2.3-1

REACTOR PROTECTION SYSTEM TRIP SETTING LIMITS (5)

	Four Reactor Coolant Pumps Operating (Nominal Operating) Power - 100%	Three Reactor Coolant Pumps Operating (Nominal Operating) Power - 100%	One Reactor Coolant Pump Operating in Each Loop (Nominal) Operating Power - 49%)	Shutdown Bypass
1. Nuclear power, max. % of rated power(6)	105.1	105.1	105.1	5.0(2)
2. Nuclear power based on flow (1) and imbalance max. of rated power	1.08 times flow minus reduction due to imbalance	1.08 times flow minus reduction due to imbalance	1.08 times flow minus reduction due to imbalance	Bypassed
3. Nuclear power based (4) on pump monitors max. % of rated power	NA	NA	55%	Bypassed
4. High reactor coolant system pressure, psig max.	2355	2355	2355	1720(3)
5. Low reactor coolant system pressure, psig min.	1900	1900	1900	Bypassed
6. Reactor coolant temp. F., max.	618.8	61[illegible].8	618.8	618.8
7. High Reactor Building pressure, psig max.	4	4	4	4

(1) Reactor coolant system flow, %.
(2) Administratively controlled reduction set during reactor shutdown.
(3) Automatically set when other segments of the RPS (as specified) are bypassed.
(4) The pump monitors also produce a trip on: (a) loss of two reactor coolant pumps in one reactor coolant loop, and (b) loss of one or two reactor coolant pumps during two-pump operation.
(5) Trip settings limits are limits on the setpoint side of the protection system bistable connectors.
(6) During plant startup from 0% to 25% power, this setpoint shall be lowered to 50% Full Power. During plant shutdown, the high flux trip setpoint change to 50% power shall be initiated within 4 hours of reaching a power level at or below 25% full power.

4.7 REACTOR CONTROL ROD SYSTEM TESTS

4.7.1 CONTROL ROD DRIVE SYSTEM FUNCTIONAL TESTS

Applicability

Applies to the surveillance of the control rod system.

Objective

To assure operability of the control rod system.

Specification

4.7.1.1 The control rod trip insertion time shall be measured for each control rod at either full flow or no flow conditions following each refueling outage prior to return to power. The maximum control rod trip insertion time for an operable control rod drive mechanism, except for the axial power shaping rods (APSRs), from the fully withdrawn position to 3/4 insertion (104 inches travel) shall not exceed 1.66* seconds at hot reactor coolant full flow conditions or 1.40 seconds for the hot no flow conditions (Reference 1). For the APSRs it shall be demonstrated that loss of power will not cause rod movement. If the trip insertion time above is not met, the rod shall be declared inoperable.

4.7.1.2 If a control rod is misaligned with its group average by more than an indicated nine inches, the rod shall be declared inoperable and the limits of Specification 3.5.2.2 shall apply. The rod with the greatest misalignment shall be evaluated first. The position of a rod declared inoperable due to misalignment shall not be included in computing the average position of the group for determining the operability of rods with lesser misalignments.

4.7.1.3 If a control rod cannot be exercised, or if it cannot be located with absolute or relative position indications or in or out limit lights, the rod shall be declared to be inoperable.

*For Cycle 10, the maximum safety and regulating control rod trip insertion time for an operable control rod drive mechanism from the fully withdrawn position to 3/4 insertion shall not exceed 3.0 seconds at hot reactor coolant full flow conditions, unless it is demonstrated that all accident analyses meet their event safety limits. Additional control rod testing will be performed at a frequency agreed upon between NRC and Licensee. For Cycle 10, the 1.40 second value for hot no flow conditions is not applicable.

Bases

The control rod trip insertion time is the total elapsed time from power interruption at the control rod drive breakers until the control rod has actuated the 25% withdrawn reference switch during insertion from the fully withdrawn position. The specified trip time is based upon the safety analysis in UFSAR, Chapter 14 and the Accident Parameters as specified therein. The specified trip time of 3.0 seconds for Cycle 10 is based upon reanalysis of these limiting safety analyses at hot reactor coolant full flow conditions.

Each control rod drive mechanism shall be exercised by a movement of at least two inches of travel every two weeks. This requirement shall apply to either a partial or fully withdrawn control rod at reactor operating conditions. Exercising the drive mechanisms in this manner provides assurance of reliability of the mechanisms.

A rod is considered inoperable if it cannot be exercised, if the trip insertion time is greater than the specified allowable time, or if the rod deviates from its group average position by more than nine inches. Conditions for operation with an inoperable rod are specified in Technical Specification 3.5.2.

REFERENCE

(1) UFSAR, Section 3.1.2.4.3 - "Control Rod Drive Mechanism"

Enforcement Discretion
Regarding
TMI-1 Control Rod Trip Insertion Time Testing Criterion

Requirement from Which Relief Is Requested

Relief is requested from the maximum allowable control rod trip insertion time for an operable control rod drive mechanism from the fully withdrawn position to 3/4 insertion of 1.66 seconds at hot reactor coolant full flow conditions, specified in TMI-1 Technical Specification Section 4.7.1.1. Specifically, safety and regulating rod group control rods would be considered operable with an insertion time of 3.0 seconds.

This acceptance criteria for rod insertion time would apply rather than the existing Technical Specification 4.7.1.1 limit of 1.66 seconds from the fully withdrawn position to 3/4 insertion until issuance of a Technical Specification amendment incorporating the revised control rod drop criteria requested in TSCR No. 242.

Event Circumstances and Need For Prompt NRC Action

On March 17, 1994 at 1600, TMI-1 began a plant shutdown to hot shutdown conditions to repair a leak in the pressurizer spray valve (RC-V-1) body to bonnet flange. During this shutdown control rod trip insertion time testing was performed. These tests indicated control rod insertion times in excess of 1.66 seconds for certain rods. The exercising of the rods typically results in improvement in the insertion time and after multiple tests the acceptance criteria has been met except for Rod 1-3. Rod 1-3 is currently testing at 1.81 seconds at hot reactor coolant full flow conditions. Since this insertion time is >1.66 seconds, this rod would be declared inoperable in accordance with existing Technical Specification Section 4.7.1.1.

Although not required by Technical Specifications, this testing was performed because of the slow rod insertion times initially experienced during Technical Specification required surveillance testing in the last refueling outage (10R - October 1993). Control Rods 1-3 (Group 1, Rod 3) 3-6, and 4-5 initially experienced insertion times in the range of 1.72 seconds to 1.83 seconds in the 10R outage testing. Each retest of these three rods in 10R resulted in shorter insertion times to the extent that the final tests fell well within the acceptance criteria. The cause of the initial test failures was likely due to crud buildup in the area of the CRDM thermal barriers and the ball check valves.

This situation occurred as a result of the shutdown of TMI-1 which provided an opportunity to perform additional testing of the control rods which experienced slow insertion times during 10R testing. The proposed control rod insertion time criteria of 3.0 seconds is considered acceptable since the additional analysis to support TSCR No. 242 has determined that with all control rods dropping at 3.0 seconds, the existing safety analyses remain

bounding with an administrative limit of 50% FP when the power level is less than 25% FP.

Prompt NRC action on this matter will allow TMI-1 restart to proceed within the current Technical Specification requirements considering the criteria for an operable control rod. Since Rod 1-3 is testing at 1.81 seconds, which exceeds the current criteria of 1.66 seconds, this rod would be declared inoperable. One inoperable control rod requires entry into Technical Specification Section 3.5.2 action statements. Continued plant shutdown and corrective maintenance on the control rod drive mechanisms at this time adds negligible safety benefit.

Safety Significance of the Enforcement Discretion

Recent testing of control rod insertion times has resulted in the identification of insertion times which are in excess of the expected Technical Specification acceptance criterion for insertion time which is 1.66 seconds to 3/4 inserted. Rod 1-3 is currently testing at 1.81 seconds at hot reactor coolant full flow conditions. All remaining rods have achieved drop times of ≤1.5 seconds. This evaluation determines whether there is any safety significance associated with all safety and regulating control rods having a 3.0 second insertion time for Cycle 10.

The FSAR Chapter 14 analyses assume that a reactor trip results in the insertion of negative reactivity consistent with the 1% shutdown margin Technical Specification, including the most reactive control rod stuck in the fully withdrawn position. The rate of negative reactivity insertion is based on the combination of an assumed rod position vs. time curve and a reactivity worth vs. position curve, both of which are conservative for the core design and control rod design. The rod position vs. time curve includes the effect of the rod drop time. An increase in rod drop time requires evaluation of the existing safety analysis to assure that the margin of safety is not compromised.

A maximum allowable control rod insertion time of 3.0 seconds was evaluated by adjusting the scram curve (negative reactivity insertion versus time) assumed in the affected FSAR accident analyses to reflect the assumption that all control rods insert in 3.0 seconds rather than the current value of 1.66 seconds. This approach applies a 1.34 second delay to the existing FSAR scram curve and is more conservative than redefining the scram curve over a 3 second period.

The accident analyses in Chapter 14 of the TMI-1 FSAR were reviewed to determine the consequences of the accidents with a 1.34 second time delay in scram time. The accident analyses which are limiting in terms of control rod insertion times have been reanalyzed. A review of the remaining FSAR accident analyses determined that these analyses are either not affected by the revised control rod insertion times or remain conservatively bounding for Cycle 10 operation. A detailed discussion of these evaluations is provided in the safety evaluation portion of Enclosure 1 for the proposed Cycle 10 Technical Specification Change.

The results of the above evaluation support the conclusion that a control rod drop time acceptance criterion of 3.0 seconds to 3/4 insertion is acceptable for all safety and regulating control rods, and therefore, there is no safety significance associated with the possibility that a control rod might have a rod drop time longer than the current Technical Specification limit. On this basis, it is requested that Control Rod 1-3 be declared operable.

