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Installation of Packers and Hydraulic Testing of Core Holes CH-1 Through CH-5 ORNL Plant Area Volume 1 of 2

William B. Lozier
Ray Pearson

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INSTALLATION OF PACKERS AND HYDRAULIC TESTING OF CORE HOLES CH-1 THROUGH CH-5 ORNL PLANT AREA VOLUME 1 OF 2

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ABSTRACT

Geohydraulic packer testing was completed in coreholes CH-1 through CH-5 in Bethel Valley at the Oak Ridge National Laboratory X-10 Plant Area. The coreholes penetrate rocks of the Chickamauga Group and range in depth from 350 feet to about 400 feet. A straddle packer assembly consisting of two sliding-end pneumatic packers, a downhole pneumatically activated shut-in valve and three downhole vibrating wire pressure transducers was utilized to complete the testing.

The transducers were used to monitor the rock formation hydraulic pressure above the top packer, in the tested interval, and below the bottom packer. The upper transducer was used to monitor the open annulus water pressure and the effectiveness of the upper packer seal. The middle transducer was used to measure the response of the test section. The lower pressure transducer was used to monitor the water pressure in the sealed borehole beneath the lower packer and the effectiveness of the lower packer seal. The transducer readings were recorded using a multi-channel datalogger in conjunction with a portable microcomputer.

A total of 38 packer tests were completed. Hydraulic conductivity results from corehole 1 ranged from about 5×10^{-9} cm/s to 1×10^{-4} cm/s. Corehole 2 results ranged from about 1×10^{-5} cm/s to 8×10^{-6} cm/s. Corehole 3 results ranged from about 2×10^{-5} cm/s to about 1×10^{-8} cm/s. Corehole 4 results ranged from about 4×10^{-5} cm/s to 5×10^{-9} cm/s, and those in corehole 5 ranged from about 4×10^{-7} cm/s to 6×10^{-9} cm/s.

The static head distribution across coreholes CH-1 through CH-5 indicate significant artesian pressures at depth with a general upward gradient. These pressures may be remnant, but the overall flow pattern at the plant area in the tested section is hypothesized to be downward from the recharge areas on top of Haw and Chestnut Ridges, with upward flow near the valleys. Preferential weathering along bedding planes and differential fracturing have created a system that, in a vertical section, may contain discreet zones of high head and low permeability. The groundwater flow directions will likely be controlled by bedding strike in a direction orthogonal to the tested cross section. The average permeability appears to increase across the section from the Rome Formation to the Knox Formation.

1.0 INTRODUCTION

Martin Marietta Energy Systems is currently engaged in several hydrogeologic investigations at the Oak Ridge facilities (ORNL) near Knoxville, Tennessee. To supplement the on-going investigations, Golder Associates was retained by Martin Marietta to perform the installation of packers and subsequent hydraulic testing of existing rock core holes.

The packer testing of rock core holes CH-1, CH-3, and CH-5 was performed in the field from December 2, 1986 to December 19, 1986. Packer testing of rock core holes CH-2 and CH-4 was performed under a contract extension. These tests were completed in the field from March 30, 1987 to April 10, 1987. Volume I of this report presents the scope of work for the packer testing, the field test methodology, the analysis methodology, discussion of the results, and conclusions. Volume II of this report presents the field data and the packer test analyses.

1.1 Scope of Work

The original scope of work for the packer testing called for installation of packers and subsequent hydraulic testing of five existing core holes at ORNL. A maximum of five intervals in each core hole was to be selected for testing for a maximum of 25 tests. The packer testing methodology was to include instrumentation capable of monitoring pressures above, within, and below the packers and to estimate the static head and hydraulic conductivity of the tested zone.

Prior to commencement of the field packer testing program, Golder Associates and Martin Marietta reviewed the core hole geophysical logs for preliminary selection of appropriate test intervals. After selection of the tested intervals (based on geophysical logs) Golder Associates and Martin Marietta examined the actual rock core represented by these intervals. It became apparent, after examining the actual core that the geophysical logs alone would not be adequate for selection of test intervals. Golder Associates and Martin Marietta agreed that all of the rock core should be examined for selection of appropriate test intervals. Golder geologists examined the rock core and prepared general descriptive logs (no detailed geologic logging was completed) for each core hole CH-1 through CH-5. The logs are presented in Appendix A. Subsequent to the logging, Martin Marietta and Golder Associates agreed that a test section interval of about 36 feet would be appropriate for this project based on cost, frequency of fracturing and lithological variation within the rock.

Packer testing of core hole CH-1 commenced on December 2, 1986. Six intervals had been selected based on review of the rock core and geological information. In the field, a decision was made to perform one additional test in CH-1 that had not originally been selected. The additional section was chosen on the basis of further examination of the Golder core logs which indicated the presence of fractures filled with calcite, mylonite and trace pyrite. This test (259.9 ft. to 295.2 ft.) revealed substantial permeability and possible artesian conditions. Consequently, Golder Associates and Martin Marietta considered it appropriate to increase the number of test zones in each core hole so that the probability of missing key hydrogeologic zones would be reduced. As a result of this change of scope a total of 21 tests were completed in core holes CH-1, CH-3, and CH-5.

Subsequent to the testing of the core holes CH-1, CH-3, and CH-5, Golder Associates completed an additional 18 tests in core holes CH-2 and CH-4. The results of the additional tests are included in this report for completeness, although the tests were actually performed under a separate contract extension.

2.0 PHYSICAL SETTING

2.1 General

The Oak Ridge Reservation lies in East Tennessee, principally within the Valley and Ridge geological province, although portions of both the Blue Ridge and the Appalachian Plateau provinces are included in the area (Figures 1 and 2).

Rocks within East Tennessee range in age from pre-Cambrian to Pennsylvanian, with unconsolidated residual clay and terrace deposits overlying the bedrock. Southeast dipping imbricating thrust faults cause long, narrow, outcrop belts which strike northeast.

The principal water-bearing rocks of the area include limestone, dolomite and calcareous shale of Cambrian and Ordovician age. The usable groundwater is usually restricted to solution enlarged fractures, with the quantity available for well use being dependent on size and number of fractures encountered.

2.2 Climate

East Tennessee climate is primarily influenced by storms moving from the Gulf Coast to the Atlantic Coast, and to a lesser extent by storms moving northeastward from Oklahoma to Maine. The elevation differences between mountain tops and valleys cause a considerable variation in temperature. The mean annual temperature is between 57° and 58°F, with temperature extremes between -32°F and 111°F. July is the hottest month and January the coldest.

Precipitation is controlled in part by topography, being heavier in the Blue Ridge and Appalachian Plateau than in the Valley and Ridge province. This is because the moist air masses are forced over the Cumberland Plateau to the northwest, and the Unaka Mountains to the southeast of the Valley and the Ridge, and thus moisture is condensed and precipitated in these elevated areas producing comparatively dry conditions between them. Average annual precipitation in East Tennessee is about 53 inches in the Valley and Ridge near ORNL, and about 55 inches average on the Cumberland Plateau. Precipitation in excess of 80 inches has fallen in the Unaka Mountains. Rainfall is well distributed throughout the year with January through March being wettest, and September through November being driest.

3.0 Geologic Setting

3.1 The Valley and Ridge Province

The Valley and Ridge province is the major geological environment with respect to this report. The region is characterized by numerous elongated ridges and intervening valleys, all trending in a northeast-southwest direction, as a result of folding and fracturing caused by a major orogeny some 230 to 260 million years ago during the Permian geologic period. Ridges within the Province range in elevation from 1495 feet at White Oak Mountain near Chattanooga to 3097 feet at Bays Mountain near Kingsport. Valleys to the north average 1000 feet in elevation, and to the south about 750 feet.

Stream courses in the Valley and Ridge are closely related to the structure and composition of the rocks. Most of the smaller streams are in the northeast-southwest trending valleys. However, several large streams flow almost at right angles to these valleys, possibly guided by major rock fractures (cross-faults).

3.2 Oak Ridge Reservation

The Oak Ridge Reservation lies in Anderson and Roane Counties in East Tennessee. Anderson County is nearly triangular in shape and is bounded by the Clinch River on the southeastern edge, and by Knox, Roane, Morgan, Scott, Campbell and Union Counties elsewhere.

The southeastern half of Anderson County lies in the Valley and Ridge province and consists of alternating ridges and valleys, reflecting the varying resistance to weathering of the folded and faulted calcareous rocks. The major ridges at the Oak Ridge Reservation are Pine Ridge, an overthrust ublock underlain by sandstone and shale of the Rome Formation (Cambrian); Black Oak, Chestnut and Copper Ridges, underlain by dolomite and limestone of the Knox Group (Ordovician); and Haw and Bull Run ridges, also underlain by the Rome formation. The major valleys at Oak Ridge are Bethel Valley, underlain by Ordovician limestone and shale (Chickamauga Group); and Bear Creek Valley, underlain by limestone and shale of Cambrian age (Conasauga Group). East Fork Ridge to the northwest is capped by rocks of Mississippi Age.

3.3 The Test Site

The test site, as shown in Figure 3, consists of a line of five 380 feet to 470 feet deep 3.7" diameter core holes located in Bethel Valley between Chestnut Ridge (Knox Group) and Haw Ridge (Rome formation), (Figure 3). The core holes penetrate rocks of the Chickamauga Group.

The Chickamauga group is classified as Middle to Upper Ordovician in age, and at the test site has been subdivided into eight units by Stockdale, (1951). Table 1 lists the lithological descriptions of the eight groups. The core from each core hole has been examined by Golder (approximate logs are presented in Appendix A), but no attempt has yet been made to correlate core with the above groupings.

Core holes CH-1 through CH-5 at the ORNL plant area penetrate units A through G of the Chickamauga Group. In general, the rock consists of limestones with some shale and calcareous shale. The limestones primarily include massive sparite, and micritic and lithographic limestone. These units are laminated with dark gray calcareous shale. The shale layers are partly fossiliferous, mottled, and occasionally contain chert nodules or layers.

There is evidence of solutioning and intense weathering of the limestone. However, the depth of weathering decreases significantly where the rock type is predominantly shale. This preferential weathering pattern is of primary importance in interpreting the results of the packer tests completed.

The presence of both structural and lithological variations in the subsurface is pertinent to this work. Slickensided fractures accounted for the majority of fractures observed in the rock core. The fractures were primarily oriented 20 degrees to 35 degrees from horizontal. Fractures that were noted outside the weathered zones were fresh and appeared to be tight. However, there is evidence for offsetting of high angle calcite stringers in the lower, unweathered, parts of core hole number 3 indicating groundwater flow has been altered by structural movement. A packer test in this zone indicated high permeability ($\sim 2 \times 10^{-5}$ cm/sec) at depths of about 335 ft., (Table 4). The role of fracture frequency, orientation and type has not been characterized in this study since the core fracture data requires a greater degree of quantification than presently available.

4.0 FIELD TEST METHODOLOGY

4.1 Equipment

Golder Associates utilized a straddle packer assembly depicted in Figure 4, consisting of two sliding-end pneumatic packers connected with perforated pipe and drill rods. The packer assembly was installed in each core hole using NX drill rods. The straddle packer assembly utilized a downhole pneumatic shut-in valve depicted in Figure 5 and three downhole vibrating wire pressure transducers.

High pressure nitrogen cylinders were used to inflate the packers and operate the downhole shut-in valve. Normal inflation time for the packers was about 2.5 minutes. The shut-in valve required about 1.5 minutes to open from the closed position or visa versa. The packers and shut-in valve were generally inflated to a pressure of 130 to 150 psi above the static water pressure at the top of the tested interval. The packers had a gland length of five feet before inflation and an estimated gland length of about four feet after inflation.

Three downhole vibrating-wire pressure transducers were used to monitor the pressure above the top packer, in the tested interval, and below the bottom packer. The three transducers were physically located above the top packer. The middle (in the tested interval) and lower (below the bottom packer) transducers were ported to the prescribed location using water filled tubing open at one end as depicted in Figure 4. The transducer readings were recorded using a multi-channel datalogger in conjunction with a Portable Microcomputer. The frequency of reading could be varied, but was generally held constant at a 30 second scan rate. The transducers were calibrated in each core hole to within about 0.5 psi of the calculated static water pressure. The actual transducer readings were accurate to within about 0.5 psi under static conditions. However, under dynamic (transient) pressure conditions, the relative readings in time appeared to be quite stable.

4.2 Procedures

Packer testing is not limited to one specific procedure. There are many types of tests that can be performed such as pressure build up, pressure decay, constant pressure injection or constant flow withdrawal, pulse testing, etc. The primary objective of the test, the available time, equipment and budget will often dictate which type of test is performed. Often a combination of different types of tests may be performed depending on the observed hydraulic response of the tested interval. The test method chosen for this series of tests is the well established pressure build-up drill stem test (Reference 1). This method is appropriate for strata with hydraulic conductivity in the range of about 10^{-4} cm/s to about 10^{-8} cm/s. The hydraulic conductivity of the strata to be tested was considered to most probably fall within this range.

A general description of the field testing procedure that was employed at ORNL is as follows:

1. Read and record the initial water level in the core hole (assumed static), unless the borehole is flowing.
2. Assemble the straddle packer assembly as depicted in Figure 1 and lower the assembly into the core hole to the prescribed depth.
3. Connect the vibrating wire pressure transducers to the datalogger.

4. Calibrate the pressure transducers to the calculated static water pressure in the borehole above the transducers depth. In the case of a flowing hole the pressure is calculated as the head above the transducers to the top of the borehole casing.

5. Allow the datalogger to obtain several initial readings to assure that the instruments are operating properly and to observe a drop in water level that may be occurring as a result of the fluid displaced by the rods and instruments.

6. Inflate the packers to about 130 to 150 psi above the calculated static water pressure at the top of the upper packer.

7. Shut the downhole valve.

8. Wait approximately five minutes to allow adequate pressure to build in the packers and valve.

9. Remove about one-third of the standing water from the drill rods using a swabbing tool. Note that removal of too much water could alter the formation properties due to increased effective stress at the core hole face when the downhole valve is opened.

10. Monitor the water level in the drill rods to determine the rod leakage rate.

11. Open the downhole valve to allow the tested interval to flow. Monitor the water level in the rods during this flow period to provide a preliminary assessment of the flow rate. The duration of the flow period should be such that a constant flow rate can be determined, but preferably short enough so as not to allow the formation to fully recover or the flow rate to decline significantly. The time required will depend on the hydraulic properties of the tested zone.

12. Shut the downhole valve to allow a pressure pulse to build within the tested zone. The duration of the first shut in period should be long enough to allow a pressure build-up trend to develop which can be used to calculate the hydraulic conductivity of the tested zone and extrapolated to estimate the static head of the tested zone. Usually 15 to 30 minutes is sufficient.

13. Swab more water out of the drill rods if necessary so that a second flow period can be completed.

14. Open the downhole valve to allow a second flow period to take place. Again, allow sufficient time for a constant flow rate to develop, but not so long that the formation recovers or the flow rate declines significantly. Note that the second flow rate will likely be lower than the first if no additional swabbing was completed during the shut-in period (item 13).

15. Shut the downhole valve to allow a second pressure pulse to build within the tested zone. Again, allow sufficient time for a trend to develop. Preferably the duration of the second shut-in period should exceed the first. If detailed static head measurements are preferred the second shut-in duration may be on the order of hours or even days.

16. Open the downhole valve.

17. Deflate the packers.

18. Allow sufficient time for the packers and valve to deflate. Disconnect the transducers from the datalogger during this time.

19. Remove or add drill rods to position the straddle packer assembly at the new location.

20. Reconnect the transducers and repeat steps number 5 through 19.

4.3 Data Recording

As previously mentioned, the pressure transducer data were recorded and stored on an electronic data logging device. This device could store about 1800 units of data after which the data had to be down loaded to the computer. However, the data could be instantly observed in the form of pressure readings every 30 seconds, or at whatever scan rate was prescribed, on the computer monitor screen. This allowed the progress of the test to be monitored and any problems to be instantly seen. For example, if the pressure readings for all three transducers stabilized at the same static head the packers may not have been properly sealed against the rock.

5.0 ANALYSIS METHODOLOGY

5.1 Data Reduction

An arithmetic plot of the transducer readings for each test is provided in Appendix B and the reduced field data are presented in Volume II of this report. The transducer readings were first converted to total hydraulic head by expressing the pressure as feet of water and adding it to the elevation of the transducer. For example, a transducer located at 800 FT MSL reading 100 psi would be equal to about 1030 feet of total hydraulic head. These hydraulic head values are expressed in terms of a fresh water head; density gradients due to salinity and temperature variations are ignored, since neither groundwater samples nor in situ specific conductance measurements were required during this test sequence, and hence density calculations could not be made.

The second step of data reduction was to calculate the elapsed shut-in time data. Shut-in data refers to the transducer readings obtained immediately after a flow period. During the flow period the downhole valve is open. Once the valve is shut, the flow period ends and the shut-in period begins. The elapsed shut-in time data have been calculated for both the first and second flow periods in Volume II.

The final step of data reduction was to calculate the elapsed time since packer inflation for the lower transducer. These data can in some cases be used to calculate the vertically averaged hydraulic conductivity of the core hole between the bottom of the lower packer and the bottom of the core hole. Again, Volume II presents this data reduction.

