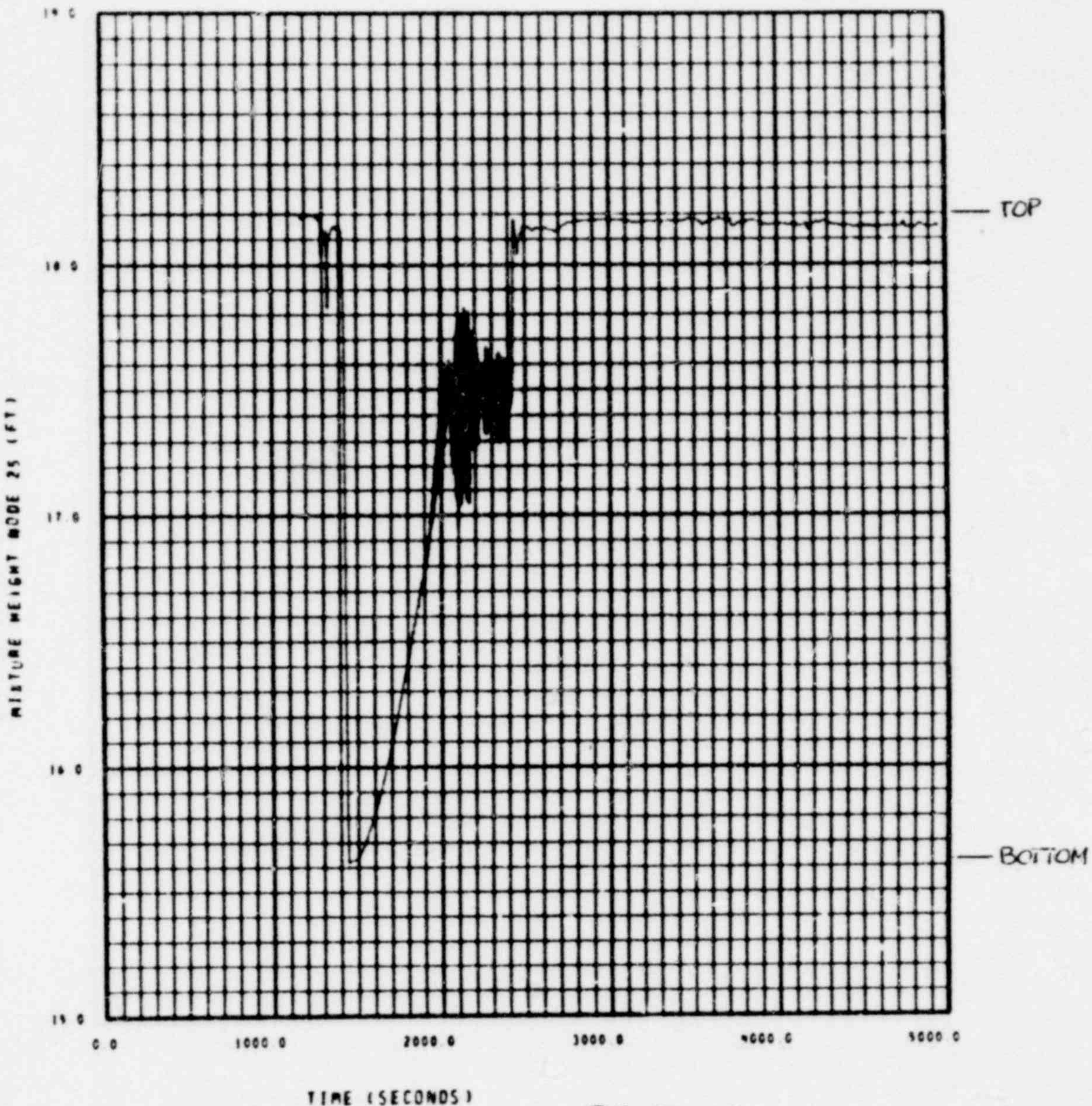


RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 48

1105 172

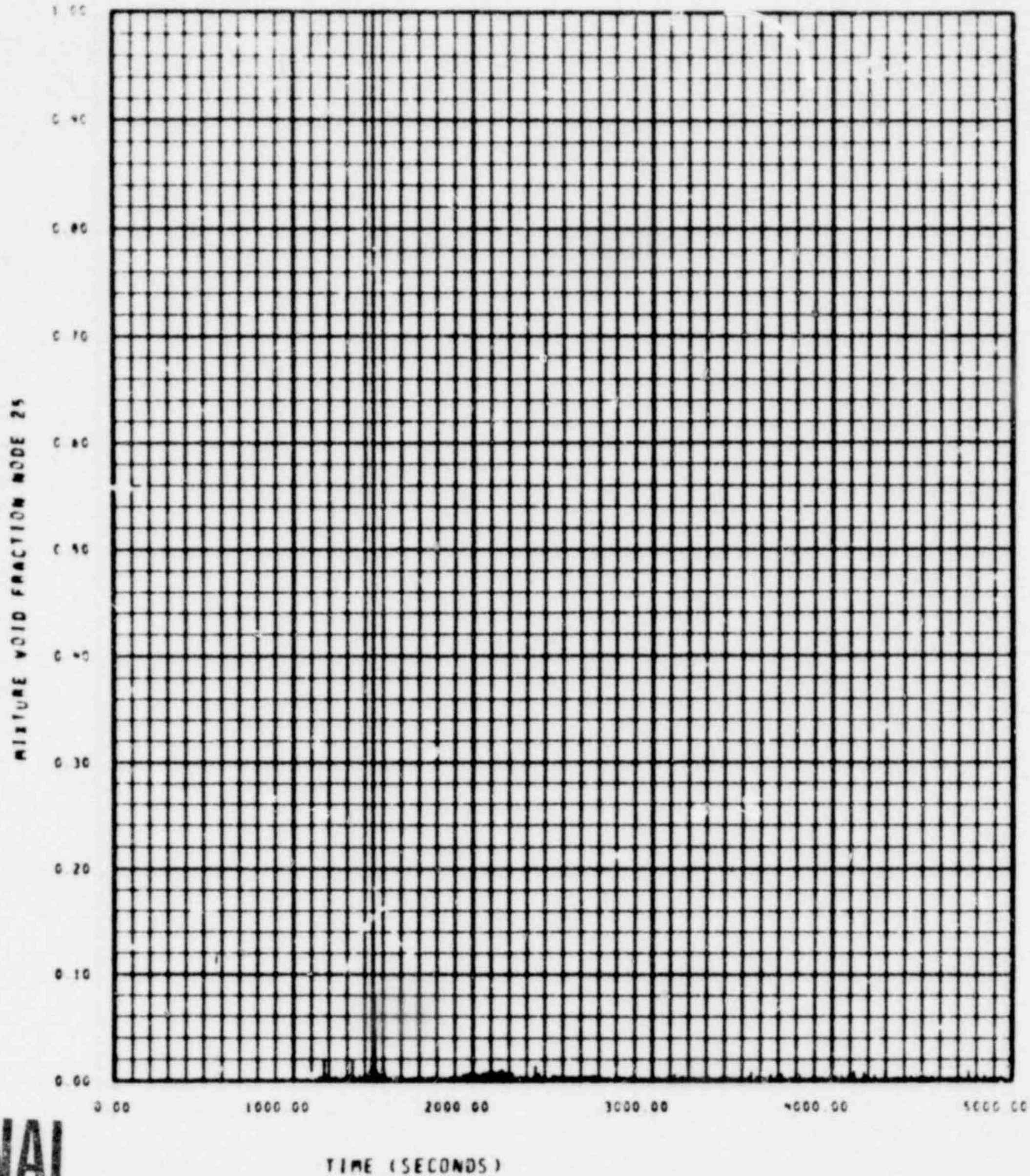
POOR ORIGINAL



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 49

1105 173

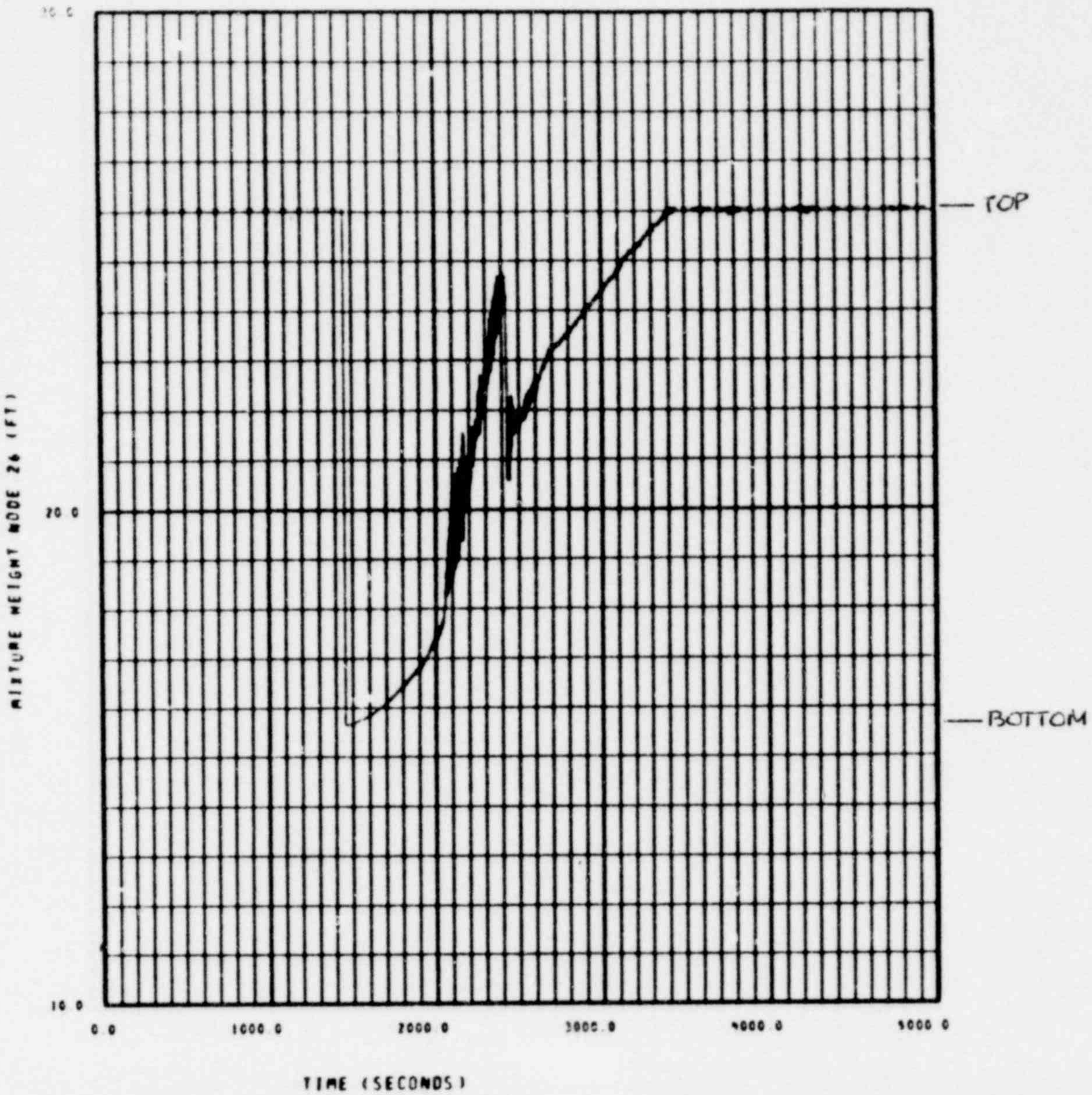


RESAR3 2 IN CL WFLASH-NOTPUMP

FIGURE 50

1105 174

POOR ORIGINAL



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 51

1105 175

POOR ORIGINAL

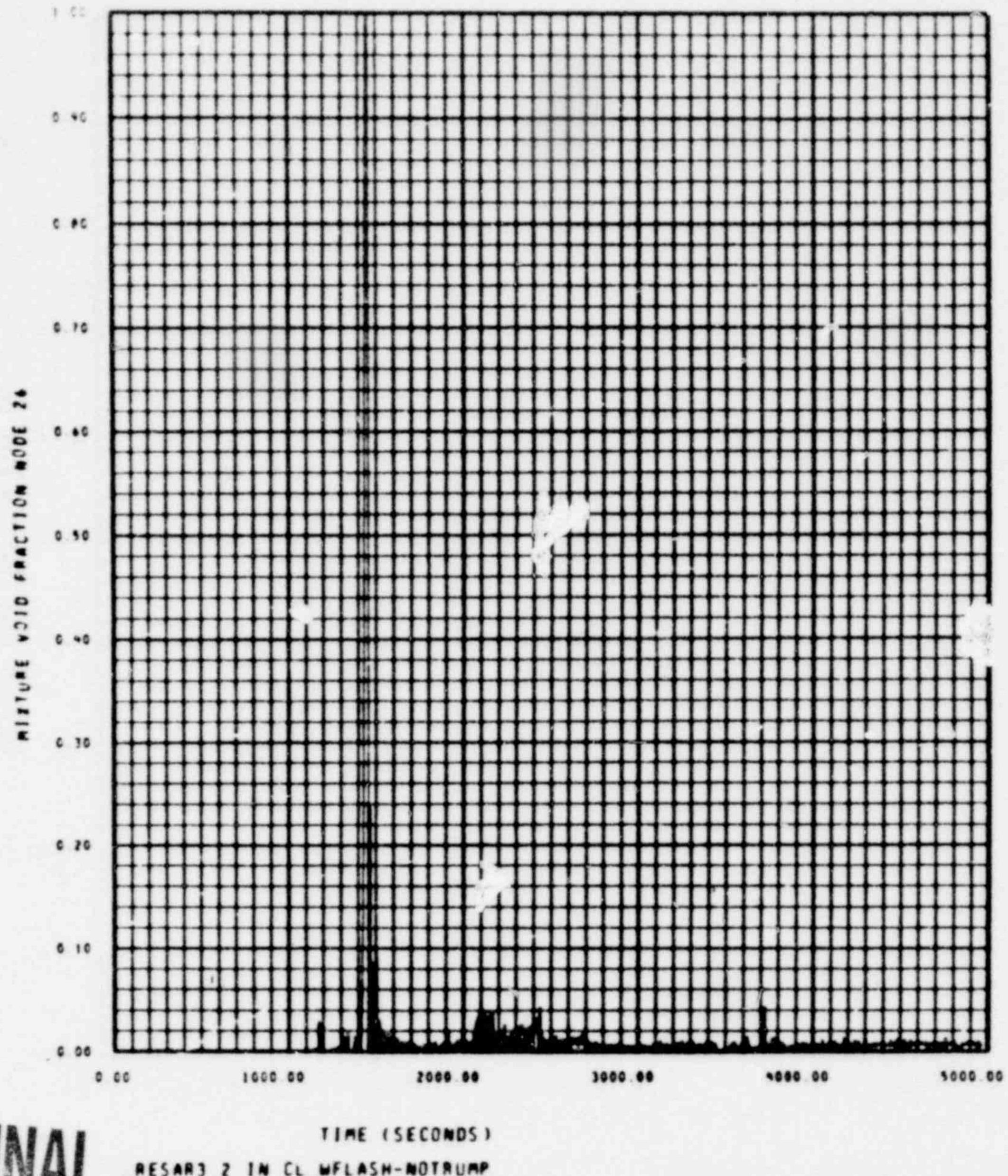
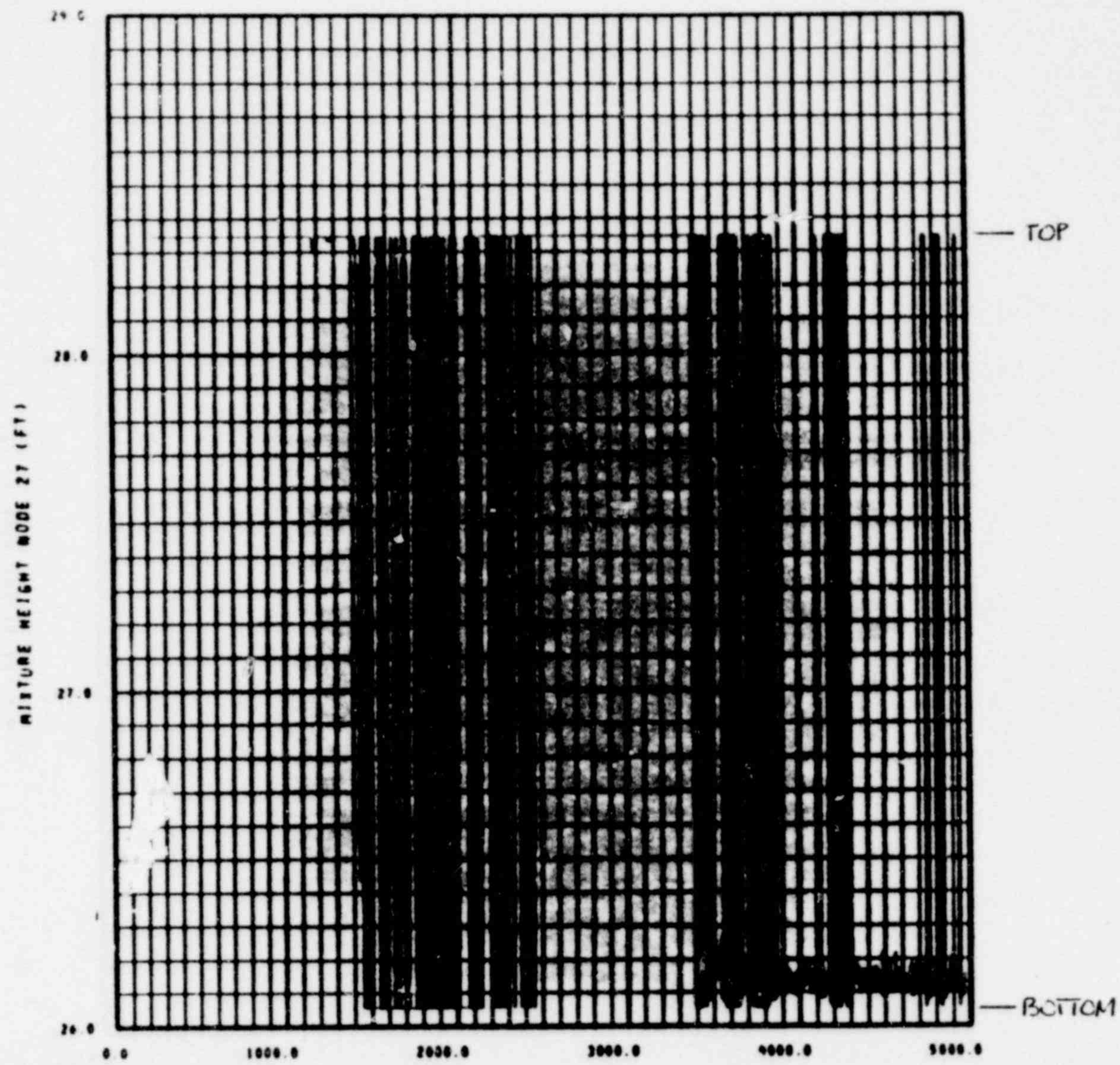