Compensatory Measures:

The following compensatory measures have been established:

1. All Control Rods have subsequently achieved drop times of ≤1.5 seconds, except for Rod 1-3.

2. A review of design basis accident analyses has confirmed that a control rod drop time acceptance criteria of 3.0 seconds for all safety and regulating control rods is acceptable.

3. As noted in TSCR No. 242 for Cycle 10, additional control rod testing will be performed at a frequency to be agreed upon between NRC and the licensee.

4. During plant startup from 0% to 25% power, this setpoint shall be lowered to 50% Full Power. During plant shutdown, the high flux trip setpoint change to 50% power shall be initiated within 4 hours of reaching a power level at or below 25% full power.

Duration of the Enforcement Discretion (ED)

It is requested that this ED remain in effect until such time as the NRC approves the attached TSCR. Further, we request that the TSCR be processed on an exigent basis to support the plant operation schedule. We anticipate your approval of the TSCR within about 25 days of the date of this letter.

No Significant Hazards Consideration for the Enforcement Discretion

GPUN has concluded that no significant hazards considerations are created by the ED in that:

1. The ED does not involve a significant increase in the probability or consequences of an accident previously evaluated. The revised test acceptance criteria assures the ability of the control rods to mitigate design basis accidents. Specifically the revised acceptance criteria assures the negative reactivity insertion rate maintains the event acceptance criteria of the safety analysis.

2. The ED does not create the possibility of a new or different kind of accident since the revised control rod insertion time test acceptance criteria will not create any failure modes not bounded by previously evaluated accidents.

3. The ED does not involve a reduction in the margin of safety since the revised control rod insertion time test acceptance criteria assures that the negative reactivity insertion rate is sufficient to maintain the margin of safety in the accident analysis. The margin of safety is defined as the margin between the safety limit and fission product barrier failure. Since none of the accident analyses exceed the event safety limit, the margin of safety is not reduced.

Environmental Considerations

The ED has no impact on environmental considerations in that:

1. No significant hazards considerations are involved as shown above,
2. No changes in effluent limits or types are involved, and
3. No increase in the individual or cumulative occupational radiation exposures are involved.

Based on this, the request for revision to the acceptance criteria of control rod insertion time tests meets the criteria given in 10 CFR 51.22 (c)(9) for categorical exclusion from the requirement for an Environmental Impact Statement.

Enclosure 3

Root Cause Evaluation of Slow CRDM Drop Times at TMI Unit 1

1.0 Introduction

Control rod (CR) drop times are verified during startup at each nuclear facility after each refueling outage. These times are required by technical specification to be less than 1.66 seconds from full rod withdrawal to three-fourths rod insertion. Recently, drop times of a few control rod drive mechanisms (CRDMs) at some B&W-designed 177 FA plants have been slower than allowed by the technical specification criterion.

During hot shutdown at Three Mile Island Unit 1 (TMI-1), the CR drop times were measured and found to be greater than the technical specification limits. Some of the CR locations had unusually long (>2.0 seconds) drop times. This evaluation, to determine the most probable root cause considers the effects of primary coolant chemistry control, mechanical aspects (e.g., CRDM alignment, material galling or wear, and fuel assembly bow), and hydraulic aspects on the CRDM drop time.

2.0 Background

CRDM 153 was removed from Oconee 2, Core Location G-7 (a safety group rod) in May 1993 because of a slow drop time. During plant shutdown for Refuel 13 (April 29, 1993), the successive drop times for CRDM 153 were reported to be 1.965, 1.974, and 1.915 seconds, respectively, which exceeded the Tech Spec allowable drop time of 1.66 seconds. When BWNT performed the inspection, significant crud deposition was noted on the thermal barrier. The ball-check valves were stuck closed and could not be moved prior to removal of the crud deposits. The purpose of these ball-check valves is to permit water in-flow through the thermal barrier into the CRDM to replace the volume vacated by the falling leadscrew during a rod drop. These stuck ball-check valves were concluded to be the cause for the slow drop time. BWNT had previously tested the effect on drop time with stuck ball-check valves and identified that this condition would increase the CRDM drop time by 0.40 seconds.

A CRDM from core location H12 (a regulating group rod) at the Oconee Unit 1 plant was also removed and inspected for wear following Cycle 13 (8/91). During plant startup for Cycles 8, 9, 10, 11, 12, and 13 the trip time for this CRDM was reported to be 1.310, 1.324, 1.312, 1.308 1.316, and 1.323 seconds, respectively. When BWNT performed the inspection following Cycle 13, crud deposition was noted to be in the thermal barrier and the ball-check valve balls would not move freely when operated. This CRDM was cleaned and returned to service; its Cycle 14 and 15 trip time was 1.271 and 1.281 seconds, respectively. Thus, the reported trip times decreased after cleaning.

A CRDM from Core Location H12 (a regulating group rod) was also removed from TMI-1 and inspected for wear in 1993 as part of the B.W.O.G. Life Extension Program. At the time of this inpsection, this CRDM was not covered with heavy deposits of crud and the ball-check valves operated freely. The drop times for this CRDM during plant startup after 10R and on 3/17/94 were 1.28 and 1.272 seconds respectively, which are considered to be normal.

BWNT has also been acquiring CR drop times at each of the 177-fuel assembly (FA) plants for the past several years. It has been observed that within the last few cycles, CR drop times have increased at

certain plants. The increase in rod drop times seems to only be associated with the Type A CRDMs at this time.

3.0 Evaluation of TMI-1 Trip Time Data

3.1 Trip and Snubber Analysis

BWNT has developed an analytical model which can be used to predict trip performance of the control rod drive line (CRDL) of a [illegible]-FA reactor operating at various power levels. This model is based on dynamic equations which predict the velocity, acceleration, and time characteristics of the CRDL translating components at varying positions along the control rod stroke.

The input parameters for this analysis include the dry weight of the translating assembly, the net drag and lifting forces which are independent of velocity, and a drag coefficient for the hydraulically induced forces. The weights, drag forces, and drag coefficients which define the trip performance for a normal control rod drive line have been determined empirically from control rod drive line testing performed at specific temperatures and pressures in the reactor operating envelope.

When small changes in CRDL geometry and/or reactor operating conditions occur, the Trip and Snubber Analysis (TASA) can be used to evaluate the effect on reactor trip performance. Analytical methods are normally used to calculate incremental changes in the drag forces and coefficients associated with modified geometry and fluid properties and modifications are made to the input data for the TASA program. The resulting analysis provides an estimate of the control rod drive line trip characteristics.

As the leadscrew is translated into or out of the CRDM, there is a net change in the volume of water which is contained in the CRDM pressure housing. The thermal barrier (see Figures 2 and 3) serves as a flow restrictor for the flow of water which is displaced by the leadscrew. The thermal barrier is equipped with seven parallel passages through which the water flows as the leadscrew is translated. These passages include the four ports for the ball check valves, the annulus between the leadscrew and the thermal barrier guide bushing, and the two passages formed by the threads of the leadscrew. The resulting resistance factor ,K, for the flow across the thermal barrier region is based on a network of seven resistances in parallel.

The change in pressure drop can then be equated to a change in the hydraulic drag coefficient for the CRDM since the pressure drop is proportional to the square of the flow (and leadscrew) velocity.

3.2 TMI-1 Trip Performance

Trip charts taken 3/15/94 to 3/20/94 were provided for three Control Rod Drive Lines on the TMI-1 reactor. Two of these charts (Group 6, rod 4 and Group 5, rod 9) indicated normal trip performance with 3/4 insertion times of approximately 1.24 and 1.43 seconds, respectively. The other drive line, Group 6-rod 5, exhibited slower trip velocity with trip time to 3/4 insertion of 2.18 seconds. The time and distance coordinates of these three charts were read at 10 inch increments of stroke length and curves relating both distance versus time (Figure 4) and velocity versus time were plotted (Figure 5).

Analytical trip models were used to understand the trip behavior of the CRDMS at TMI-1. Utilizing the analytical trip models and past experience, combinations of F_{kms} and C_H were investigated to

determine what parameters best fit the data. F_{loss} is a term representing flow loads and mechanical loads on the leadscrew, i.e., independent of leadscrew velocity. C_H is a hydraulic coefficient which is used in the expression C_H*V^2 to represent the velocity dependent drag. Figure 6 illustrates the effects on the velocity curve versus time for variations in F_{loss} and C_H. It is observed that the most pronounced differentiation is the flattening of the velocity curve with larger C_H values. Figure 7 illustrates theoretical velocity curves superimposed on the data for Group 6, Rods 4 and 5. It should be noted that the F_{loss} terms are identical and only the C_H term has been modified. A second check was a verification that the time to 100 inches insertion were consistent.

The predicted time at 100 inch insertion for Group 6, Rod 4 was 1.22 seconds versus 1.11 measured. The predicted time at 100 inch insertion for Group 6, Rod 5 was 2.02 seconds versus 1.98 measured. It should be noted that the measured times are .135 seconds less than actual to account for unlatch time correction.

The correlation between the field data and the analytical model indicates that the deviation is in the hydraulic term, C_H. Interferences in the drive line path would be most pronounced in the F_{loss} term. Increases in the F_{loss} term would also increase the drop time but the velocity profile would not be flattened as the data for Group 6, Rod 5 indicates.

4.0 Review of the CRDM, Plenum, Control Rod and Fuel Assembly System

This is a summary of a review conducted by BWNT Engineering using the available information related to slow drop times of control rod assemblies (CRAs) at TMI-1 Cycle 10 on 3/17/94.

4.1 CRDM

The following operational and design factors were evaluated for the effect on CR drop times.

1. Crud deposition in CRDM. The effect of crud is reviewed for three effects; the plugging of the thermal barrier check valves, the reduction in clearance between the leadscrew OD and thermal barrier bushing ID, and the clearance between the torque taker piston OD and the torque tube ID. Crud layers form on CRDM components during operation reducing the area of flow passages in the CRDM and increasing the rod drop times.