5.2 Horner Method

The shut-in data presented in Appendix B was analyzed (where applicable) according to the method described by Horner (Reference 2). The Horner method is a semi-log method in which the head (or pressure) is plotted against the log of the ratio of the duration of the flow period (T) plus the elapsed shut in time (t'), to the elapsed shut in time i.e.

$$H \text{ vs. } \log [(T + t')/t']$$

Where:

H = Total Hydraulic Head (FT MSL)
T = Duration of Flow Period (Min)
t'= elapsed time since shut-in (Min)

It can be seen from the above that, as the elapsed shut in time (t') increases, the log [(T +t') /t'] will decrease. Consequently, for convenience, the function is often plotted on a reversed X-axis i.e. decreasing to the right. Also note that as the shut-in time increases the value of [(T + t') /t'] will approach unity and the log will approach zero.

According to Horner, a portion of the shut-in data plotted as described will fall on a straight line. However, the early and late data may deviate from the straight line due to wellbore storage and boundary effects, respectively. The slope of the straight line portion can be used to calculate the Hydraulic Conductivity of the tested interval:

$$K = \frac{2.303Q}{4 \pi L S}$$

Where,

Q = Flow rate during the flow period (cm^3/sec)
L = Length of tested interval (cm)
S = Slope of straight line portion (cm)

In addition to Hydraulic Conductivity, the Horner plot can be used to estimate the static head of the tested interval. As previously stated, as the elapsed shut-in time (t') increases, the value of log [(T + t') /t'] will approach zero. Consequently, the straight line portion of the Horner plot can be extrapolated to log [(T + t') /t'] = 0 which will correspond to large values of elapsed shut-in time (t').

The Horner analysis method presented above is essentially the same as the Theis recovery method (Reference 3). Both methods are based on the solution to the partial differential equation governing groundwater flow, which in radial coordinates can be written as:

$$\frac{\partial^2 s}{\partial r^2} + \frac{1}{r}\frac{\partial s}{\partial r} = \frac{S_s}{K}\frac{\partial s}{\partial t}$$

The Horner method assumes a constant flow rate during the flow period and does not consider the effects of wellbore storage, skin, or boundary effects. For more detailed procedures and theory regarding the Horner analysis see Reference 2 and 3.

5.3 Variable Head Analysis

In some instances, a tested zone recovered so rapidly during the flow period or after shut-in that sufficient data could not be obtained to construct the Horner Plot. For example, the transducer plot for test CH-1-2 (Appendix B) clearly indicates that during both flow periods transducer number two nearly recovered to its original position. Consequently, the tested interval was very near steady state at the time of shut-in. The Horner Plot is relatively flat with no straight line portion. A second example is test CH-4-1.

The transducer plot indicates that, after shut-in, the tested interval recovered within 30 seconds. Consequently, again the Horner plot is relatively flat (very near steady state) which is insufficient to properly interpret the formation response.

In these two cases, and others, (CH-1-3, CH-2-4, CH-3-1, CH-4-10) the hydraulic conductivity of the tested interval was calculated by analyzing the data obtained during the flow period. The flow period response was analyzed as a rising head test.

The rising head analyses were completed according to the method described by Hvorslev (Reference 4). The method is a semilog method that is well documented in the literature. For detailed information on the method see Reference 4.

5.4 Pressure Slug Analysis

One type of field testing procedure which is often used to determine the hydraulic conductivity of tight formations ($K < 1 \times 10^{-8}$ cm/s) is the pressure slug decay test. The field procedure presented in Section 2.2, although not specifically intended to perform this type of test, may produce data which can be analyzed as a pressure slug decay.

When the packers are inflated, if the core hole is sufficiently tight below the lower packer, a pressure pulse may develop in the core hole below the bottom packer. This pressure pulse is effectively shut-in until the packers are deflated at the end of the test. The decline of this lower pressure pulse over time can be analyzed to determine the vertically averaged hydraulic conductivity of the core hole below the bottom of the lower packer.

The pressure slug decay data (when available) were analyzed according to the method described by Bredehoeft and Papadopulos (Reference 5). The method is a type curve procedure in which the head ratio (head above static at any instant in time after shut-in divided by the initial head above static) is plotted against the log of time since pressure slug shut-in. The method results in an estimate of transmissivity and storativity, although as stated in Reference 5, the estimates of storativity may in some cases be of questionable reliability. For the tests conducted at ORNL, only estimates of transmissivity were calculated. These estimates were then used to calculate values of hydraulic conductivity by dividing the transmissivity by the length of the tested interval.

5.5 Storage, Skin, and Boundary Effects

In addition to the standard methods of analysis discussed in Sections 5.2 to 5.4 several methods of analysis are available to investigate the effects of wellbore storage, skin, and boundary effects.

Wellbore storage and skin effects generally manifest themselves in the early time data of pressure build-up. Immediately after shutting in a producing well, a small amount of flow may still be occurring at the core hole face. This volume of water may be stored in the wellbore due to compliance or "give" in the rock mass immediately surrounding the borehole and in the down hole equipment such as packers and plastic tubing. As a result, the pressure in the tested interval may not build up as rapidly as would be expected.

Skin effects are a result of damage to the core hole face during drilling. The face can become smeared, fractured, or filled with fine cuttings, etc. As a result, the early pressure response during shut-in may be more representative of the hydraulic characteristics at the core hole face rather than the geologic formation itself. Skin effects can be either positive or negative and may cancel or compound wellbore storage effects. For these reasons, the early shut-in time data may be misleading.

Boundary conditions manifest themselves in the late shut-in data. Impermeable, layered, or constant head boundaries all may effect the late time data. In addition, other active wells in the vicinity may cause boundary effects. Generally, major boundary features will be evidenced as significant changes in slope of the late time data of the Horner plots.

In instances where wellbore storage, skin, or boundary effects may be strongly evident, the data most likely will not be suitable for Horner semi-log methods of analysis. The data may have to be analyzed using type curve methods that deal specifically with skin and wellbore storage or corrected using correction factors prior to applying the semi-log methods. In some instances, the data may not be suitable for analysis at all.

6.0 RESULTS

A total of 38 packer tests were completed in core holes CH-1 through CH-5. The results are presented in Tables 2 through 6 respectively. Test results are plotted on a cross section through the five core holes on Figure 6. Thirty-two tests were analyzed using the Horner Semi Log method and six were analyzed as a rising head test during the flow period. In addition, five hydraulic conductivity estimates were calculated based on the analysis of the shut in pressure data obtained below the lower packer. In total, the hydraulic conductivity was estimated for 43 different intervals. The field data for each test, the Horner analyses, the rising head analyses, and the shut-in pressure slug analyses are presented in Volume II of this report.

The following is a brief summary of the packer results. The implications of these results on the hydrogeologic model are presented in Section 7.0.

Seven tests were conducted in core hole CH-1. The core hole was under flowing artesian conditions at the time of testing. The resulting permeability estimates ranged from a low value of 3.9 X 10^{-9} cm/s for the interval of 299.2 ft. to 385.2 ft. BTC (Below Top of Casing) to a high value of 2.0 X 10^{-4} cm/s for the 89.6 ft. to 125.0 ft. interval. The static head for each tested interval appeared, in general, to increase with depth to a maximum value of about 960.0 ft. MSL at the bottom of the core hole, beneath the lowest tested section (Table 1).

Eight packer tests were completed in core hole CH-2. The resulting hydraulic conductivity estimates ranged from a low value of 7.2 x 10^{-8} cm/s for the interval 161.1 ft. to 196.6 ft. to a high value of 1.0 x 10^{-5} cm/s for the zone 201.1 ft. to 236.6 ft. The distribution of hydraulic head varied with depth although not in any regular pattern. Deep within core hole CH-2 (372.1 ft. to 472.8 ft.) the transducers behaved very sporadically. The readings fluctuated, possibly due to electrical short circuiting which may be an indication of a brine solution, or of a grounding problem with the transducers. Data interpretation was more difficult for the tests completed in this zone (CH-2-6 and CH-2-8), since pressure fluctuations were frequent. The data was interpreted with reasonable accuracy by interpolating between the fluctuations.

Six packer tests were completed in core hole CH-3. The resulting hydraulic conductivity estimates ranged from 1.4. X 10^{-8} cm/s to 2.3 X 10^{-5} cm/s for the 129.0 ft. to 164.3 ft. interval and 319.3 ft. to 354.6 ft. interval, respectively. The core hole was under flowing artesian conditions at the time of testing. The distribution of static head with depth throughout the core hole was somewhat irregular. The highest static head was measured in excess of 1000 ft. MSL for the 129.0 ft. to 164.3 ft. interval. Note that this zone also indicated the lowest hydraulic conductivity. In general the static head then declined with depth with a slight rise at 279.3 ft. to 314.6 ft.

The results of the ten packer tests completed in core hole CH-4 ranged from 1.1 x 10^{-9} cm/s to 7.0 x 10^{-5} cm/s for the test intervals 110.6 ft. to 380.6 ft. and 106.1 ft. to 141.6 ft. respectively. The hydraulic head again varied with depth with no apparent pattern.

Eight packer tests were conducted in core hole CH-5. The resulting hydraulic conductivity estimates ranged from 5.8 X 10^{-9} cm/s to 2.4 x 10^{-7} cm/s for the 218.3 ft. to 446.4 ft. interval and 369.4 to 304.7 ft. interval, respectively. The distribution of the static head with depth was, again, somewhat irregular, although artesian heads do exist in isolated zones within the core hole.

7.0 DISCUSSION OF RESULTS

As noted on Tables 2 through 6 the hydraulic conductivity estimates presented do not include estimates of the effects of rod leakage, wellbore storage, skin, or boundary effects. However, for completeness, several of these effects were qualitatively investigated.

Rod leakage was calculated for all tests in which the leakage rate was of a measurable quantity. Where measurable, the leakage rate was less than 0.07 gallons per minute (gpm) and in most cases was less than 0.01 gpm. This slight leakage rate can be considered negligible relative to the flow rates and will not cause significant error in the calculation of hydraulic conductivity.

To help quantify the effects of wellbore storage and skin effect, three tests (randomly selected) were re-analyzed according to a type curve procedure outlined by Gringarten et al (Reference 6). The procedure results in an estimate of hydraulic conductivity, wellbore storage coefficient, and a skin factor.

The Gringarten et al type curve analysis of the test data from tests CH-4-6, CH-4-5, and CH-2-2 resulted in geometric mean values of hydraulic conductivity of 2.2×10^{-5} cm/s, 8.0×10^{-7} cm/s, and 9.8×10^{-6} cm/s respectively. These values are higher than the corresponding values obtained from the Horner analyses of 5.6×10^{-7} cm/s, 1.3×10^{-8} cm/s and 7.2×10^{-8} cm/s. The resulting skin factors for the three tests ranged from about +26 to +40, which appears to indicate severly damaged coreholes. Drill cuttings may have been forced into the fractures near the corehole face. Alternatively, the results may indicate the close presence of higher permeabililty zones within the layered rock mass. Consequently, the Horner analyses probably represent the area around the borehole rather than the intact geologic media. In addition wellbore storage coefficients for the three tests were calculated as 0.05 cm^2 to 1.6 cm^2, i.e. one to three orders of magnitude greater than can be attributed to the compressibility of water, (10^{-3} cm^2) (Reference 9), and indicate significant storage capacity.

The estimated static head for each test interval presented in Tables 2 through 6 were calculated by extrapolating either the Horner plots or plots of the transducer readings verses time. To investigate the reliability of the short term Horner projections several tests which were shut-in overnight were reviewed. The estimated static heads based on the Horner projection of short shut-in time data for the second flow period was compared to the long term arithmetic plot of the shut-in data (Table 7). For example, the Horner projection for test CH-2-1 resulted in an estimated static head of 808 FT. MSL. after 30 minutes, 810 FT. MSL. after 90 minutes and 815 FT. MSL. after 12 hours.

The results indicate the static heads measured at 30 minutes and 90 minutes after shut-in were within $\pm$ 1% of the static heads at 12 hours. In one case, test CH-2-5, the results were much more varied at +18% and +8%, respectively. However, the shape of this curve at early times made is obvious during the test that the pressure would take many hours to stabilize. It should also be pointed out that boundary effects interfere with all pressure readings, and may occur at any time during the test.

Core Hole CH-5 appeared to be most affected by possible boundary effects. At late shut-in times the Horner plots for tests CH-5-4, CH-5-6, and CH-5-7 all indicated strong boundary effects. In addition, the lower transducer for test CH-5-4 indicated a possible boundary effect about 150 minutes after the packers were inflated. The boundary effects are manifested in a short decrease in pressure, as if a production well had suddenly turned on, or the rock mass was responding elastically.

8.0 HYDROGEOLOGIC CONCEPTUAL MODEL

Figure 6 represents an approximate cross-section at the ORNL X-10 area. The cross-section depicting the various units of the Chickamauga group is based on a geologic map of the area prepared by Harry J. Klepser (Figure 3) of which a portion was provided to Golder Associates by Martin Marietta. The section runs from core hole CH-1, through core holes CH-2, CH-3, and CH-4 and terminates at core hole CH-5. Surveyed locations and elevations for each core hole were provided by Martin Marietta. The five core holes fall on a line drawn about 34^{o} west of north.

The hydraulic conductivity results, derived from the Horner and rising head analyses, and estimated static head for each tested interval are also presented on Figure 6. Initial review of the results indicates only one readily apparent trend. The average permeability increases across the section from the Rome to the Knox. Decreasing permeability with depth or geologic unit, or increasing hydraulic head with depth (with the exception of CH-1) are not readily apparent. However, it is apparent that, in general, high heads appear to correlate with low hydraulic conductivities. In addition, discrete zones of higher permeability do exist, and in some instances appear to be bounded by zones of relatively low permeability.

These seemingly erratic and inconsistent results are interpreted to be a result of two phenomena; preferential weathering patterns along bedding planes in the various geologic units of the Chickamauga Group; and differential fracturing in response to historical deformation. Examination of core logs indicates that zones comprised primarily of limestone may be subject to intense weathering to great depths along the bedding planes. However, zones comprised primarily of shale appear more resistant to weathering. These weathering-resistant zones are closer to ground surface. The highly weathered zones exhibit relatively higher hydraulic conductivity values (10^{-5} to 10^{-6} cm/s) whereas the weathering resistant zones exhibit hydraulic conductivities in the range of 10^{-8} cm/s or lower.

The alteration and solution of rock by chemical weathering is largely caused by infiltrating rain water acting as a carrier of dissolved oxygen and carbon dioxide, together with various acids and organic products derived from the soil cover. An increase in acidity increases the rate of weathering; rain water pH ranges from 4 to 7, its acidity coming mainly from dissolved carbon dioxide. Calcium carbonate in limestone is dissolved and removed as calcium bicarbonate. The process is enhanced by the presence of deformation fractures, such as those described in Section 3.3. Surface water can infiltrate to great depths in fractured rock and, thus, the weathering and solutioning process, starting with surface weathering of fracture planes, can also occur at great depth.

Figure 7 presents a schematic diagram depicting this type of weathering pattern. The weathering profile has been depicted in three zones: Zone A represents values of hydraulic conductivity greater than 10^{-5} cm/s. The zone is comprised of highly weathered and fractured rock, with deeper weathering in the limestone units. Zone B represents values of hydraulic conductivity in the range of 10^{-5} cm/s to 10^{-8} cm/s, and is mainly composed of partially weathered rock and discrete fracturing. The fracturing is composed of both high angle, tensional (sometimes offset) and low angle, slickensided, sheared fractures. Zone C represents values of hydraulic conductivity less than 10^{-8} cm/s, and is composed of unweathered units with occasional open fractures. As can be seen, this geologic interpretation offers a clear explanation of the apparent isolated zones of high hydraulic conductivity such as in the lower portion of core hole CH-3.

With regard to hydraulic head, the preferential weathering pattern also offers an explanation of the apparent isolated high heads observed in several of the core holes. For instance, the high heads observed in core holes CH-3 and CH-4 appear to coincide with the relatively tight zones, defined by the above described hydraulic conductivity boundaries, that may have resisted weathering. The sources of the high heads may be associated with recharge areas on Chestnut and Haw Ridges, as illustrated in Figure 8.

The concept of high pore pressure development at permeability boundaries, such as those suggested above, can be explained by examination of a hypothetical flow system stream-tube. Assuming the stream-tube has a constant area, and variable permeability over constant lengths then, by continuity;

$$\text{Flow } Q = K_1 \Delta h_1 = K_2 \Delta h_2$$

where K_1 and K_2 are permeabilities and Δh_1 and Δh_2 are head drops;

If K_1 is much greater than K_2

then $$\Delta h_1 = \frac{K_2}{K_1} \Delta h_2$$

and hence Δh_2 is much greater than Δh_1

Therefore, a very low permeability strata next to high permeability strata will result in a very high pressure drop across the interface. It is possible the high heads (pore pressures) are caused by remnant, stress related fluid pressures, however, they should have been relieved during the tests, rather than risen in value.

In addition to the above description, local flow systems, as indicated in Figure 8, appear to be generated within the section in the weathered zones. These local flow systems may well penetrate to depths greater than 200 feet, and most probably flow along strike, orthogonal to the cross-section.

The preferential weathering pattern, described above, can also account for the apparent boundary effects observed in several of the tests. A relatively permeable zone may feel the effect of a tight zone immediately above or below the tested zone. In addition, the apparent skin effects observed in some tests, may be further evidence of variable hydraulic conductivity. Finally, the observation of brine at variable depths at ORNL by other investigations may be explained by the above conceptual model.