FIGURE 52

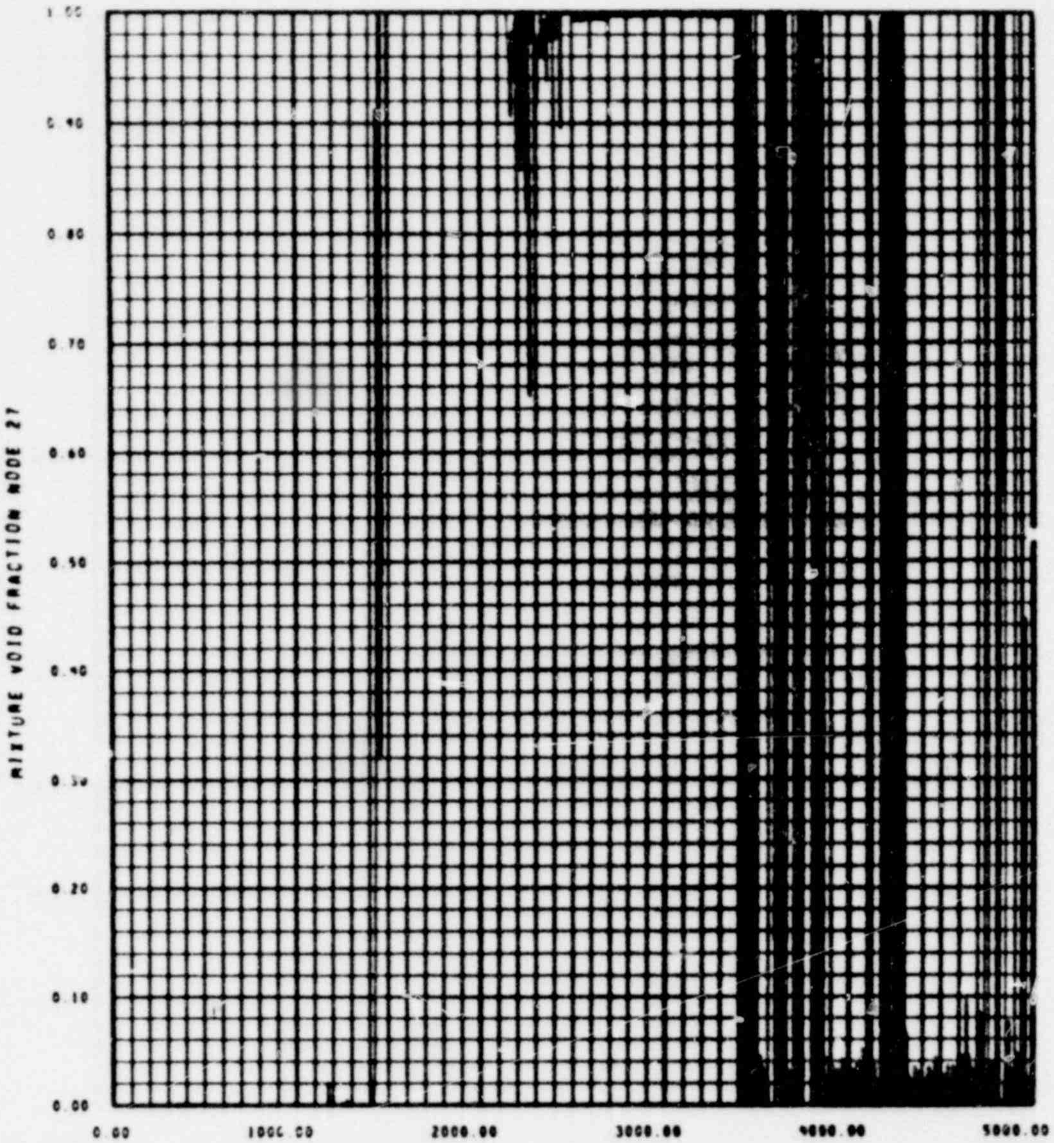
1105 176



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 53

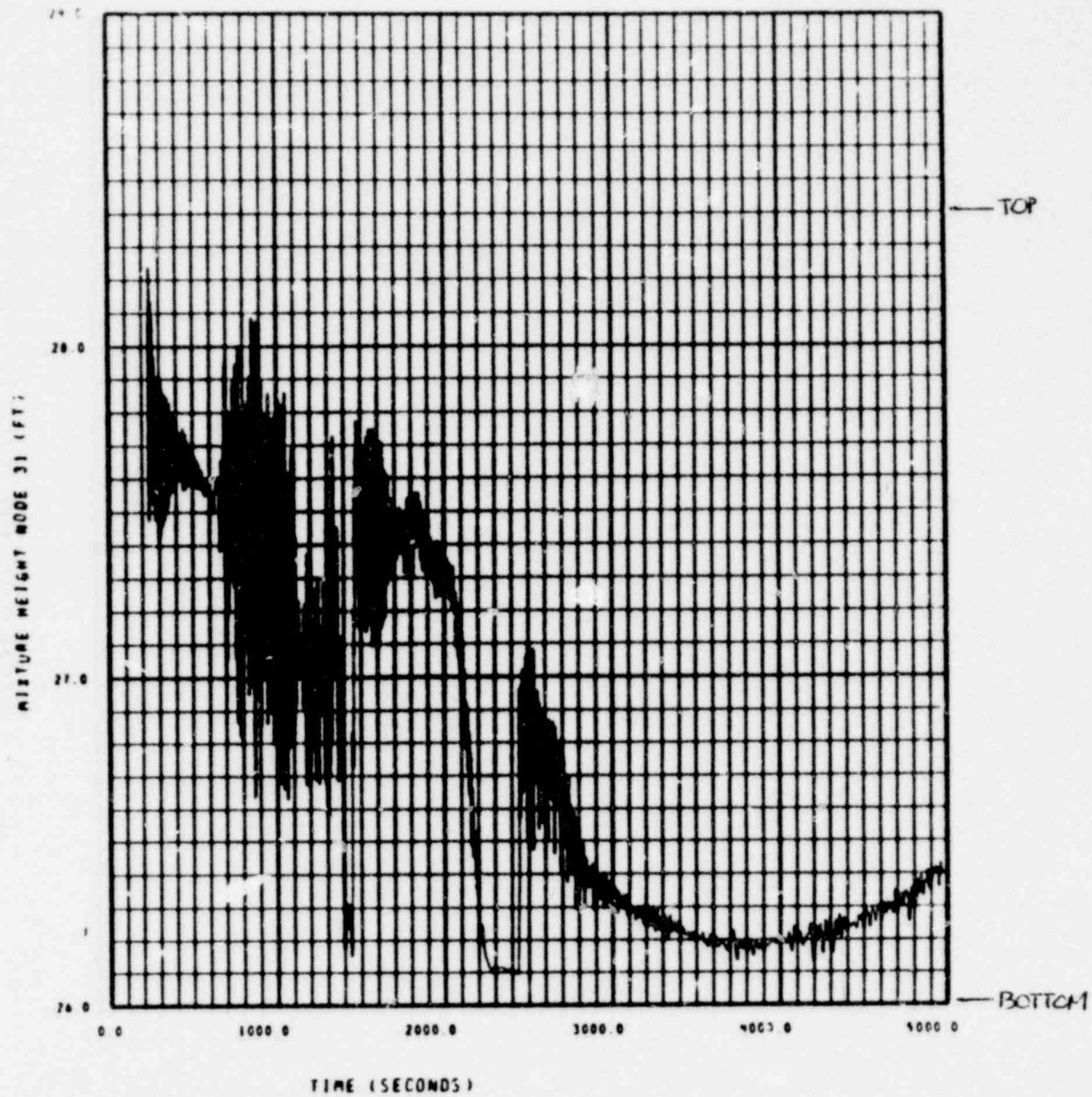
1105 177



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 54

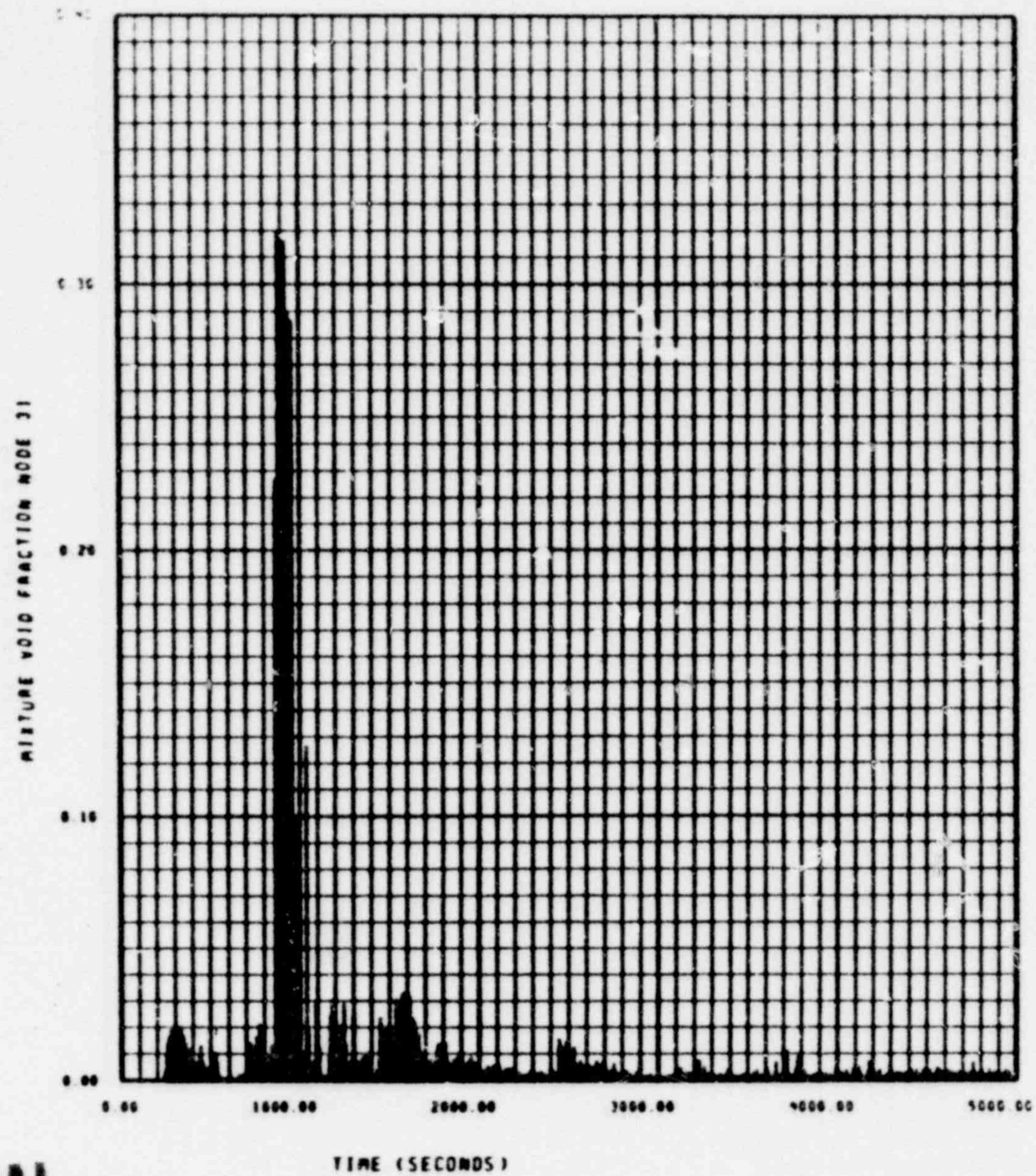
1105 178



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 55

1105 179

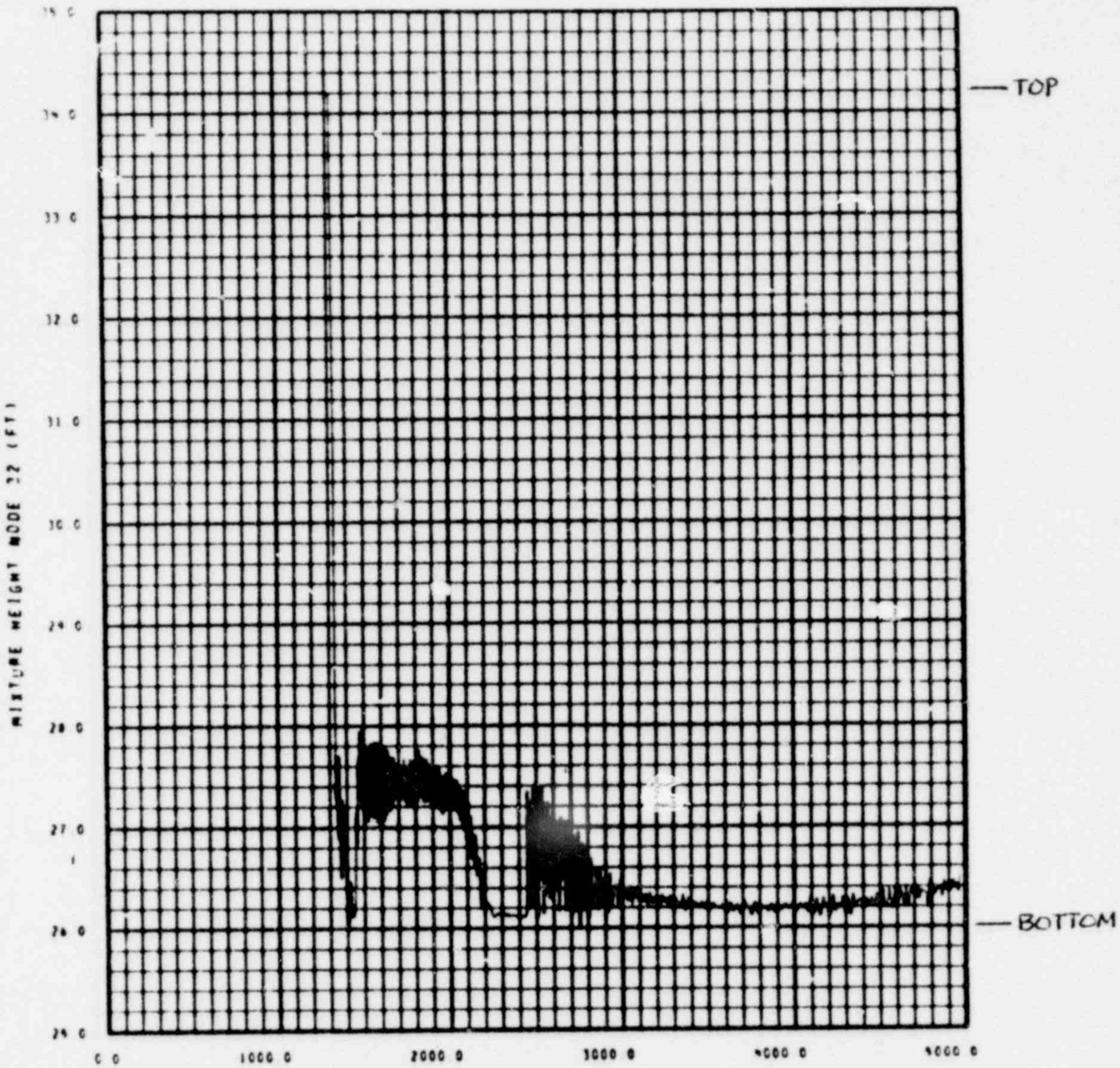


RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 56

POOR ORIGINAL

1105 180

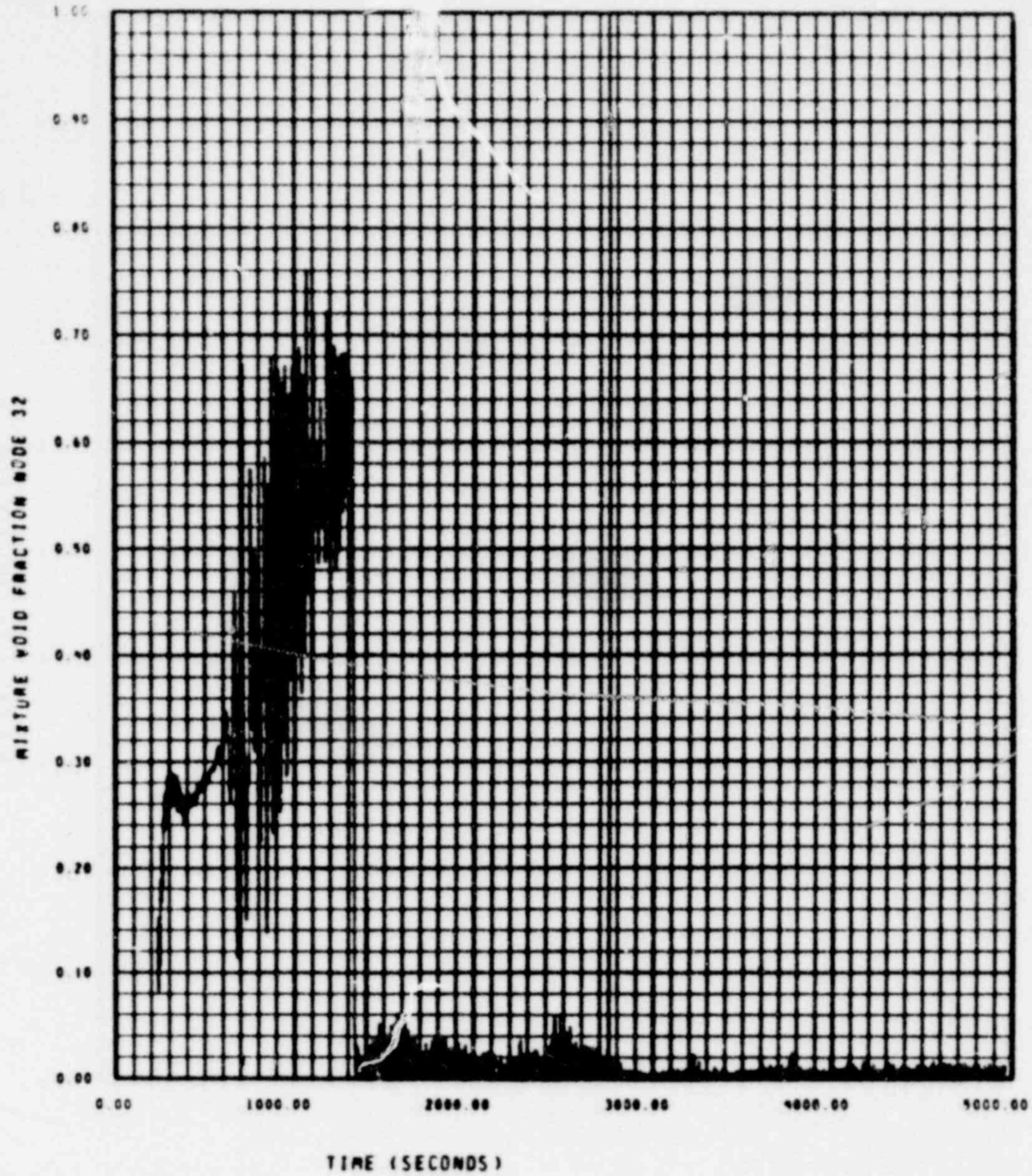


RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 57

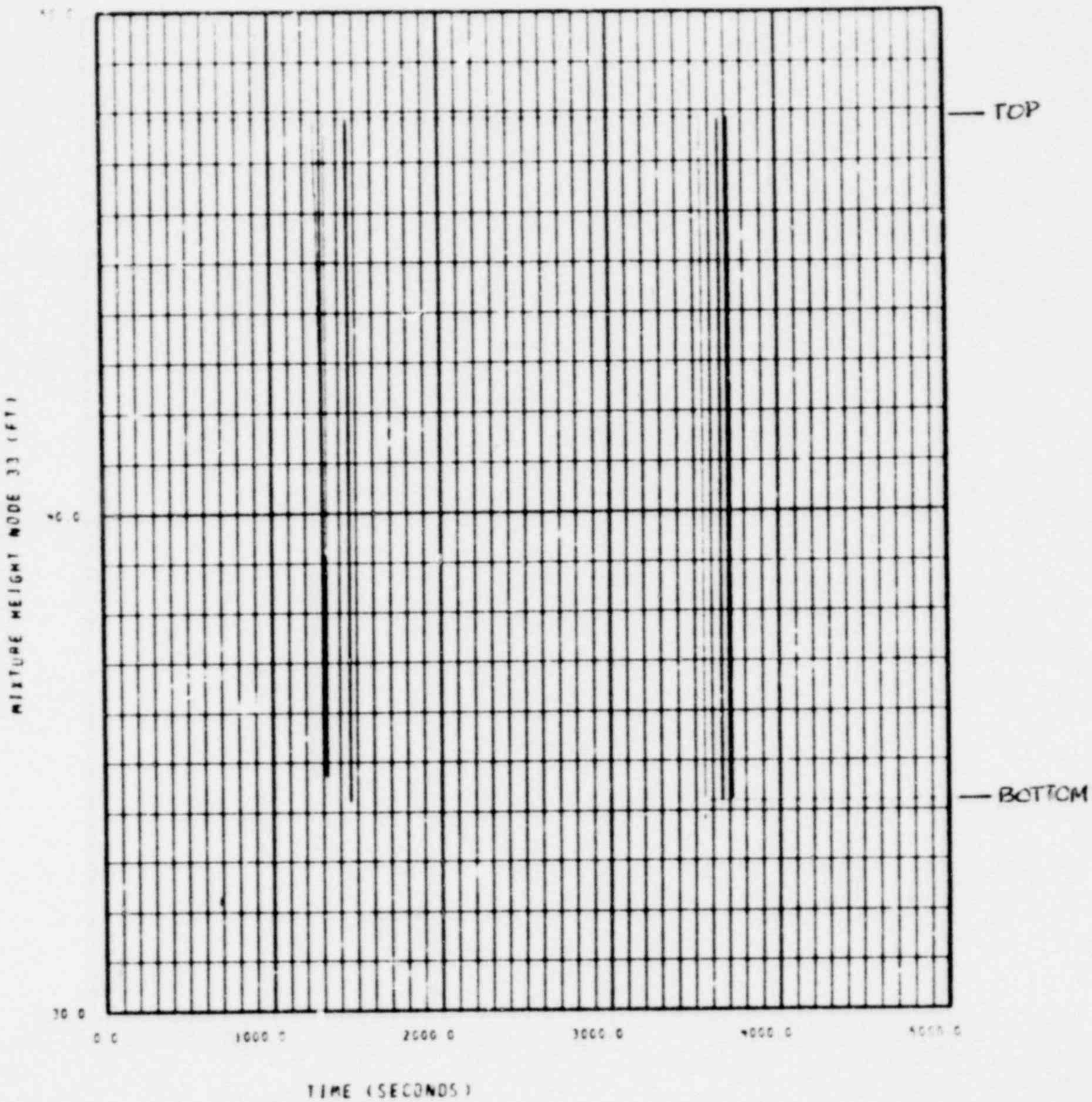
POOR ORIGINAL

1105 181



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 58



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 59

1105 183

POOR ORIGINAL

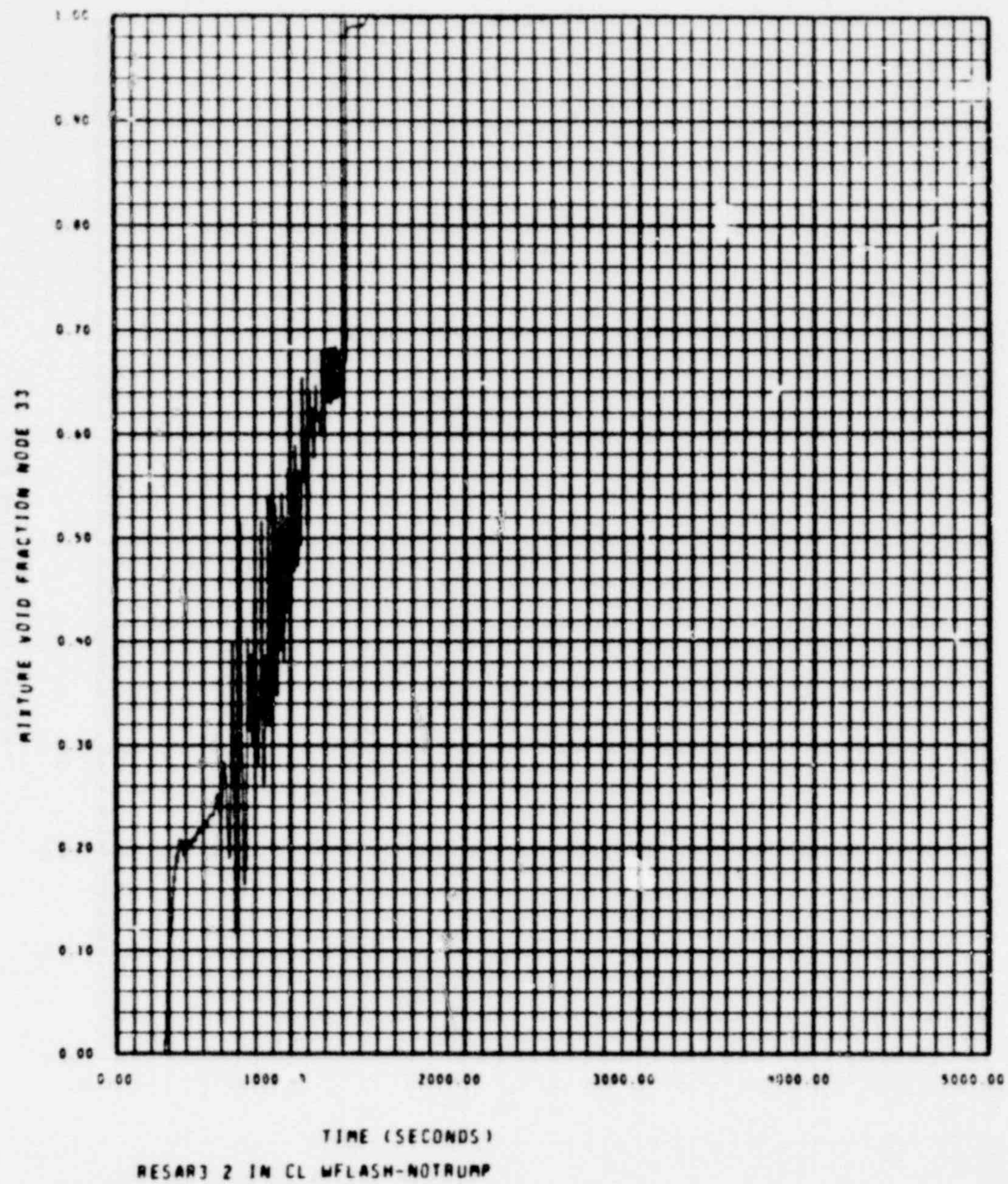
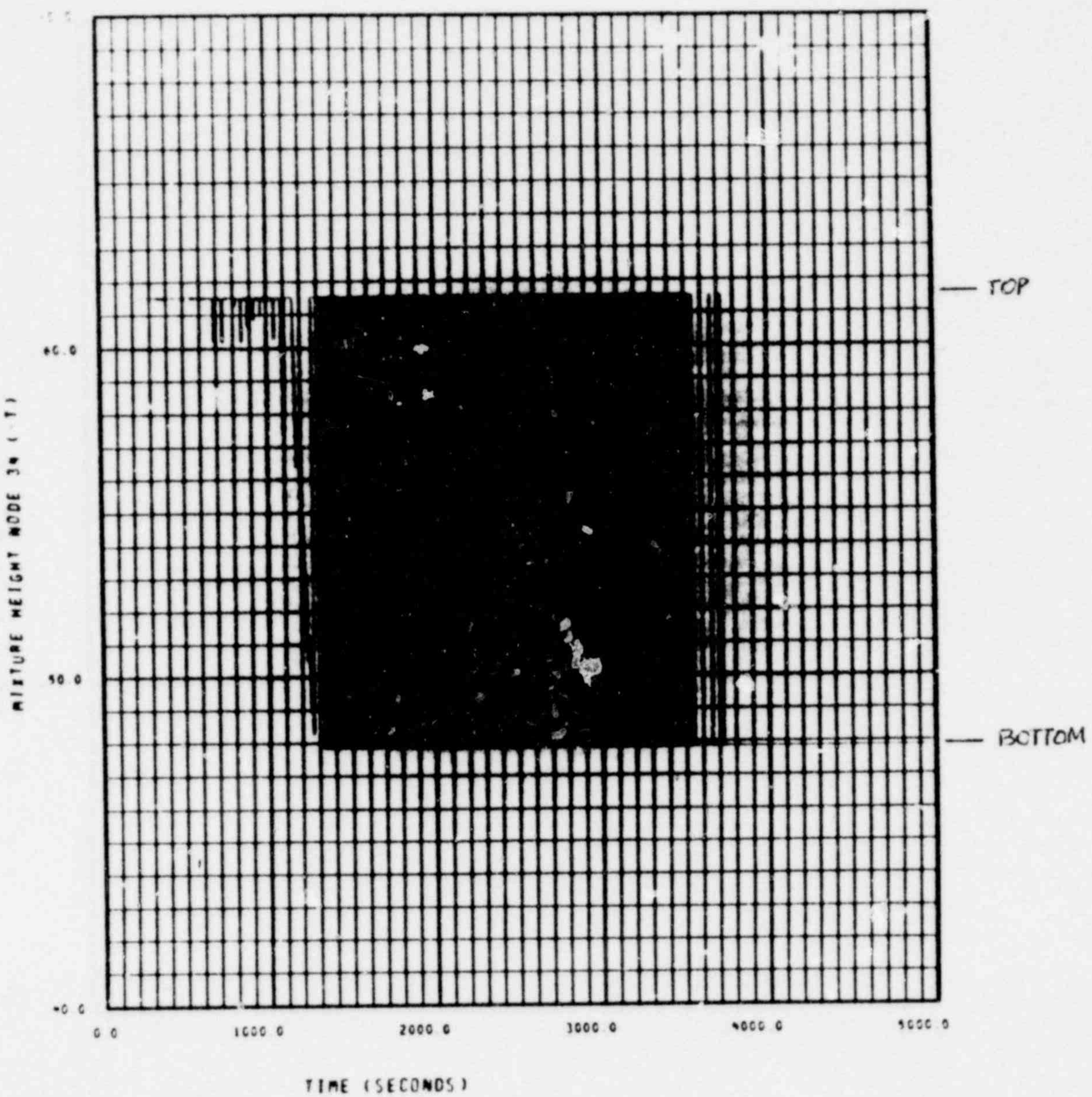