Thermal Barrier Check Valves

Significant crud deposition has been observed covering the thermal barrier in the field. The ball-check valves on a CRDM from Oconee 2 were stuck in place and could not be moved prior to removal of the crud deposits. These stuck ball-check valves were concluded to be the cause for the slow rod drop time. BWNT had previously tested the effect on drop time with stuck ball-check valves and identified that this condition would increase the CR drop time by 0.40 seconds, with all ball check valves stuck closed.

Clearance between the Leadscrew OD and Thermal Barrier Bushing ID

Significant crud deposition has been observed covering the thermal barrier in the field including crud accumulation on the thermal bushing ID. The clearance between the leadscrew OD and thermal barrier bushing ID is relatively small (0.033 inches) and a crud accumulation in this area can be expected

to decrease the flow area and increase the hydraulic drag. Reduction of this flow area combined with the thermal barrier balls stuck closed can significantly increase control rod drop times.

Clearance in other regions of the CRDM were evaluated. The only other area with relatively small clearance is between the Torque Taker Piston OD and the Torque Tube ID. Significant crud deposition has not been observed covering the torque taker piston OD or torque tube ID in the field. The clearance between the torque taker piston OD and torque tube ID is 0.27 inches. Since the piston is designed to float laterally, this clearance does not contribute to mechanical friction in the CRDL.

2. The effects of wear in the CRDM were evaluated with respect to the effects on trip time. Life testing of CRDMs has shown that wear on CRDMs increases clearances, particularly in the torque tube assembly, and reduces the control rod drop times.

3. Design Changes. There have not been any design changes made to the CRDM internals.

4. Broken Parts. Since the increased drag of the control rod drive line is hydraulically induced, based on the BWNT trip analysis, there is no reason to expect that the CRDM to have broken parts or foreign material.

5. Misalignment With Brazement. Extensive testing of control rod drive lines which were configured at the maximum misalignment at the CRDM/brazement interface have not shown a measurable effect on mechanical drag or trip performance.

6. The operational and maintenance history of TMI CRDMs was reviewed and compared to drop time performance. The following factors were reviewed.

   a. CRDM Gasket Replacement

      Work in 8R, 9R and 10R has completed the gasket replacement in all but 17 mechanisms. 3 of the slow rods have old gaskets and 9 of the slow rods have replaced gaskets.

      There was no apparent affect on control rod drop time from the gasket maintenance performed in recent outages.

   b. Rod Group Movement during Cycle operation.

      Group 7 rods have averaged approximately .9 ft of normal travel per day in Cycles 7 and Cycle 8 and averaged .4 ft of normal daily travel during Cycle 9. Safety Rod Groups are traveling approximately 4 inches each bi-weekly Rod Movement Surveillance which equates to approximately 0.024 ft of travel per operating day. Although there are no travel times recorded for recent cycles, it is also known that Group 6 will normally have more travel than all other groups with the exception of Group 7.

      Since Rods in Group 7 have not shown an increase in average drop time since the beginning of the cycle and half the Group 6 rods have shown no significant drop time increase. It follows that rod movement may slow or prevent the mechanism that is causing slow drop times.

Moving the rods may flush the mechanisms of CRUD or simply improve local chemistry of the fluid in the mechanism.

c. Vented CRDMs during Startups.

All CRDMs were vented during initial cycle Heatup and then a second vent is performed with the center mechanism and one from each quadrant of the core. No data correlation can be made from the CRDM venting configuration with regard to drop times.

d. Repeated Rod Drops

The execution of repeated rod drops appears to loosen the crud leading to improved drop times. Eventually the action frees the ball check valves in the thermal barrier. This results in an apparent step reduction in rod drop time. This effect is illustrated in the plots of rod drop times for sequential drops attached in Figures 8, 9 and 10.

4.2 Plenum (Brazement and CRA Guide Tubes)

The brazement provides a guide path for the control rods as they are withdrawn from the fuel assembly. The configuration incorporates an array of guide tube (C-tubes and split tubes), which are supported by a series of spacer plates located along its length. Some of the reactor coolant (approx. 40%) flows along the axis of the brazement and provides a scrubbing effect which minimizes the quantity of particulate and foreign material which accumulates in the control rod guide path. Consequently, the control rods are not expected to exhibit high mechanical drag characteristics which would inhibit the trip performance of the CRDL.

Although the brazements have been in service since the initial start-up of TMI-1, recent visual examinations have not revealed any evidence of wear in the C-tubes and split tubes which would introduce an increase in mechanical drag. In addition, there have not been any design changes made to the brazements since they were initially installed in the reactor.

Since the clearances between the control rod and the brazement guide tubes are large (.060 diametral clearance), the likelihood of control rod rubbing on the guide tubes is minimal.

The misalignment between the fuel assembly guide tubes and the brazement guide tubes has been maintained within the limits of the diametral clearance between the control rods and the brazement guide tubes. Extensive testing of control rod drive lines which were configured at the maximum misalignment at the brazement/fuel assembly interface have not shown a measurable effect on mechanical drag or trip performance.

Since the mechanical drag of the control rod drive line appears to be normal, there is no reason to expect that the brazement has shifted laterally due to a breakage of parts used to secure it to the upper grid.

4.3 Fuel Assembly and Control Rod

This is the summary of a review conducted by Fuel Engineering on some factors which may be related to slow drop times of control rod assemblies (CRAs) at TMI-1 Cycle 10. Figure 1 gives the location of control rods which had slow drop times. Table 1 gives

FA designs, CRA exposure and BOC and EOC burnups for the CRA locations which have times.

Fuel Assembly Factors:

These operational and design factors were evaluated for the effect on CR drop times. These are:

1. Fuel assembly bow. As the fuel assembly burnup increases, the fuel assembly irradiation growth increases. Along with the irradiation growth, the fuel assembly bow increases. Fuel assembly bow is related to fuel assembly growth. The slow drop times do not appear to be related to any of the factors that influence fuel assembly bow.

   The largest fuel assembly bow appears to be related to operation on the core periphery where the fast flux gradient is steep across the fuel assembly. This results in uneven growth of the guide tubes and bows the assembly. A review of the shuffle pattern (Ref 17) shows no relation between previous peripheral operation and slow drop times. The current operational locations which show problems are closer to the core periphery. However these locations are far enough from the periphery that no large flux gradient across the fuel assembly would occur. In addition, the problem is largely on one side of the core. The symmetry of the core is such that bow problems should be nearly identical from one side to the other side of the core. No such relationship is observed.

2. Crud deposition in fuel assembly. The effect of crud deposits was reviewed for two effects; the reduction in clearance between the control rod (CR) and guide tube (GT), and the second is plugging of the GT flow holes. Nominal diametral clearance between the GT ID and the CR is 0.057 inches. Crud layers form on core components during operation. There are no measurements available on crud deposits on GTs. However, GTs and spacer grids are similar in that they are non-heated components at equilibrium thermal conditions with coolant flow. Measurements of oxide thickness (which measures both crud and oxide) on spacer grids show a maximum thickness of 38 μm (1.5 mils). It is estimated that the oxide should be in the range of 10 to 20 μm. Therefore the crud thickness is in the range of 18 to 28 μm. Heated components such as fuel rods have thinner crud thicknesses in the range of 3 to 6 μm. Assuming a crud deposit of 28 μm on both GT ID and CR OD, and an oxide thickness of 20 μm on the GT ID, a reduction in flow area of 8.8 % would result. This flow area would not have a significant impact on drop times.

   In the Mark-B8V FA design, there are 6 holes near the bottom of each guide tube for cooling flow. Each hole is 0.191 inches in diameter. In the Mark-B9 and B10 FA designs there are 2 holes in the same area for cooling flow. The size of those holes is 0.141 inches in diameter. The Mark-B8V has flow holes of 0.1719 in^2 flow area. The Mark-B9 and B10 have flow holes of 0.0312 in^2 flow area. This is a reduction of 81.9%. Analyses of trip times for Mark-B9 and B10 FAs shows that this reduction results in an increase of 0.16 seconds in the trip time to 3/4 insertion. It is unlikely that all 96 (6 x 16) flow holes in the Mark-B8V FA could be plugged to that degree.

3. Fuel assembly life. All of the CRAs are in first or second burn fuel assemblies. The locations showing the largest problems are in batch 11C fuel assemblies. The peripheral core locations are showing the most problems, however interior locations have the highest burnups.

4. Wear on fuel assembly and control rods. Wear marks could provide additional drag or hangup depending on the geometry of the wear mark. A review of the problem locations and a comparison with the non problem locations shows no evidence of a wear related problem. All of the CRAs with slow SCRAM times are of the extended life design (ELCRA). These are clad with Alloy 625 which has shown much less wear than Type 304 stainless steel clad control rods in high wear plants (Catawba). These were fresh or had one cycle of exposure at the start of Cycle 10.

5. Design Changes. The design changes that were made going from the Mark-B8V fuel assembly to the Mark-B9 fuel assembly were the fixturing of the upper and lower end spacer grids and a reduction in the size of the flow holes in the guide tubes. All of the problem locations have the Mark-B8V with the larger flow holes. There were no changes in the Mark-B8V FA design which would effect FA/CRA performance.

6. Interface with control rod. The interface between the CRA and FA are unchanged for cycle 10 from previous cycles at TMI-1 and at other Mark-B 177FA plants.

7. Debris. The effect of debris on CRA drop times could result in an increase of drop time if the debris became trapped between the guide tube ID and the CR OD. This is unlikely as the path into the guide tube for flow would not readily permit debris to enter through the flow holes near the bottom of the guide tube. The flow holes are on the side on the guide tube. There is no path through the bottom end plug. In plants and cycles with extensive debris where fuel failures have occurred, no problems with the CRA drop times have been reported.