9.0 CONCLUSIONS

The results of the 38 packer tests completed in core holes CH-1 through CH-5 indicate the following:

1. The hydraulic conductivity in core hole CH-1 ranges from about 2×10^{-4} cm/s to about 4×10^{-9} cm/s.

2. The hydraulic conductivity in core hole CH-2 ranges from about 1×10^{-5} cm/s to about 7×10^{-8} cm/s.

3. The hydraulic conductivity in core hole CH-3 ranges from about 2×10^{-5} cm/s to about 1×10^{-8} cm/s.

4. The hydraulic conductivity in core hole CH-4 ranges from about 7×10^{-5} cm/s to 1×10^{-9} cm/s.

5. The hydraulic conductivity in core hole CH-5 ranges from about 2×10^{-7} cm/s to about 6×10^{-9} cm/s.

6. The core holes may have been damaged during drilling and as a result hydraulic conductivity estimates that do not consider skin effects may underestimate the hydraulic conductivity of the formation. Alternatively, many test zones may be reflecting the presence of higher permeability within the influence of the test.

7. The static head distribution throughout core holes CH-1 through CH-5 indicate significant artesian pressures at depth with an overall upward gradient.

8. The overall flow pattern at the plant area appears to be downward from the recharge areas on top of Haw and Chestnut Ridges with upward flow near the valleys. Preferential weathering along bedding planes has created a system that, in a vertical section, may contain discreet zones of high head and low permeability. The groundwater flow directions will likely be controlled by bedding strike in a direction orthogonal to the tested cross-section.

9. The average permeability of the test cross-section increases across the section from the Rome Formation to the Knox Formation.

10.0 RECOMMENDATIONS

The following suggestions and recommendations are made, based on the above testing program:

1. The data generated in this report can be used to select permeable zones within the tested boreholes for monitoring well installation.

2. The testing techniques used during the program can be used in other holes at Oak Ridge to select appropriate monitoring well locations.

3. Analysis of static head values indicates that the second flow period should be run for a minimum period of two hours when permeabilities are judged less than 1×10^{-7} cm/sec to avoid errors greater than 1% in static head value in this formation.

4. Groundwater samples should be taken from test sections and analysed for major ions and pH as a matter of course in future testing.

5. Boundary conditions noted in this test sequence will most probably be observed in other boreholes at the Oak Ridge Reservation. Cross-hole hydraulic tests should be performed between boreholes to further examine the value of boundaries.

6. Selected test sections in the existing boreholes should be instrumented with long-term monitoring equipment to establish the trends of hydraulic head and chemistry variations with depth.

7. The conceptual hydrogeologic model developed from this testing program should be further validated by a testing program in boreholes orthogonal to the existing borehole section to establish a third dimension, and examine the role of flow along strike.

8. The presence of natural gases and oil in one borehole is

acknowledged, however, higher level data analysis to account for multi-phase flow was not performed. If, in the future, similar conditions are met, then higher level analysis should be done.

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TABLE 1

DESCRIPTION OF ROCK UNITS IN CHICKAMAUGA GROUP, BETHEL VALLEY (Reference 8)

Unit	Description of Rock	Thickness (in feet)
H	Siltstone, calcareous, gray, olive, maroon; with shaly partings and thin limestone lenses	85
	Limestone of varied types, gray, olive-gray buff, drab; mostly thin-bedded; with argillaceous partings; weathers to shaly appearance; with fossiliferous zones	180
	Limestone, argillaceous (calcareous siltstone), gray, olive-gray, "pinkish" maroon; even-bedded, with shale partings	35
		300
G	Limestone of varied types, dark gray to brownish gray; mostly nodular with abundant black irregular clay partings; dense to medium-grained; mostly thin-bedded, partly massive; with shale partings; weathers to a lighter colored shaly or "nodular" appearance; with some fossiliferous horizons; mostly covered in lowlands	300
F	Siltstone, calcareous, alternating with shale; olive-gray to maroon; even-bedded; laminated; weathers to a red shaly appearance; produces a slight rise in topography; a very distinctive unit	25
E	Limestone, mostly gray to drab, partly pinkish maroon, mottled; brittle, thin-bedded to massive; with shaly partings	60
	Limestone, similar to "G" above, mostly covered in lowlands	220
	Calcareous shale and argillaceous limestone, gray to buff; in alternating thin even beds; yielding small roundish slabs upon weathering, with yellow-buff color	45
	Limestone of varied types, gray; mostly argillaceous and nodular; in thin irregular beds with shale partings; abundant fossils	55
		380
D	Limestone and chert; limestone is gray to olive-gray, in part nodular, shaly, and thin-bedded; in part massive; with abundant chert in thin, even, bands, breaking into angular fragments upon weathering; produces a chain of low hills	160
C	Shale, calcareous, olive-gray to light-maroon; fissile; evenly-laminated	10
	Limestone of varied types, gray; fine to coarse-grained, partly crystalline, partly nodular; mostly massive; with occasional patches of chert; partly fossiliferous; "quarry beds"	105
B	Siltstone, in even beds up to 2 feet thick, laminated, alternating with calcareous shale; olive-gray, buff, maroon; some limestone, non-resistant; more shale at base	215
A	Limestone of varied types, dark gray to buff; with shale partings; with gray to black chert in nodules and lenses	80
	Chert, thin-bedded, with shaly partings	15
	Siltstone, calcareous, olive-gray to maroon; weathers to shaly appearance	30
	Siltstone and chert, in alternating beds; siltstone is calcareous, gray, olive, maroon; weathers to shaly appearance; with abundant granular chert in even beds up to 6 inches thick, breaking into angular blocks upon weathering	90
	Limestone; mostly covered	25
		240
	Total Thickness	1735

TABLE 2

CORE HOLE CH-1
SUMMARY OF PACKER TEST RESULTS (1)

TEST NO.	TESTED ZONE FT. BELOW T.O.C. (T.O.C.=823.72 FT MSL)	ESTIMATED STATIC HEAD (FT MSL)	HYDRAULIC CONDUCTIVITY 1st FLOW PERIOD (CM/S)	HYDRAULIC CONDUCTIVITY 2nd FLOW PERIOD (CM/S)	HYDRAULIC CONDUCTIVITY PRESSURE SLUG (CM/S)	GEOMETRIC MEAN HYDRAULIC CONDUCTIVITY (CM/S)
CH-1-7	0.0 to 35.7	823.3	-	-	-	-
CH-1-7	39.7 to 75.0	824.7	(3) 1.2E-04	(3) 3.2E-05	-	6.2E-05
CH-1-7	79.0 to 385.2	824.5	-	-	-	-
CH-1-2	0.0 to 85.6	823.4	-	-	-	-
CH-1-2	89.6 to 125.0	825.0	(2) 1.5E-04	(2) 2.6E-04	-	2.0E-04
CH-1-2	129.0 to 385.2	827.5	-	-	-	-
CH-1-3	0.0 to 145.8	823.2	-	-	-	-
CH-1-3	149.8 to 185.1	825.5	(2) 2.1E-06	(2) 1.7E-06	-	1.9E-06
CH-1-3	189.1 to 385.2	827.0	-	-	-	-
CH-1-4	0.0 to 175.9	823.0	-	-	-	-
CH-1-4	179.9 to 215.2	825.0	(3) 5.0E-06	(3) 6.3E-06	-	5.6E-06
CH-1-4	219.2 to 385.2	830.0	-	-	-	-
CH-1-6	0.0 to 215.7	822.2	-	-	-	-
CH-1-6	219.7 to 255.1	853.0	(3) 8.3E-08	(3) 8.1E-08	-	8.2E-08
CH-1-6	259.1 to 385.2	829.0	-	-	-	-
CH-1-5	0.0 to 255.9	822.5	-	-	-	-
CH-1-5	259.9 to 295.2	830.0	(3) 6.7E-06	(3) 7.1E-06	-	6.9E-06
CH-1-5	299.2 to 385.2	828.7	-	-	(4) 3.9E-09	3.9E-09
CH-1-1	0.0 to 335.4	(5)	-	-	-	-
CH-1-1	339.4 to 374.7	950.0	(3) 4.1E-09	-	-	4.1E-09
CH-1-1	378.7 to 385.2	960.0	-	-	-	-

NOTES:

(1) THESE RESULTS DO NOT INCLUDE ANALYSIS OF WELLBORE STORAGE, SKIN EFFECTS, ROD LEAKAGE OR BOUNDARY EFFECTS.
(2) CALCULATED AS A RISING HEAD TEST DURING THE FLOW PERIOD.
(3) CALCULATED USING HORNER METHOD FOR SHUT IN PRESSURE BUILD-UP.
(4) CALCULATED USING BREDEHOEFT & PAPADOPULOS METHOD FOR SHUT IN PRESSURE DECAY.
(5) THE UPPER TRANSDUCER FOR THIS TEST WAS NOT OPEN TO THE BORE HOLE/ROD ANNULUS THEREFORE, STATIC HEAD COULD NOT BE ESTIMATED FOR THIS ZONE.

TABLE 3

CORE HOLE CH-2
SUMMARY OF PACKER TEST RESULTS (1)

TEST NO.	TESTED ZONE FT. BELOW T.O.C. (T.O.C.=825.12 FT MSL)	ESTIMATED STATIC HEAD (FT MSL)	HYDRAULIC CONDUCTIVITY 1st FLOW PERIOD (CM/S)	HYDRAULIC CONDUCTIVITY 2nd FLOW PERIOD (CM/S)	HYDRAULIC CONDUCTIVITY PRESSURE SLUG (CM/S)	GEOMETRIC MEAN HYDRAULIC CONDUCTIVITY (CM/S)
CH-2-9	0.0 to 37.1	(2)	-	-	-	-
CH-2-9	41.1 to 76.6	814.6	(3) 4.3E-06	(3) 1.7E-06	-	2.7E-06
CH-2-9	80.6 to 472.8	810.3	-	-	-	-
CH-2-1	0.0 to 117.1	804.8	-	-	-	-
CH-2-1	121.1 to 156.6	813.5	(3) 1.7E-06	(3) 2.2E-06	-	1.9E-06
CH-2-1	125.1 to 472.8	812.6	-	-	-	-
CH-2-2	0.0 to 157.1	804.6	-	-	-	-
CH-2-2	161.1 to 196.6	901.0	(3) 8.4E-08	(3) 6.2E-08	-	7.2E-08
CH-2-2	200.6 to 472.8	811.7	-	-	-	-
CH-2-3	0.0 to 197.1	803.9	-	-	-	-
CH-2-3	201.1 to 236.6	808.4	(3) 1.2E-05	(3) 9.1E-06	-	1.0E-05
CH-2-3	240.6 to 472.8	813.7	-	-	-	-
CH-2-4	0.0 to 237.8	805.3	-	-	-	-
CH-2-4	241.8 to 277.3	809.4	(4) 1.6E-06	(4) 2.1E-06	-	1.8E-06
CH-2-4	281.3 to 472.8	819.6	-	-	-	-
CH-2-5	0.0 to 287.1	805.3	-	-	-	-
CH-2-5	291.1 to 326.6	975.0	(3) 2.8E-08	(3) 2.1E-07	-	7.7E-08
CH-2-5	330.6 to 472.8	823.0	-	-	-	-
(5) CH-2-6	0.0 to 368.1	806.5	-	-	-	-
(5) CH-2-6	372.1 to 407.6	876.0	(3) 1.6E-07	(3) 9.6E-07	-	3.9E-07
(5) CH-2-6	411.6 to 472.8	757.6	-	-	-	-
(5)(6) CH-2-8	0.0 to 417.1	993.1	-	-	-	-
(5)(6) CH-2-8	421.1 to 456.6	(5)	(3) 3.1E-06	(5)	-	3.1E-06
(5)(6) CH-2-8	460.6 to 472.8	927.6	-	-	-	-

NOTES:
(1) THESE RESULTS DO NOT INCLUDE ANALYSIS OF WELLBORE STORAGE, SKIN EFFECTS, ROD LEAKAGE OR BOUNDARY EFFECTS.
(2) THE UPPER TRANSDUCER WAS NOT IN OPERATION DURING TEST NUMBER CH-2-9.
(3) CALCULATED USING HORNER METHOD FOR SHUT IN PRESSURE BUILD-UP.
(4) CALCULATED AS A RISING HEAD TEST DURING THE FLOW PERIOD.
(5) DURING TESTS CH-2-6 AND CH-2-8 THE DOWNHOLE ELECTRICAL EQUIPMENT APPEARED TO RESPOND SPIRATICALLY. THE TRANSDUCER READINGS FLUCTUATED THROUGHOUT THE TESTS. THIS MAY HAVE BEEN AN INDICATION OF BRINE SOLUTION DEEP WITHIN THE CORE HOLE. CONSEQUENTLY, DATA INTERPRETATION WAS DIFFICULT AND IN SOME CASES NOT POSSIBLE.
(6) TEST NUMBER CH-2-7 WAS NOT COMPLETED DUE TO EQUIPMENT FAILURE. THE TEST WAS RESTARTED AS TEST NUMBER CH-2-8.

TABLE 4

CORE HOLE CH-3
SUMMARY OF PACKER TEST RESULTS (1)

TEST NO.	TESTED ZONE FT. BELOW T.O.C. (T.O.C.=797.98 FT MSL)	ESTIMATED STATIC HEAD (FT MSL)	HYDRAULIC CONDUCTIVITY 1st FLOW PERIOD (CM/S)	HYDRAULIC CONDUCTIVITY 2nd FLOW PERIOD (CM/S)	HYDRAULIC CONDUCTIVITY PRESSURE SLUG (CM/S)	GEOMETRIC MEAN HYDRAULIC CONDUCTIVITY (CM/S)
CH-3-1	0.0 to 85.3	795.6	-	-	-	-
CH-3-1	89.3 to 124.6	797.8	(2) 1.1E-05	(2) 1.4E-05	-	1.2E-05
CH-3-1	128.6 to 400.6	801.0	-	-	-	-
CH-3-2	0.0 to 125.0	796.0	-	-	-	-
CH-3-2	129.0 to 164.3	1031.0	(3) 2.5E-08	(3) 7.7E-09	-	1.4E-08
CH-3-2	168.3 to 400.6	804.0	-	-	-	-
CH-3-3	0.0 to 195.3	791.8	-	-	-	-
CH-3-3	199.3 to 234.6	967.5	(3) 1.4E-07	(3) 2.0E-08	-	5.3E-08
CH-3-3	238.6 to 400.6	809.0	-	-	-	-
CH-3-4	0.0 to 235.3	791.8	-	-	-	-
CH-3-4	239.3 to 274.6	831.0	(3) 3.6E-06	(3) 8.4E-07	-	1.7E-06
CH-3-4	278.6 to 400.6	809.5	-	-	-	-
CH-3-5	0.0 to 275.3	795.5	-	-	-	-
CH-3-5	279.3 to 314.6	1030.0	(3) 1.1E-07	(3) 6.2E-08	-	8.3E-08
CH-3-5	318.6 to 400.6	809.0	-	-	-	-
CH-3-6	0.0 to 315.3	796.2	-	-	-	-
CH-3-6	319.3 to 354.6	807.0	(3) 2.3E-05	(4)	-	2.3E-05
CH-3-6	358.6 to 400.6	806.0	-	-	-	-

NOTES:

(1) THESE RESULTS DO NOT INCLUDE ANALYSIS OF WELLBORE STORAGE, SKIN EFFECTS, ROD LEAKAGE OR BOUNDARY EFFECTS.
(2) CALCULATED AS A RISING HEAD TEST DURING THE FLOW PERIOD.
(3) CALCULATED USING HORNER METHOD FOR SHUT IN PRESSURE BUILD-UP.
(4) ONLY ONE FLOW PERIOD WAS COMPLETED FOR CH-3-6.