FIGURE 60

1105 184

POOR ORIGINAL



RESAH3 2 IN CL WFLASH-NOTRUMP

FIGURE 61

1105 185

POOR ORIGINAL

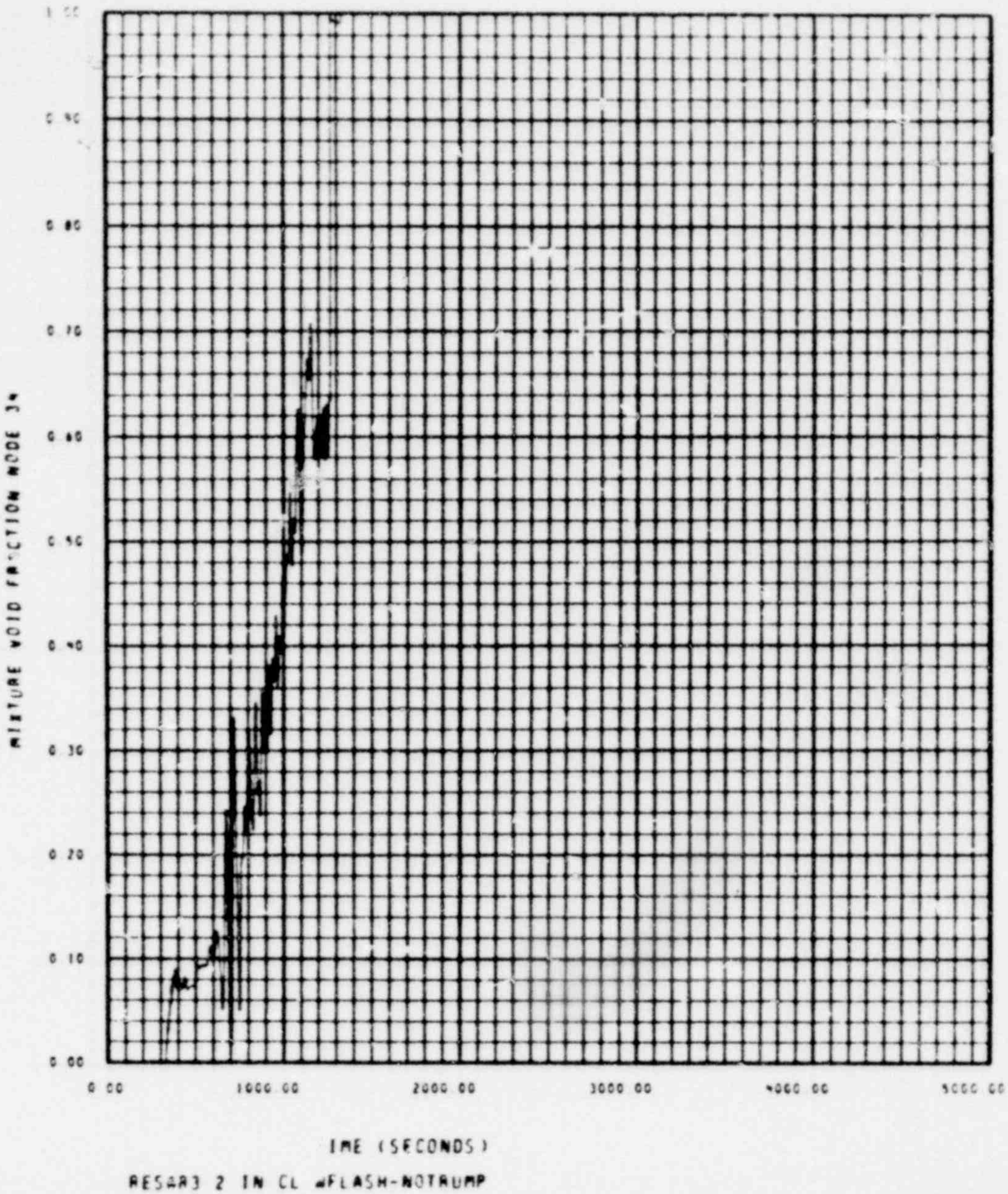
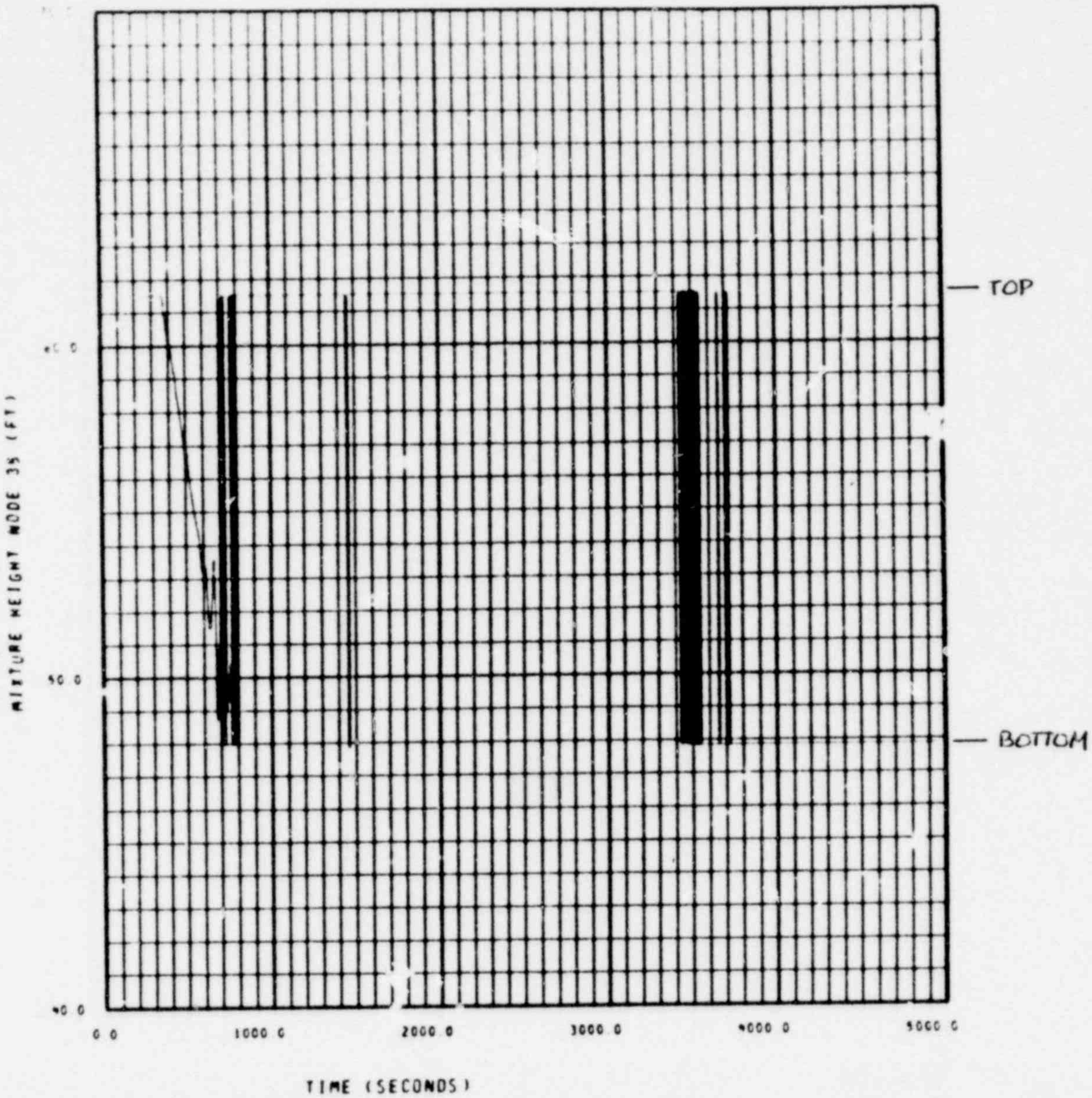


FIGURE 62

1105 186

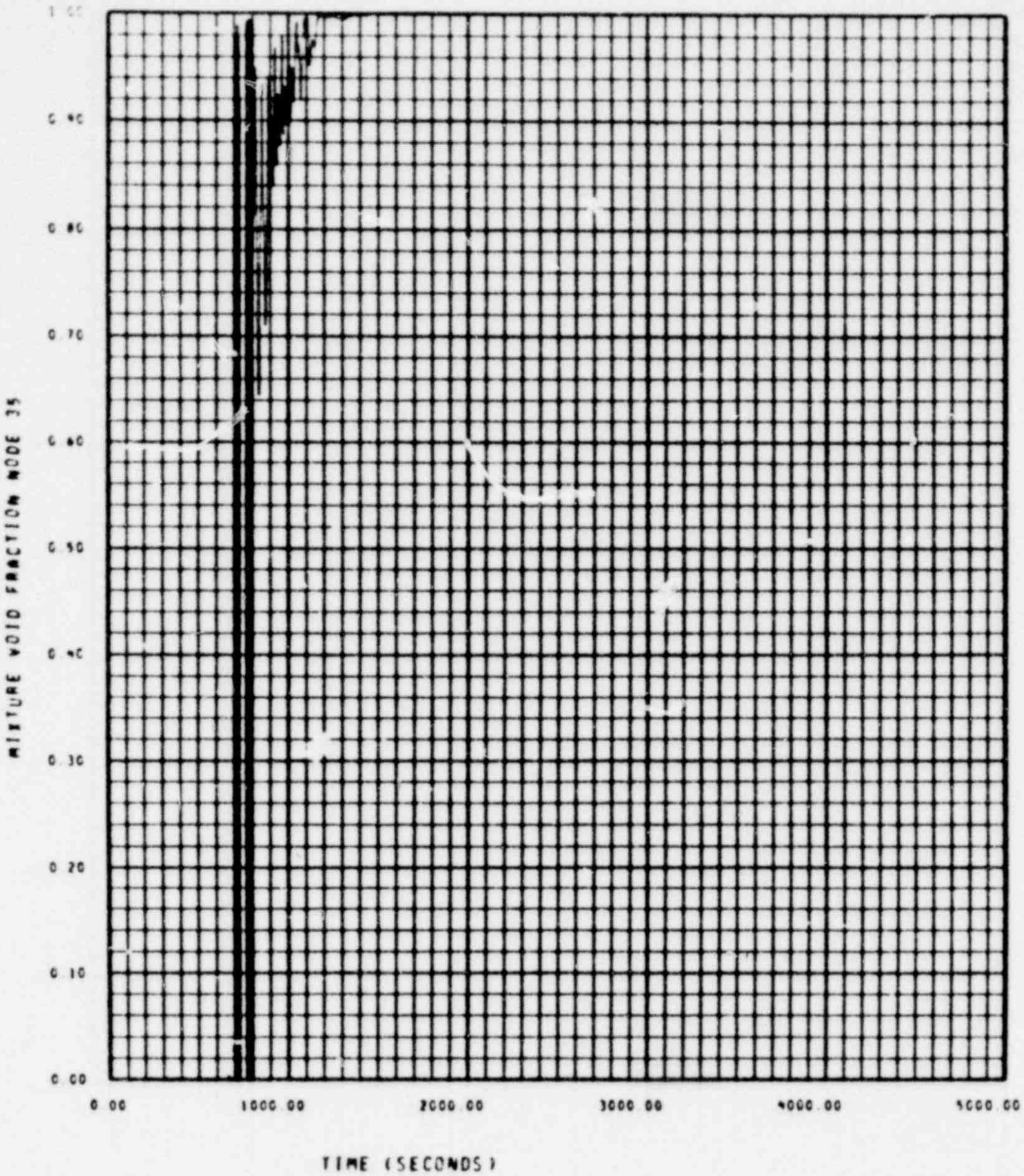
POOR ORIGINAL



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 63

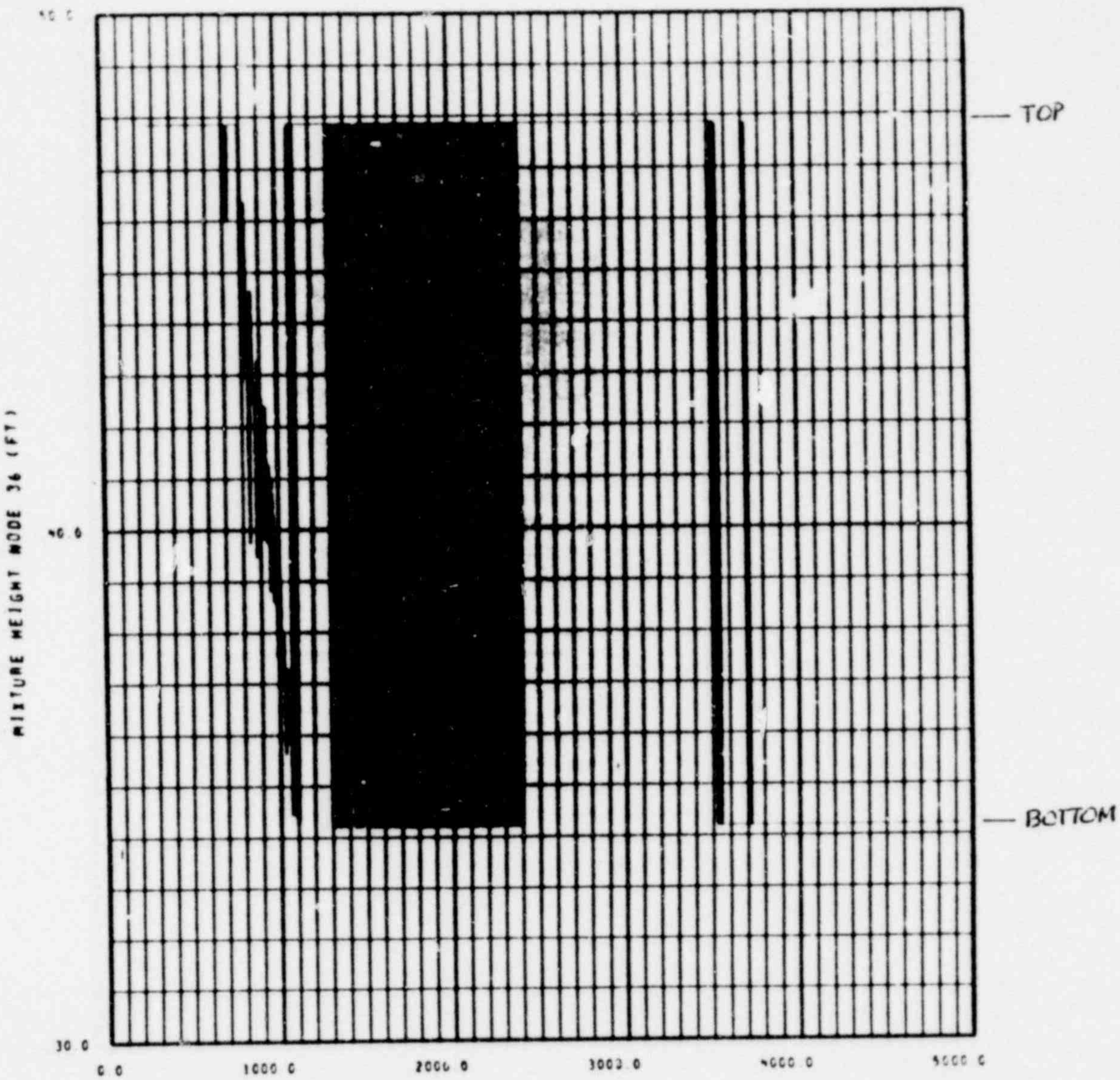
1105 187



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 64

1105 188



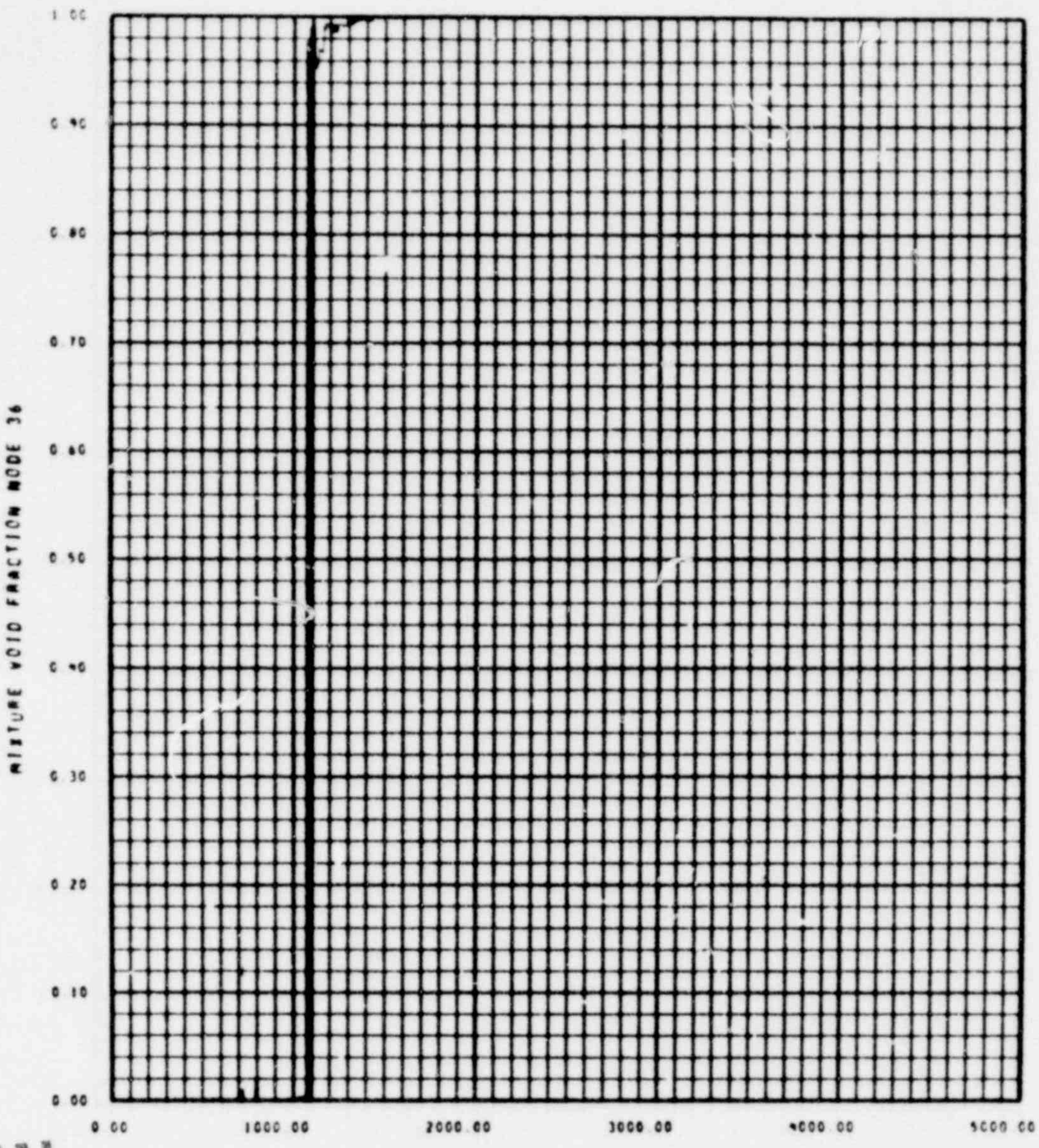
TIME (SECONDS)

RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 65

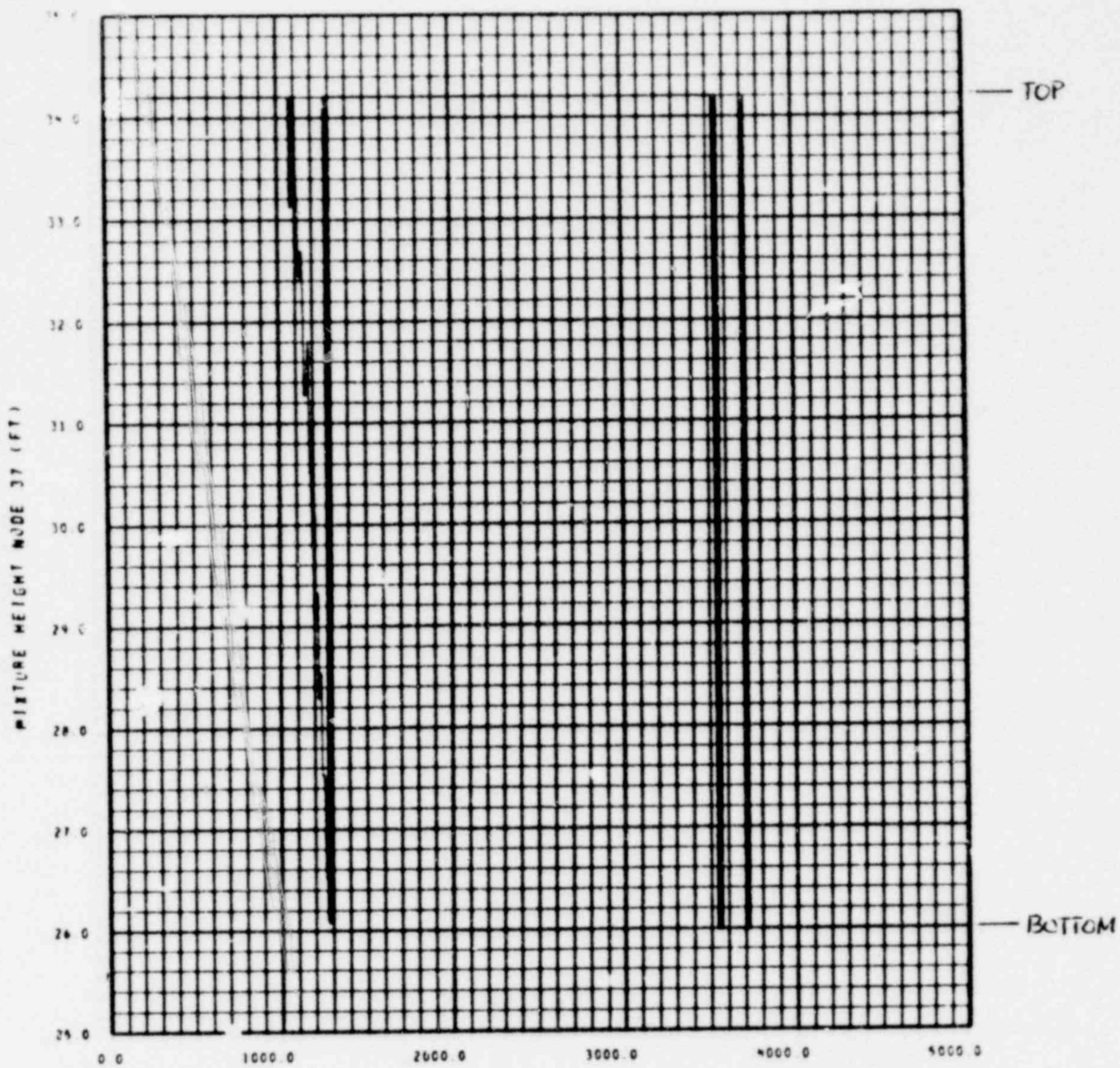
1105 189

POOR ORIGINAL



RESAR3 2 IN CL WFLASH-NOTRUMP

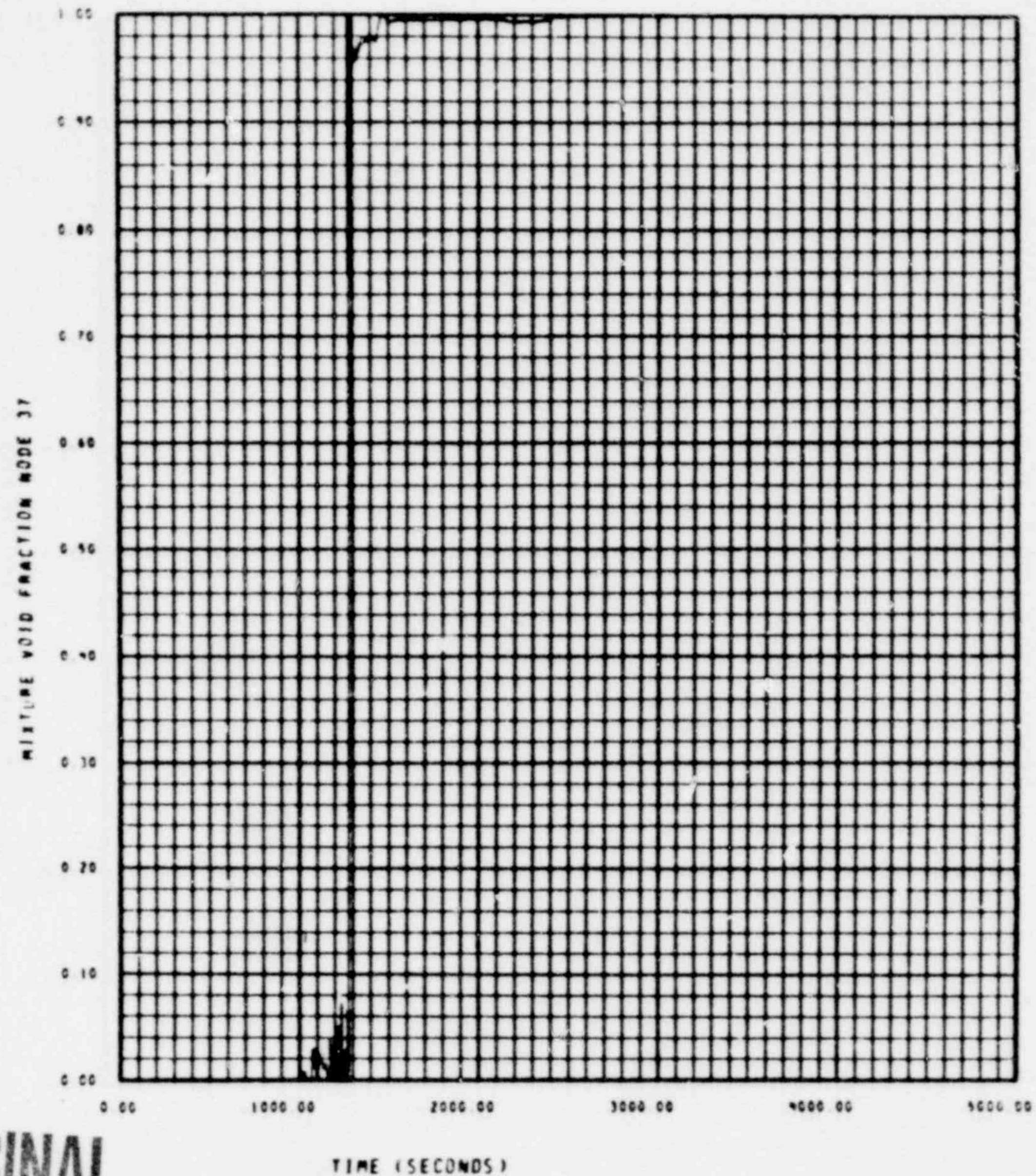
FIGURE 66



RESARJ 2 IN CL WFLASH-NOTRUMP

FIGURE 67

1105 191

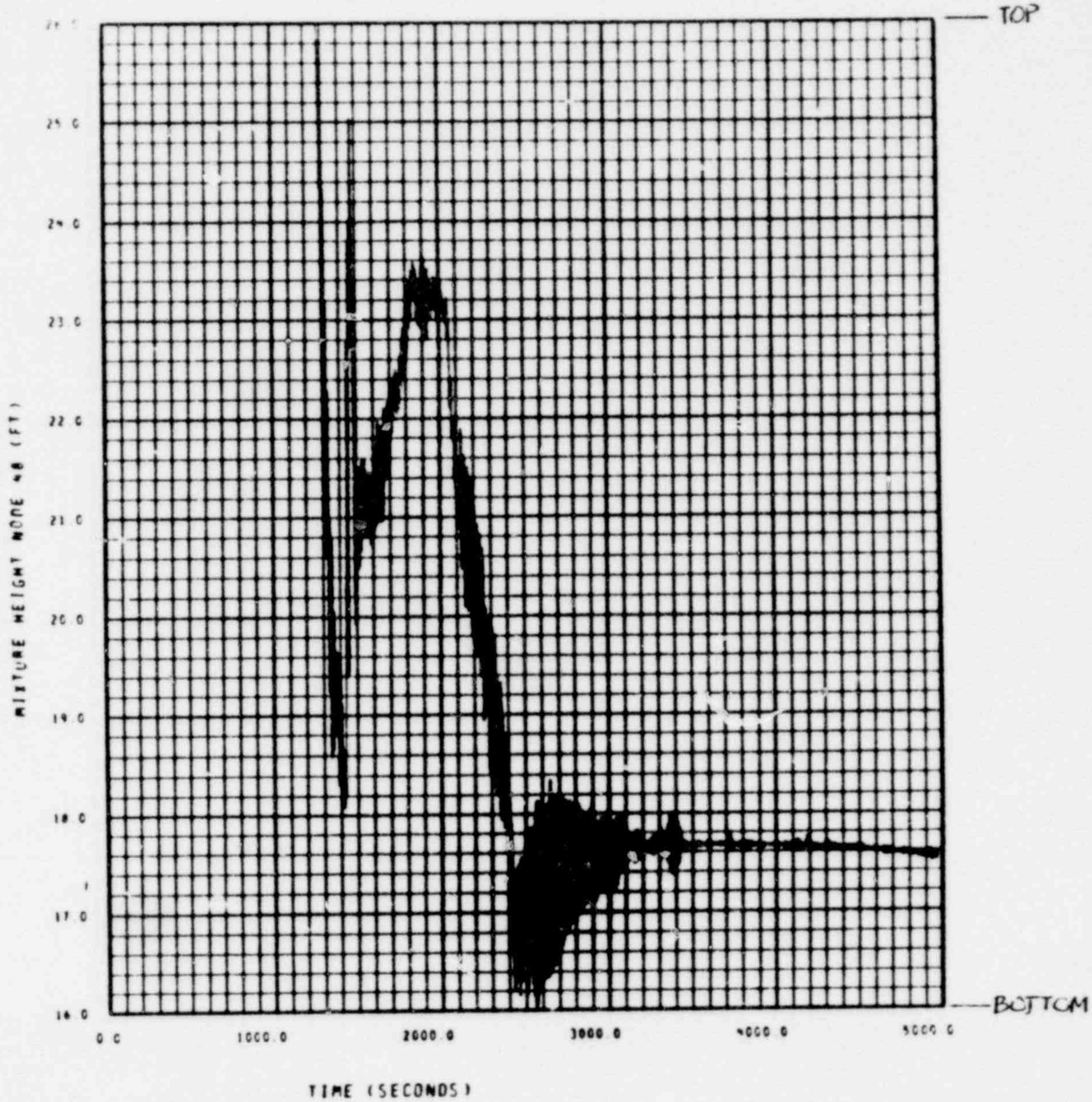


RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 68

1105 192

POOR ORIGINAL

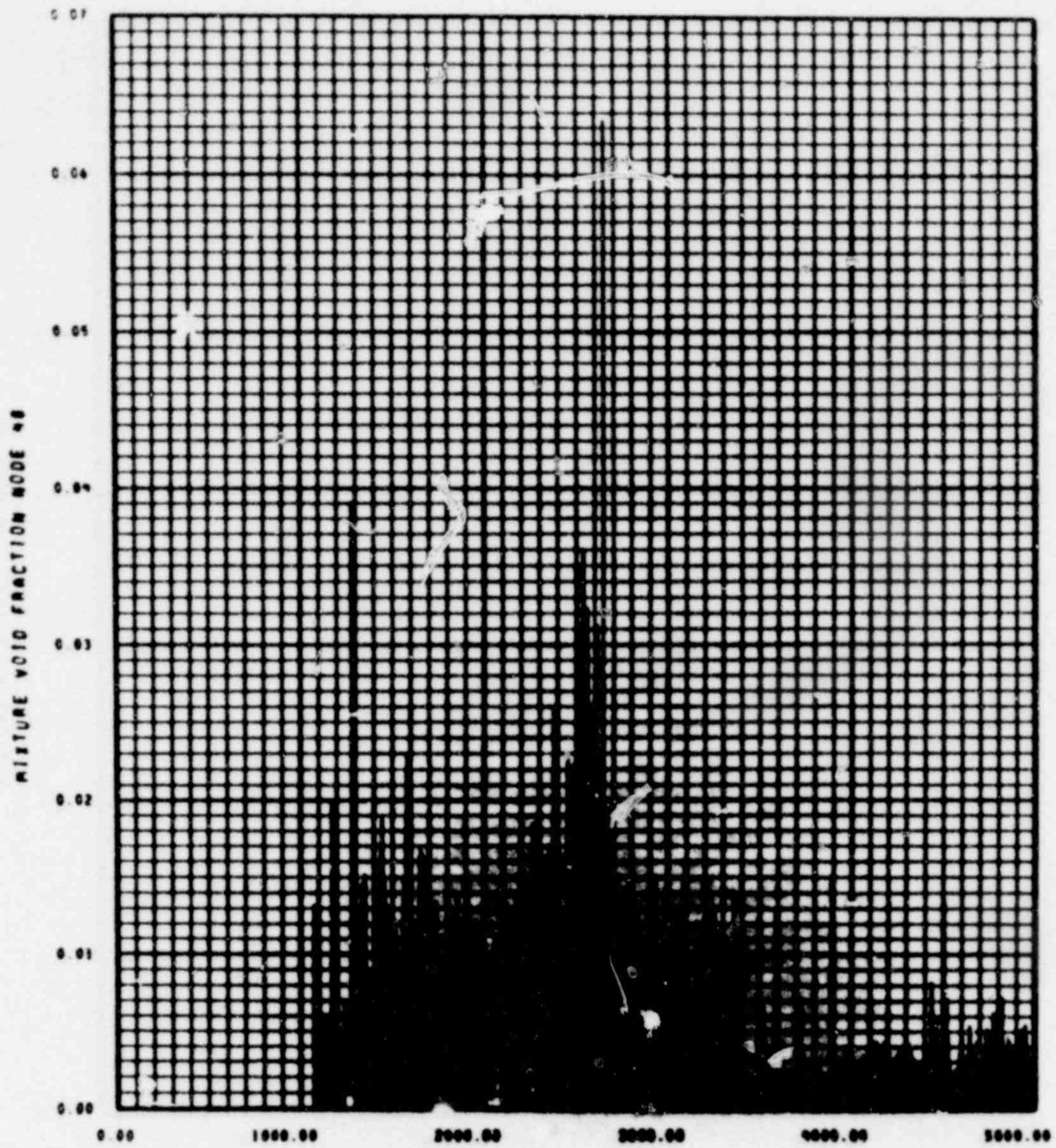


RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 69

POOR ORIGINAL

1105 193



RESAR3 2 IN CL WFLASH-NOTRUMP

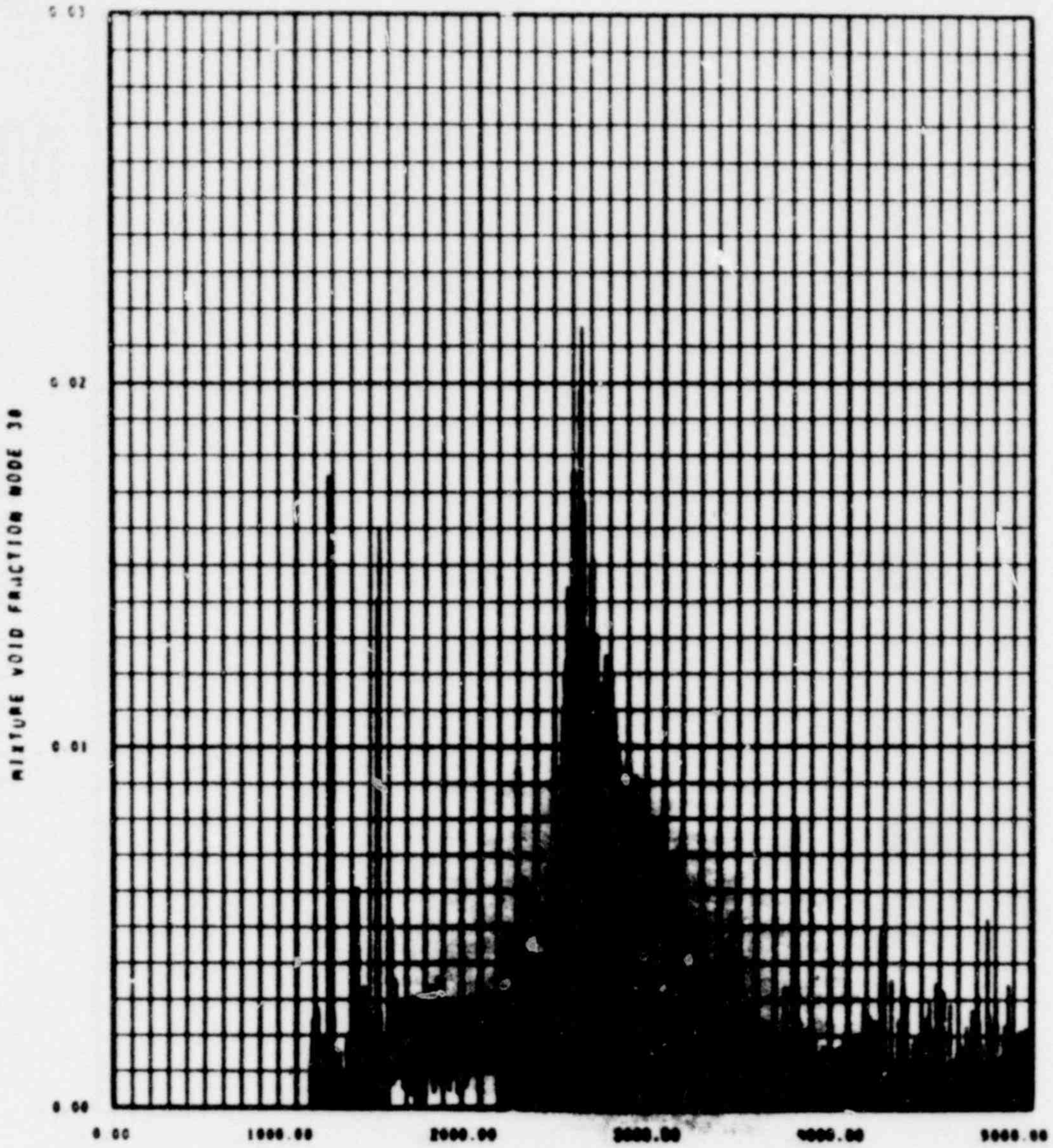
FIGURE 70

1105 194

POOR ORIGINAL

RESAR3 2 IN CL WFLASH-NOTRUMP

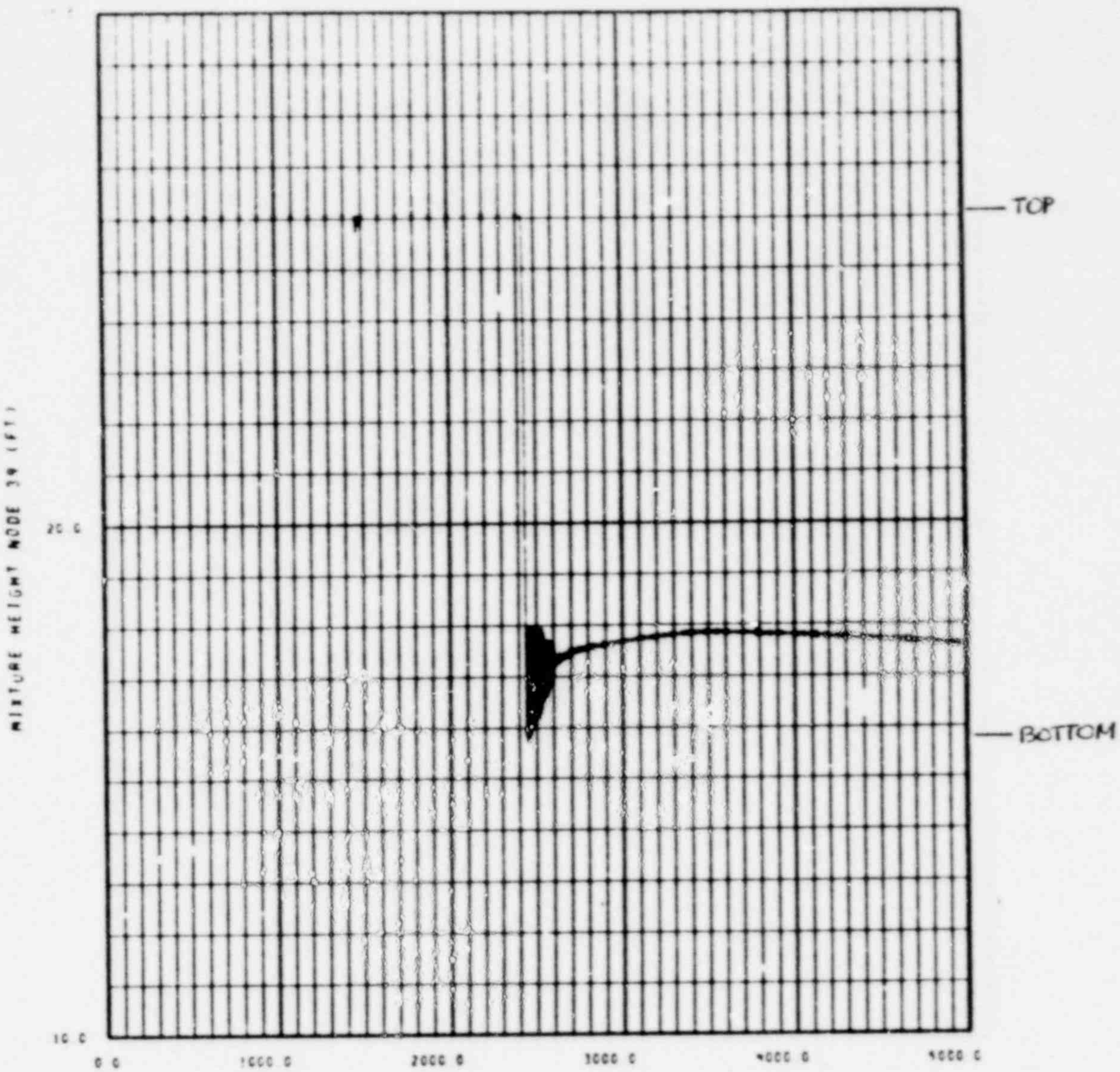
FIGURE 71



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 72

1105 196



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 73

1105 197

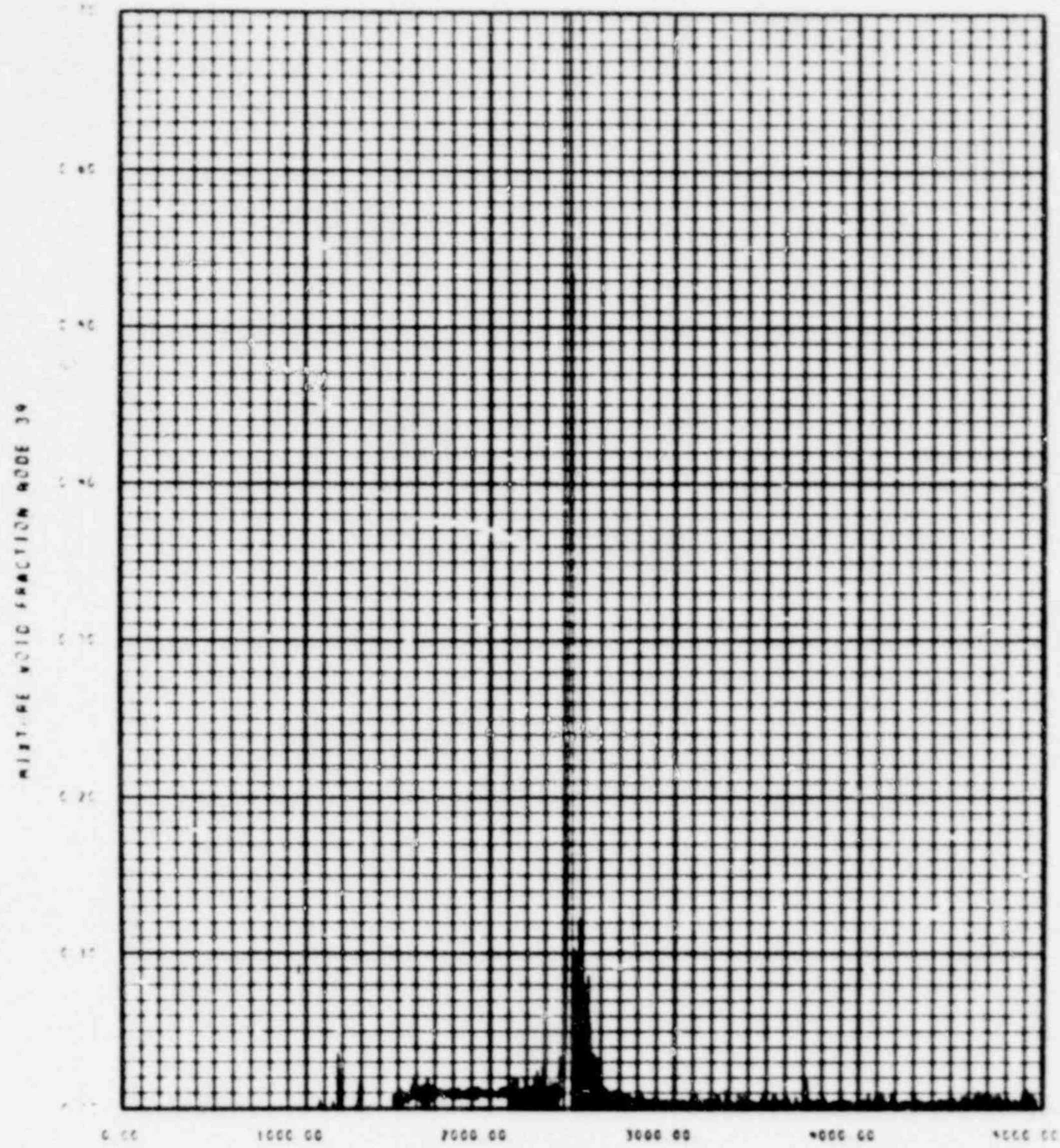
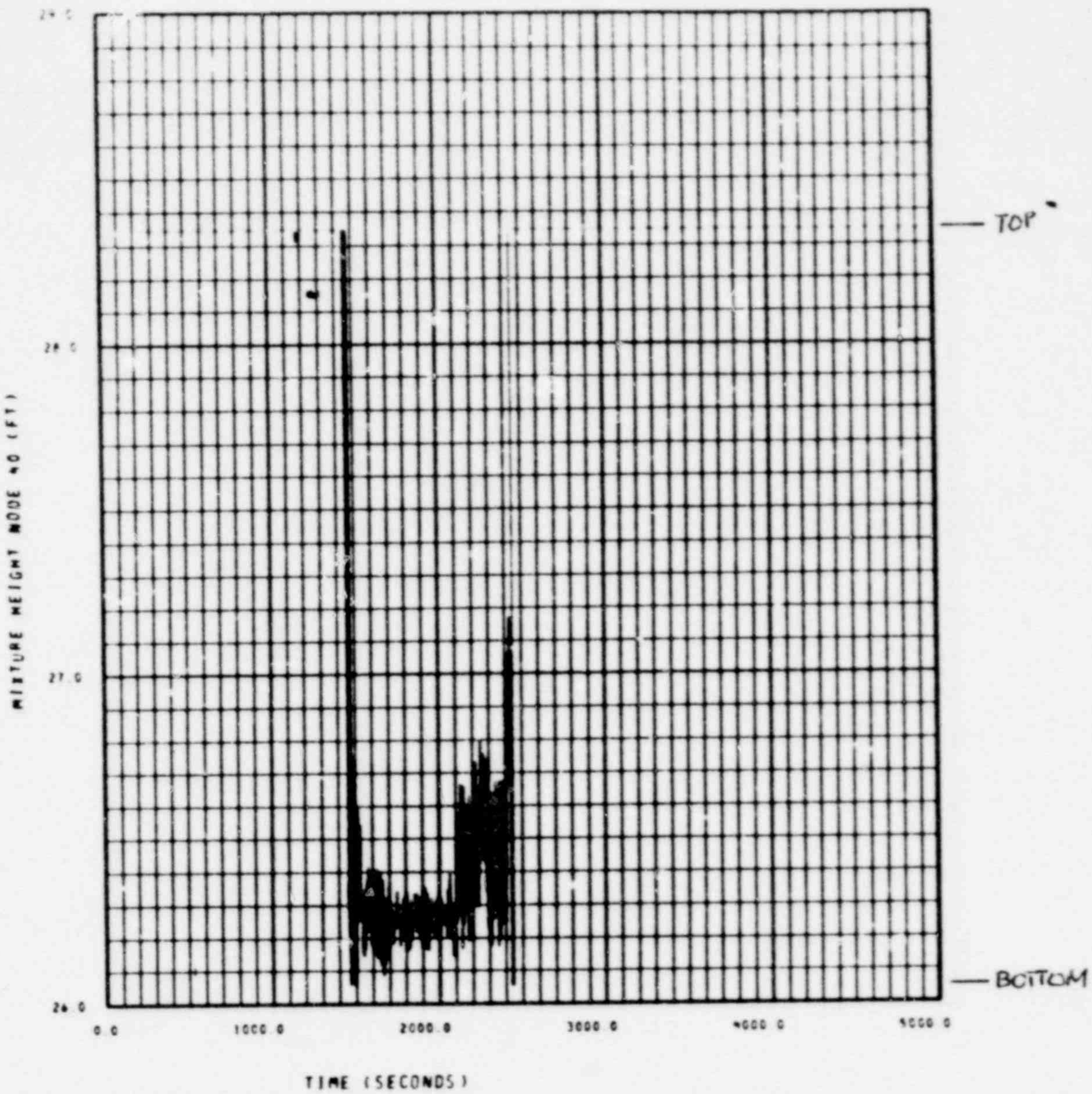