Control Rods Factors:

1. Crud deposition. The effect of crud deposition would be to reduce the clearance between the GT ID and the CR OD. The amount of crud expected to be deposited would have only a minimal impact of the flow areas. No effect of crud deposits on the coefficient of friction μ for pull forces in FA reconstitution have been observed. Therefore, no additional drag is expected due to crud deposits. In the brazement no problems with hydraulic drag are expected as the C tubes and split tubes are open by the presence of the slits and perforations. The slits allow for passage of the spider arms. It is possible that accumulation of crud in the brazement might result in drag on the CRA during a rod drop. However, the evaluation of the TMI-1 rod drops did not show evidence of increased drag.

2. Control rod life. All of the effected locations have CRAs that are fresh, or have one cycle exposure with the start of cycle 10. In cycle 10, 48 new ELCRAs were introduced. In cycle 9, 4 ELCRAs were introduced. Therefore most of the CRAs in core are new. The ELCRA design was first introduced into Oconee 3 Cycle 8 in May 1984. It has now seen service in all operating B&W Mark-B 177 FA plants.

5.0 Coolant Chemistry Considerations

5.1 Background

The role of primary coolant chemistry on crud precipitation and deposition both in the core region and other areas of the reactor coolant system (RCS) has been extensively studied. Corrosion products generally consist of nickel-substituted spinels of

magnetite ($Ni_xFe_{3-x}O_4$). Analysis of crud samples from the Oconee CRDM inspections have this type of composition. In general, the pH level determines the solubility of corrosion products (crud). The crud solubility is also a strong function of the water temperature and the type of spinel that precipitates. A pH of 6.9 or greater results in less production of corrosion products.

5.2 Considerations for TMI-1

As stated above, the role of primary coolant chemistry on crud precipitation, deposition, and transport is a complicated phenomenon with many variables to consider. Several of the important variables that require evaluation are as follows:

A. Temperature
B. Time
C. Lithium and boron concentrations
D. Location
E. RCS filtration
F. Surface roughness
G. Fluid velocity

The primary coolant chemistry data at TMI-1 during the last two cycles of operation have been reviewed. Due to extended cycles, initial boron concentration at TMI-1 has been higher for Cycle 9 and 10. With a fixed upper limit of 2.2 ppm lithium, the pH at the beginning of Cycle 9 and 10 was lower than 6.9. This condition could have lead to increased corrosion product production. The observations seen on CRDMs removed and inspected by BWNT provided in Section 2.0 above suggest that both crud buildup and probably individual CRDM operating history could be factors in the slow drop times.

6.0 Conclusions

The evaluation of the 3/17/94 control rod drop time strip charts from TMI-1 using the BWNT analytical model for predicting control rod drop times indicates that the slow drop times are most probably hydraulically induced. An evaluation of the CRDM, plenum, control rod and fuel assembly system revealed that the CRDM thermal barrier area is the only place in the system considered to be capable of creating the sufficient hydraulic drag to produce the slow drop times experienced at TMI-1. Thermal barrier balls stuck closed in combination with reduced clearance between the leadscrew OD and thermal barrier bushing ID can be expected to provide the required hydraulic drag increase. The behavior of the control rod drop times shows two effects. In many of the rods, initial drops show small improvements followed by a sharp decrease of approximately .4 to .5 seconds. This indicates improvement of hydraulic resistance followed by freeing of the thermal barrier balls. The observations of crud seen on CRDM thermal barriers removed from operating plants and inspected by BWNT suggest that crud buildup is the primary factor in the slow drop times seen.

7.0 Recommendations

1. Trip the CRDMs with slow drop times until they fall within the technical specification criterion. If one or more CRDMs do not appear to be improving in rod drop time, then consider the safety aspects of allowing these to remain above the technical specification limits.

2. Maintain the pH levels at 6.9-7.3. Early in the cycle life when this is not possible, maintain a lithium concentration at the maximum recommended by BWFC within normal Li concentration control band.

3. Initiate a surveillance program to verify the CRDM drop times. Initially, the drop times should be obtained within four months after reactor startup. Additional intervals can be recommended following the initial testing based on the results.

4. Exercise each CRDM periodically during fuel cycle.

8.0 References

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2. BWNT Doc. No. 51-1217950-00, Inspection Report - CRDM No. 153 (Oconee 2).

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5. 51-1224712-00 Extended Life CRA Precharacterization, M.A. Gilliam, 6-30-93.

6. 51-1228110-00 TMI-1 Cy 10 Mech Design Infor, M.A. Gilliam, 12-15-93.

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12. Jones, R.H., "Some Radiation Damage Stress Corrosion Synergisms in Austenitic Stainless Steel", Proceedings of the Second International Symposium on Environmental Degradation of Materials in Nuclear Power Reactors, Monterey, California, September 9-12, 1985, pp. 173-180.

13. Fukuya, K., et.al., "Grain Boundary Segregation of Impurity Atoms in Irradiated Austenitic Stainless Steel", Third International Symposium On Environmental Degradation of Materials in Nuclear Power Systems-Water Reactors, Traverse City, Mi, August 30 - Sept. 3, 1987.

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15. Hanninen, H. et.al., "Environment-Sensitive Cracking of Reactor Internals and Bolts", Third International Symposium On Environmental Degradation of Materials in Nuclear Power Systems-Water Reactors, Traverse City, Mi, August 30 - Sept. 3, 1987.

16. Chung, H.M., and Chopra, O.K., "Kinetics And Mechanisms of Thermal Aging Embrittlement", Third International Symposium On Environmental Degradation of Materials in Nuclear Power Systems-Water Reactors, Traverse City, Mi, August 30-Sept. 3, 1987.

17. 86-1227988-00 TMI-1 Cy 10 Redesign, C.M. Hove, 10-8-93.

Mark-B7, B8, B8A & B8V Fuel Assemblies:

18. 02-1165290D-2 Guide Tube Assembly

19. 02-1155390C-6 Guide Tube (Annealed)

Mark-B9 & B10 Fuel Assemblies:

20. 02-1207138E-2 Restraining Upper End Grid Guide Tube Assembly

21. 02-1207135C-0 Guide Tube Tubing

22. TMI-1 FSAR, Chapter 3

23. Trip report, T.D. Pyecha, NNFDRL to Distribution, 3-Cycle MK-BZ Grid Oxide Thickness Measurements 7/12-17/87 (NJ02D3; Oconee-1, EOC-9) Sept. 16, 1987.

24. Design Summary of MK-B Extended Life Control Rod Assembly. G.T. Williams, July 1983.

TABLE 1
PROBLEM CRDM - CRA - FA CHARACTERISTICS

CORE FA LOCATION	TYPE	FA BATCH	CRA EXPOSURE	FA BOC GWd/mtU	FA EOC GWd/mtU
M3	B8V	11C	FRESH	26.1	46.2
K3	B8V	11C	FRESH	26.1	46.3
O5	B8V	11C	FRESH	21.3	44.6
O7	B8V	11C	FRESH	21.3	44.6
P8	B8V	11C	FRESH	18.2	36.9
M9	B8V	11C	FRESH	25.8	47.8
B10	B8V	12A	1 CYC	0	22.8
O11	B8V	11C	FRESH	26.1	46.3
M13	B8V	11C	FRESH	26.1	46.2
K13	B8V	11C	FRESH	21.3	44.6
L14	B8V	12A	1 CYC	0	22.8
F14	B8V	12A	1 CYC	0	22.8