TABLE 5

CORE HOLE CH-4
SUMMARY OF PACKER TEST RESULTS (1)

TEST NO.	TESTED ZONE FT. BELOW T.O.C. (T.O.C.=796.41 FT MSL)	ESTIMATED STATIC HEAD (FT MSL)	HYDRAULIC CONDUCTIVITY 1st FLOW PERIOD (CM/S)	HYDRAULIC CONDUCTIVITY 2nd FLOW PERIOD (CM/S)	HYDRAULIC CONDUCTIVITY PRESSURE SLUG (CM/S)	GEOMETRIC MEAN HYDRAULIC CONDUCTIVITY (CM/S)
CH-4-10	0.0 to 31.6	790.2	-	-	-	-
CH-4-10	35.6 to 71.1	788.2	(2) 1.7E-05	(2) 1.9E-05	-	1.8E-05
CH-4-10	75.1 to 380.6	788.7	-	-	-	-
CH-4-1	0.0 to 67.1	788.6	-	-	-	-
CH-4-1	71.1 to 106.6	788.7	(2) 1.2E-05	(2) 1.3E-05	-	1.2E-05
CH-4-1	110.6 to 380.6	796.2	-	-	(3) 1.1E-09	1.1E-09
CH-4-2	0.0 to 102.1	790.4	-	-	-	-
CH-4-2	106.1 to 141.6	788.4	(4) 7.4E-05	(4) 6.6E-05	-	7.0E-05
CH-4-2	145.6 to 380.6	790.4	-	-	-	-
CH-4-3	0.0 to 137.1	792.8	-	-	-	-
CH-4-3	141.1 to 176.6	809.5	(4) 6.5E-08	(4) 7.2E-08	-	6.8E-08
CH-4-3	180.6 to 380.6	791.9	-	-	-	-
CH-4-9	0.0 to 172.1	798.4	-	-	-	-
CH-4-9	176.1 to 211.6	1042.5	(4) 5.9E-09	(4) 3.6E-09	-	4.6E-09
CH-4-9	215.6 to 380.6	788.0	-	-	-	-
CH-4-4	0.0 to 207.1	796.0	-	-	-	-
CH-4-4	211.1 to 246.6	795.0	(4) 2.0E-07	(4) 1.5E-07	-	1.7E-07
CH-4-4	250.6 to 380.6	789.6	-	-	-	-
CH-4-5	0.0 to 256.6	800.5	-	-	-	-
CH-4-5	260.6 to 296.1	851.5	(4) 1.3E-08	(4) 1.4E-08	-	1.3E-08
CH-4-5	300.1 to 380.6	789.0	-	-	-	-
CH-4-8	0.0 to 266.1	802.1	-	-	-	-
CH-4-8	270.1 to 305.6	1050.0	(4) 6.1E-09	(4) 1.2E-08	-	8.6E-09
CH-4-8	309.6 to 380.6	783.0	-	-	-	-
CH-4-6	0.0 to 306.6	803.9	-	-	-	-
CH-4-6	310.6 to 346.1	771.5	(4) 4.4E-07	(4) 7.1E-07	-	5.6E-07
CH-4-6	350.1 to 380.6	788.0	-	-	(3) 2.5E-09	2.5E-09
CH-4-7	0.0 to 328.1	805.2	-	-	-	-
CH-4-7	332.1 to 367.6	754.0	(4) 3.1E-07	(4) 6.3E-06	-	1.4E-06
CH-4-7	371.6 to 380.6	785.0	-	-	(3) 3.0E-09	3.0E-09

NOTES:
(1) THESE RESULTS DO NOT INCLUDE ANALYSIS OF WELLBORE STORAGE, SKIN EFFECTS, ROD LEAKAGE OR BOUNDARY EFFECTS.
(2) CALCULATED AS A RISING HEAD TEST DURING THE FLOW PERIOD.
(3) CALCULATED USING BREDEHOEFT & PAPADOPULOS METHOD FOR PRESSURE SLUG DECAY.
(4) CALCULATED USING HORNER METHOD FOR SHUT IN PRESSURE BUILD-UP.

TABLE 6

CORE HOLE CH-5
SUMMARY OF PACKER TEST RESULTS (1)

TEST NO.	TESTED ZONE FT. BELOW T.O.C. (T.O.C.=801.42 FT MSL)	ESTIMATED STATIC HEAD (FT MSL)	HYDRAULIC CONDUCTIVITY 1st FLOW PERIOD (CM/S)	HYDRAULIC CONDUCTIVITY 2nd FLOW PERIOD (CM/S)	HYDRAULIC CONDUCTIVITY PRESSURE SLUG (CM/S)	GEOMETRIC MEAN HYDRAULIC CONDUCTIVITY (CM/S)
CH-5-8 (2)	0.0 to 45.3	-	-	-	-	-
CH-5-8 (2)	49.3 to 84.6	-	-	-	-	-
CH-5-8 (2)	88.6 to 446.4	-	-	-	-	-
CH-5-1	0.0 to 115.3	782.5	-	-	-	-
CH-5-1	119.3 to 154.6	873.0	(3) 5.0E-08	(3) 7.9E-09	-	2.0E-08
CH-5-1	158.6 to 446.4	780.0	-	-	-	-
CH-5-2	0.0 to 175.0	785.0	-	-	-	-
CH-5-2	179.0 to 214.3	790.0	(3) 1.4E-08	(3) 1.3E-07	-	4.3E-08
CH-5-2	218.3 to 446.4	787.0	-	-	(4) 5.8E-09	5.8E-09
CH-5-3	0.0 to 215.3	778.0	-	-	-	-
CH-5-3	219.3 to 254.7	770.0	(3) 2.4E-07	(3) 5.5E-08	-	1.1E-07
CH-5-3	258.7 to 446.4	822.0	-	-	-	-
CH-5-4	0.0 to 265.4	781.0	-	-	-	-
CH-5-4	269.4 to 304.7	980.0	4.5E-07	1.3E-07	-	2.4E-07
CH-5-4	308.7 to 446.4	812.0	-	-	-	-
CH-5-5	0.0 to 295.1	771.0	-	-	-	-
CH-5-5	299.1 to 334.4	941.2	(3) 2.7E-07	(3) 1.4E-07	-	1.9E-07
CH-5-5	338.4 to 446.4	812.0	-	-	-	-
CH-5-6	0.0 to 325.0	760.0	-	-	-	-
CH-5-6	329.0 to 364.4	920.0	(3) 3.3E-08	(3) 8.5E-09	-	1.7E-08
CH-5-6	368.4 to 446.4	754.0	-	-	-	-
CH-5-7	0.0 to 385.0	780.0	-	-	-	-
CH-5-7	389.0 to 424.4	890.0	(3) 1.4E-07	(3) 4.2E-08	-	7.7E-08
CH-5-7	428.4 to 446.4	(5)	-	-	-	-

NOTES:

(1) THESE RESULTS DO NOT INCLUDE ANALYSIS OF WELLBORE STORAGE OR SKIN EFFECTS, ROD LEAKAGE OR BOUNDARY EFFECTS.
(2) CH-5-8 COULD NOT BE COMPLETED BECAUSE THE WATER LEVEL IN THE BORE HOLE WAS AT OR BELOW THE LEVEL OF THE TRANSDUCERS. THE WATER LEVEL HAD NOT RECOVERED TO STATIC CONDITIONS FROM PREVIOUS TESTING.
(3) CALCULATED USING HORNER METHOD FOR SHUT IN PRESSURE BUILD-UP.
(4) CALCULATED USING BREDEHOEFT & PAPADOPULOS METHOD FOR SHUT IN PRESSURE DECAY.
(5) THE LOWER TRANSDUCER WAS NOT IN OPERATION DURING THE CH-5-7 TEST THERFORE THE STATIC COULD NOT BE ESTIMATED FOR THIS ZONE.

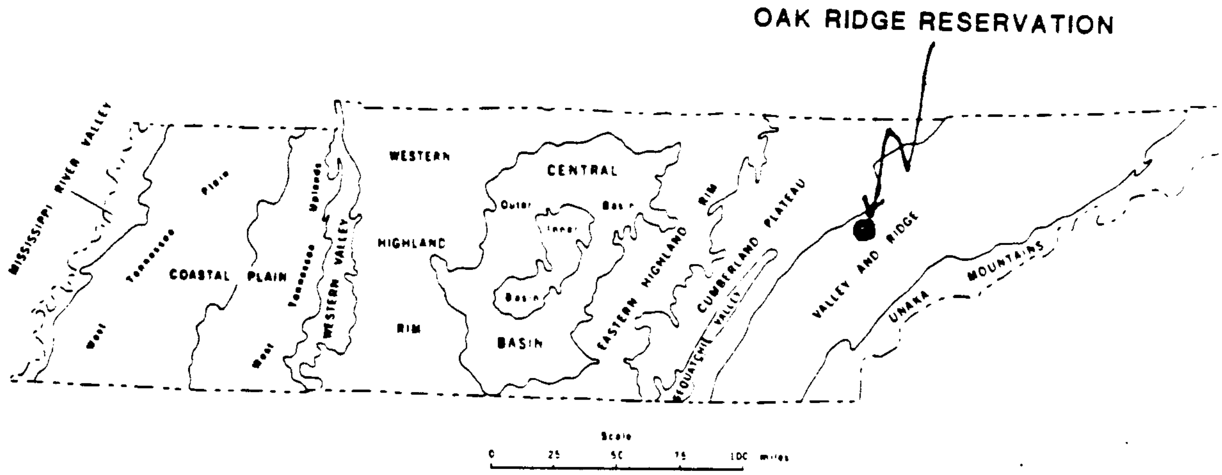
TABLE 7

Short-Term and Long-Term Hydraulic Head Comparisons
(Second Flow Period unless noted otherwise)

Test Number	Static Head Estimate After 30 Mins. (Ft. MSL) (P30)	Static Head Estimate After 90 Mins. (Ft. MSL) (P90)	Static Head Estimate After 12 Hrs. (Ft. MSL) (P12)	Difference P12 to P30 %	Difference P12 to P90 %	Comments
CH-1-6 (1st)	842	845	846	+0.48	+0.12	
CH-2-1	808	810	815	+0.87	+0.62	
CH-2-5	830	900	975	+17.5	+8.3	Long Response
CH-3-4	833	834	835	+0.24	+0.12	
CH-4-3	808	808	805*	-0.37	-0.37	Boundary Noted
CH-4-8	945	935	942**	-0.32	+0.75	Boundary Noted
CH-5-1 (1st)	847	848	848	+0.12	0	
CH-5-7	896	900	890	-0.67	-1.1	Boundary Noted

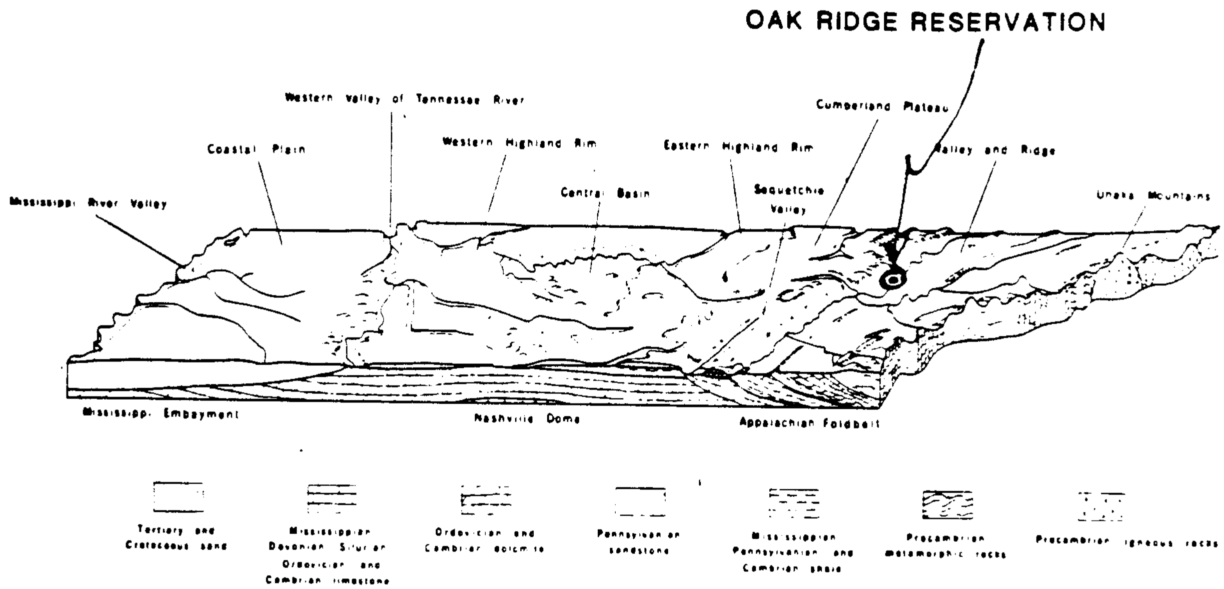
* Test run longer than 12 hours; final head is 835 Ft. MSL, but boundaries are influential.

** As above; final head 852 Ft. MSL.



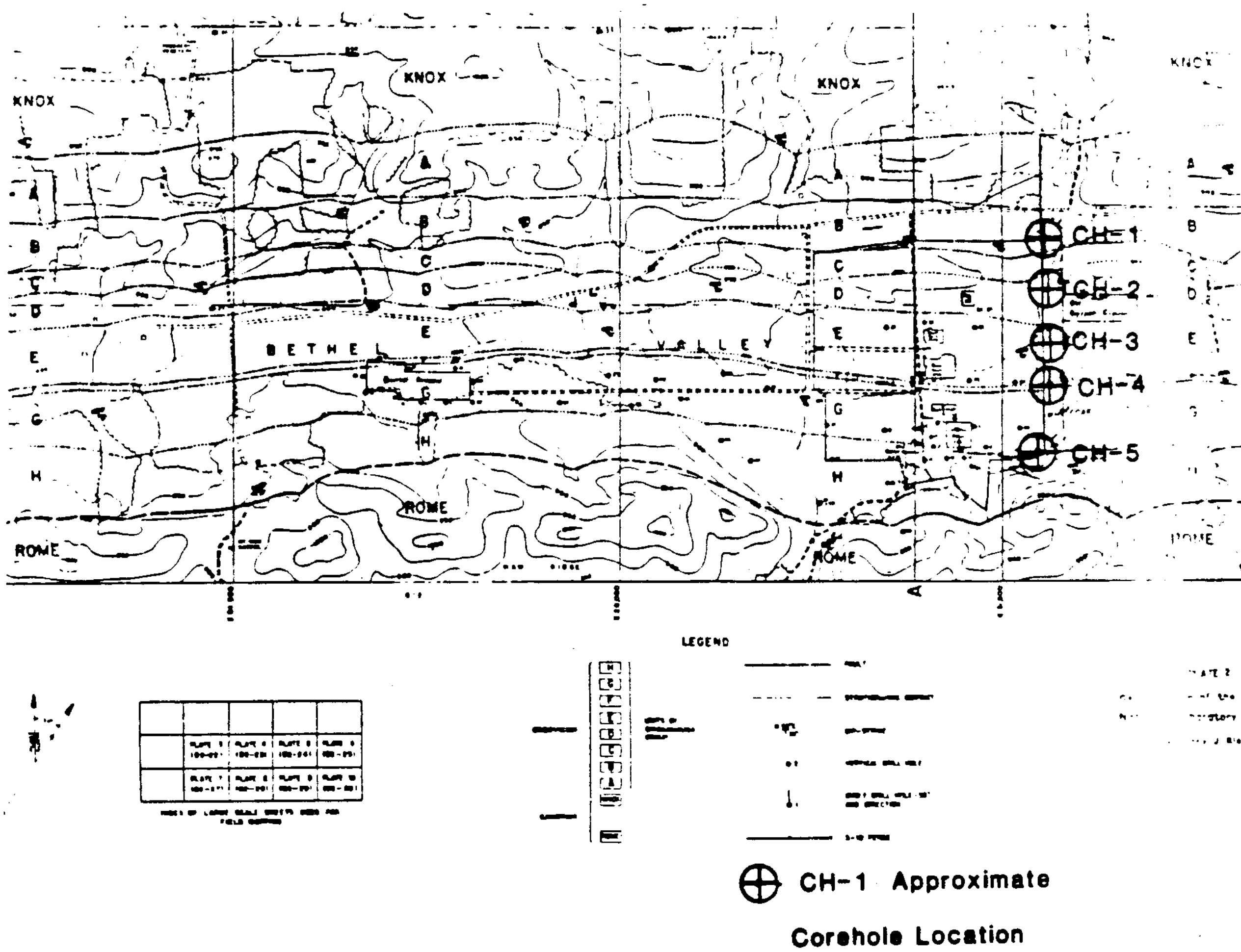
AFTER MILLER AND MAHER (REFERENCE 7)

JOB NO. 863-3386.3	SCALE N.T.S.	PHYSIOGRAPHIC MAP OF TENNESSEE AND LOCATION OF OAK RIDGE RESERVATION	
DRAWN RP	DATE 6/3/87		
CHECKED WBL	DWG NO. 21		
Golder Associates			FIGURE 1