FIGURE 74

POOR ORIGINAL

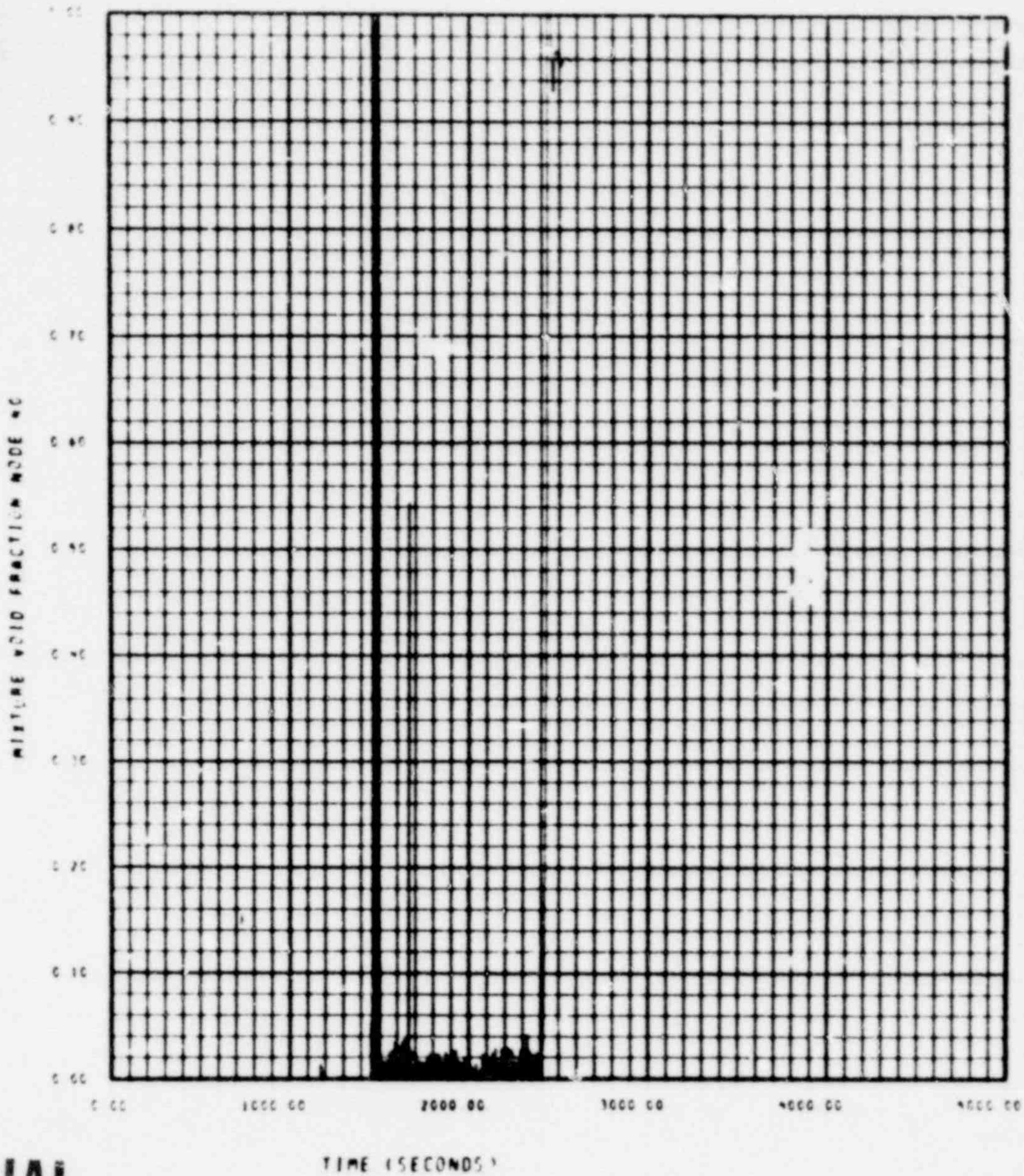
1105 198



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 75

1105 199



RESTART 2 IN CL WFLASH-NOTRUMP

FIGURE 76

POOR ORIGINAL

1105 200

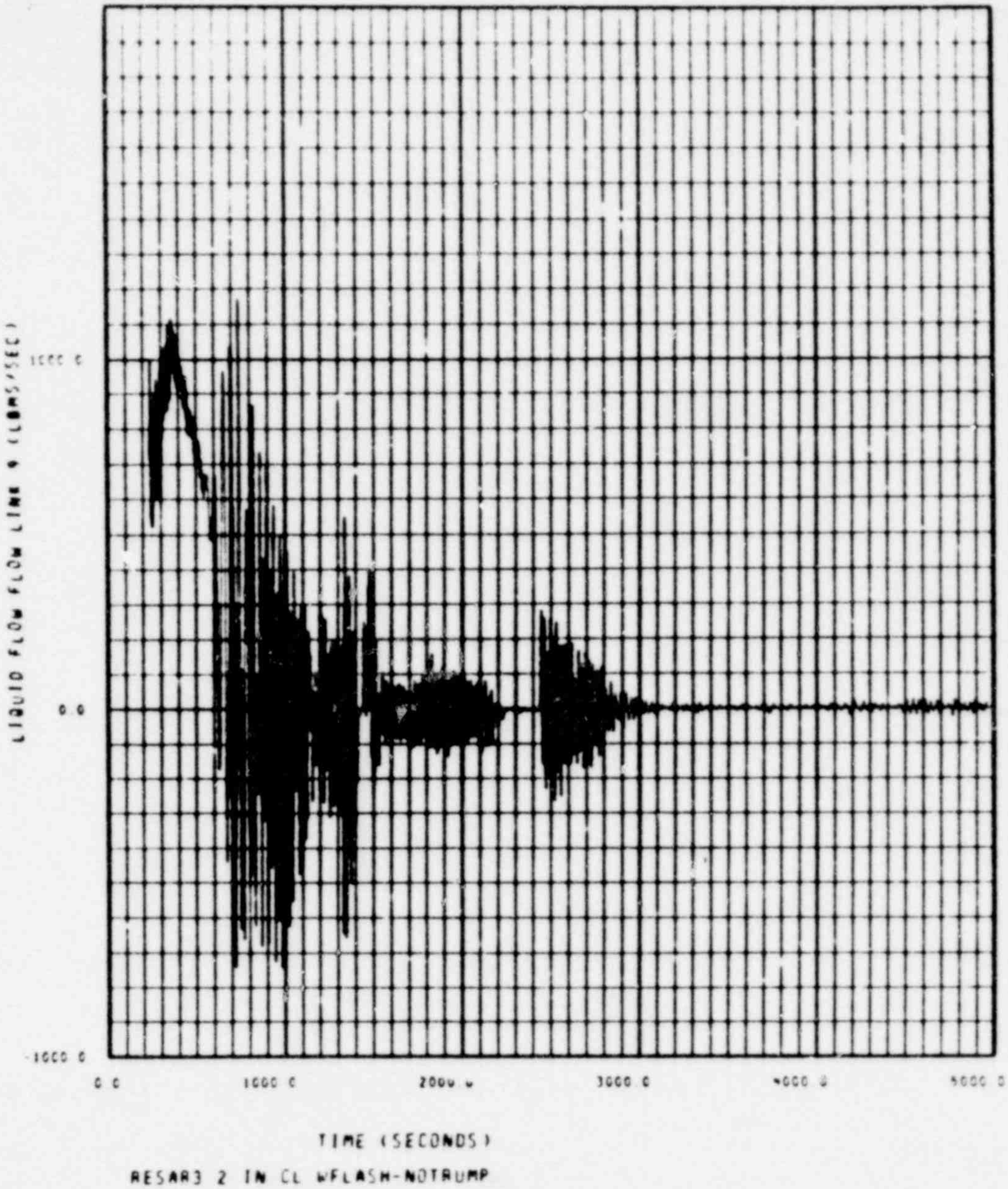
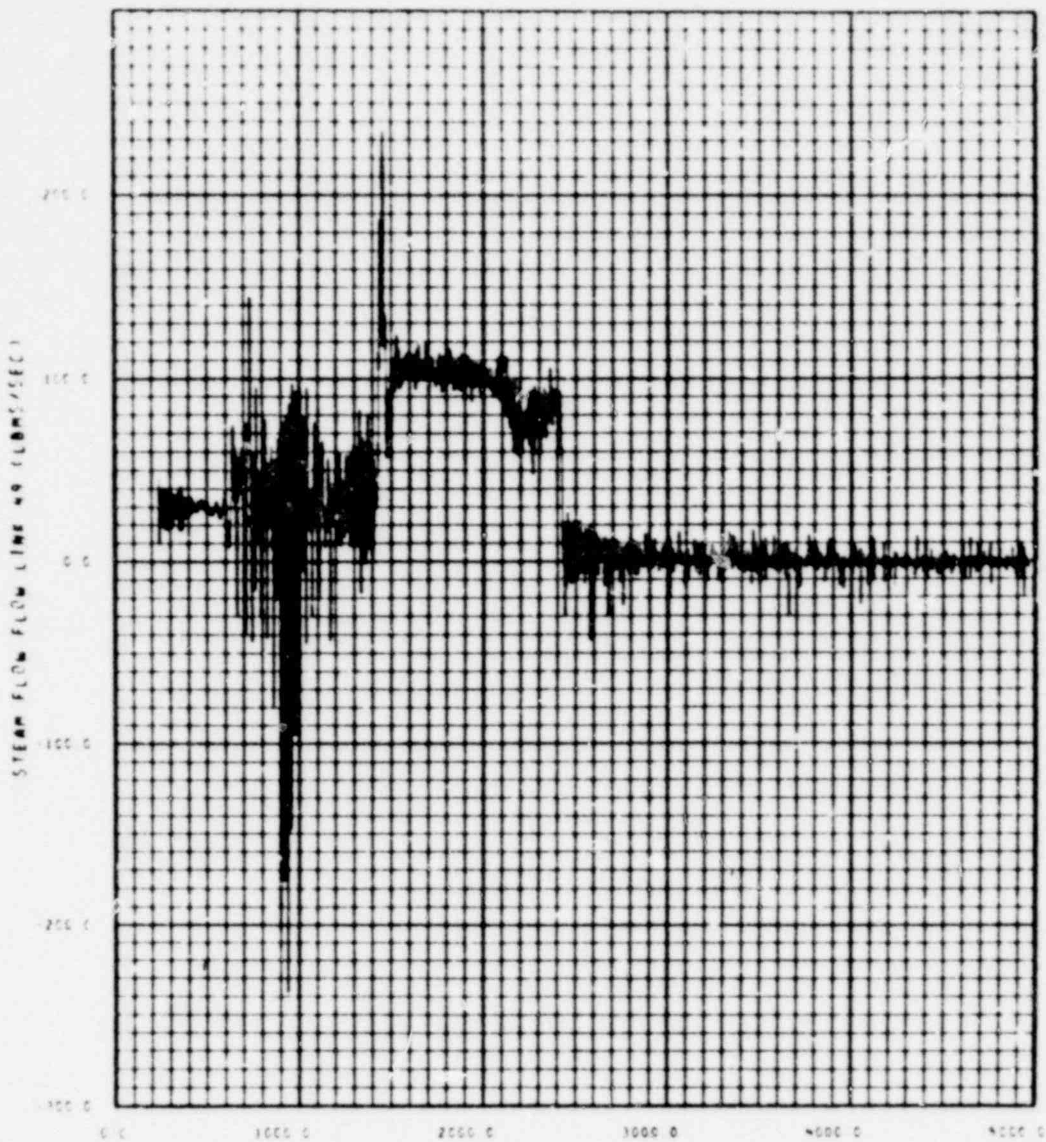


FIGURE 77

1105 201

POOR ORIGINAL

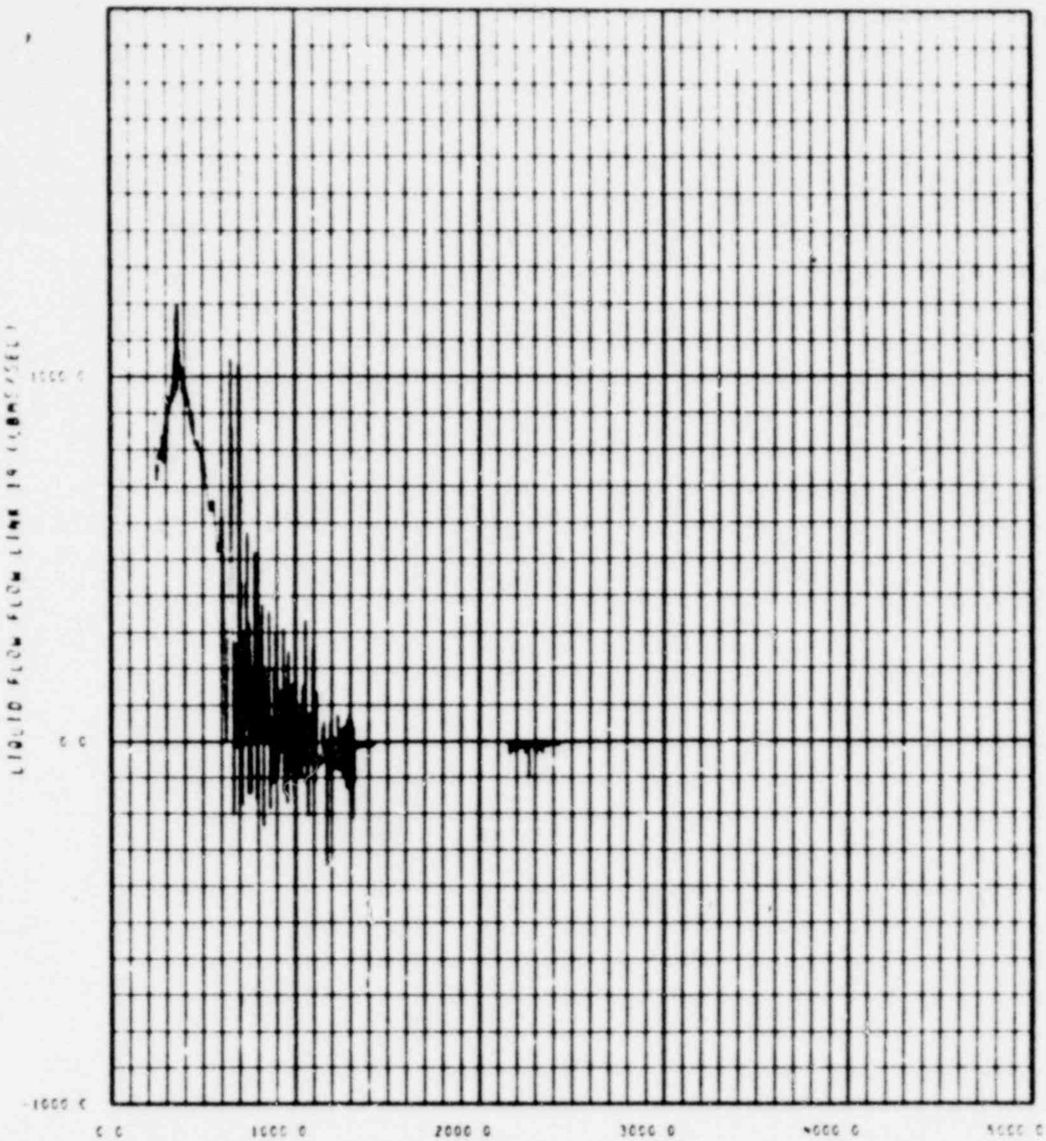


RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 78

1105 202

POOR ORIGINAL



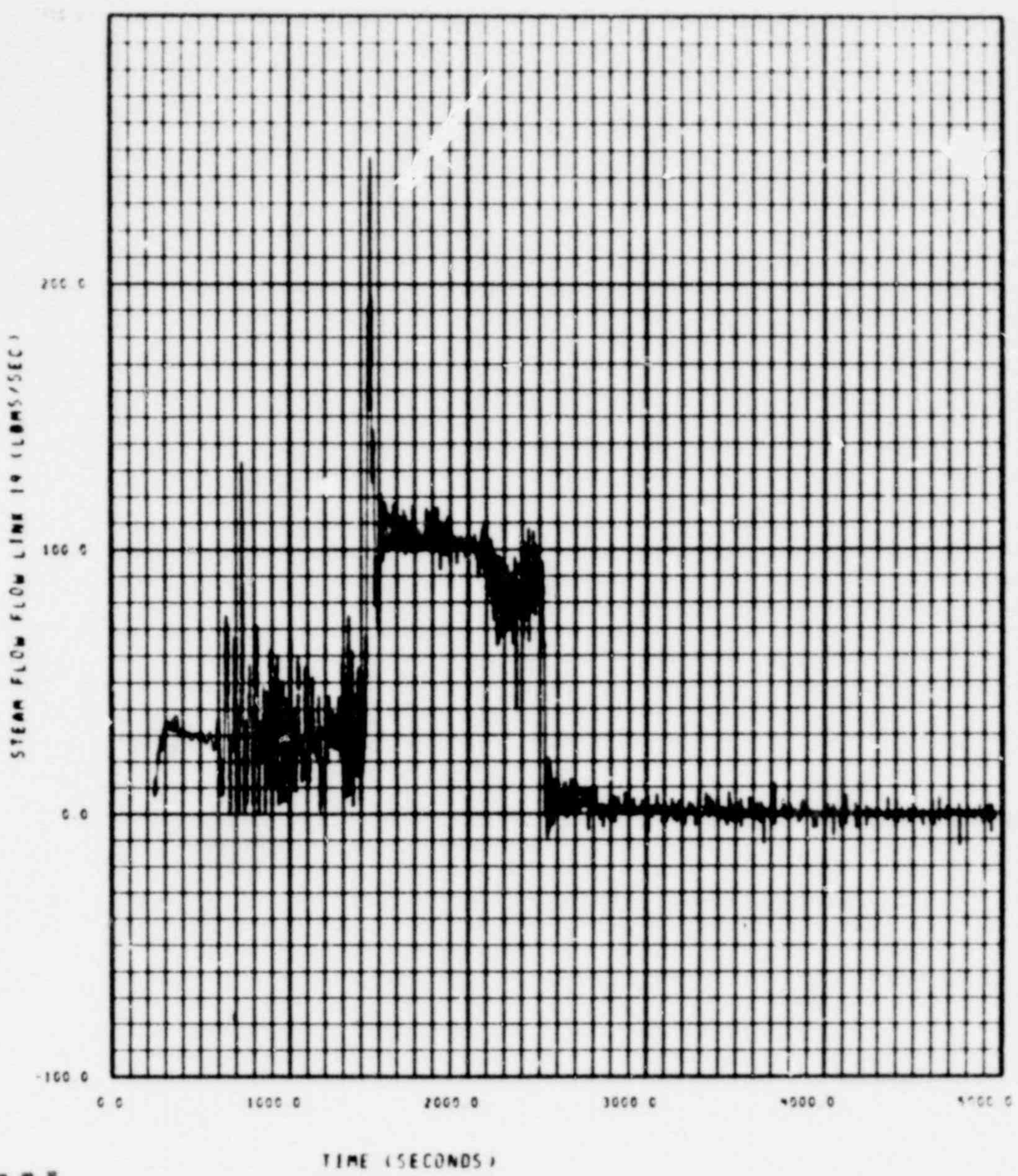
TIME (SECONDS)

RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 79

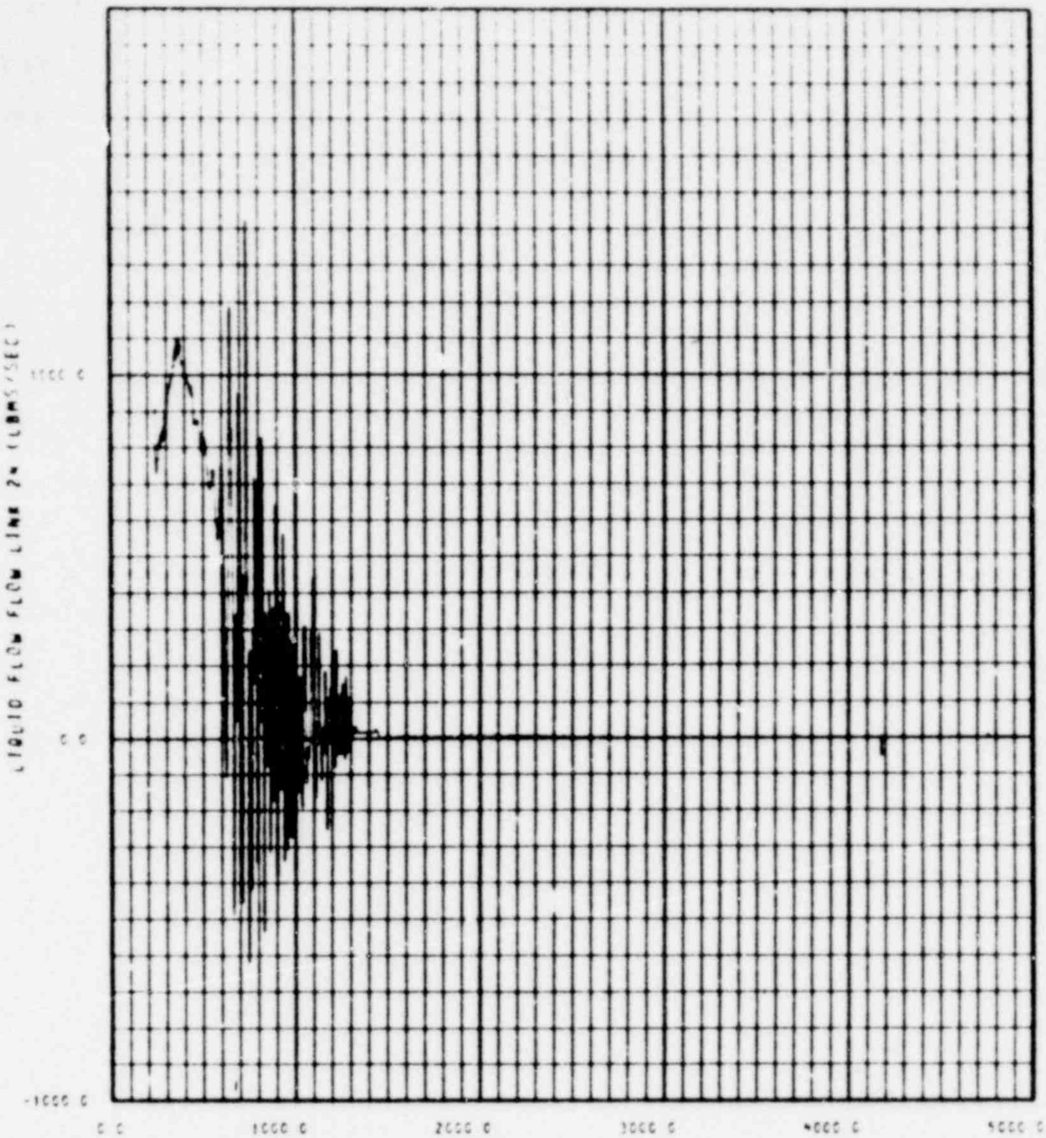
1105 203

POOR ORIGINAL



RFSAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 30



RECARJ 2 IN CL WFLASH-NOTRUMP

FIGURE 81

POOR ORIGINAL

1105 205

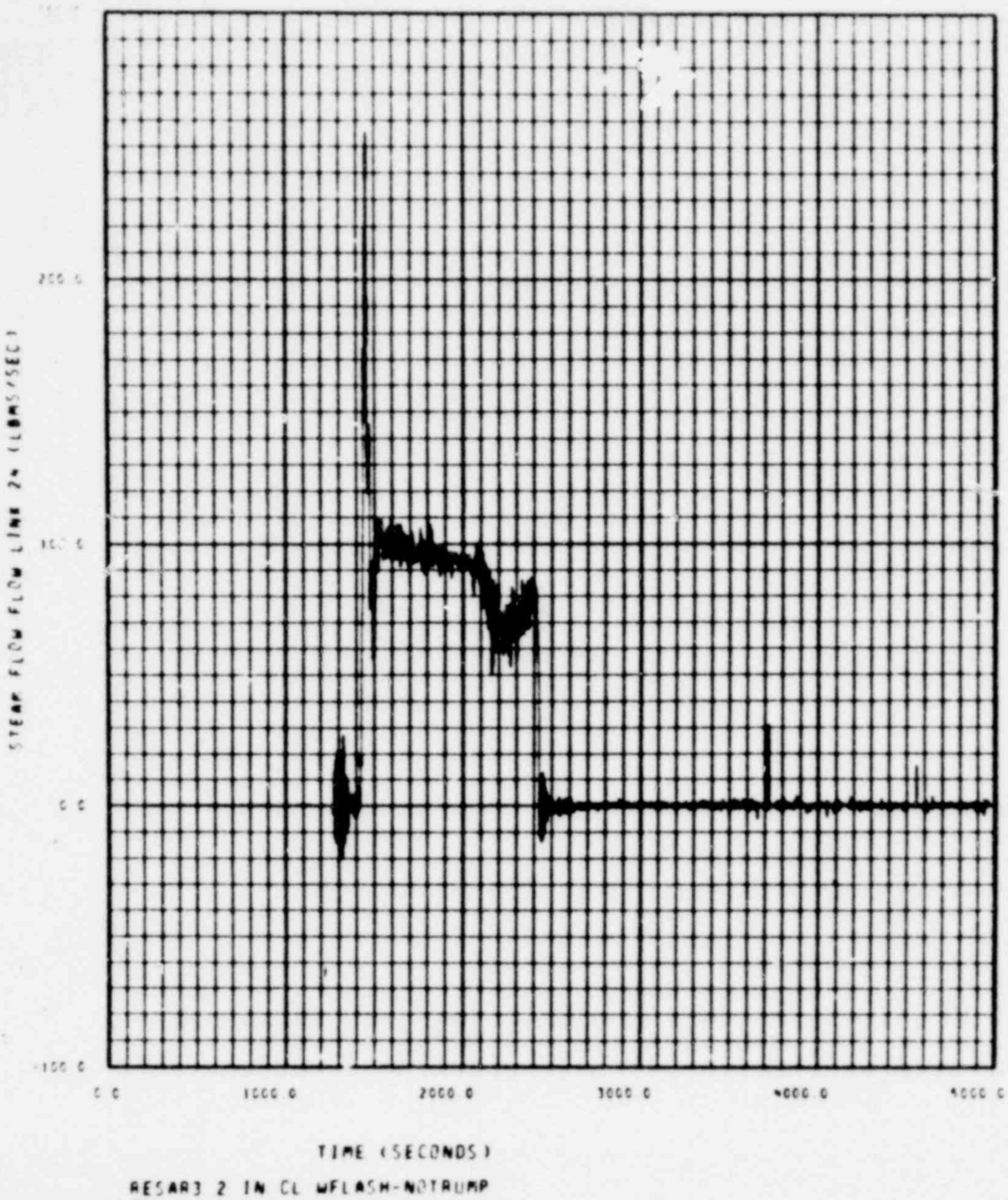
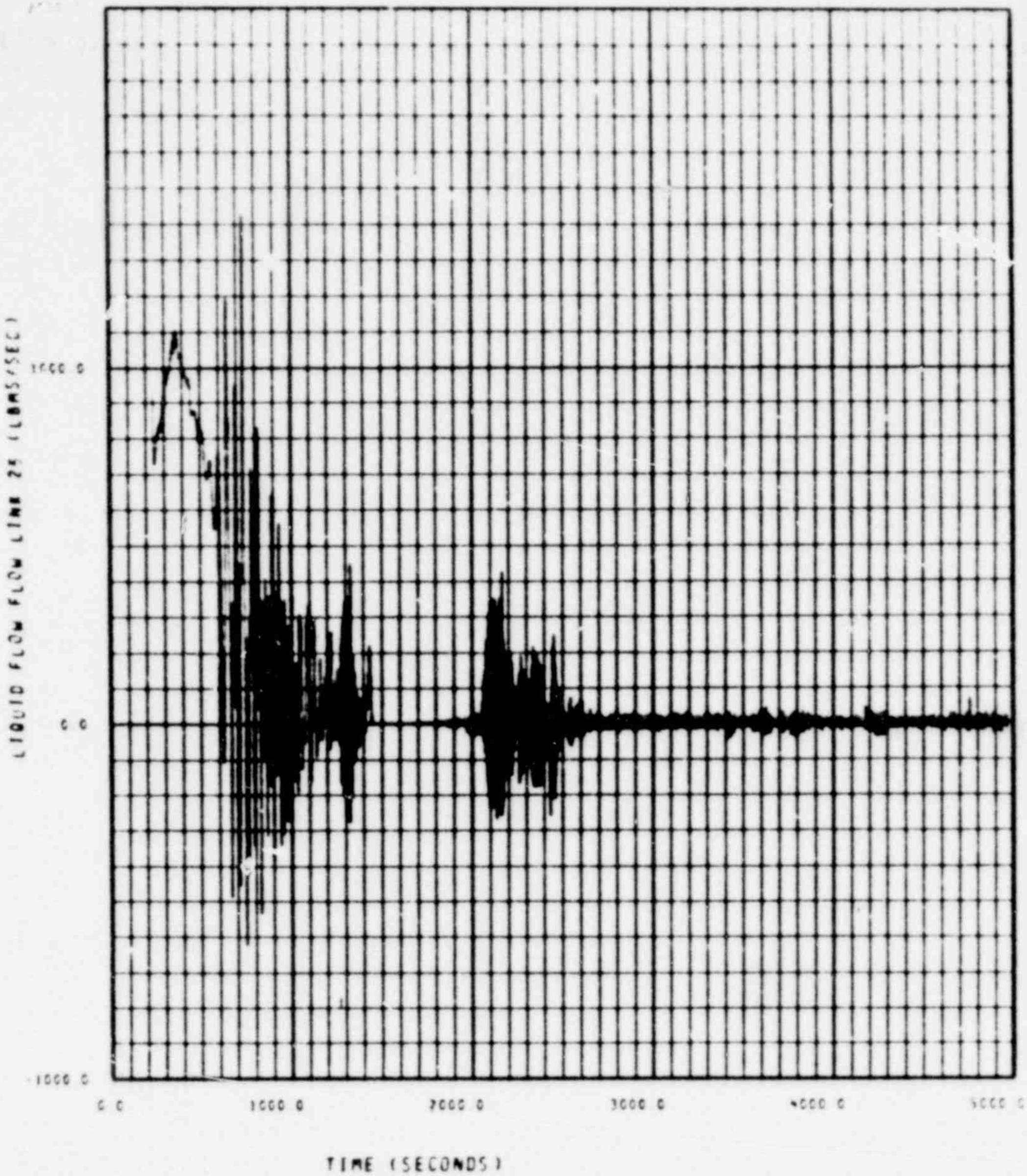
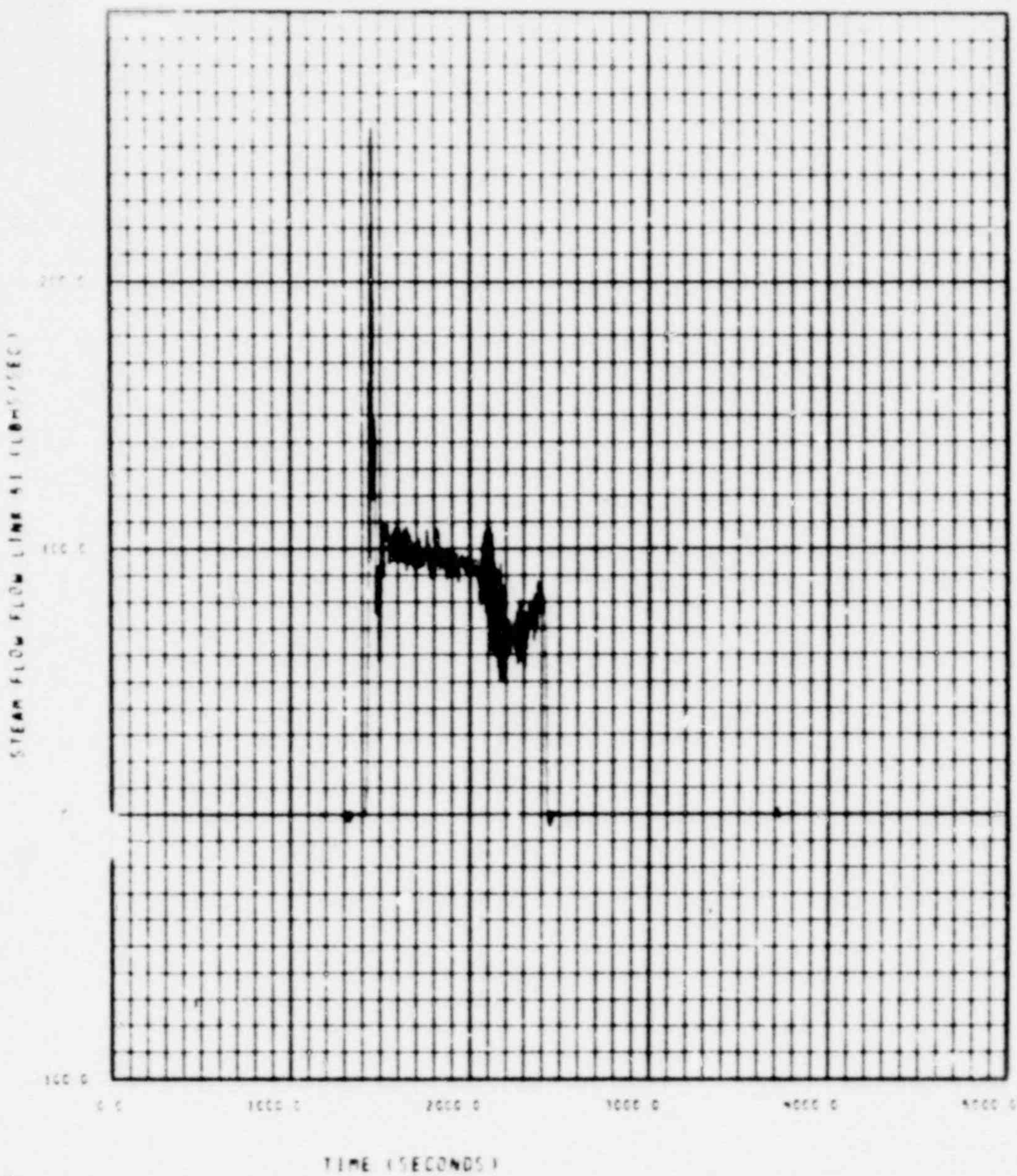