Figure 1

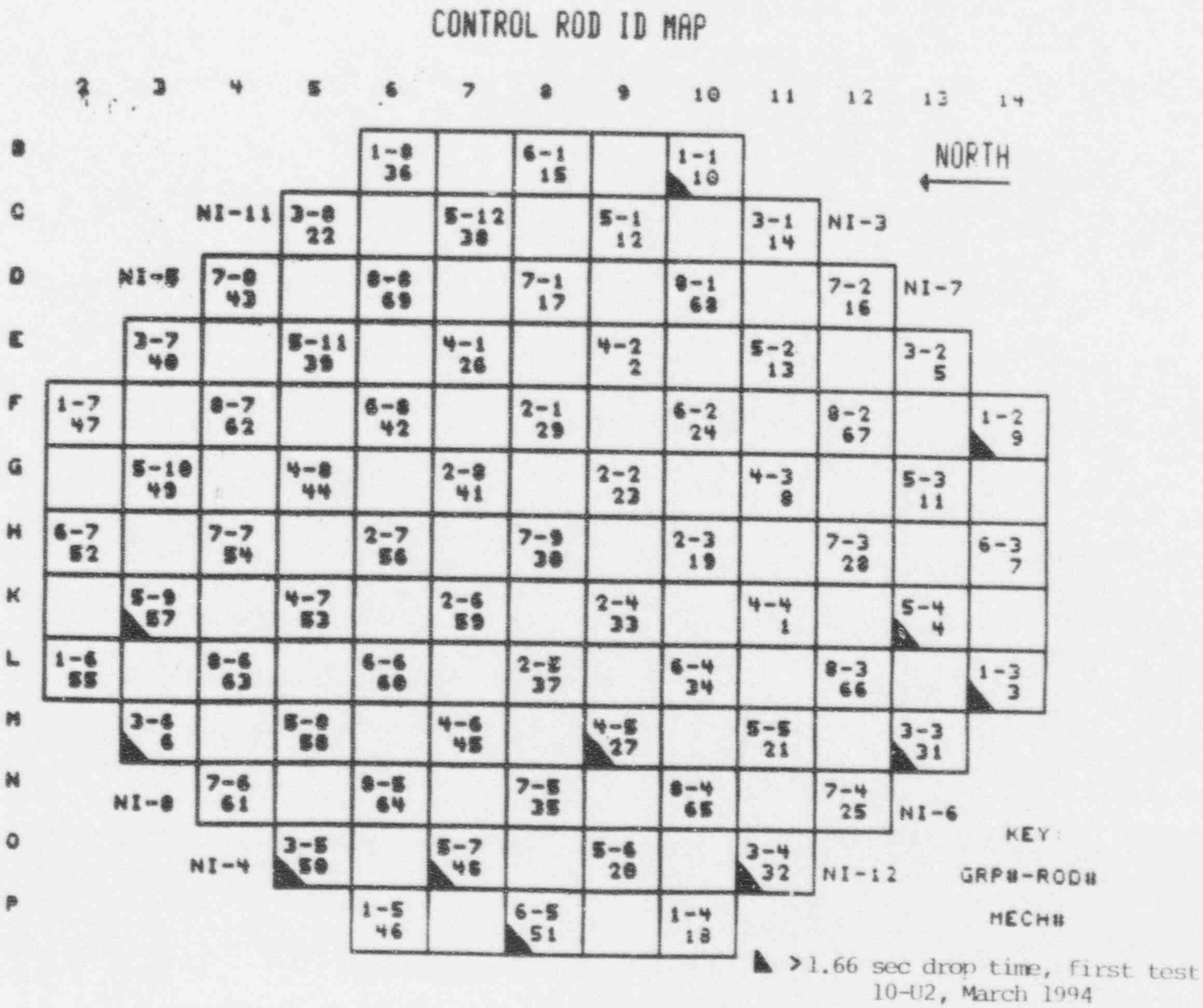

CONTROL ROD ID MAP
2 3 4 5 6 7 8 9 10 11 12 13 14
B C D E F G H K L M N O P
NORTH
1-8 36
6-1 15
1-1 10
NI-11
3-8 22
5-12 38
5-1 12
3-1 14
NI-3
NI-5
7-8 43
8-8 69
7-1 17
8-1 68
7-2 16
NI-7
3-7 40
5-11 39
4-1 26
4-2 2
5-2 13
3-2 5
1-7 47
8-7 62
6-8 42
2-1 29
6-2 24
8-2 67
1-2 9
5-10 49
4-8 44
2-8 41
2-2 23
4-3 8
5-3 11
6-7 52
7-7 54
2-7 56
7-9 30
2-3 19
7-3 28
6-3 7
5-9 57
4-7 53
2-6 59
2-4 33
4-4 1
5-4 4
1-6 55
8-6 63
6-6 60
2-5 37
6-4 34
8-3 66
1-3 3
3-6 6
5-8 58
4-6 45
4-5 27
5-5 21
3-3 31
NI-8
7-6 61
8-5 64
7-5 35
8-4 65
7-4 25
NI-6
NI-4
3-5 50
5-7 46
5-6 20
3-4 32
NI-12
1-5 46
6-5 51
1-4 18
KEY:
GRP#-ROD#
MECH#
>1.66 sec drop time, first test
10-U2, March 1994

Figure 2

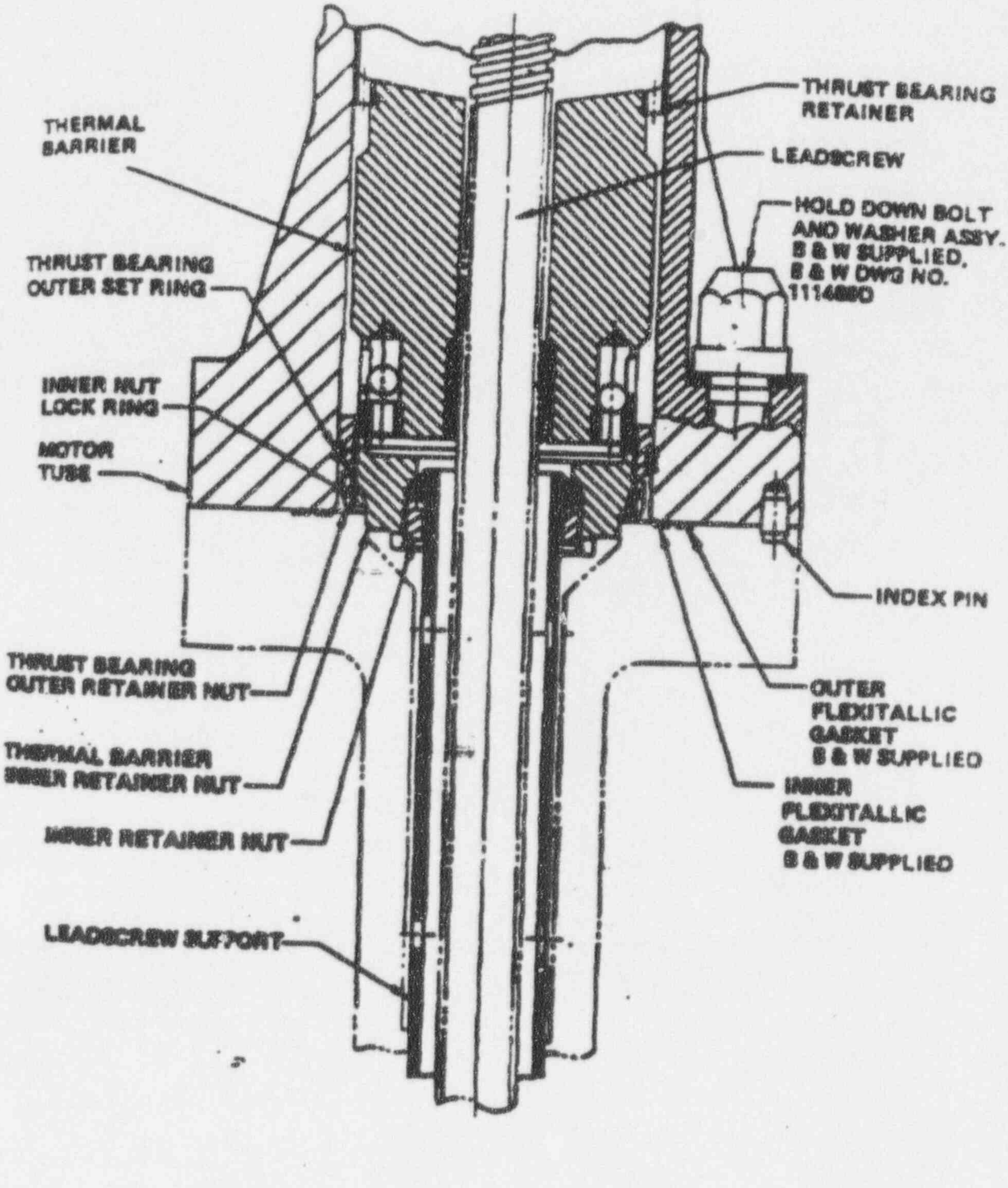
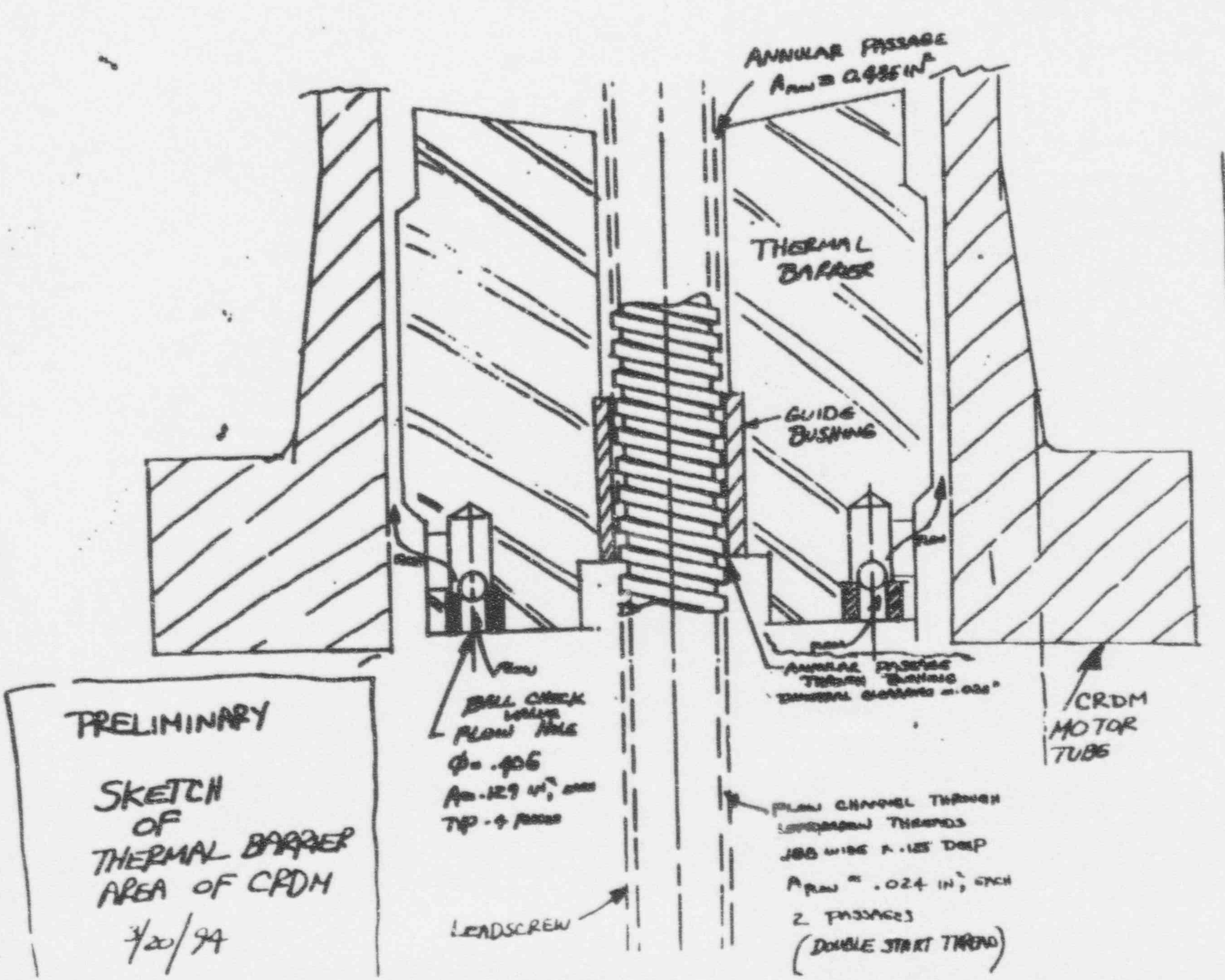