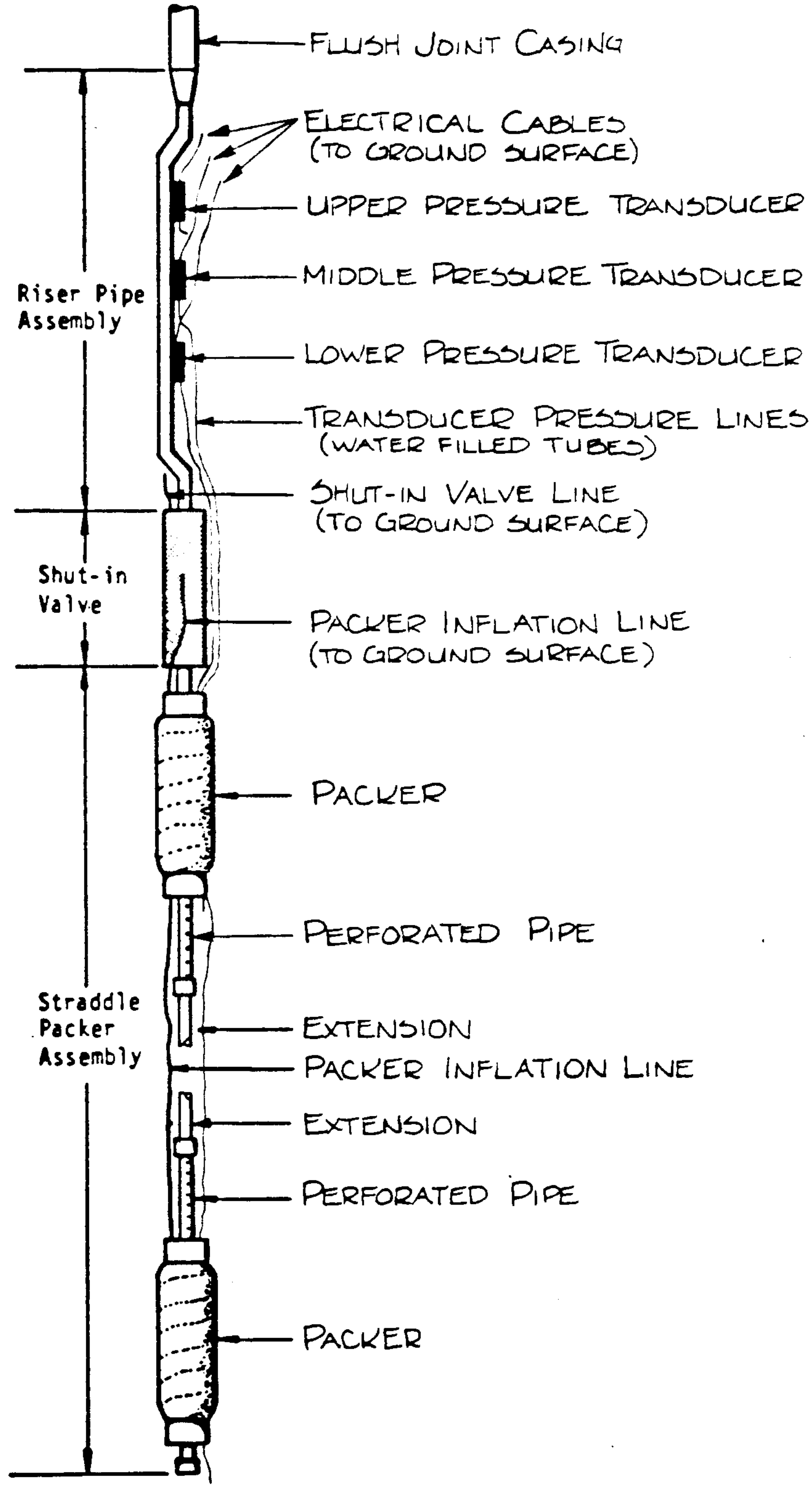
AFTER MILLER AND MAHER (REFERENCE 7)

JOB NO. 863-3386.3	SCALE N.T.S.	RELIEF MAP OF TENNESSEE SHOWING THE RELATIONSHIP OF MAJOR GEOLOGIC STRUCTURES TO PHYSIOGRAPHIC UNITS
DRAWN RP	DATE 6/3/87	
CHECKED WBL	DWG NO 22	
Golder Associates		FIGURE 2

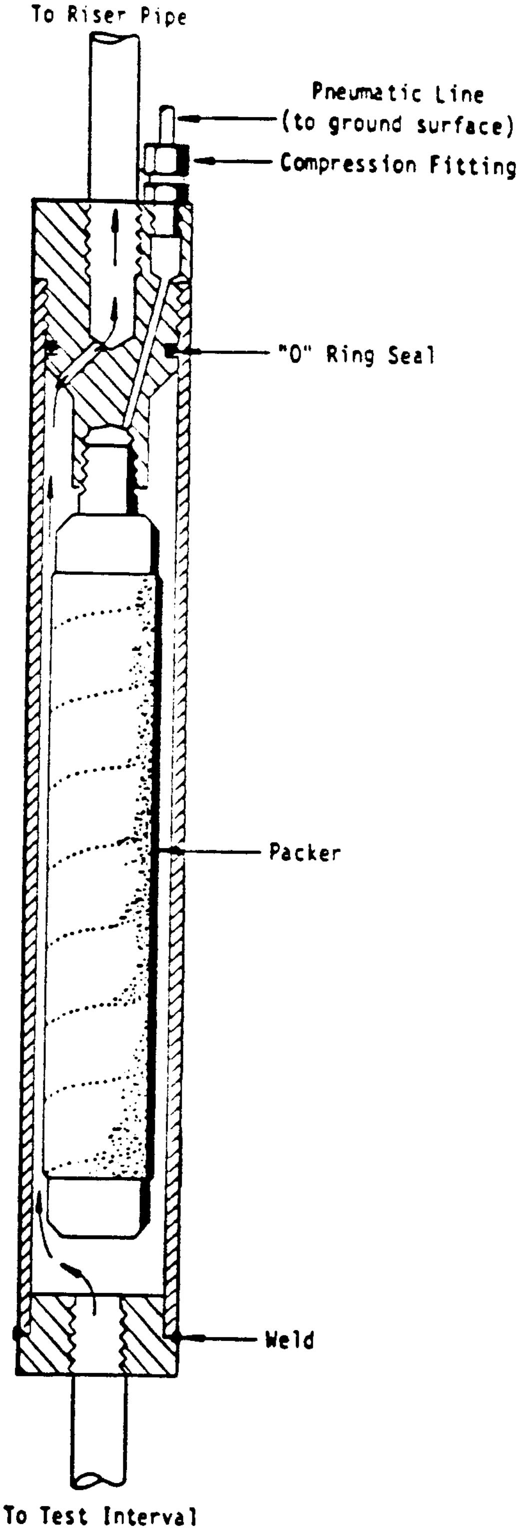


NOTE: GEOLOGIC MAP (REFERENCE 8) PROVIDED BY MARTIN MARIETTA.

JOB NO 863-3386.3	SCALE AS SHOWN	GEOLOGICAL UNITS AND CORE HOLE LOCATIONS AT THE TEST SITE
DRAWN RP	DATE 6/3/87	
CHECKED WBL	DWG NO 23	
Golder Associates		FIGURE 3

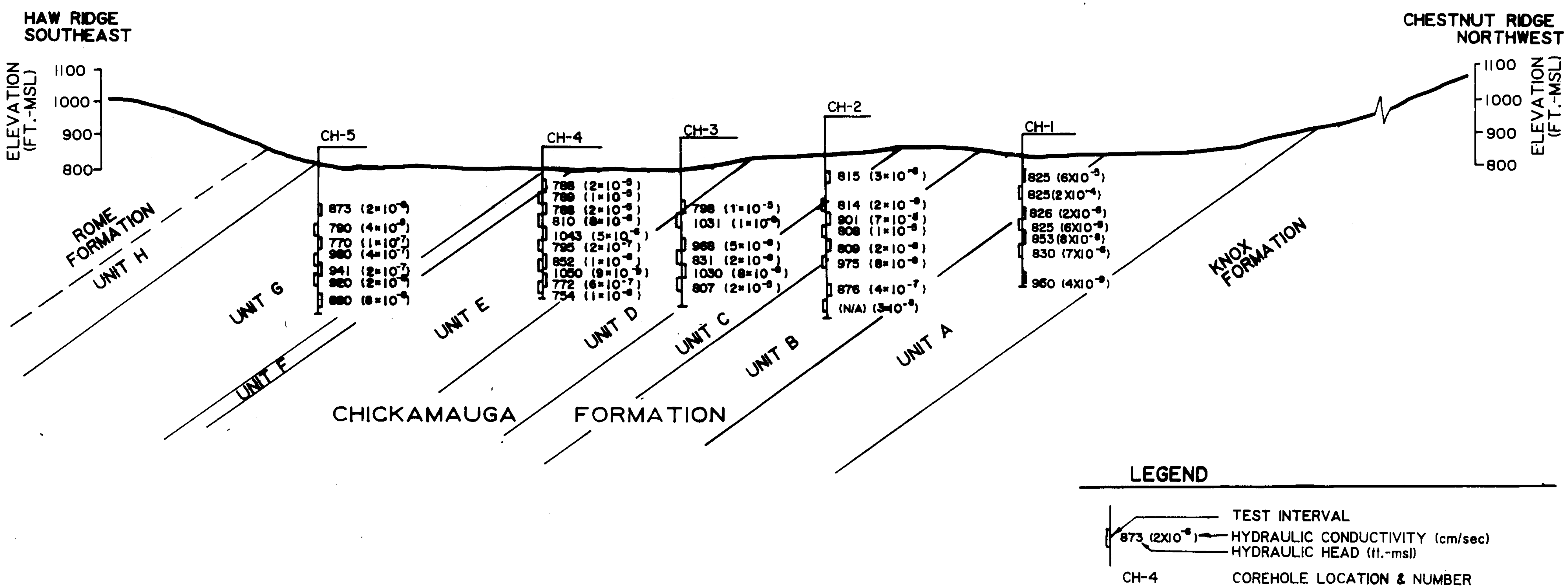


JOB NO. 863-3386.3	SCALE N.T.S.	DRILLSTEM TOOL
DRAWN LJW	DATE 2/19/87	
CHECKED WBL	DWG NO. 17	
Golder Associates		MARTIN MARIETTA, INC. — FIGURE 4



JOB NO. 863-3386.3	SCALE N.T.S.	SHUT IN VALVE DETAIL	
DRAWN LJW	DATE 2/19/87		
CHECKED WBL	DWG. NO. 18		
Golder Associates		MARTIN MARIETTA, INC.	FIGURE 5

A F 20440C-C



SCALE IN FEET

0 300 600 900

NO VERTICAL EXAGGERATION

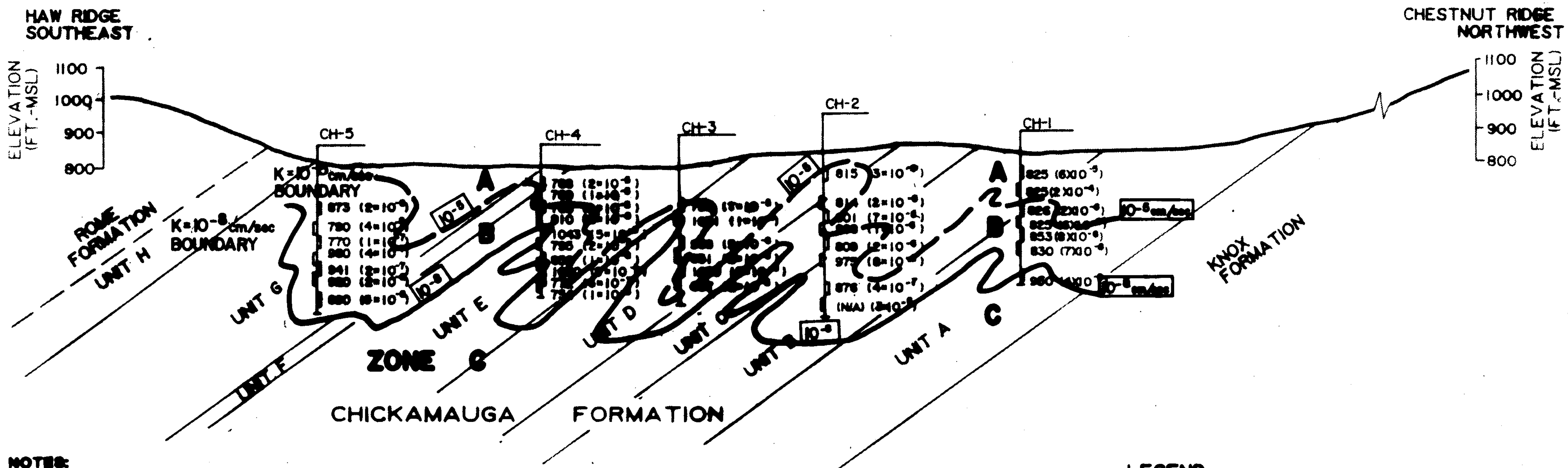
STRATIGRAPHY BASED ON DATA PUBLISHED IN "GEOLOGIC CONDITIONS AT THE OAK RIDGE NATIONAL LABORATORY (X-10) AREA RELEVANT TO THE DISPOSAL OF RADIOACTIVE WASTE" P.B. STOCKDALE, AUGUST, 1951 REPORT NO. ORO-58

SUPERCEDED BY REV. ___
DATE ___

FILE No. 863-3386

JOB NO. 863-3386.3	SCALE AS SHOWN	SOUTHEAST-NORTHWEST GEOLOGICAL CROSS-SECTION-BETHEL VALLEY OAK RIDGE NATIONAL LABORATORY	
DRAWN T.s. R.	DATE 3/31/87		
CHECKED RP	DWG. NO. 20/REV. 1		
Golder Associates		MARTIN-MARIETTA	FIGURE 6

A F 20440C-D



NOTES:

ZONE A FLOW SEMI-INDEPENDENT OF BEDDING. LOCAL FRESH WATER FLOW CELLS ARE DEVELOPED IN HIGHLY WEATHERED AND FRACTURED ROCK ($K>10^{-5}$ CM/SEC)

ZONE B FLOW CONTROLLED BY BEDDING. FLOW MAINLY ALONG STRIKE IN PARTIALLY WEATHERED AND DISCRETELY FRACTURED ROCK (10^{-8} CM/SEC $< K < 10^{-5}$ CM/SEC)

ZONE C LOW FLOW UNITS IN UNWEATHERED ROCK HEADS 950 FT. MSL INFLUENCED BY NEARBY RIDGES AND LOW PERMEABILITY ($K< 10^{-8}$ CM/SEC) BOUNDARY CONDITIONS, OR BY REMNANT PORE PRESSURES.

LEGEND

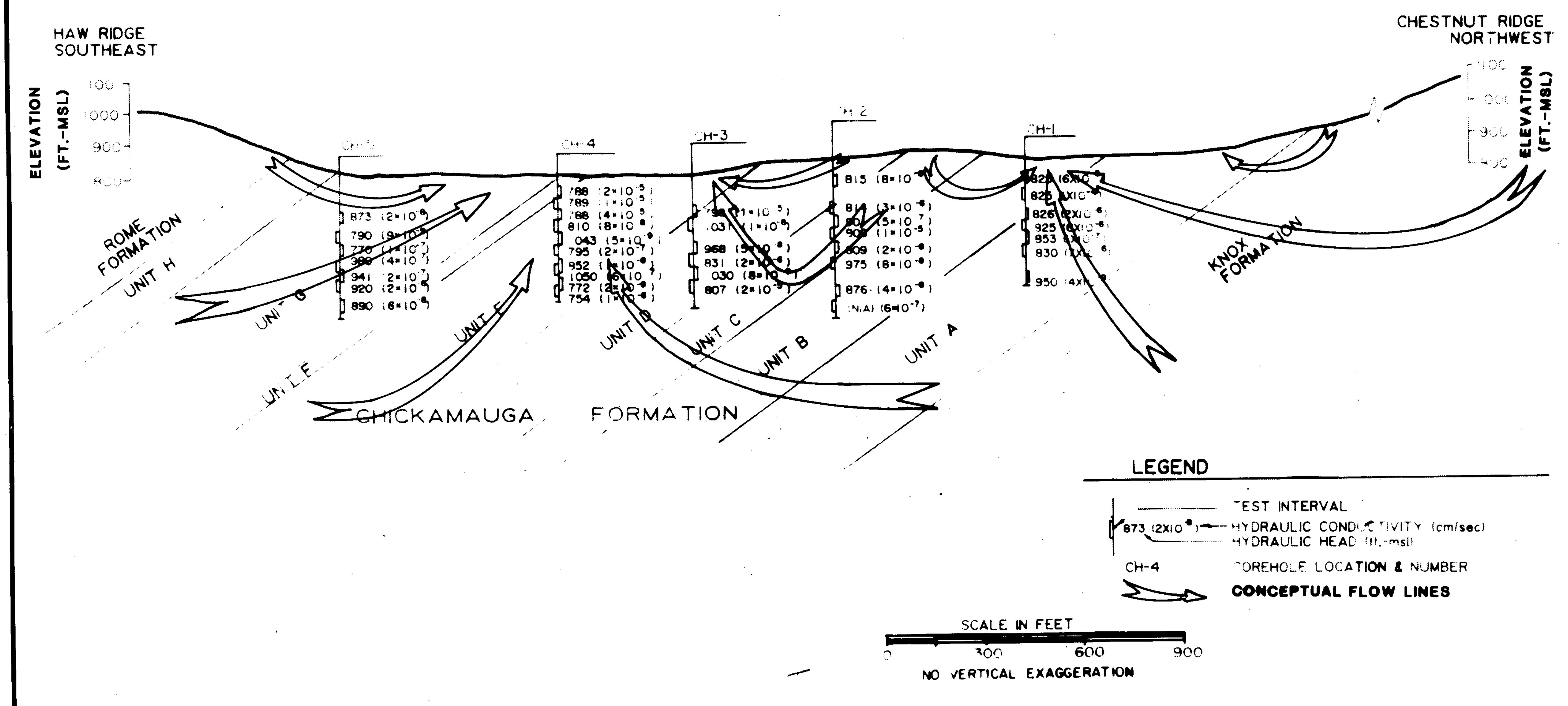
- TEST INTERVAL
- 873 (2×10^{-8}) — HYDRAULIC CONDUCTIVITY (cm/sec); HYDRAULIC HEAD (ft.-msl)
- CH-4 — COREHOLE LOCATION & NUMBER
- 10^{-8} — $K = 10^{-8}$ cm/sec PERMEABILITY BOUNDARY
- 10^{-5} — $K = 10^{-5}$ cm/sec PERMEABILITY BOUNDARY