300.0
200.0
100.0
0.0
-100.0
STEAM FLOW FLOW LINE 24 (LBMS/SEC)
0.0
1000.0
2000.0
3000.0
4000.0
5000.0
TIME (SECONDS)
RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 82



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 83

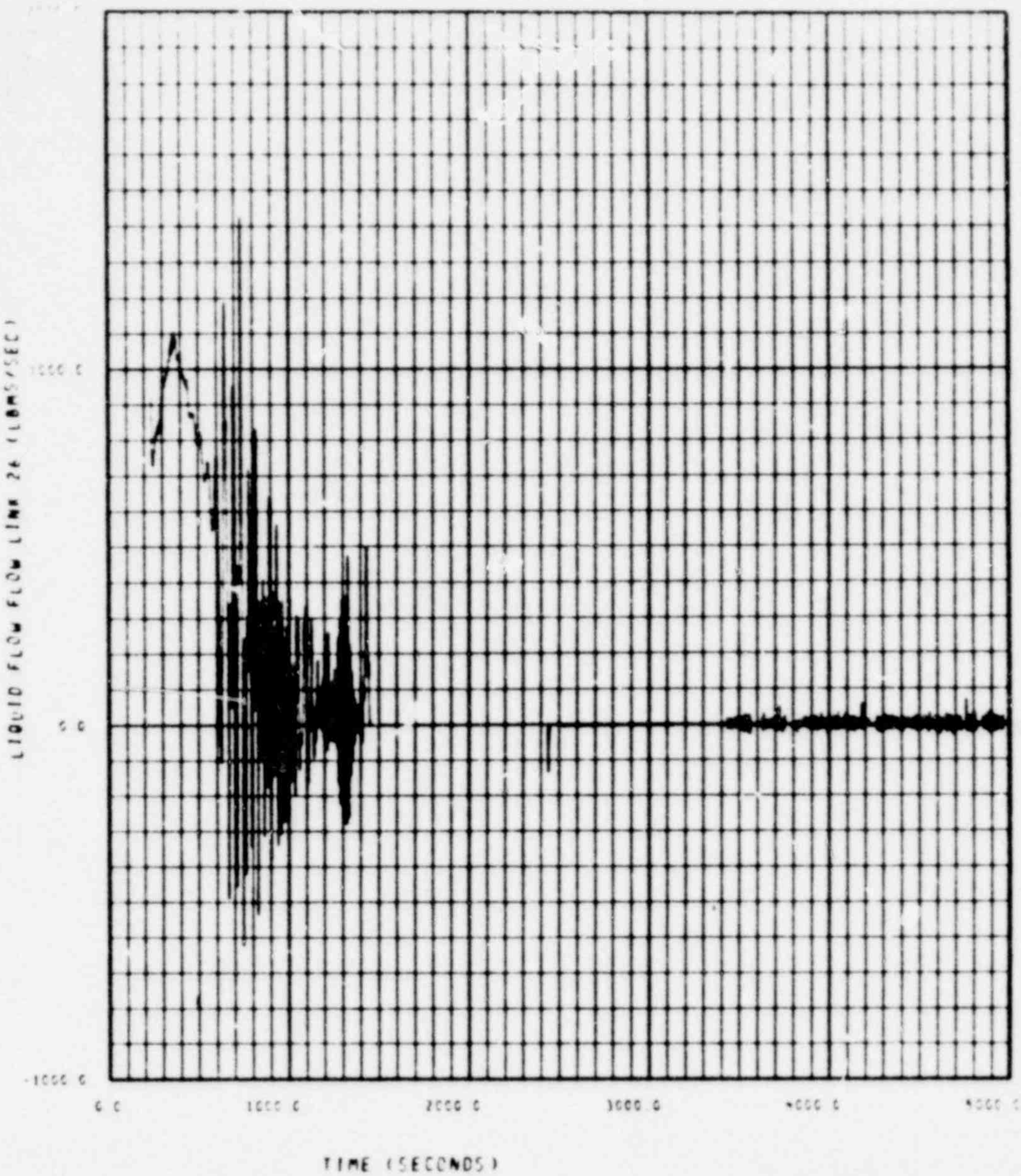


RESART 2 IN CL WFLASH-NOTRUMP

FIGURE 84

. 1105 208

POOR ORIGINAL



RELAP3 2 IN CL WFLASH-NOTRUMP

FIGURE 85

1105 209

POOR ORIGINAL

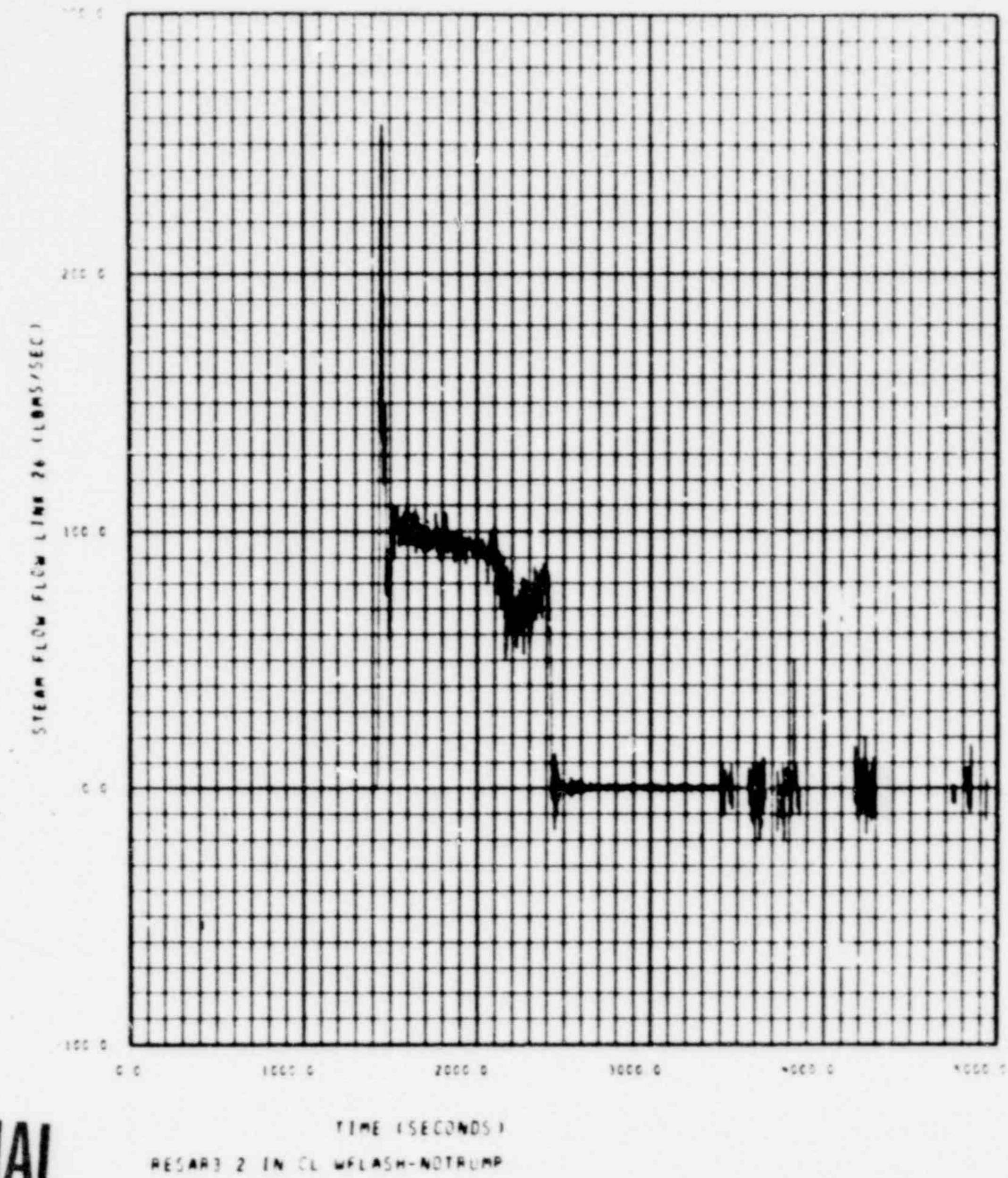
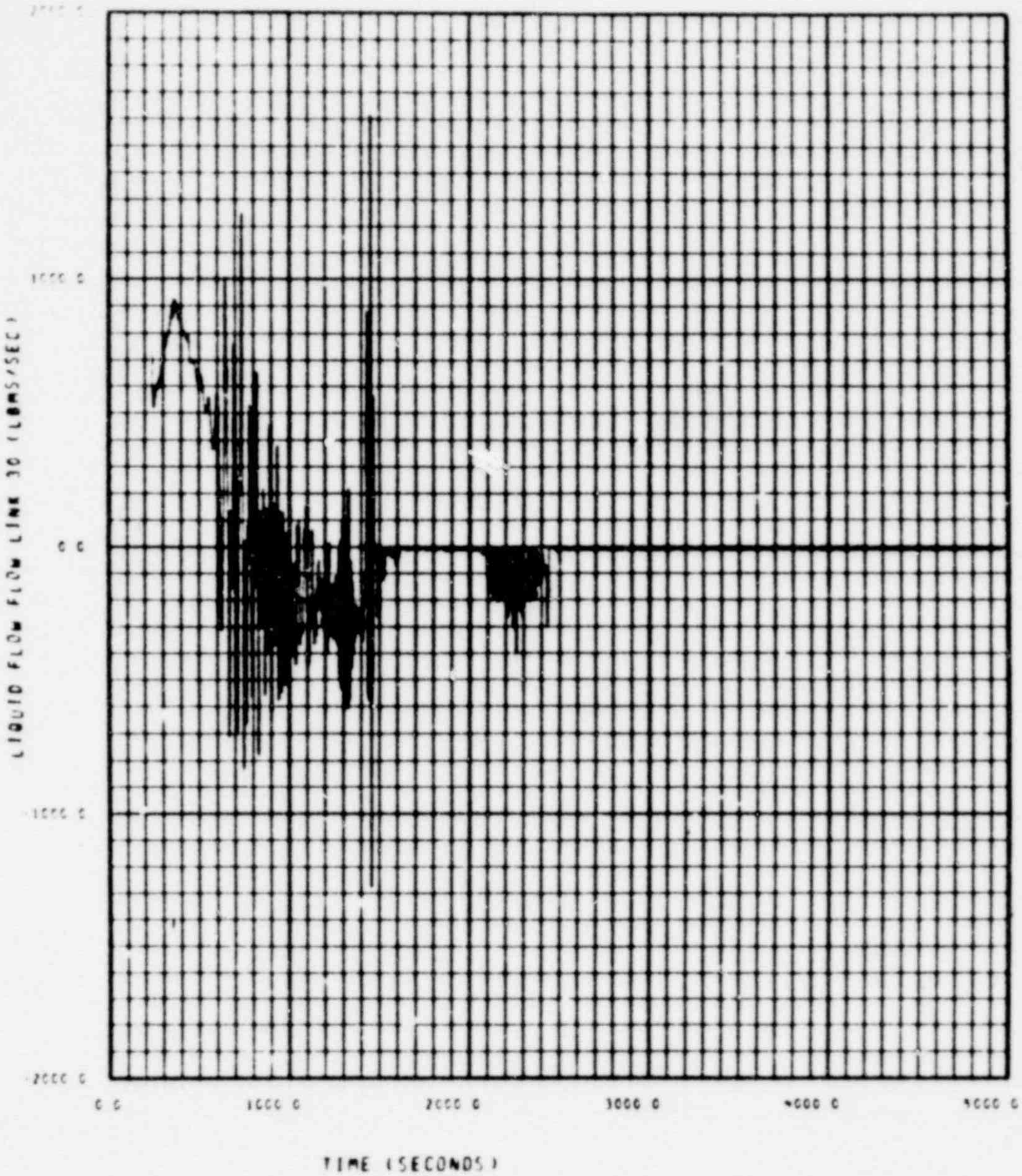


FIGURE 86

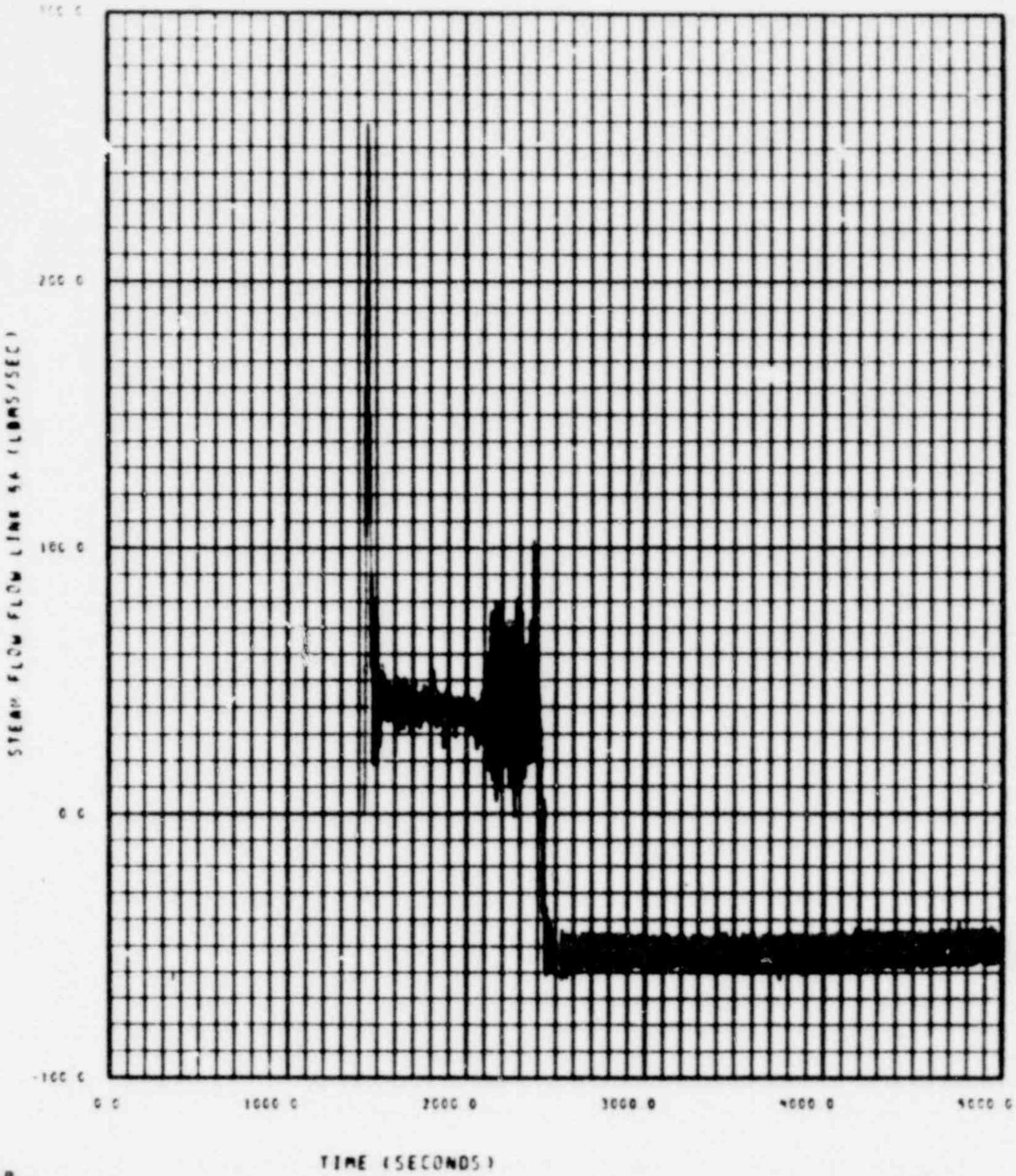
1105 210

POOR ORIGINAL



RESART 2 IN CL WFLASH-NOTRUMP

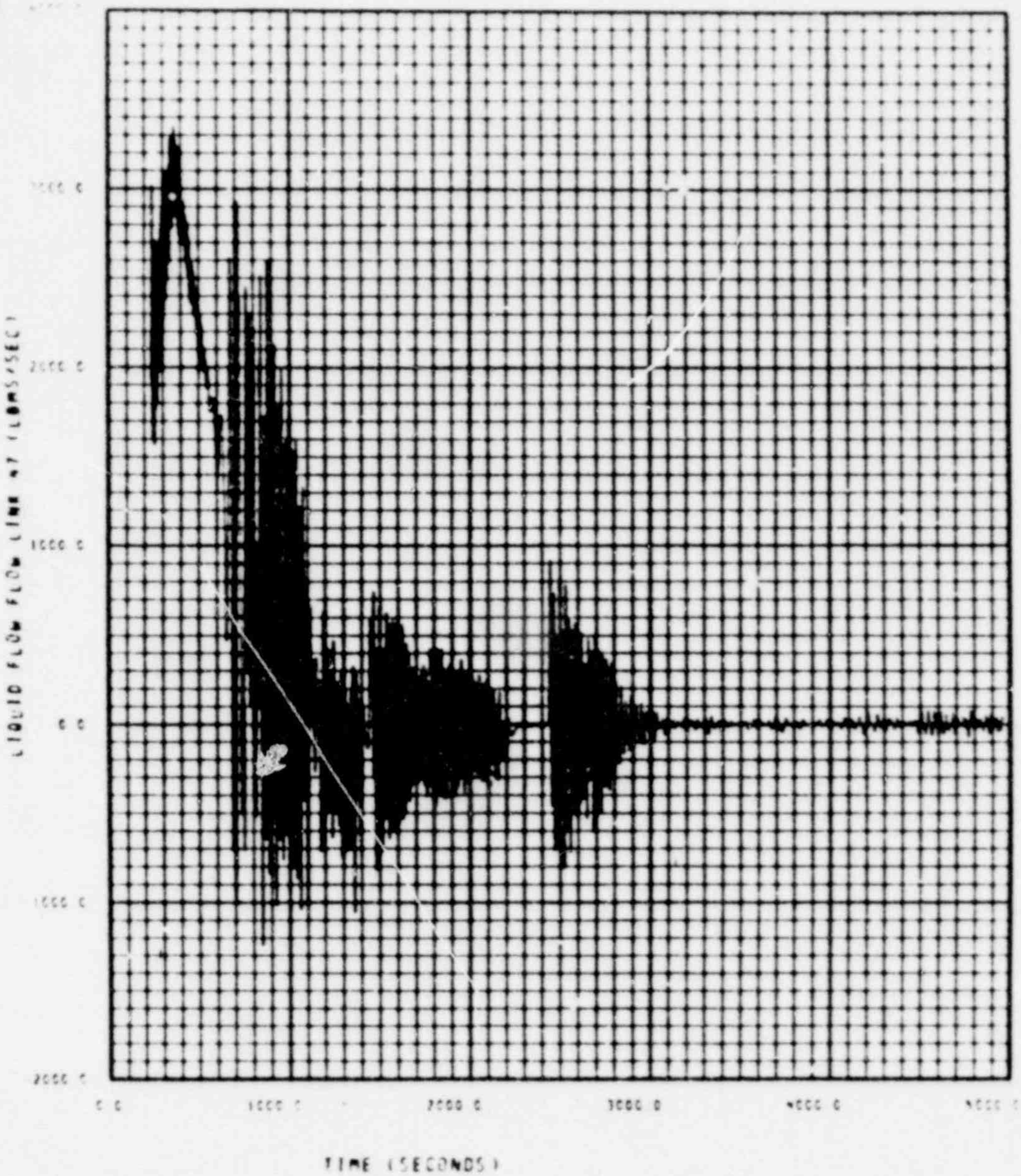
FIGURE 87



RESAR3 2 IN CL WFLASH-NOTRUMP

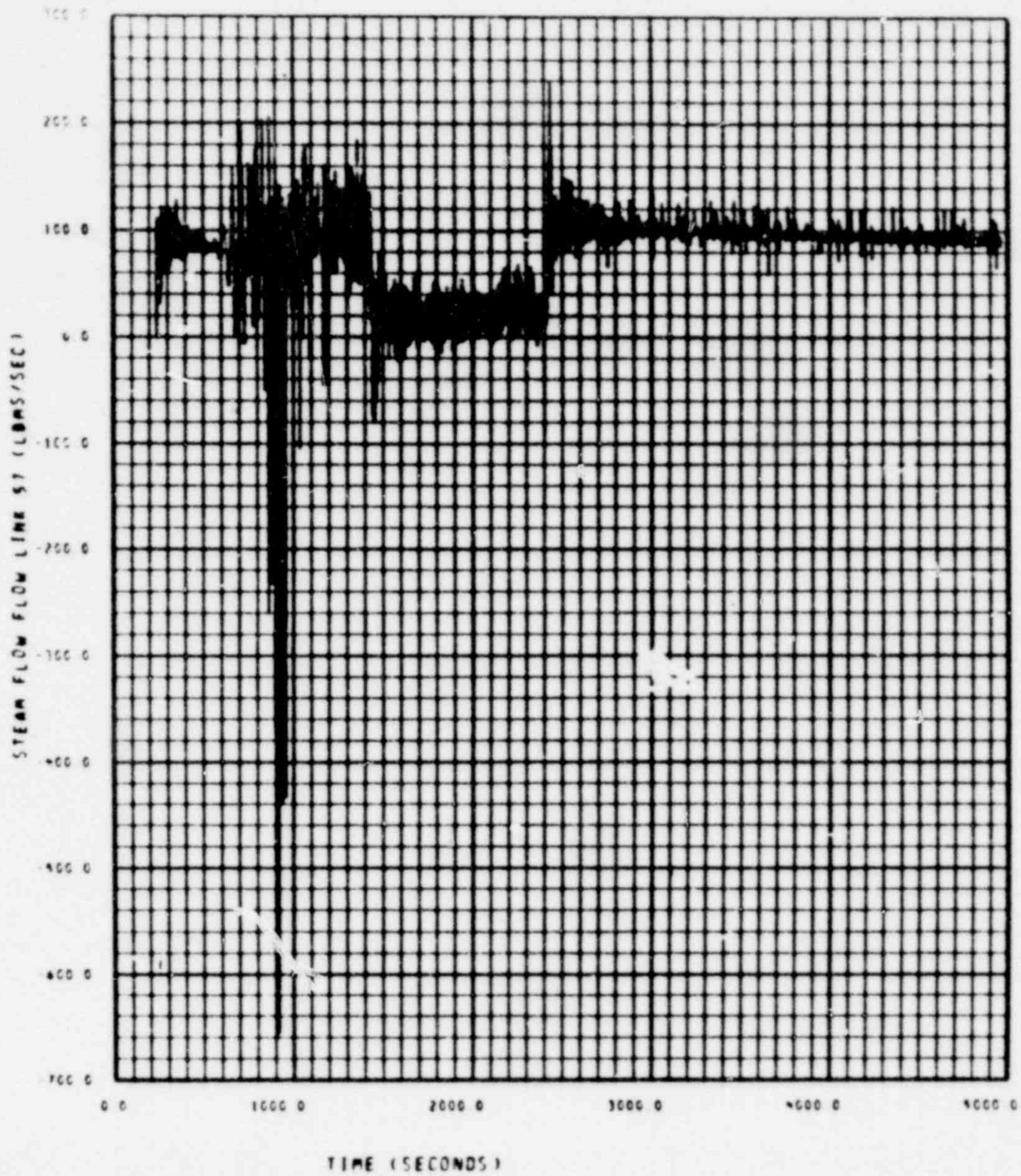
FIGURE 88

1105 212



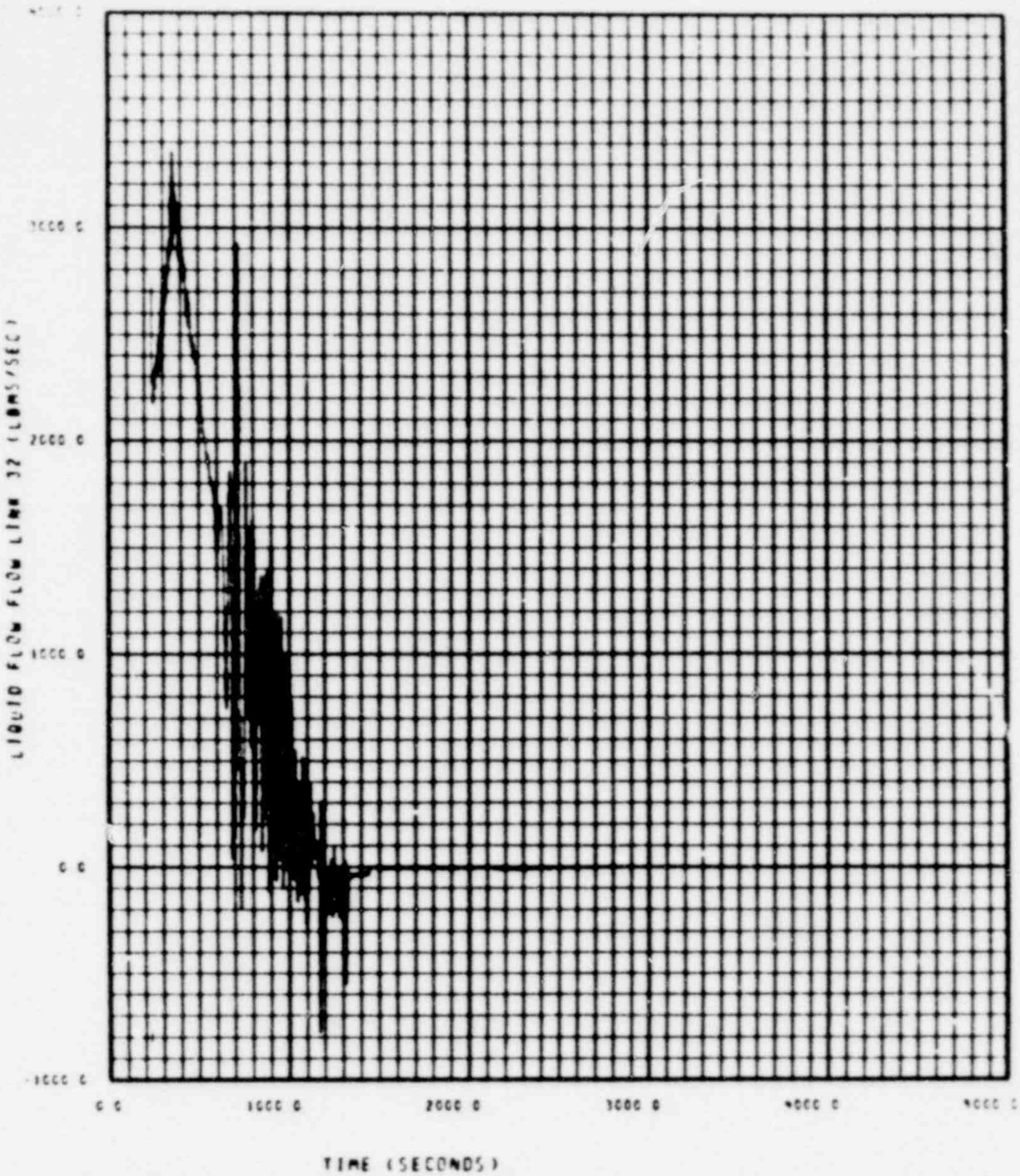
RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 89