Figure 4-2. Leadscrew Support Mounting Location

Figu 3


ANNULAR PASSAGE
THERMAL BARRIER
GUIDE BUSHING
BALL CHECK VALVE FLOW HOLE
ϕ = .406
TYP - 4 PLACES
ANNULAR PASSAGE THROUGH BUSHING
CRDM MOTOR TUBE
FLOW CHANNEL THROUGH
.024 IN²; EACH
2 PASSAGES
(DOUBLE START THREAD)
LEADSCREW
PRELIMINARY
SKETCH OF THERMAL BARRIER AREA OF CRDM
3/20/94

LEADSCREW POSITION VS TIME
DATA FROM STRIP CHARTS

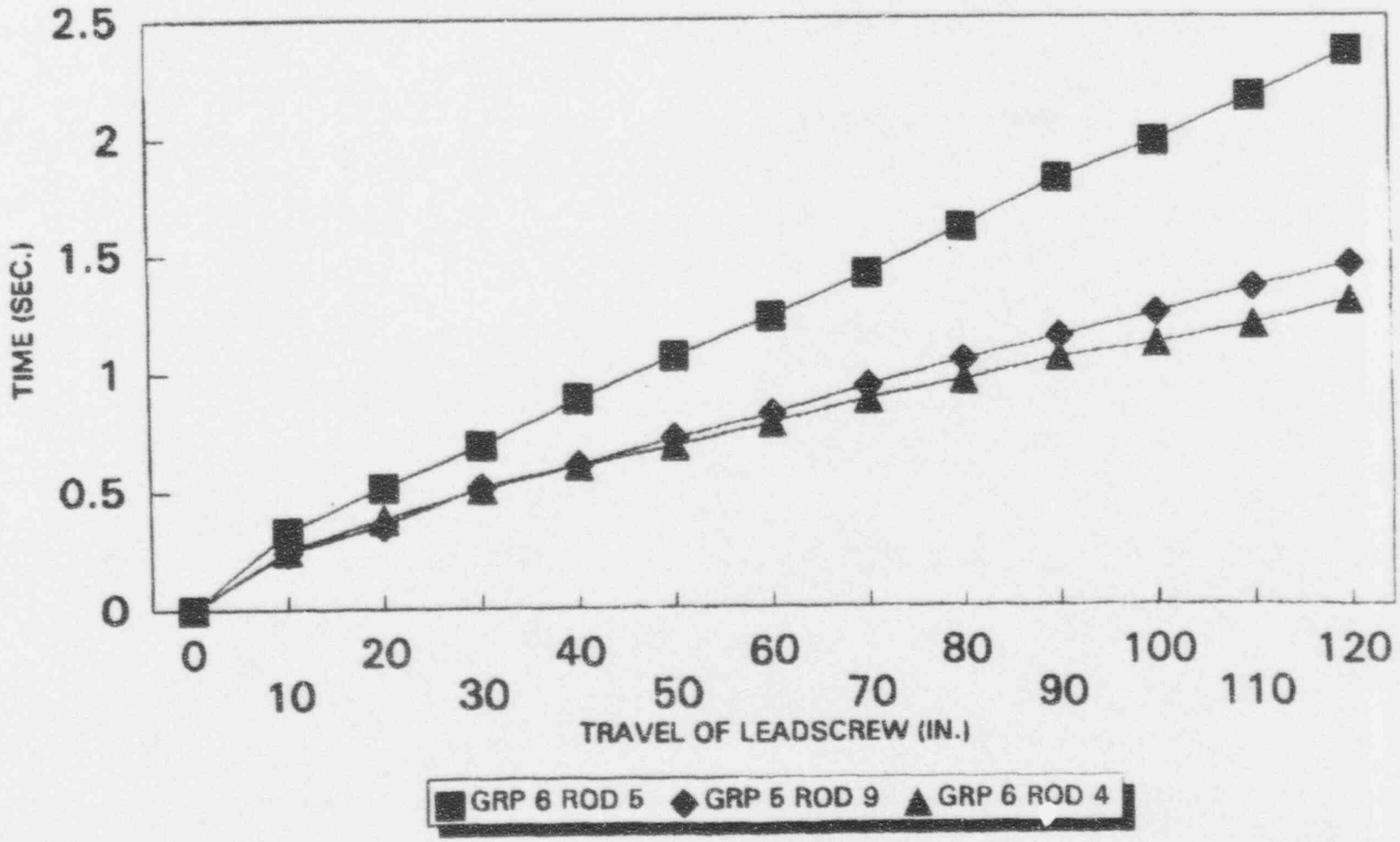


FIG. 4

CALCULATED VELOCITY

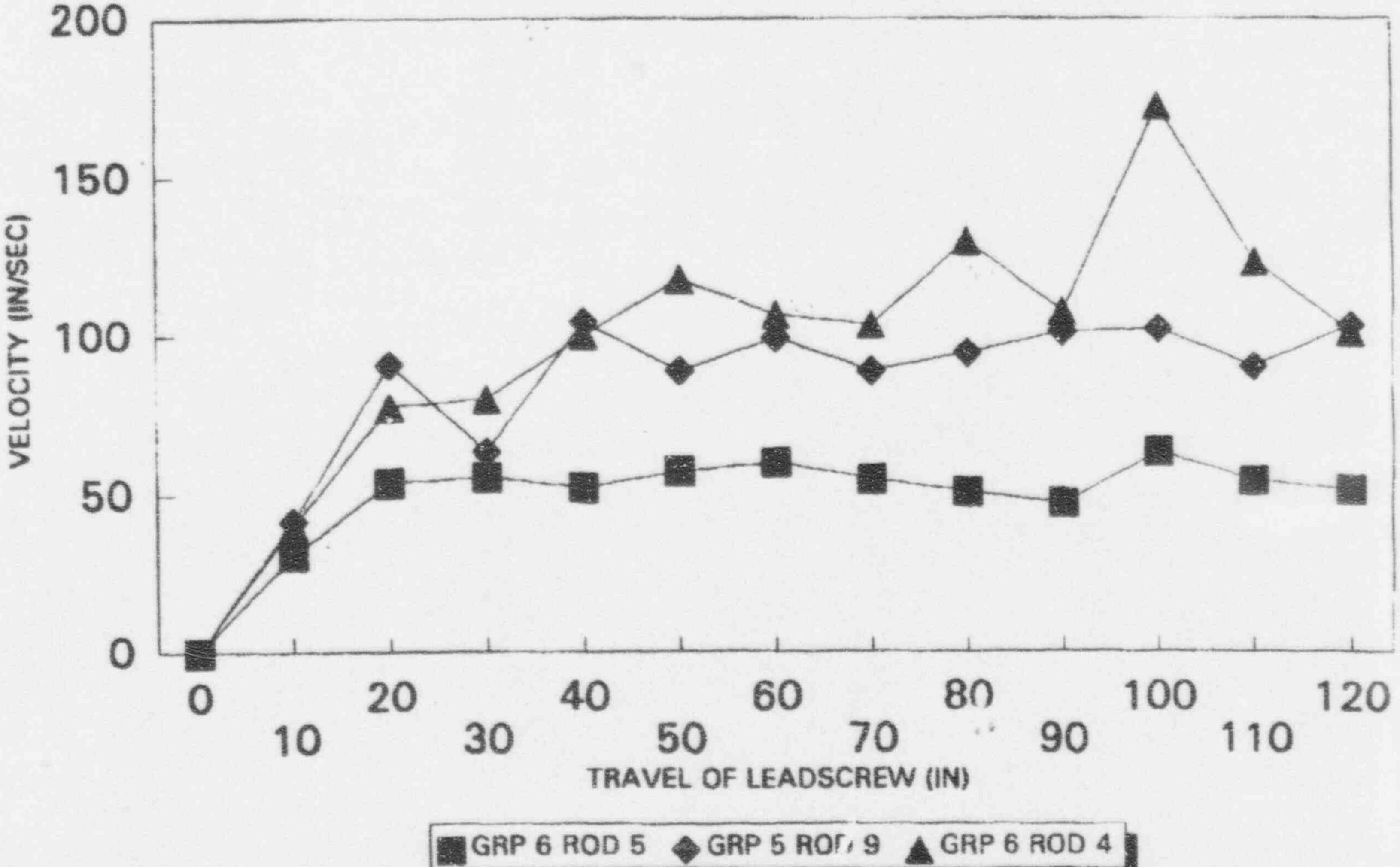


FIG. 5

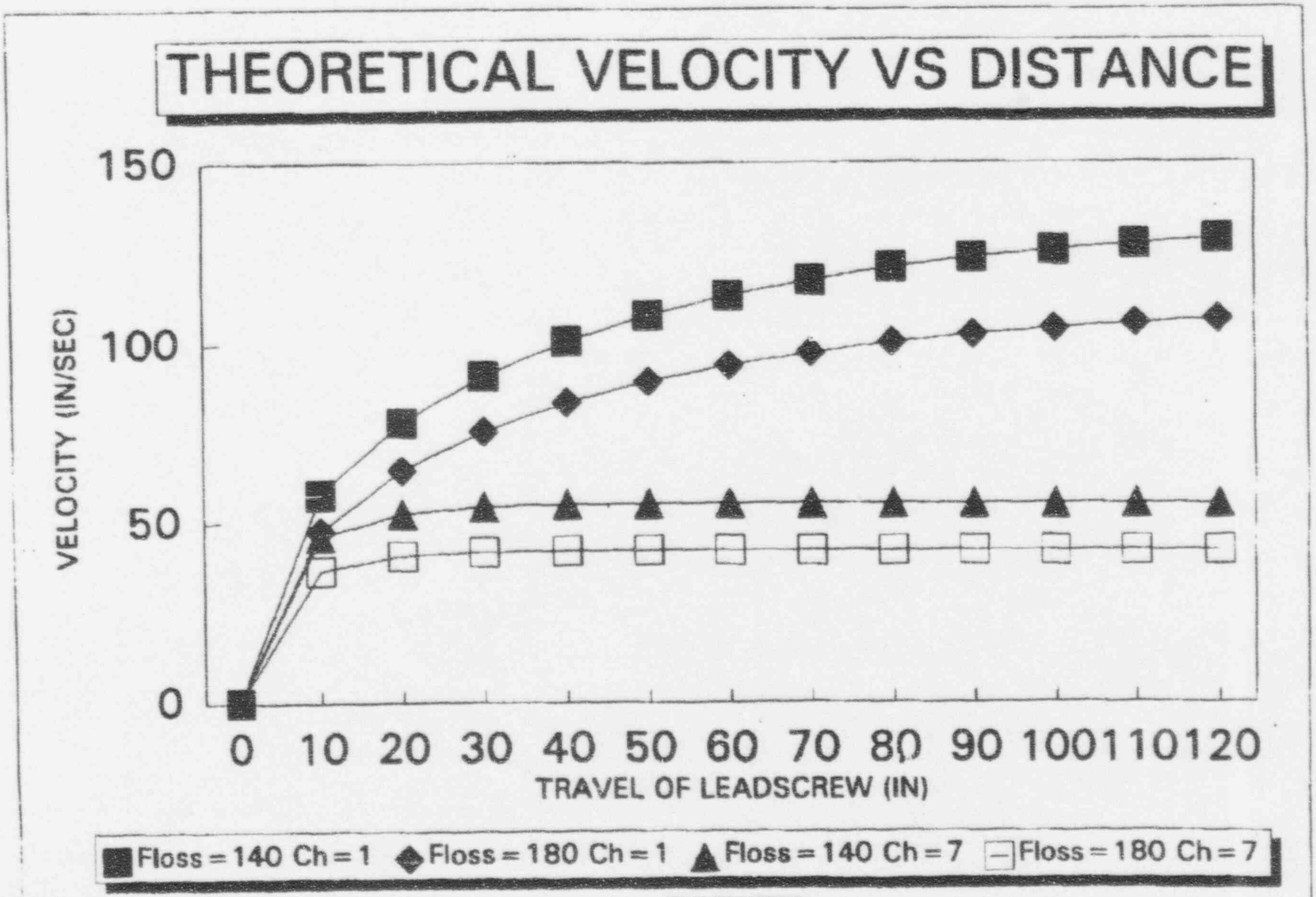
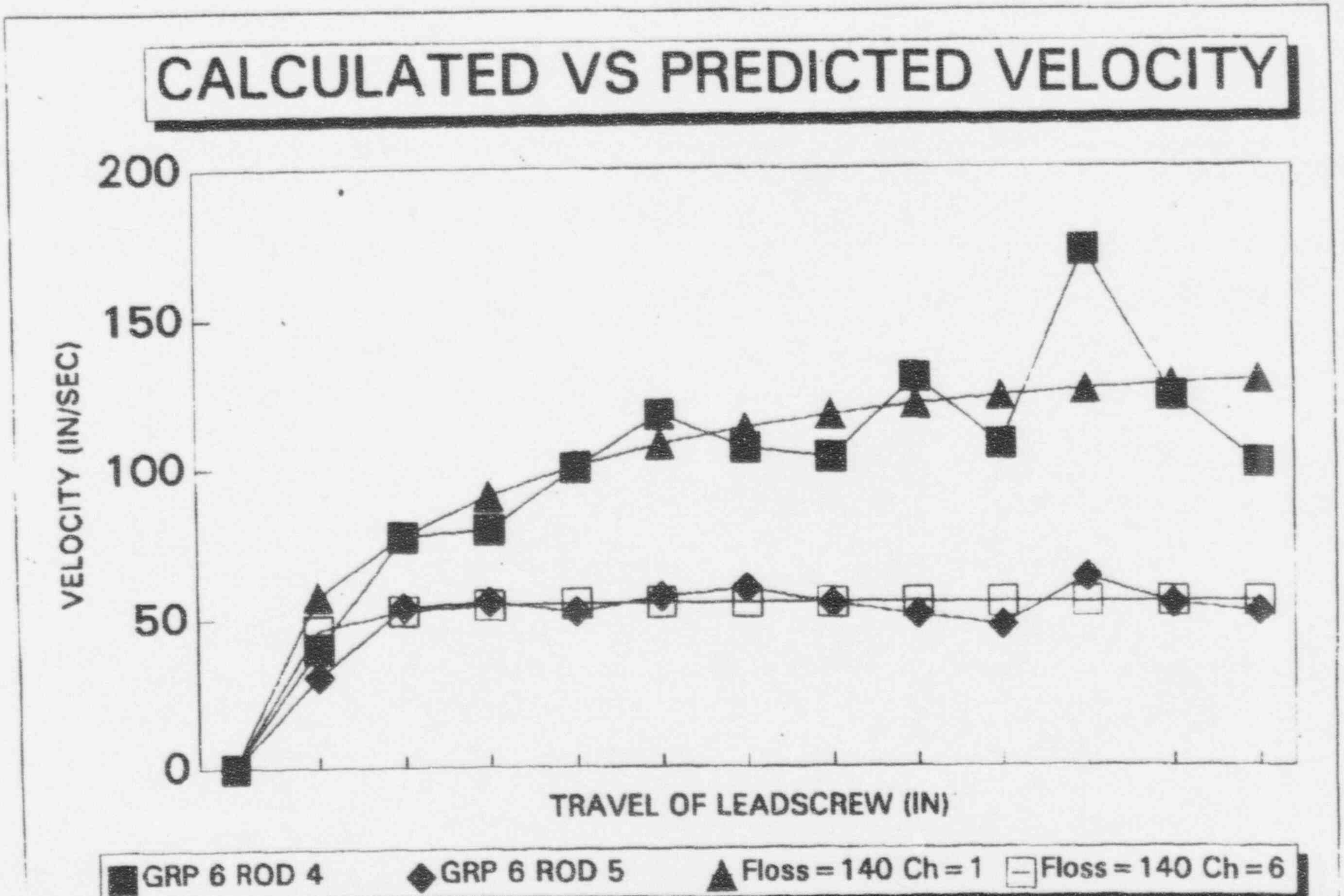

THEORETICAL VELOCITY VS DISTANCE
150
100
50
0
VELOCITY (IN/SEC)
0
10
20
30
40
50
60
70
80
90
100
110
120
TRAVEL OF LEADSCREW (IN)
Floss = 140 Ch = 1
Floss = 180 Ch = 1
Floss = 140 Ch = 7
Floss = 180 Ch = 7