SCALE IN FEET
0 300 600 900
NO VERTICAL EXAGGERATION

JOB NO. 863-3386.3	SCALE AS SHOWN	POSTULATED WEATHERING EFFECT ON BETHEL VALLEY OAK RIDGE NATIONAL LABORATORY FLOW SYSTEM	
DRAWN JLW	DATE 8/28/87		
CHECKED RP	DWG NO 20/REV. 1		
Golder Associates		MARTIN-MARIETTA	FIGURE 7

FILE No. 863-3386

SUPERCEDED BY REV. ___ DATE ___



JOB NO. 863-3386.4	SCALE AS SHOWN	CONCEPTUAL FLOW MODEL BETHEL VALLEY OAK RIDGE NATIONAL LABORATORY
DRAWN AMC	DATE 6/3/87	
CHECKED	DWG. NO. 25	
Golder Associates		MARTIN MARIETTA — FIGURE 8

APPENDIX A

GOLDER FIELD CORE LOGS

PROJECT Martin Marietta / Groundwater / Oak Ridge	JOB NO. 863-3386	BORING NO. CH-1 /DATE	SHEET 1 OF 2
BORING BEGAN –	BORING COMPLETED –	CORE HOLE LOCATION –	
METHOD OF CORING –	DRILLING FLUID –	GR.ELEV – WEATHER –	
CASING USED – SIZE –		INSPECT – OPERAT. –	WATER LEVEL,TIME,DATE –

DEPTH (FT.)	RUN NUMBER	RECOVERY est	RQD est	DISCONTINUITIES: DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY	LITHOLOGY	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
								frac/ft	sea/30	10/3			NO CALCAREOUS				
				25									START CORING @ 21.5' / INTERBEDDED RED SHALE (70%) AND LIGHT GREY LIMESTONE (30%) (MICRITIC) / BEDS PLANAR TO CONTORTED 0.5 TO 15 CM THICK FRACTURES MOST COMMON IN CONTORTED BEDDING				
		~.95	~.40		F1 FR	CLAY	60	2-10	35								
		~.95	~.75	31'				2-5	17				NO LIMESTONE 32' - 42'				
		~.95	~.65		F1P R-S	LIMONITE, CALCITE		0-5	12				42'-44' - RED, PALE GREEN AND GREY MED. GR SPARRY LS VERTICAL FRAC. COMPLETELY HEALED W. COARSE PINK CALCITE SOME THIN, IRREGULAR SHALE PARTINGS				
50		~.90	~.65		F1PR			1-5	35				44' - RED CALC SHALE 90% / GREY MIC. LS 10% FRACS 30-60° LINED WITH LIMONITE OR LIMONITE COATED CALCITE XLS				
		~.95	~.75					0.5	12				60' AS ABOVE, LS ~5%, WEATHERED & FRAC. ZONES @ 60.5' & 63-64				
		~.95	~.95	73	F1PS	LIMONITE	30	0.2	5				73 LIMONITE STAINED JOINT FRACS PLANE CLEAR, MOSTLY INDUCED BELOW 73'				
		~.95	~.80	86	F1FR	CLAY	70	0.4					82-83.5 - RED, MED. GREEN & GREY THIN BEDDED MED GR SPARRY LS / high ∠, clay lined frac. @ 86'				
		~.90	~.85	83.5 88.5	F1PS	CLAY	30	0.4	10				LIMESTONE AS ABOVE, 93.5-96' FRACTURE ZONE WITH CALCITE & LIMONITE FILLED FRACTURES AT 94' LOST ~0.5' CORE HERE				
				94	F1IR	CLAY	30-50						LIMONITE FILLED FRAC. AT LS-SHALE CONTACT AT 96'				
100					INDUCED												
		~95	~95										107' MED GREY MIC. LIMESTONE				
		~.95	~.95										117' LIGHT GREY MED GR LIMESTONE WITH CONTORTED SHALY PARTINGS (BIOTURBATED) 0.2' SHELL FRAGS AT TOP OF UNIT				
		~.95	~.95														

NOTES: CLAY FILLED BEDDING PLANE FRACTURES PREDOMINATE TO ABOUT 73'
HIGH ANGLE FRACTURES PREDOMINATE TO 126'
SLICKENSIDED FAIRLY TIGHT FRAC'S THROUGHOUT, CONCENTRATED AT 195-205
BRECCIATED ZONES AT 279' AND 299'

SCALE: 1 DIVISION= FEET

DATE

LOGGED BY AES

Golder Associates

PROJECT *Martin Marietta / Groundwater / Oak Ridge* JOB NO. *8633286* BORING NO. *CH 1* DATE *10-22* SHEET *2* OF *?*

BORING BEGAN – BORING COMPLETED –

CORE HOLE LOCATION –

METHOD OF CORING – DRILLING FLUID – GR.ELEV – WEATHER –

CASING USED – SIZE INSPECT – OPERAT. –

WATER LEVEL,TIME,DATE –

DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES: DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY	LITHOLOGY	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
125'		>95	>95	126	FIPR	PYRITE, CALCITE	~70°	0-1					LIGHT GREY MED. GR LIME-STONE WITH CONTORTED SHALY PARTINGS AND BEDS (1-20 CM) OF DARK GREY MICRITE (BIOTURBATED)				
		>95	>95		INDUCED			0					138' V THIN BEDDED LIGHT-MED GREY VF-F GR LIMESTONE				
		>95	>95					0					146-148 LIGHT GREY MED GR LS WITH CLASTS OF DARK GREY MICRITE ~5 CM AND THIN (~2 MM) IRREGULAR FRACTURES COMPLETELY HEALED WITH WHITE CALCITE				
150		>95	>95					0					– BRYOZOANS @ 157.5				
		>95	~90					0					158 – THIN BEDDED TO CONTORTED BEDDED LIGHT GREY MED GR LS & DARK GREY MICRITE WITH SOME MICRITE CLASTS, CALCITE FILLED FRACTURES ASSOCIATED WITH MICRITE CLASTS, AND ~4 CM CHERT BEDS				
		>95	>95	167.1	FIPKC	NO SIGN OF WEATH. OR FILLING		3/FT					STYLOLITES 167-177				
		>95	>95	187	FIPKC		30°	2/FT									
				188	FIPKC			1/FT									
		>95	~90	195.5	FIPKC		30°	2/FT					190.0 <u>OIL</u> FILLED VUGS IN CALCITE FILLED FRACTURE	*			
200'		>95	~80	195-205	FIPK	C	30°	1-5/FT					~195 MED GRAINED LIGHT GREY LIMESTONE WITH PLANAR SHALY PARTINGS AND THIN BEDDED MICRITE – THICK-NEAR VERTICAL FRACTURES COMPLETELY HEALED WITH WHITE CALCITE – SLICKENSIDED FRACTURES ALONG SHALE PARTINGS – SOME CHERT BEDS	*			
		>95	~90										210 V. THICK (~3 CM) NEAR VERT. CALCITE FILLED FRACTURE				
		>95	>95					0					THIN BEDDED TO MASSIVE LT GREY MED GR LS, SOME MICRITE				
		>95	>95										228-232 GRADING TO DUSKY RED CALCAREOUS SHALE				
		>95	>95	243'	FIPK	C	30°	1					235 INTERBEDDED DUSKY RED CALCAREOUS SHALE 50% & LT GREY F-MED GR LIMESTONE (50%)				
250'		>95	>95					0					247 AS ABOVE, LIMESTONE 70% SHALE 30%				

NOTES:

0-107' SHALE
107-230' LIMESTONE
230'- SHALE & LIMESTONE

SCALE: 1 DIVISION = 10 FEET

DATE LOGGED BY *AES*

PROJECT Martin Marietta / Groundwater / Oak Ridge JOB NO. 863-3386 BORING NO CH-1 DATE SHEET 2 OF 3

BORING BEGAN – BORING COMPLETED – CORE HOLE LOCATION –

METHOD OF CORING – DRILLING FLUID – GR.ELEV – WEATHER –

CASING USED – SIZE – INSPECT – OPERAT. – WATER LEVEL,TIME,DATE –

DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY	LITHOLOGY	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
250'		>95	>95					0					INTERBEDDED LT GREY MED GR LIMESTONE (60%) AND DUSKY RED CALCAREOUS SHALE (30%) BEDS .5-5 CM				
		>95	>95														
				264.5	FIPK	C	30°	2/ft					265 SHALE 80% LS 20%				
								0									
		>95	>95	272.5	FIPK	C	30°	1/ft									
								0									
		>95	85	278	FIPR	MYLONITE	30°	4/FT					278.5-279.5 LIMESTONE, AS ABOVE, WITH ROUGH FRACTURES, FILLED WITH CALCITE MYLONITE AND TR PYRITE	*			
								0									
		>95	>95										280' SHALE 50% LIMESTONE 50%; 286 SHALE 70% LIMESTONE 30%				
300		>95	85	299	FIPR	CLAY	30°	6/ft					BROKEN ZONE IN SHALE 299-299.5 THICK CLAY (= SHALE MYLONITE) FILL - CHIPS ~1 CM THICK	*			
								0									
		>95	90	306	FIPS	PYRITE	60°	1/ft					306 - high ∠ frac in L.S. SOME PYRITE - OTHERWISE VERY FRESH LOOKING				
								0					THICK CALCITE FILLED NEAR VERT. HEALED FRAC AT 313'				
		>95	>95										CHERT BED AT 322				
		>95	90	323.5	FIPK	C	30°	2/FT					321.5 - GRADES TO LIGHT GREY MED GR LIMESTONE WITH THIN BEDS CONTORTED BEDS AND CLASTS OF SHALE AND MICRITE SOME CALCITE FILLED FRACS AND VUGS				
		>95	>95										AS ABOVE, WITH DUSKY RED SHALY MICRITE AND CALCAREOUS SHALE (50%)				
								0									
		>95	>95														
350													CHERT BEDS BELOW 352				
		>95	>95														
		>95	90	365	FIPK	C	30°	2/FT									
													370 AS ABOVE W/O SHALE				
		>95	>95	372	FIPK	CLAY	30°	1/FT									

NOTES: >95 90 380 FIPK C 30° 3/FT

SCALE: 1 DIVISION = 10 FEET

TD LOGGED = 385.2'

DATE LOGGED BY AES

PROJECT MARTIN MARIETTA / GROUNDWATER / OAK RIDGE / TN JOB NO. 865-3386 BORING NO. CH 2 DATE 2-3 SHEET OF 5

BORING BEGAN — BORING COMPLETED — CORE HOLE LOCATION CH-2

METHOD OF CORING — DRILLING FLUID — GR.ELEV — WEATHER —

CASING USED — SIZE — INSPECT WGG OPERAT. — WATER LEVEL, TIME, DATE —

DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES: DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY/FT	LITHOLOGY	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
5													CORING BEGAN @ 7.9'				
7.9 10	1	40/41 ~98%	25/41 61%	8.2' 8.3' 8.5' 8.7'	FIPS & FIPK	— CL	25- 30°	0-5	L.S. (11)	LT GR	FINE-COARSE XLN	SL-none	GRAY XLN LIMESTONE + lithographic (10%) W/DK GRAY LAMINATIONS w/occ. STYOLITES BEDDING ≈ 25° @8.7 sl-v. s' @12.4 SL-SL				
12.0 15	2	7.3/8.0 91%	6/8.0 75%	12.4' 13.5' 15' 17.3' 17.8 SL-VSL	FIPK FIIR FIIR FIPR FIPR	— MU/CA CA MU —	10° 5° 10° 40° 25°	0-3	LS. (17)		XLN	SL-NON	SAME LITH. ONLY BEDDING SLIGHTLY VUGGY @ 15.0' w/STYOLITE TYPE STRUC. @18.2' 9" CAVITY (black marl)				
20.0 25	3	10.1/10.2 99%	7.8/10.2 76%	25.7' 26.1 27.1 28.1 29.4 30.0	FIPS FIPS FIPK FIPR FIPK FIPS	CA CA/MU — FE/CA — FE/CA	30° 40° 30-40°	0-2	LS (3)			NON	SAME LITH @30 SL WEATH FRAC.				
30.2 35	4	10/10 100%	>95%	31.3 40.0	FIPS FIPS	CL SILT	 35°	0-1	LS (11)				- SL. WEATH FRAC. @ 31.3 32.5 - 37.5 Abun. Styolites - @ 40' FRAC SL WEATH.				
40.3 45	5			41.4 42.5 42.7 42.9 44.0 44.3	FIPS FIPS FIPR FIPS	— CL/CA	35° 35° 60° 40 60	0-3	LS. 17			NON	@42.7 60° FRAC — MOD WEATH. @42.9' - FRAC. SL. WEATH.				
50.3 55	6			50.7	FIPR		~30	0-2	LS (7)				GRAY XLN & LITHOGRAPHIC L.S.				
60.4	7			60.1		FE	45										

NOTES: SCALE: 1 DIVISION = FEET

DATE 1-25 LOGGED BY WGG.

Golder Associates

PROJECT MARTIN MARIETTA/GROUNDWATER/OAK RIDGE, TN	JOB NO. 863-3356	BORING NO. CH2 DATE – SHEET 2 OF 5
BORING BEGAN – BORING COMPLETED –		CORE HOLE LOCATION CH-2
METHOD OF CORING – DRILLING FLUID –	GR.ELEV. – WEATHER –	
CASING USED – SIZE –	INSPECT WGG OPERAT. –	WATER LEVEL, TIME, DATE

Scale	DEPTH (FT.)	RUN/BOX NUMBER	RECOVERY	RQD	DISCONTINUITIES DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY	LITHOLOGY	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
60	60.4	Box 6-7 7	>98%	>98%	60.7	FIJR	Rf/ca			LS	GR	Xln/lith	None					
					~68.0	FIPK	CA	~90°	0-1	(2)				Fresh S.S.				
					~65.4	FIPS	Cly/ca	~35						@ infilling/weath.				
70	70.6	Box 7&8 8	>95%		~71.0	FIPS	Cly/mu	~40						[illegible] w/ occ. lithograph LS; [illegible] light & dark gray laminations/[illegible]				
						FIPX 600 Fresh Tight			0-9	LS (21)								
80	80.8	Box 8&9 9	9.2/9.9 >95%	>95%		FIPK	CA	50-60°	0.2	~6				S.S. Frac @ ~55° from ~78.6-79.6' mod fresh w/minor Ca infill				
90	88.7		>95%	~60%		FIPK	[illegible]/CA		0-4	~11				Frac generally fresh - S.S. ~5 fresh S.S. frac ~91-92'; ~98' - more open frac.				
100	98.4		>95%	>95%		–			0	0								
	100.9		>95%	>95%		FIPK	–		0-1	2-3				All frac fresh				
110	110.6	Box 11/12				FIFR	Cly/Fr		0-1	2				@ ~113.6 small clay-filled 'spot' - alter to clay.				
120	120.6													Note - [illegible] CHERT NODULES & lenses from 20.5' to ~102'				

NOTES:

SCALE: 1 DIVISION= FEET

DATE LOGGED BY

PROJECT MARTIN MARIETTA/GROUNDWATER/OAK RIDGE, TN JOB NO. 863-3586 | BORING NO. CH 2 DATE 12-4 SHEET 3 OF 5

BORING BEGAN — BORING COMPLETED —

CORE HOLE LOCATION CH-2

METHOD OF CORING — DRILLING FLUID — GR.ELEV — WEATHER —

CASING USED — SIZE — INSPECT WGC OPERAT. — WATER LEVEL,TIME,DATE —

Scale	DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY	LITHOLOGY	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
120	120.6	12/13	>95%	>95%	—	FIPK 2 FIPS	CL/CA		0-1	4				– 2 cl/sl f. frac @ ~125 & 127.5' – weath majority of frac are along – dark gray lithographic LS Bands.				
130	130.8	13/14	>95%	>95%	—	—			0	0								
140	140.7	14/15	>95%	>95%	—	FIPK			0-2	3				Fracs fresh				
150	150.9	15/16	>95%	>95%	—	FIIR			0-1	3				Fracs – mod fresh – sl. weath				
160	161	16/17	>95%	>95%	—	FIPK	occ CA.	25-35°	0-2	4	dk gray			ss. frac fairly fresh ~178-183.4 are xln LS – not banded or mottled. Dark gray.				
170	171	17/18	>95%	>95%	179.4	FIPK(8) FIPR(1)		30-40 [illegible]	0-1	4				FIPK – fresh FIPR @ ~ has sign amount of CA * xln precip along frac – appeared open				
180	180.4	18/19	>95%	>95%	–	FIPK			0.2	4				– ss frac fresh (prob mech break) tight				
190	190.6	19/20	>95%	>95%		FIPK & FIIR		30-40°	0-2	4				@ 190 ft – Change from banded/mottled light & dark gr xln & lith LS to dark gray lith LS. w/occ stylolite type structure ss. frac fresh non weath tight				
200	200.8	20/21	>95%	>95%	~209.2 ~210'	FIPS 2 FIPK	CA/[illegible] CA	[illegible]° 60°	0-1	2				* Frac appear open & mineralized – w/ weath 210.6-211 – purple color				
210	211	21/22	>95%	>95%		—	–	–	0	0	Purple			featureless – nondescript – lithographic LS				
220	221	22/23	>95%	>95%	225'	FIPK		~25-30° ~60° & 25°	0-2	5	purple & gray			@ 227.5' – change in color from dk gray lith LS to purple (~60-70%) alternating w/ laminations (often crenulated) and mottle greenish gray lith LS – deform. in lamin. is from soft sediment deform. features & prob. dysl [illegible].				
230	231	23/24		[illegible]	~237.3 ~238	FIPK FIPK	CA/w/ Si weath		0-2	3				all ss frac fresh & tight except @ ~228 – sl. weath – poss – open				
240	241	24/25																