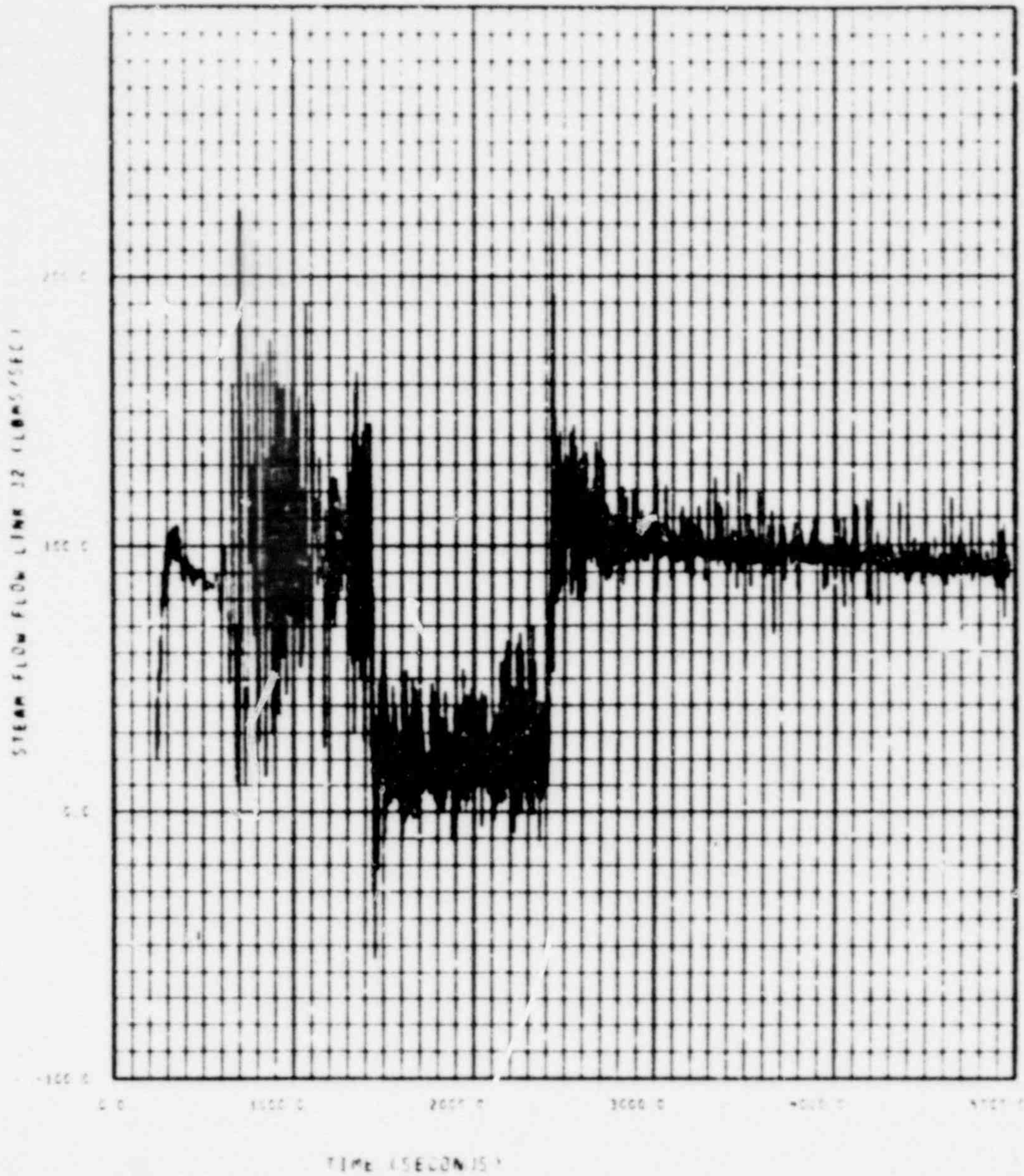
RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 9C



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 91

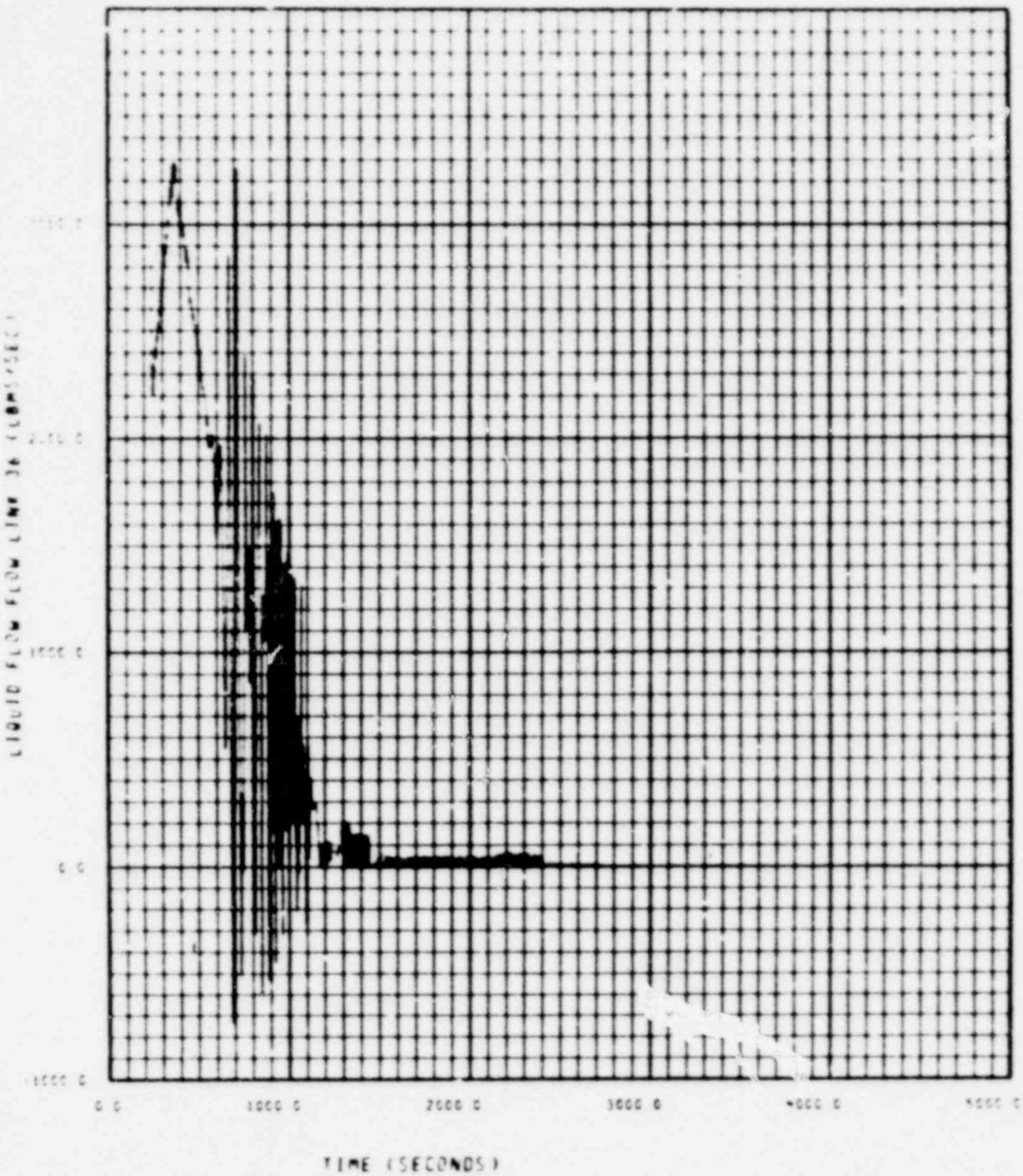


RESAR3 2 IN CL WFLASH-NOTR MP

FIGURE 92

1105 216

POOR ORIGINAL



RELAP3 2 IN CL WFLASH-NOTRUMP

FIGURE 93

1105 217

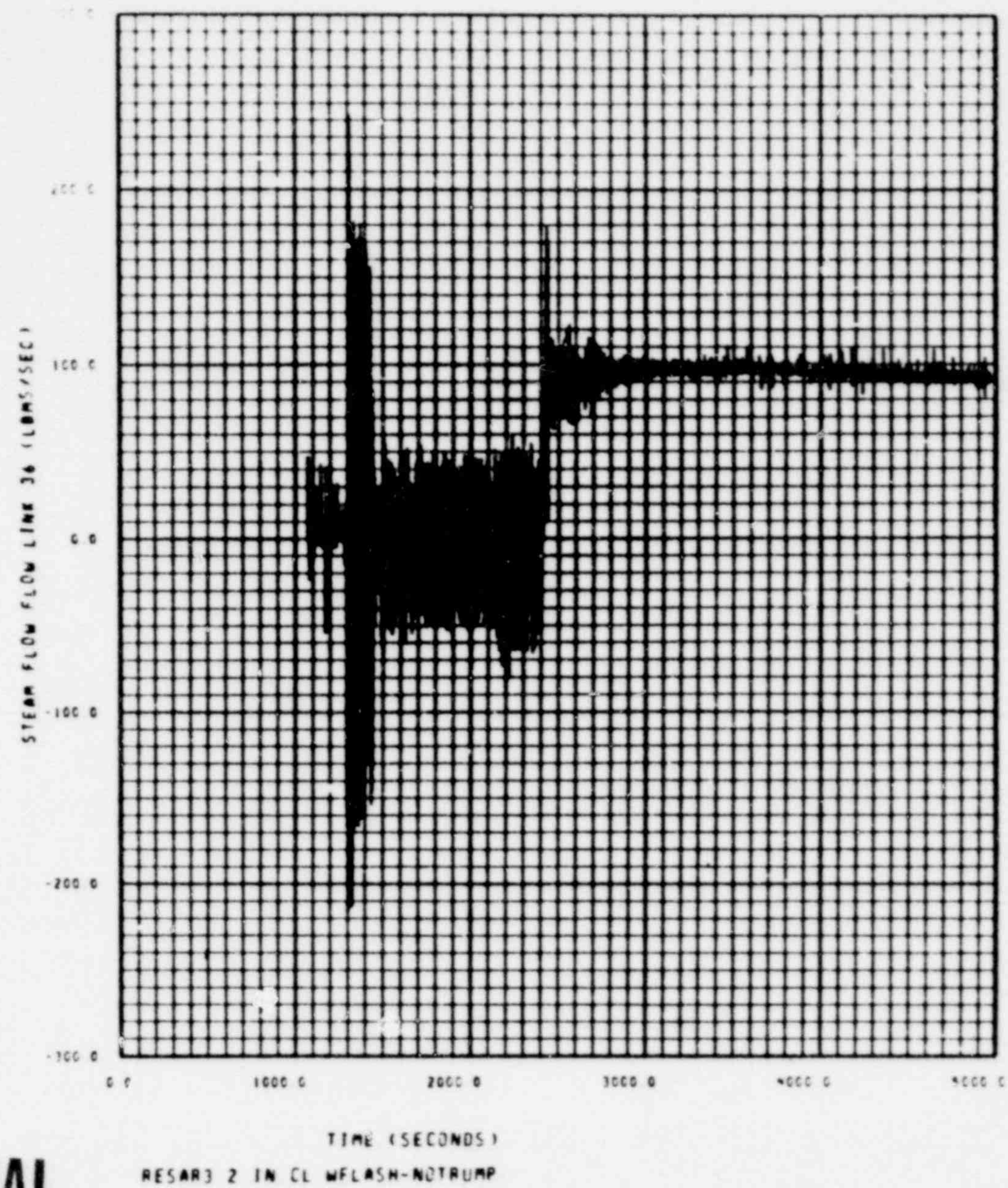
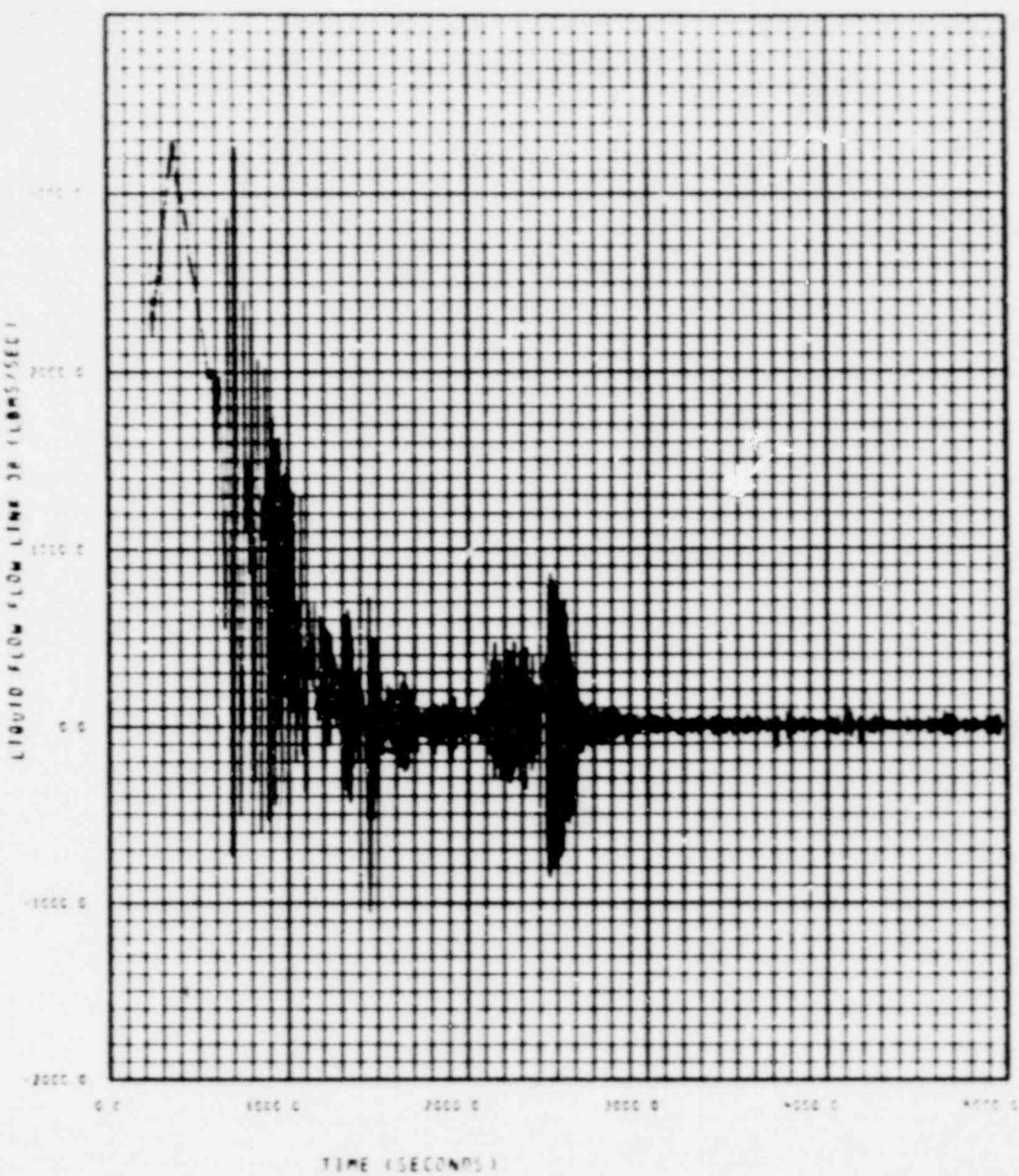


FIGURE 94

1105 218

POOR ORIGINAL

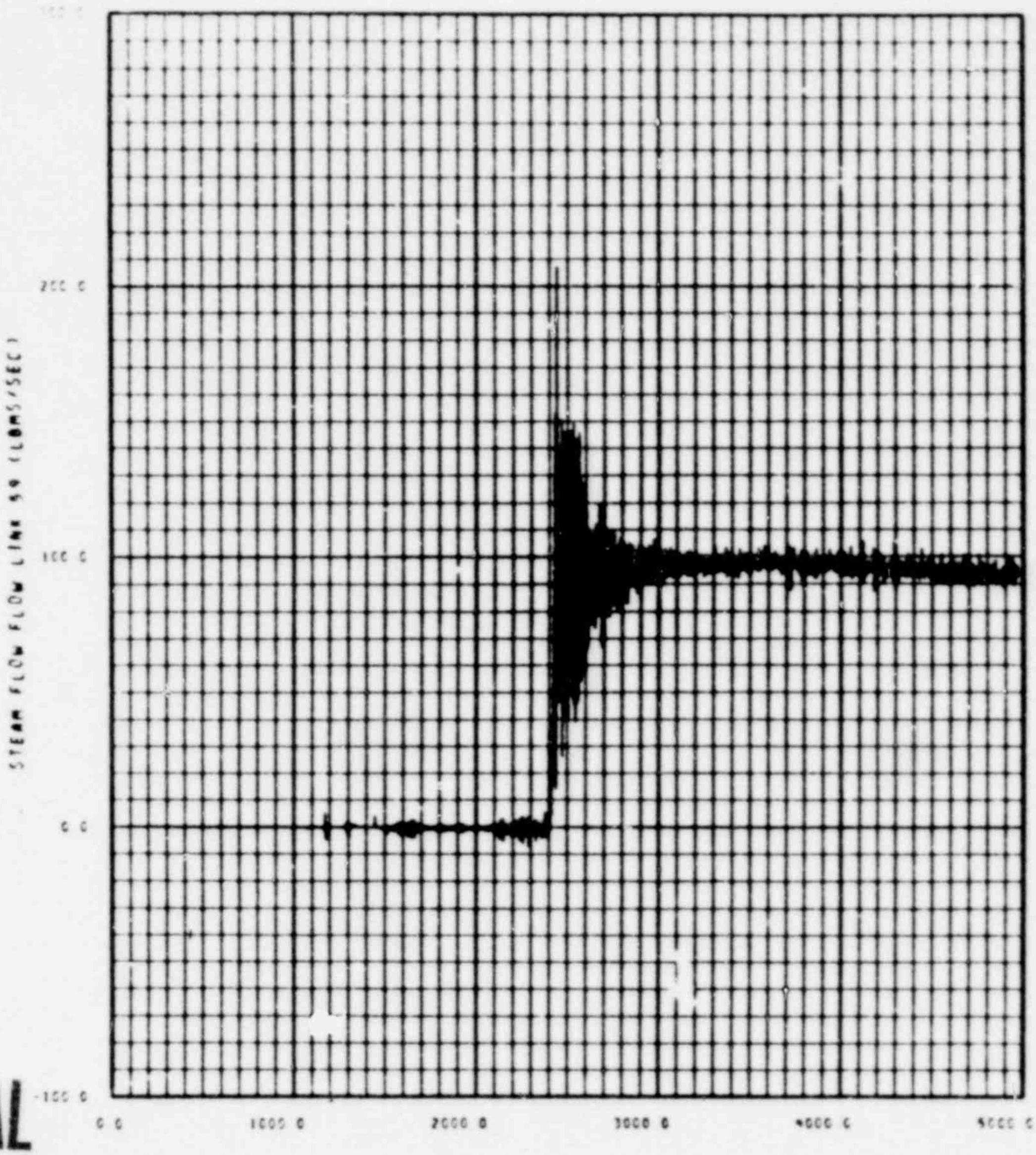


RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 95

1105 219

POOR ORIGINAL



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 96

1105 220

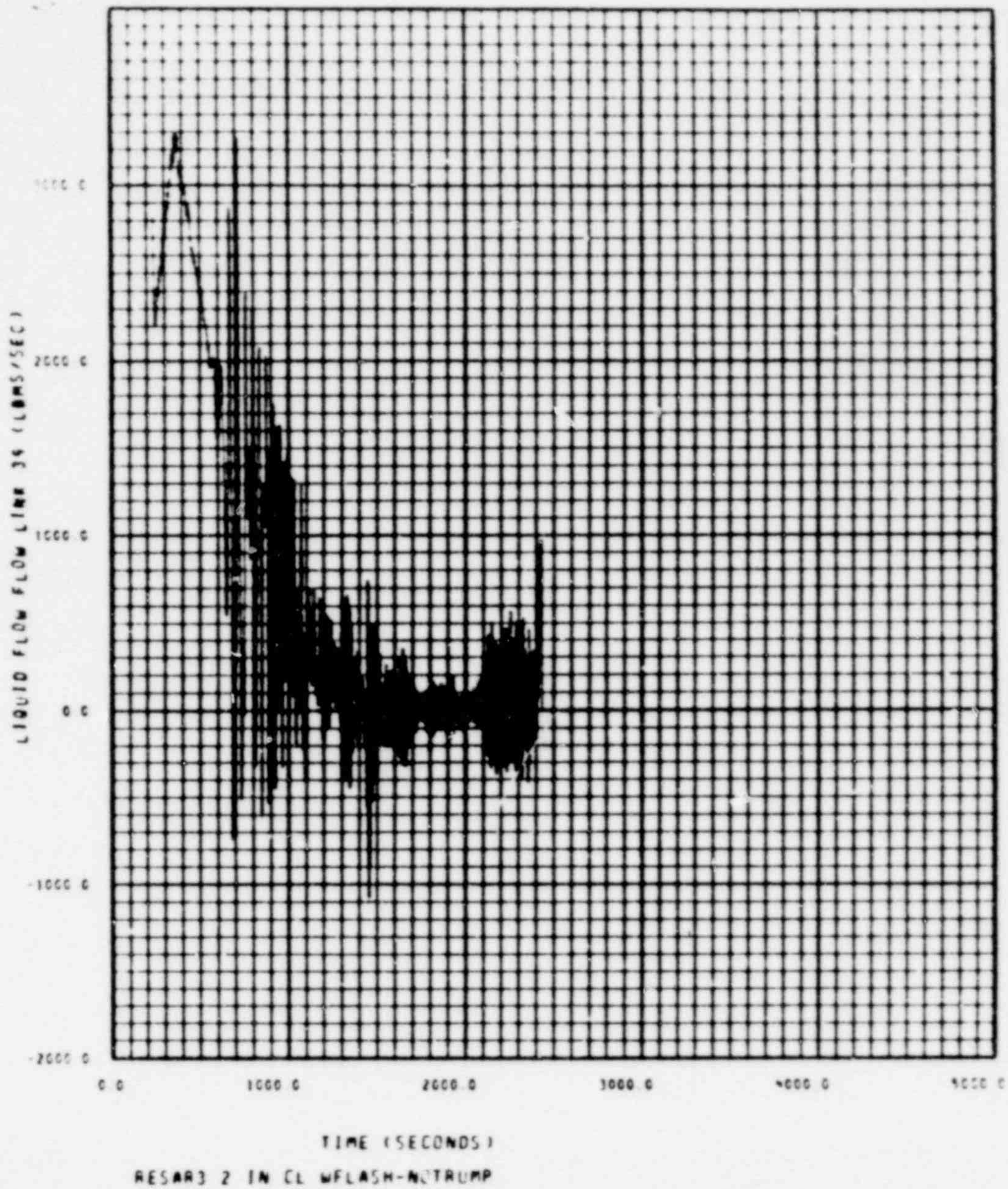
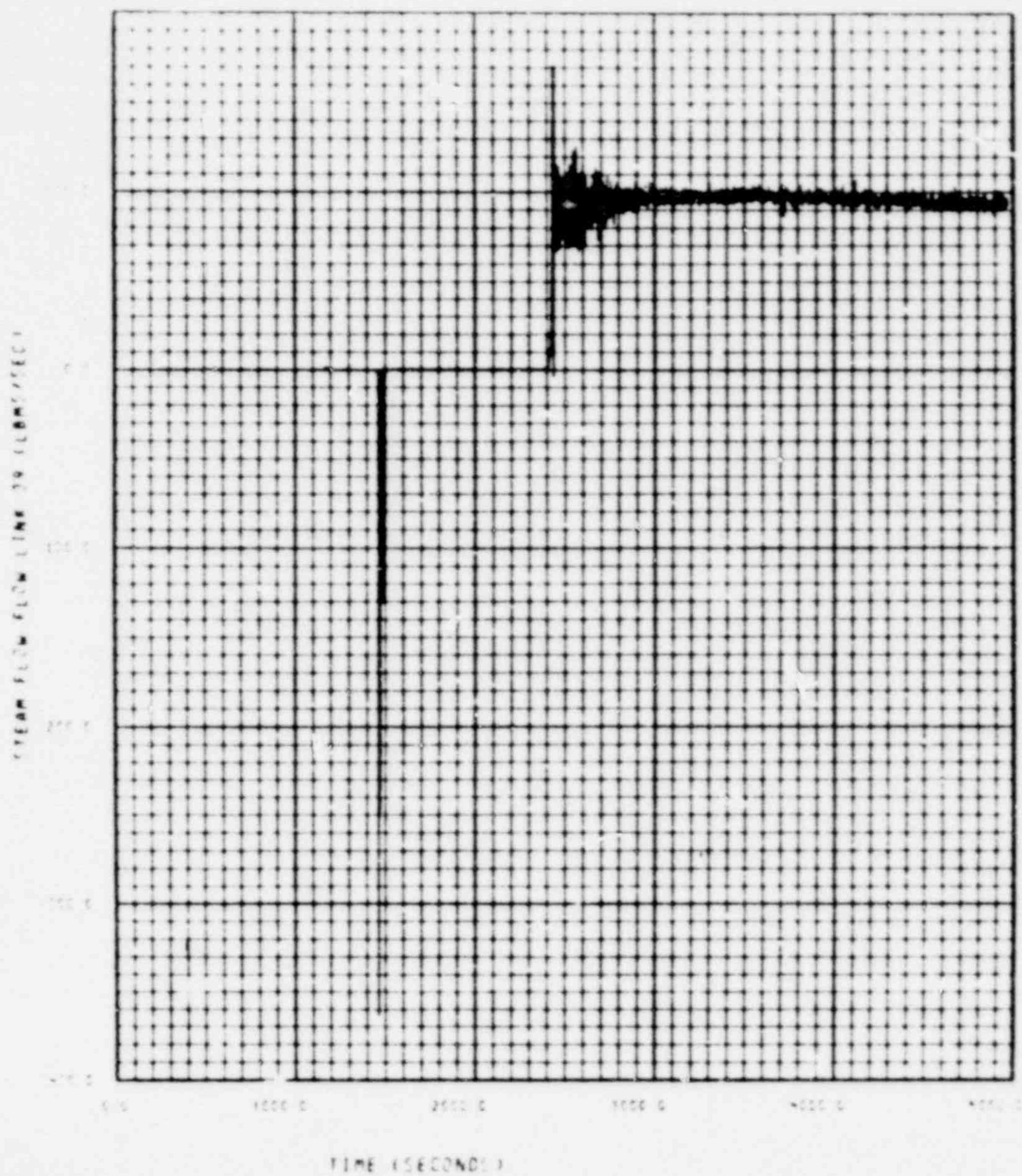