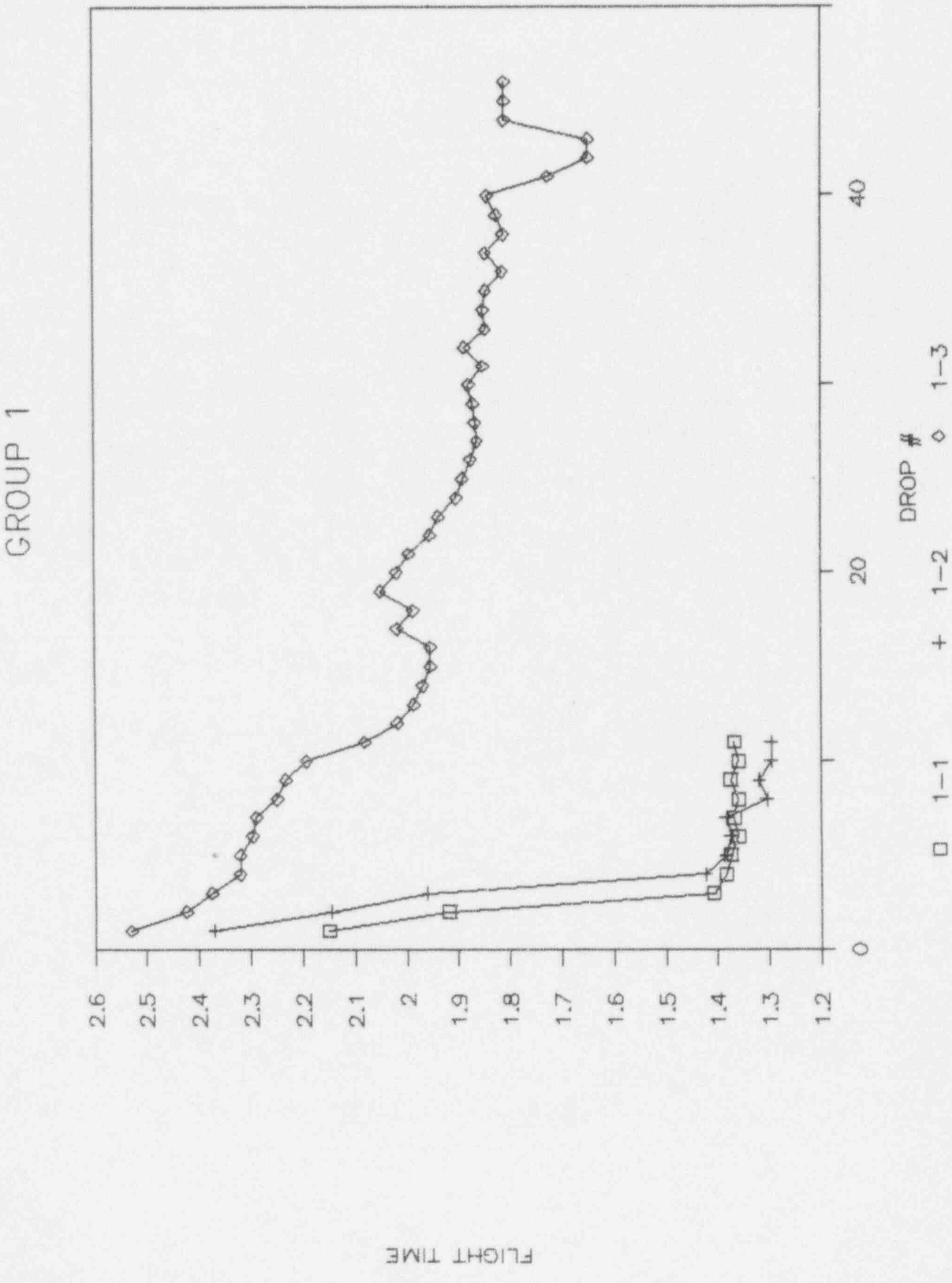
FIG. 6



CALCULATED VS PREDICTED VELOCITY
200
150
100
50
0
VELOCITY (IN/SEC)
TRAVEL OF LEADSCREW (IN)
GRP 6 ROD 4
GRP 6 ROD 5
Floss = 140 Ch = 1
Floss = 140 Ch = 6

FIG. 7

FIGURE 8



GROUP 1
FLIGHT TIME
DROP #
□ 1–1
+ 1–2
◇ 1–3
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
0
20
40

GROUP 3

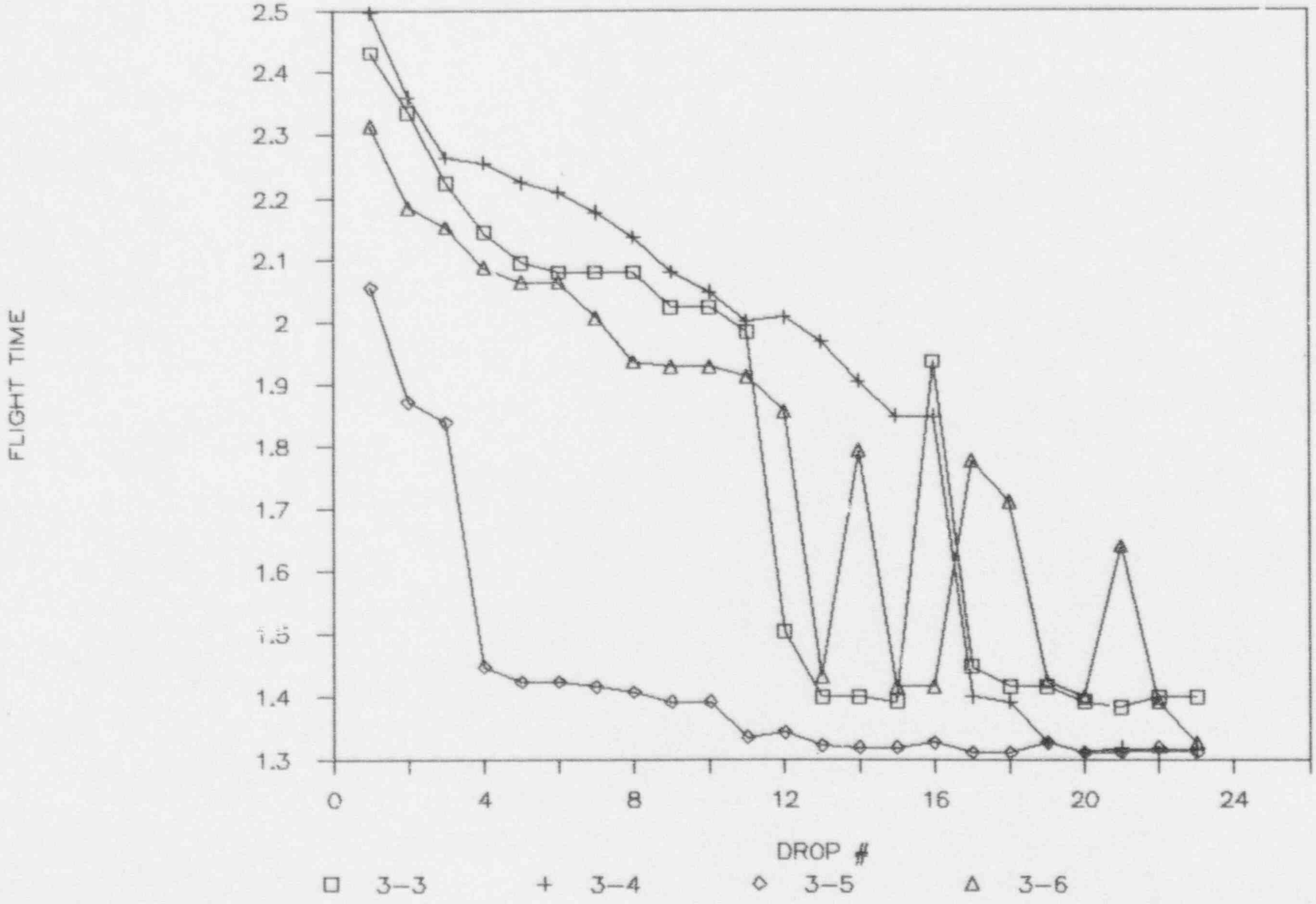
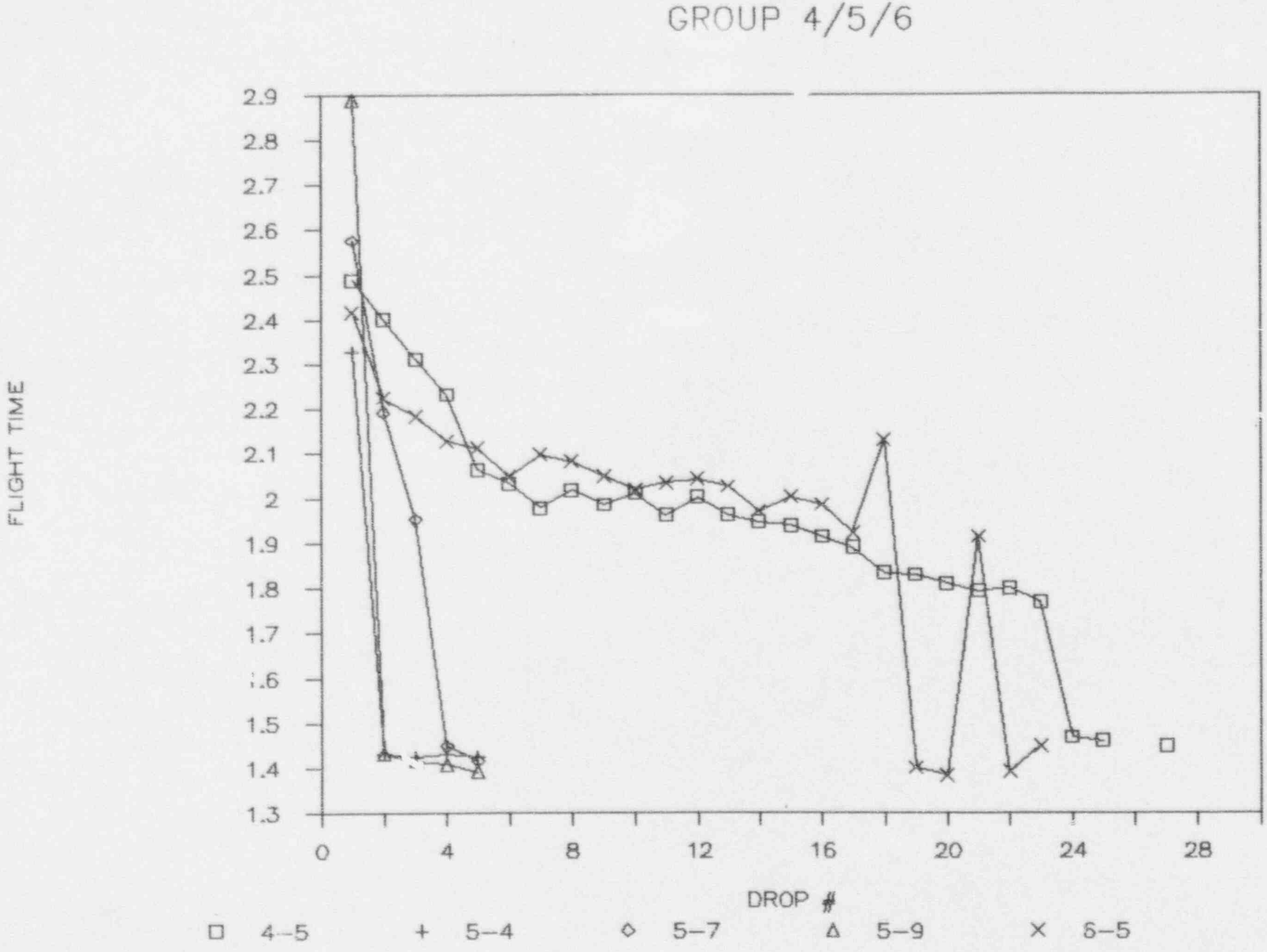


FIGURE 9



GROUP 4/5/6
FLIGHT TIME
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
0
4
8
12
16
20
24
28
DROP #
4-5
5-4
5-7
5-9
6-5

FIGURE 10