NOTES: CONT NEXT PAGE

SCALE: 1 DIVISION = 10 FEET

DATE 12-4 LOGGED BY WGC

Golder Associates

PROJECT MARTIN MARIETTA/GROUNDWATER/OAK RIDGE, TN	JOB NO 83-5386 3	BORING NO CH2	DATE 7-11	SHEET 4 OF 5
BORING BEGAN –	BORING COMPLETED –	CORE HOLE LOCATION CH-2		
METHOD OF CORING –	DRILLING FLUID –	GR.ELEV –	WEATHER –	
CASING USED – SIZE –		INSPECT –	OPERAT. –	WATER LEVEL,TIME,DATE –

Scale	DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES: DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY Fract/ft	Total Fracs	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
240	241	23/26	>95%	>95%	249.8 251.3	FIPK	– Tr of CL Tr of CL	10-30°	0-2	5	Purple &			SAME AS PREV PAGE. – All fracs but 2 (@~249.8' & 251.3') sl weath are fresh & tight				
250	251.3	26/27	>95%	>95%				–	0	0				Purple & gray Lith. LS.				
260	261.7	27/28	>95%	>95%	~266	FIPS FIPS	– CL	~30 ~30	0-1	3				@ 266' sl weath frac.				
270	271.5	28/29	>95%	>95%		FIPS	.	25°	0-3	6				Bedding @ ~25° - frac // to bedding along shaly parting. All frac fresh & appear tight except @ ~276 - 1 frac sl weath				
280	281.7	29/30	>95%	>95%		FIPK		25-45°	0-1	3				Frac. appear fresh & tight				
290	291.9	30/31	>95%		296.8	FIPR & FIPR	CA	30 & 60° 60°	0-1	3				~298.0 - 300.0 - gray Xln LS @ 296.8 frac w/ Ca min – appears open				
300	302.1	31/32			307.5 308.3	FIPS FIPS	–	~60° ~15	0-1	2				@ 307.5 & 308.3 fracs are sl weath				
310	312.3	32/33			320 320.5	FIPR FIPR		~30° ~30°	0-2	2				Frac fresh-clean & tight				
320	322.5	33/34			324.2	FIPR	Tr CA Fe Fe	~30°	0-2	4				@ 324.2 Frac weath & Fe stained				
330	332.7	34/35			326.8	FIPR NOT FRESH		60°	0-1	2								
340	342.9	35/36		"	351' & 352.5'	FIPR	CA	20°	0-1	2								
350	353.1		"	"		FIPK	–	25-40°	0-2	4				All 5's frac fresh & tight, prob mech induced.				
360	361.1																	

NOTES:

SCALE: 1 DIVISION = 10 FEET

DATE 12-4-86 LOGGED BY WGG

Golder Associates

PROJECT Martin Marietta / Groundwater / Oak Ridge, TN	JOB NO. 863-3386	BORING NO. CH-2	DATE — SHEET 5 OF 6
BORING BEGAN —	BORING COMPLETED —	CORE HOLE LOCATION CH-2	
METHOD OF CORING —	DRILLING FLUID —	GR.ELEV —	WEATHER —
CASING USED — SIZE —		INSPECT — OPERAT. —	WATER LEVEL, TIME, DATE —

DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES: DEPTH	DISCONTINUITIES: TYPE	DISCONTINUITIES: INFILLING	DISCONTINUITIES: ANGLE W/AXIS	DISCONTINUITIES: FREQUENCY (frac./ft)	~~LITHOLOGY~~ Total no. of fractures	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
361.1		>92% but ?	>80% ?	- 371	FIPK FIPR	Fresh Trace CA	~30 ~60	0-1	3	Purple some gr.			Note - 10.0 feet of core between 361.1 & 373.5 mon-block spacers "~2.4' error" purple w/occ. bands & laminae of greenish-gray stiff lithographic LIMESTONE w/occ. layers of reddish gray xln LS (≤ 1' thick)				
373.5		>95%	>95%	382.5	FIPK FIPS	Cont. MN	30° 60°	0-1	2				- Bedding 30° @ 382.5 frac. sl weath. w/MN-min				
383.7		100%	100%	-		-		0	0								
391.7		? >80%	? >80%		FIPK (fresh)	-		0-1	2				SS - fresh Note 10.0' of core but 404.1 − 391.7 = 12.4' marked "error marking run" 12.4				
404.1		>95%	>95%	405.5 410.9 411 413'	FIPR FIPS FIPK FIPS	CL CL CL	~60° ~30° ~30° ~30°	0-2	4				(as written on core) - @ 410.9 frac. has a dendritic clay residue feature @ 411 SS frac. sl weath. @ 413' frac. sl weath w/CL infill				
414.3		>95%	>95%		FIPK (fresh)			0-1	1								
424.5		>95%	>95%	—	FIPK (fresh)			0-1									
434.7		>95%	>95%	439' 442?	FIPK ?	CL		0-1	2				@ 442.4 - poss. frac. - core spun or rock sl weath adjacent to frac. w/tr. of clay				
444.7		>95%	>95%	453.9 454.2	FIPS FIPK	CA CA	60° 30°	0-2	2				@ 447.6' - core spun on				
454.7		>95%	>95%	455.2 463.3-463.8	FIPS FIPS(4)	CA CL	~60° & 30° ~30°	0-4	7				- fresh secondary thin calcite of frac. 463.3 - 463.8 - 4 fractures that are sl weath. that all have clay infill				
464.7		>95%	>95%	470.4	FIPK	fresh		0-1	1				SS fresh				
472.5													CORING TERMINATED @ 472.8'				

NOTES:

SCALE: 1 DIVISION = 10 FEET

DATE 12-4-86 LOGGED BY WGC

PROJECT Martin Marietta / Groundwater / Oak Ridge JOB NO. 863-3386-3 BORING NO. CH-3 DATE 12-4-86 SHEET OF 4

BORING BEGAN — BORING COMPLETED — CORE HOLE LOCATION CH-3

METHOD OF CORING HQ DRILLING FLUID — GR. ELEV — WEATHER —

CASING USED — SIZE — INSPECT — OPERAT. — WATER LEVEL, TIME, DATE —

DEPTH (FT)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY (fracs / ft)	~~LITHOLOGY~~ (# of fracs)	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
0													CHICKAMAUGA LS.				
10													STARTED CORING @ 11.1' BGS.				
11.1	1	>95%	~58% (85)		FIPS FIPR	CL & CA	25-40°	0-4	18	GR	LITH. & XLN	SL-NCN	GRAY TO DARK GRAY BANDED AND OCCASIONALLY MOTTLED LITHOGRAPHIC ALT w/ XLN. LIMESTONE (DARK GRAY BANDS GENERALLY LITH. LS.) FOSSILIFEROUS w/BRACS. 11.6-20.6 - ALL FRACS ARE SL-MOD WEATH - GENERALLY CLAY FILLED				
20.6	2/3	>95%	50%		FIPS & FIPR	CN Tr of CL	10-40°	0-8	16				20.6-30.6 majority of fracs clean-fresh occ. Tr of CL				
30.6	3/4	>95%	>95%	34.4	FIPS & FIPR (FIPR)	CA	15-35°, ~60°	0-2	6				-fracs generally fresh - BRACS - ABUNDANT @ 34.4 - frac looked pitted/solutioned				
40.6	4/5	>95%	>95%		FIPR FIPS	Tr/CAL CL	20-30°	0-3	11				- fracs mostly fresh/tight				
50.6	5/6	>95%	>95%	7 fracs 53-54'	FIPR FIPS	CL/CA & Tr FeS2	20-30°	0-7	16				majority of fracs S.S				
60.6	6/7	>95%	>95%	64.96 7 @ 60' —	FIPR FIPR & FIPS	CA / CL/CA	60° 20-30°	0-3	10				60° frac appears sl. solutioned; low & fracs generally fresh.				
70.6	7/8	>95%	>95%		FIPR FIPS	Tr of CL/CA	20-30°	0-3	7				- fracs generally tight.				
80.6	8/9	>95%	>95%	85'	FIPR FIPR	CA Tr of CL, CA, Fe, Mn?	60°	0-4	9				- @ 85' frac (60°) appears [illegible]; - many fracs SL weath				
90.6	9/10	>95%	>95%	92.6	FIPR FIPR FIPS	Tr CA; CL, CA Fe & Mn?	20-30°	0-3	14				* 3 clay filled (30°) fracs from 97.5' to 98.4'				
100.6	10/11	>95%	>95%	110.3	FIPS FIPR FIIR	Tr CL, CA Fe & Mn	10-30°	0-2	9				- other fracs [illegible] fresh to sl. weath & appear tight. @ 110.3 frac [illegible] filled [illegible] frac.				
110.6	11/12	>95%	>95%	~116.1 ~118.3 ~120.1	FIPR FIPR & FIPS	Tr CL CA Mn?	10-30°	0.2	7				- fracs generally fresh appear tight. fracs @ 116.1, 118.3, 120.1 sl. pitted/[illegible] NOTE 115.6-122.9' COARSELY XLN LIMESTONE SOLID GRAY (NO BANDS OR LAMINATIONS)				
120.6																	

NOTES:

SCALE: 1 DIVISION = 10 FEET

DATE 12-4-86 LOGGED BY WGG

PROJECT MARTIN MARIETTA/GROUNDWATER/OAK RIDGE TN	JOB NO. 863-3386	BORING NO CH-3 DATE 2-5-86 SHEET 2 OF 4	
BORING BEGAN -	BORING COMPLETED -	CORE HOLE LOCATION CH-3	
METHOD OF CORING -	DRILLING FLUID -	GR.ELEV -	WEATHER -
CASING USED - SIZE -	INSPECT -	OPERAT -	WATER LEVEL,TIME,DATE -

DEPTH (FT.)	RUN NUMBER	RECOVERY	ROD	DISCONTINUITIES DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY	LITHOLOGY (# of fract.)	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
120	12/13	795%	795%		FIPK FIPU	TI CA, MN	30°	0.5	12	GR			126.14 – 128 DISTINCTIVE LAMINATED WELL PARTED SHALEY LS. ABUNDANT SHEARING ALONG BEDDING (30°) - FRACS APPEAR FRESH AND TIGHT				
130 / 130.6	13/14	795%	795%	137' / 140	FIFR / FIPS	CL	30°	0-4	17			SL-[illegible]	BLACK STYOLITIC STRUCTURES APPEAR TO BE MANGANESE OXIDE (BLACK) WHEN SEEN BROKEN APART. @136.7 FRAC DOES NOT LOOK TIGHT. 137.5 – 138.5 – WELL PARTED ALONG BEDDING SS. @140' CLAY INFILLING (MOST FRACS APPEAR TIGHT)				
140 / 140.6	14/15	795%			FIPK SS	CA & MN	25°–30°	0-4	18				123 – 130 – GRAY XLN LS. 130 – ALT. LITHO & XLN GRAY & DARK GREY LS. majority of fracs have some to [illegible] amount of Ca infill (generally appear tight)				
150 / 150.6	15/16	..		150.6 – 151.6 (5 fracs)	FIPK	CA MN	30°	0-5	[illegible]				144.4 – 173.1 GRAY XLN LS w/ OCC. DK GR LAMINAE & OCC. CHERT NODULES & layers				
160 / 160.6		.	.	169.3	FIPK / tight FIPR	TI CL	30°	0-2	9				- ALL FRACS FRESH/TIGHT w/ EXCEPTION @169.3' TI CL / SL WEATH				
170 / 170.6		..	..		FIPK	TI CA, CL		0-2	5				- Generally fresh & tight.				
180 / 180.6		..	.	184'	FIPK / FIPK	Some CL TI CA / CL	30°	0-3	7				@184' – frac w/ clay weath.				
190 / 190.6		..	..		—	-	-	0	0			[illegible]	173 – to 215 Gray & Dark Gray mottle & laminated LS w/ occ chert nodules				
200 / 200.8		.	..		FIPK FRESH/TIGHT	TI CA	30°	0-1	3				-				
210 / 210.6		..	..	215.8	FIPS FIPK	CL		0-3	12				* NOTE – 0.2' of CLAY BETWEEN FRAC @ 215.8'. OCCASIONAL PARTIALLY HEALED FRACS (GENERALLY ~6") Between 206 – 260				
220 / 220.6		..	..	222.2 223	FIPR FIPS FIPK	TI CA		0-2	9				XLN – CALCITE – DRUSY LINING IN PARTIALLY OPEN FRACS. @ 222.2 & 223' FRAC LOOK OPEN BUT [illegible]/SL. SOLUTIONED				
230 / 230.6					FIPK FIPR FIPS	CA CA CA			8				- most fracs have Ca-[illegible] infill.				
240 / 240.6																	

NOTES:

SCALE: 1 DIVISION = 1.0 FEET

DATE

LOGGED BY WGC

Golder Associates

PROJECT MARTIN MARIETTA/GROUND WATER/OAK RIDGE	JOB NO. 843-3386 S	BORING NO. CH-3 DATE 2-5-86	SHEET 3 OF 4
BORING BEGAN –	BORING COMPLETED –	CORE HOLE LOCATION CH-3	
METHOD OF CORING –	DRILLING FLUID –	GR.ELEV – WEATHER –	
CASING USED – SIZE –		INSPECT – OPERAT. –	WATER LEVEL,TIME,DATE –

DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY (fractures/ft)	Total fract/10'	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
240		>95%	>95%		FIPR FIPS	CA MN	~30°	0-2	5			NONE	225-294' Reddish Gray XLN- fine-crs) LS. [illegible] LS w/some calcite rexlization of shell fragments (or fracs) forming large clear sparry xls occasional dark gray laminae and chert nodules				
250.6		>95	>95%	~254 – solution	FIPR	CA/MN	~70° 60°	0-1	4				– (@245 1 – partially healed [illegible] frac	3/8"	open	ns	
260.6		>9[illegible]%	>95%	261.1 / 266.5	FIPR FIPR FIPR	MN CA		0-2	7				@261 – fine pitted [illegible] (black) – 266.5 – same				
270.6		>95%	>95%		FIPR FIPK	CA/MN and CL	30°	0-3	3								
280.6		>95%	>95%		FIPR FIPS	CA MN	~30°	0-2	7				– fracs – fresh & tight. 284 to 300' Dark gray [illegible] LS w/laminations/[illegible]				
290.6		>95%	>95%	297.1 298	FIPR FIPS	CL & CA	30° 30°	0-4	6				from 297.1 – 298' – 4 fractures w/shear zones producing mylonite along shear 2 of the fractures are clay filled calcite features offset				
300.6		>95%	>95%	–	FIPR (fresh) tight			0-2	5								
310.6		>95%	>95%	~312.7	FIPR FIPK	CA/MN tight fresh CL/CA		0-2	5				@312.7 frac appears clean but solutioned. 300 – 40[illegible] – dark & lt gray laminated, banded & occ. mottled xln LS [illegible] DARK GRAY LAMINAE ARE LESS CALCAREOUS – CALCAREOUS SHALE				
320.6		>95%	>95%		FIPK (fresh/tight)		~30°	0-2	5								
330.6		>95%	>95%	~332.5	FIPR FIPK	CA/MN	70°	0-3	7				@ ~ 332-332.8 – LARGE (70°) OPEN FRAC COATED w/SECONDARY CALCITE XLS				
340.6		>95%	>95%	–	FIPK FIPR	CA MN	~30°	0-2	7				– ALL FRACS TIGHT & FRESH SS.				
350.6		>95%	>95%	~352.2	FIPR FIPS FIPK (tight)	CA CA/MN	60° 30	0-2	6				@ 352.2 – calcite coated frac appears open				
360.6																	

NOTES: 35 – most broke or were probably mech. broken along the pre-existing planes of weakness; they are fresh and tight

SCALE: 1 DIVISION = 10 FEET

DATE

LOGGED BY WGG

Golder Associates

PROJECT MARTIN MARIETTA / GROUNDWATER / OAK RIDGE, TN	JOB NO. 925-5386 5	BORING NO. CH3 DATE 12-5-86 SHEET 4 OF 4
BORING BEGAN –	BORING COMPLETED –	CORE HOLE LOCATION CH-3
METHOD OF CORING –	DRILLING FLUID – / GR.ELEV – WEATHER –	
CASING USED – SIZE –	INSPECT – OPERAT. –	WATER LEVEL, TIME, DATE –

DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES: DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY (fract/ft)	LITHOLOGY (total fracs)	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN./FT.
360 / 360.6	37/38	>95%	>95%		FIPK (fresh/tight)	Trd CA	~30°	0-2	4								
370 / 370.6	38/39	"	"	373.1	FIPR / FIPK	CA	~70°	0-4	8				@ ~373.1 - OPEN - CALCITE COATED FRAC				
380 / 380.6	39/40	"		~386'	FIPR / FIPK(s) (tight)	CA	~65°	0-2	4				@ ~386 possibly ~(65°) frac coated w/ calcite xls				
390 / 390.6	40/41				FIPK tight/ fract		~30	0-1	3				390.6-400.6 Grey lithographic L.S.				
400 / 400.6													CORING TERMINATED @ 400.6				
													NOTE: 270-390 - occ. sec. white high ∠ (~60-90°) calcite stringers have lateral offset				
													[illegible]				