FIGURE 97

1105 221

POOR ORIGINAL

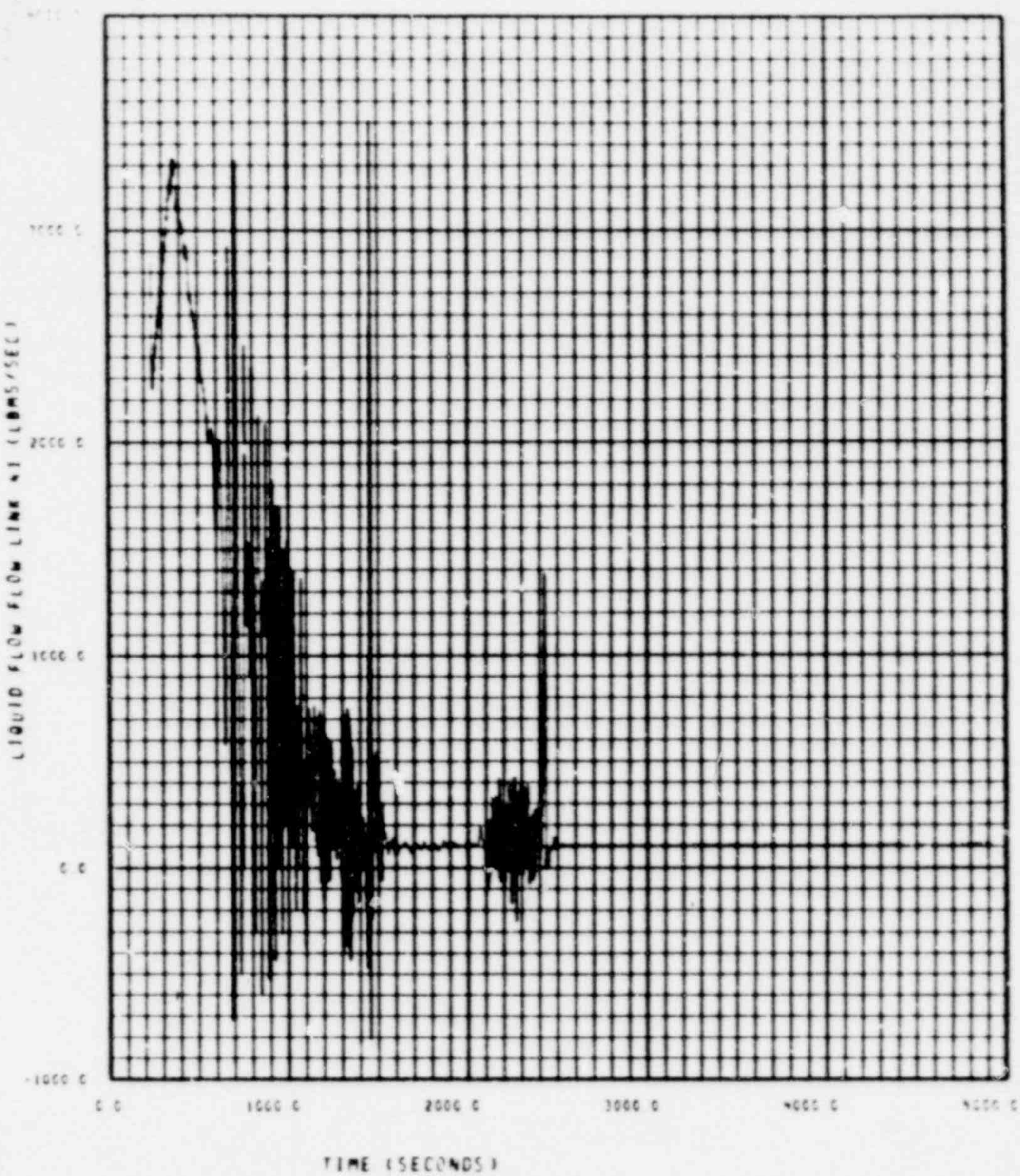


RETARB 2 IN. CL WELASH-NOTRUMP

FIGURE 98

POOR ORIGINAL

1105 222

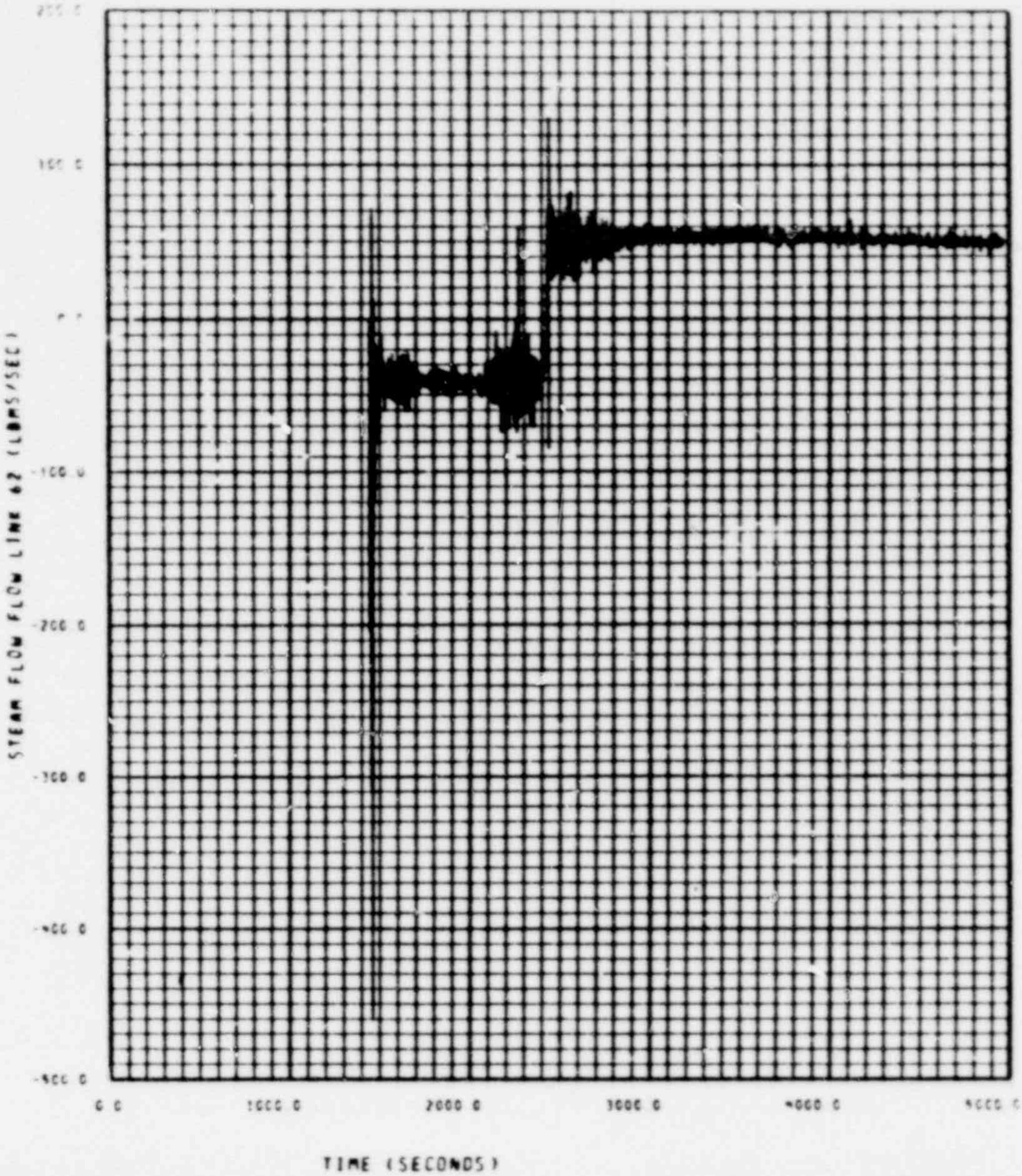


RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 99

1105 223

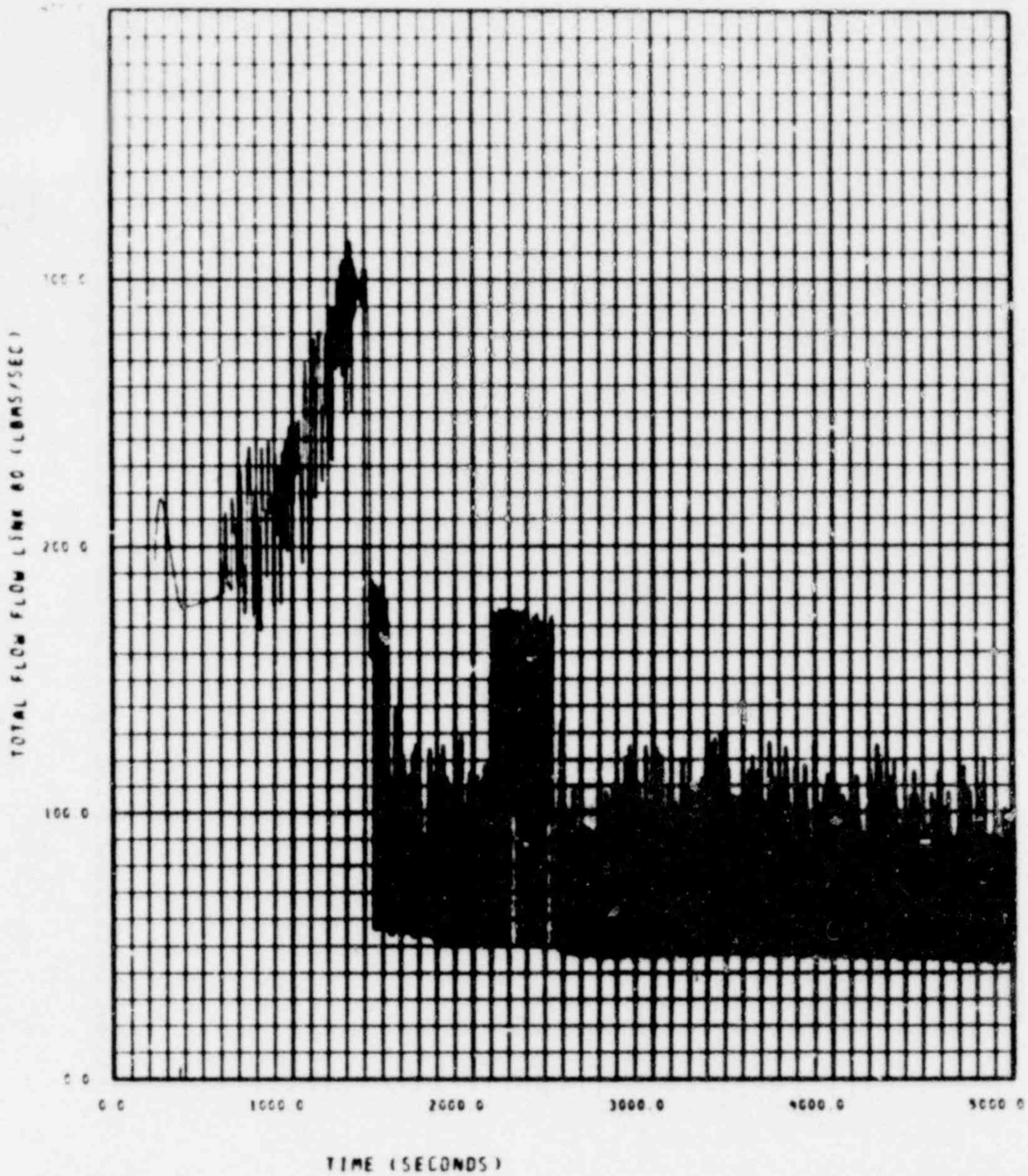
POOR ORIGINAL



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 100

1105 224

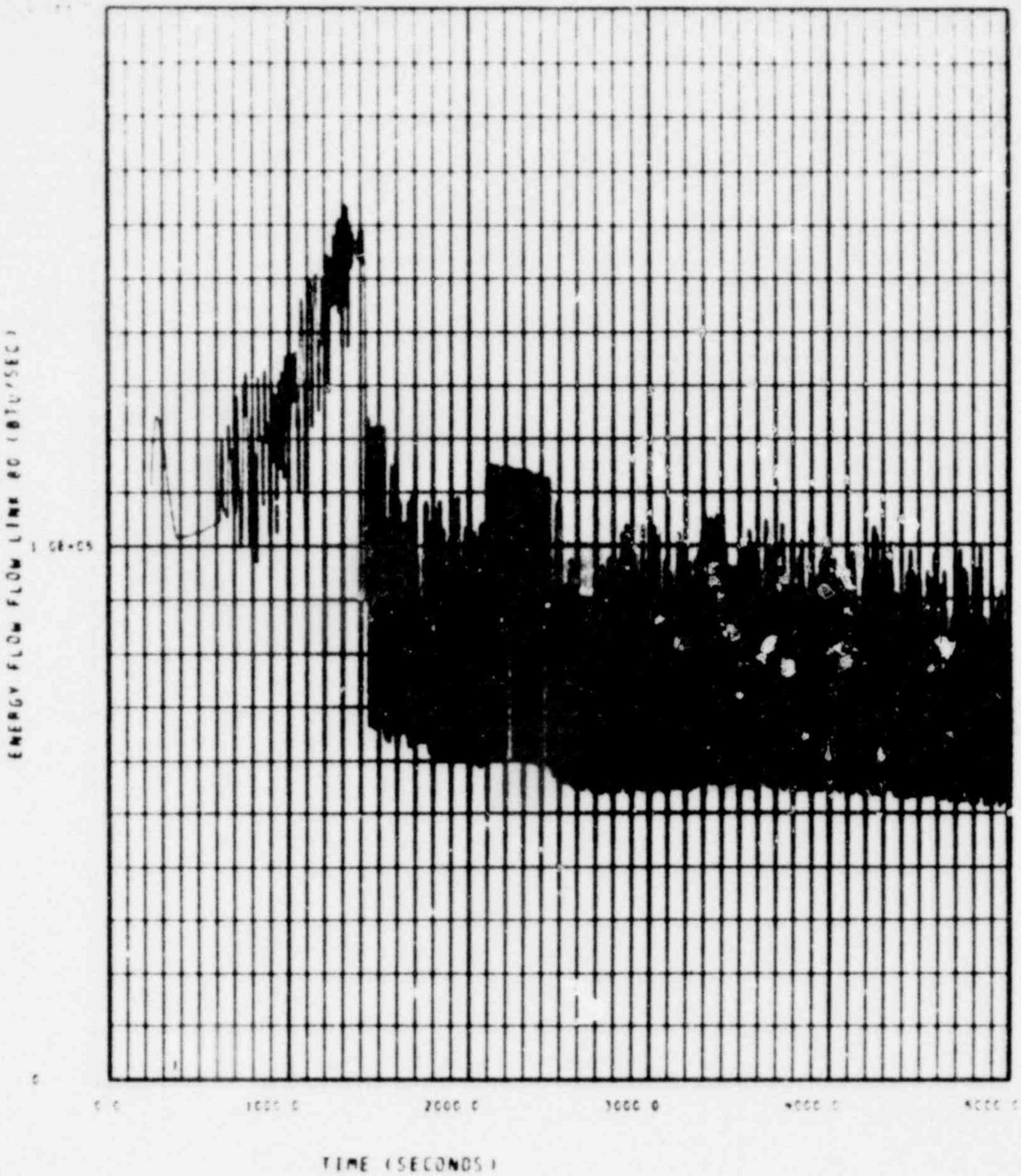


RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 101

POOR ORIGINAL

1105 225



RESAR3 2 IN CL WFLASH-NOTRUMP

FIGURE 102

1105 226

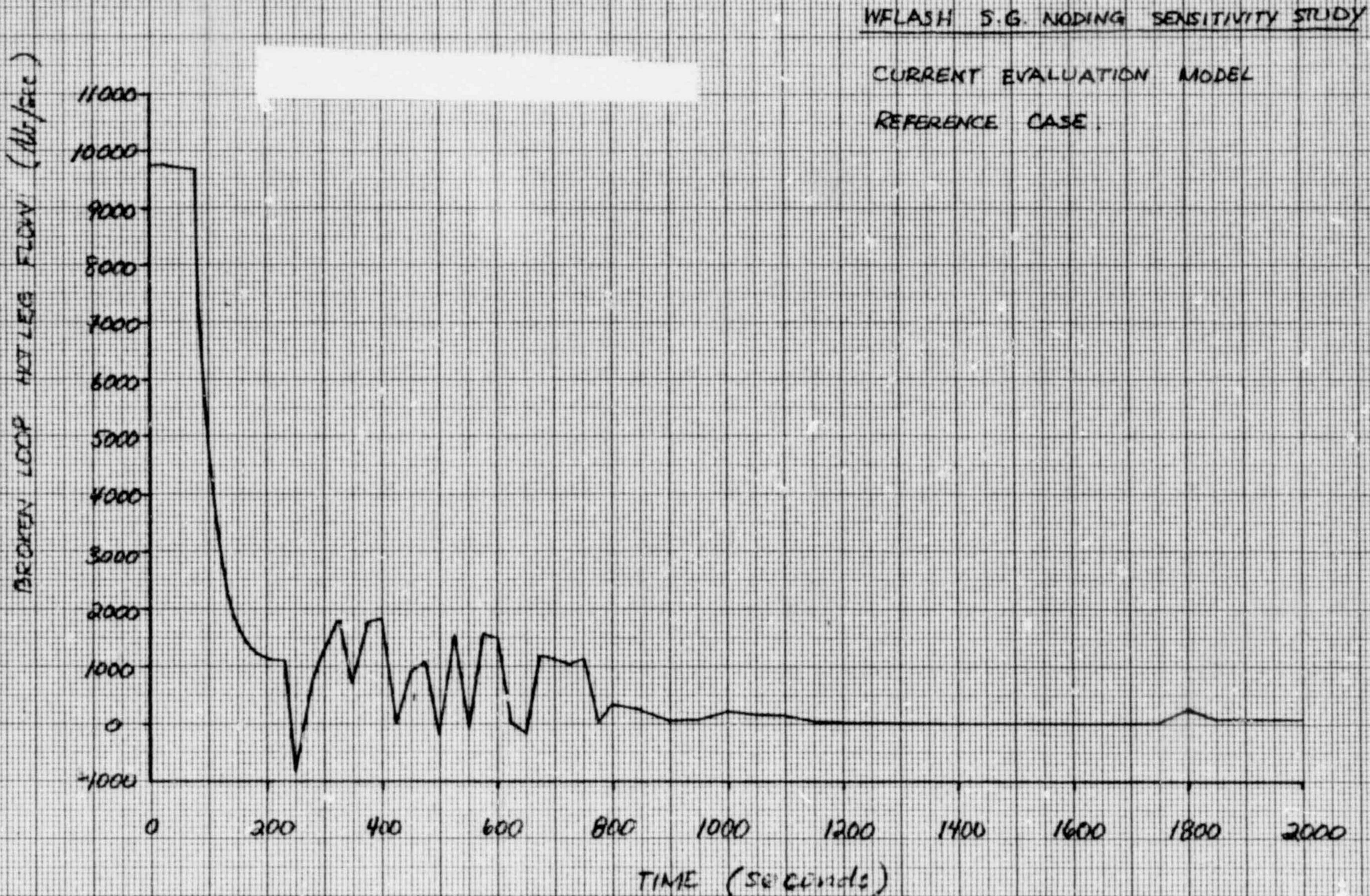

WFLASH S.G. NODING SENSITIVITY STUDY
CURRENT EVALUATION MODEL
REFERENCE CASE.
BROKEN LOOP HOT LEG FLOW (lb/sec)
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
-1000
0
200
400
600
800
1000
1200
1400
1600
1800
2000
TIME (seconds)

FIGURE 103

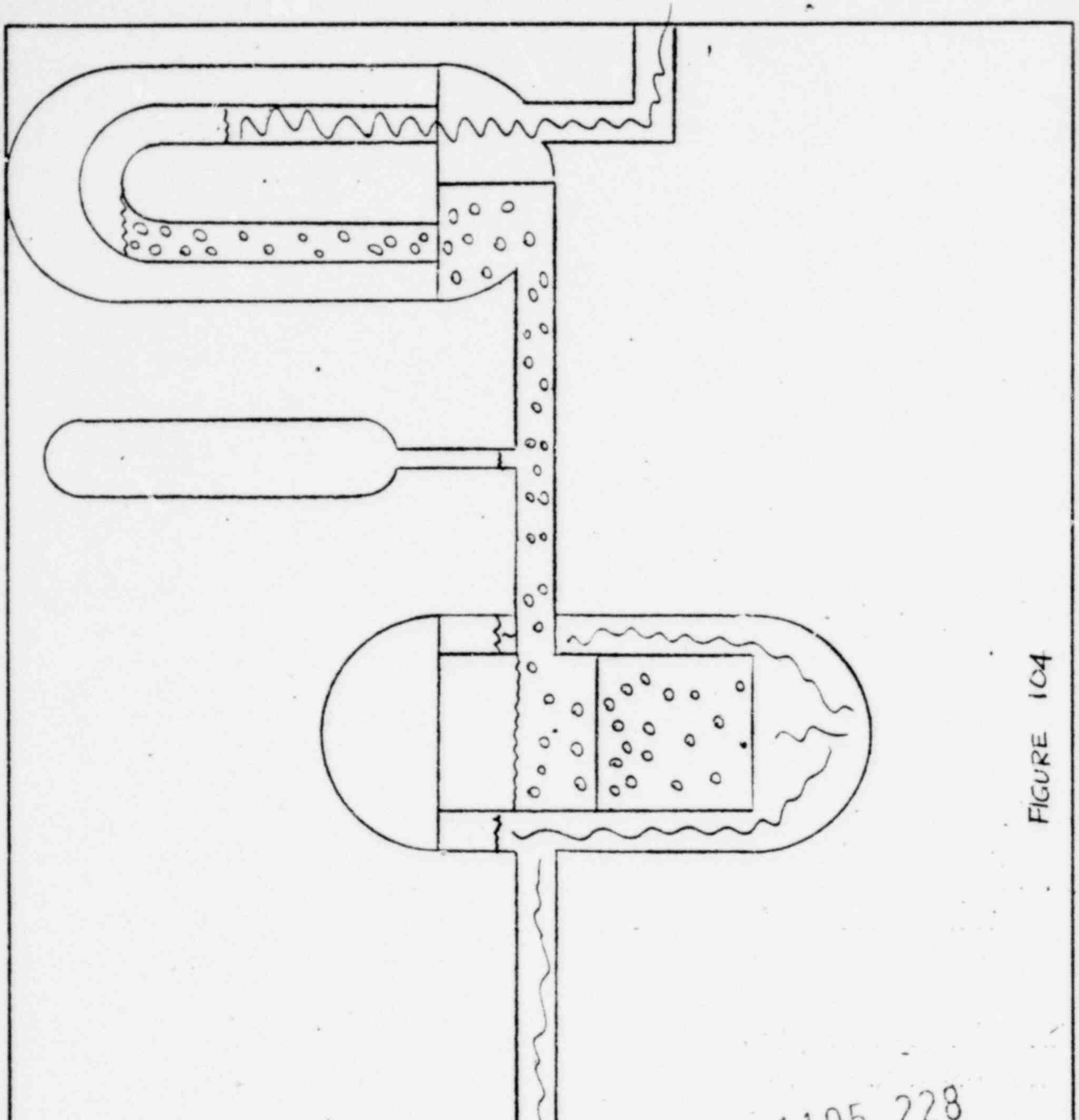


FIGURE 104

1105 228

1105 229