NOTES:

SCALE: 1 DIVISION = FEET

DATE

LOGGED BY [illegible]

Golder Associates

PROJECT Martin Marietta / Groundwater / Oak Ridge, TN	JOB NO. 863-3532.3	BORING NO. CH-4 DATE 12-5-86 SHEET 1 OF 4
BORING BEGAN –	BORING COMPLETED –	CORE HOLE LOCATION CH-4
METHOD OF CORING –	DRILLING FLUID – / GR.ELEV – WEATHER –	
CASING USED – SIZE –	INSPECT – OPERAT. –	WATER LEVEL, TIME, DATE –

DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES: DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY (fracs/ft)	Total # of fracs	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN./FT.
0													Note pieces of limonite stained limestone gravel above 14.2 (~0.4' + rubble) STARTED CORING @ 14.2'				
14.2	1	4.6'/5.9 78%	2.6'/5.9 44%		FIPS FIPK	CL RED [illegible]	20-30°	2->10	>30	Dusky Red & GR.	–	–	Gray sl. to intensely weathered GR LS and Dusky Red calcareous shale and shaly L.S. - limonite coatings on fracs -17-20' intensely weath. LS and shale (weath. to calcareous rubble)				
20.1	1/2	4.2/6 70%	1.9/6 31%		FIPS FIPK	CL LIMON.	20-30°	2-5	~15				~20.1 contact between Dusky Red LS & calc. shale (~20') and Gray sparry L.S.				
24.4	2	5.5/6.2 89%	1.6/6.2 26%		FIPK FIPS	CL/SILT	20-50°	1-5	~17				Fracs generally weath. below 30' w/ calc. filling.				
30.6	2/3	~96%	7.7/9. ~82%		FIPK LIPS	CL & some CA	~30°	0-5	~18				-39.6-40' weath. zone other fracs mod. tight but sl. weath.				
40	3/4	~95%	~86%		FIPK	CL TR/ CA	~30°	~4	~18								
50	4/5	~95%	~72%		FIPK	CL CA	~30°	0-4	~19				- many fracs have a thin clay or silt coating				
60	5/6	>95%	6.1 ~61%		FIPK FIPS	CL CA	~30°	0-6	~24				20- Gray - sparry LS w/ dark gray laminae that are less calcareous 69-70' - six (6) fractures w/ thin CL coating sl. weath. - majority of other fracs fresh.				
70	6/7	>95%	>90%		FIPK	Tr of CL & CA	~30°	0-3	9				* Below 70' very few weath. fracs. LS becomes less sparry - more lithographic				
80.2	7/8	>95%	>95%		FIPK mostly fresh & tight		~30°	0-2	8				fossil rich / pebble 81-91' & [illegible] less [illegible]				
90.2	8/9	>95%	>95%		FIPK		30°	0-2	7				Fossil rich from ~96' to 99.0' abundant pellets				
				99.6	FIPK	CL	~30°						@ 99.6 - sl. [illegible] frac				
100.7	9/10	>95%	>95%		FIPK FRESH/TIGHT			0-2	5								
110.5	10/11	>95%	>95%	110.7	FIPK	CL/CA		0-2	6				@ 110.7, 116.9, 117.6 - frac. show weath. or Ca deposition				
					FIPK												
				116.9 117.6	FIPK	CA CL/CA	~30°										
120.6																	

NOTES:

SCALE: 1 DIVISION = FEET

DATE 12-5-86 LOGGED BY WLG.

Golder Associates

PROJECT MARTIN MARIETTA/GROUND WATER/OAK RIDGE/TN	JOB NO. 863-3386	BORING NO. CH-4	DATE 2-5-86 SHEET 2 OF 2
BORING BEGAN —	BORING COMPLETED —	CORE HOLE LOCATION CH-4	
METHOD OF CORING —	DRILLING FLUID —	GR.ELEV —	WEATHER —
CASING USED — SIZE —		INSPECT —	OPERAT. —
WATER LEVEL,TIME,DATE —			

DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES: DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY	~~LITHOLOGY~~ Total Frac	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
120	12/13	>95%	>95%	~125.3	FIPK	CA	~30°	0-1	1	GR			(DARK GRAY BANDS) GRAY BANDED/LAMINATED & OCC. MOTTLED LIMESTONE				
130.6	13/14	>95%	>95%		FIPK		~30°	0-2	4				– Becoming more sparry				
				~136.5	FIPK OTHERS FRESH	CA	30°										
140.6	[illegible]	>95%	>90%		FIPK	REC. CA TI & CL	~30°	0-3	13				. A few fracs have SL WEATH & CA.				
150.6		>95%	>90%		FIPK mostly fresh & tight	OCC CA	30-40°	0-3	12								
160.6		>95%	>95%		FIPK		30-40°	0-2	7								
				168.5	FIPK	CA [illegible]	40°										
170.6		>95%	>90%		FIPK FRESH/ & TIGHT		30-40°	0-2	9								
180.6		>95%	>90%	-	FIPK ALL FRESH & [illegible] TIGHT		30-40°	0-2	13								
190.6		>9[illegible]	>95%		FIPK ALL FRESH & TIGHT		30-40°	0-3	7								
200.6		>95%	>95%		FIPK fresh/ Tight		30-40°	0-2	7								
210.6		>95%	>95%	~215.1	FIPK	CLY CL		0-3	8				@ 215.1 - frac SL WEATH other fracs · fresh/tight				
220.6		>95%	>95%	224.1	FIPS FIPK	CLY		0-4	9				@ 224.1 - mod weath frac.				
				226.2	FIPK	CL COAT							@ 226.2 - SL weath frac - clay coated All other fracs appear fresh/tight				
230.6		>95%	>95%	232.3	FIPR FIPK	60°		0-2	8				- P.Hole-/poss sol. frac (clean looking)				
240.6																	

NOTES: BOTTOM OF HOLE 380.6'
FRAC [illegible]

SCALE: 1 DIVISION = 10 FEET

DATE

LOGGED BY WGL

Golder Associates

PROJECT MARTIN MARIETTA/GROUNDWATER OAK RIDGE TN	JOB NO. 863-3386	BORING NO. CH 4 DATE 12-8	SHEET 3 OF 4
BORING BEGAN —	BORING COMPLETED —	CORE HOLE LOCATION CH-4	
METHOD OF CORING —	DRILLING FLUID —	GR.ELEV —	WEATHER —
CASING USED — SIZE —	INSPECT. —	OPERAT. —	WATER LEVEL,TIME,DATE —

	DEPTH (FT.)	BOX NUMBER	RECOVERY	RQD	DISCONTINUITIES: DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY	LITHOLOGY (total # of fract.)	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
240	240.6	24/25	>95%	>95%		FIPK tight & fresh	Tr CA	15-30°	0-2	8	GR			SAME LITH. BANDED DARK GRAY & GRAY PARTY LIMESTONE				
250	250.6	25/26	>95%	>95%		FIPK mostly fresh & tight	Tr CA/MN	25-50°	0-3	12				@ 256 & core spun on				
260	260.6	26/27	>95%	>95%	@265.1	FIPK / FIFR	CA/ sl/CL / CL	20-30°	0-3	11				@ ~265.1 - CL-FILLED/WEATH FRAC. (Remaining fracs fairly fresh & appear tight.				
270	270.6	28	>95%	>95%		FIPK fresh look tight		20-30°	0-4	10				290.5 - 299.5 DARK GRAY MICRITIC LS w/ FEW LIGHT GRAY BANDS				
280	280.6	29/30	>95%	>95%		FIPK fresh/tight	CA/MN Tr of CL	15-30°	0-3	11								
290	290.9	30/31	>95%	>95%	298.8	FIPK / FIPR	CA/Tr CL	~20°	0-2	7								
300	300.6	31/32	>95%	>95%	306.9 / 307.5	FIPK to FIPK fresh/tight	CA/Tr CL / CA/Tr CL	30° / 20-35°	0-3	12				2/SL. WEATH FRACS/TR of CL.				
310	310.6	32/33	>95%	>95%		FIPK (fresh/tight SS	MN/black stain	25-35°	0-4	14				NOTE FROM 270 - 340.6 logged when light was very poor & fracture types were difficult to distinguish				
320	320.6	33/34				FIPK mostly fresh tight	Tr CA & CL	25-35°	0-2	8								
330	330.6	34/35	>95%	>90%	337.-339.6	FIPK	CA/CL	30-60°	0-5	3				* 339.2 → 339.6 4-5 fracs that have SL-MOD weath. w/ some Tr of CL, & calcite xl coating. (Remaining fracs appear rel. tight & fresh.)				
340	340.6	35/36	>95%	>95%		FIPK tight/fresh		20-25°	0-2	7								
350	350.6	36/37	>95%	>90%	367.3 / 368.1	FIPK / FIPK / FIPR	Tr CA/CL / CA Tr CL	~35° / 15°-35° / ~60° & ~35°		11				@ ~367.3 SL-SL. very SL. weath. @ 368.1 - open frac w/ solut. pitted surface & secondary calcite xl coating. - 368.2 ft - 372.5 - solid gray (no lamin/banding) crs xln sparite				
360	360.6																	

NOTES: SLICKENSLIDED FRACTURES ARE THE PREDOMINANT FRACTURES OBSERVED - THESE FRACTURES ARE GENERALLY FRESH AND APPEAR VERY TIGHT UNLESS OTHERWISE NOTED

SCALE: 1 DIVISION= FEET

DATE [illegible] LOGGED BY [illegible]

Golder Associates

PROJECT MARTIN MARIETTA / GROUNDWATER / OAK RIDGE, TN JOB NO. 863-3386

BORING NO. CH-4 DATE 12-9-86 SHEET 4 OF 4

BORING BEGAN – BORING COMPLETED –

CORE HOLE LOCATION CH-4

METHOD OF CORING HQ DRILLING FLUID – GR.ELEV – WEATHER –

CASING USED – SIZE – INSPECT – OPERAT. –

WATER LEVEL, TIME, DATE –

DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES: DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY (fracs/ft)	LITHOLOGY (total fracs.)	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
360	57/58	~95%	~90%	~364-365	FIPK FIPK FIPS	– – –	~35° 25-35° 5-25°	0-4	9	GR			4 fracs from ~364.1-365.1 - moderately fresh w/ Tr. of weath. on occ. fracs. (Fracs. generally found in more argillaceous zones)				
370	58/59			380.3 or 380.5	FIPK Dominant FIPS FIPK 36(?)	– –	0-5° 30-45° 35-40°	0-3	18	GR			~365-370.4 Gray & Dk Gray LS thinly laminated (argillaceous laminae) w/ laminae offset occ. 370.4-380.6 TD GRAY (xln or sparry) LS sugary texture w/ occ. calcite-xl coated vugs & partially healed fracs. (appears tight)				
380 380.6													COMPLETED LOGGING CORE @ 380.6 FINAL BOX - #39 NOTE SL-SL - FRACS & 2 J.H. sets. in LS from 370.6-380.6 set 1 - 3-5° subhorizontal ?) set 2 - 30-45° (expected)				
390																	
400																	
410																	
420																	
430																	
440																	
450																	

NOTES:

SCALE: 1 DIVISION= FEET

DATE 12-9-86 LOGGED BY LWG

PROJECT Martin Marietta / Groundwater / Oak Ridge	JOB NO. 863 3386	BORING NO. CH5 DATE	SHEET 1 OF 4
BORING BEGAN –	BORING COMPLETED –	CORE HOLE LOCATION –	
METHOD OF CORING –	DRILLING FLUID –	GR.ELEV – WEATHER –	
CASING USED – SIZE –		INSPECT. – OPERAT. –	WATER LEVEL, TIME, DATE –

DEPTH (FT.)	BOX NUMBER	RECOVERY	RQD	DISCONTINUITIES: DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY	LITHOLOGY	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
10								FRAC/FT					START CORING @ 12.7				
20		~80	~60		FI PR	CLAY, LIMONITE	~20°	1-5				SL WT	DUSKY RED CALC SHALE AND SHALY MICRITE (60%) MED. LIGHT GREY MASSIVE MICRITE (40%) FRACTURES IRON STAINED & CLAY FILLED BDG ~20°				
30	1	~90	~80		FI PE	C	~20	1-3				NONE	~20' THIN BEDDED MED TO LIGHT GREY MICRITE FRAC'S CLEAN; 42- LIGHT-MED GREY MICRITE W. CONTORTED BDG & DARK GREY CLASTS ~1CM	P			
40	2	~90	~85					1-2						NE C			
50	3	>95	>95					0-1					V. LIGHT GREY W FLATTENED PELLETS & CLASTS ~5-2 CM @ 57 & 58' (WASH INS)	P			
60	4	>95	>95					0-1						M2C			
70	5	>95	>95		FI PK	C	~20°	0-1					~70' GRADES TO THICK BEDDED (2-10 CM) FINE TO MED GR LIMESTONE WITH CONTORTED SHALY LIMONITIC PARTINGS; W. SLICKENSIDED FRAC'S @ 70.5 & 72.5	C			
80	6	>95	>95					0									
90	7	>95	>95										W STYLOLITES & HEALED, CALCITE FILLED FRACS AT 97'-98.5' (5-10CM); 102' W BEDS OF V. LIGHT GREY OOLITES, FLATTENED PELLETS & CLASTS IN MED GR MATRIX	P			
100	8	>95	>95														
110	9	>95	>96														
120																	

NOTES:

SCALE: 1 DIVISION= FEET

DATE LOGGED BY AES

Golder Associates

PROJECT Martin Marietta/Groundwater/Oak Ridge	JOB NO. 863-3386	BORING NO. CH-5 DATE	SHEET 2 OF 4
BORING BEGAN —	BORING COMPLETED —	CORE HOLE LOCATION —	
METHOD OF CORING —	DRILLING FLUID —	GR.ELEV — WEATHER —	
CASING USED — SIZE —		INSPECT — OPERAT. —	WATER LEVEL,TIME,DATE —

DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES: DEPTH	TYPE	INFILLING	ANGLE	FREQUENCY	LITHOLOGY	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN./FT.
125								0					INTERBEDDED LIGHT GREY F-M GRAINED LIMESTONE WITH CONTORTED SHALY PARTINGS (50%) (V SOFT SHALE BED (2cm) @ 132') AND V LIGHT GREY TO MED GREY OOLITES, CLASTS & SHELLS (OSTRACODES, BRYOZOANS) IN LIGHT GREY MED GRAINED MATRIX (50%) 3D 5-15 CM				
	>95	>95		132	J2												
				134	F1PK	C	20°	1									
	>95	>95															
								0					142 MED GREY MICRITE WITH SMALL CALCITE FILLED BURROWS AND THIN (~.1CM) CALCITE STRINGERS ALONG BEDDING PLANES				
150	>95	95		152	F1PK	C	20°	2									
								0					20 CM BED OF PELLETS & CLASTS IN MED GR MATRIX AT 158.5-159				
				158	F1PK	C	20°	1									
	>95	>95						0					BURROWS FILLED W GREYISH OLIVE GREEN CHLORITE (?) AT 166.4				
				168	F1PK	C	20°	2					168-176 INTERBEDDED MICRITE, MED. LIMESTONE W CONT SHALY PARTINGS SOME CLAST & PELLET BEDS				
175	>95	>95											176- LIGHT GREY F-MED GR. LIMESTONE WITH SOME CONTORTED SHALY PARTINGS, SOME BURROWS				
	>95	>95															
	>95	>95		195	F1PK	C	20°										
				199	F1PK	C	20°	1									
200	>95	>95											SOME CLAST & PELLET BEDS BELOW 205'				
													CALCITE FILLED HEALED VERTICAL FRAC. AT 212'				
				211.5	F1PK	C	20°										
	>95	>95		2.45	F1PK	C	20°										
				219.5	F1PK	C	20°										
225	>95	95		224	F IR	CALCITE	0°						SOME THIN CALCITE FILLED HEALED FRAC'S BELOW 220'				
				225	F1PK	C	20°										
				232	F1PK	C	20°										
	>95	>95															
				241	F1PK	C	20°						~20% CLAST & PELLET BEDS 240'-250'				
	>95	>95		242	F1PK	C	20°										

NOTES:

SCALE: 1 DIVISION= FEET

DATE LOGGED BY ACK

Golder Associates

PROJECT *Martin Marietta / Groundwater / Oak Ridge* JOB NO. *863 3386* BORING NO. *CH5* DATE SHEET *3* OF *4*

BORING BEGAN — BORING COMPLETED — CORE HOLE LOCATION —

METHOD OF CORING — DRILLING FLUID — GR.ELEV — WEATHER —

CASING USED — SIZE — INSPECT — OPERAT — WATER LEVEL, TIME, DATE —

DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES: DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY	LITHOLOGY	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN/FT.
250		>95	>95	253 255	FIPK FIPK	C C	20° 20°	1					LIGHT GREY FINE TO MEDIUM GRAINED LIMESTONE WITH SOME CONTORTED SHALY PARTINGS AND BURROWS, SOME BEDS OF PELLETS, CLASTS & FOSSILS IN MEDIUM GRAINED MATRIX (BEDS 5-15 CM)				
		>95	95	260 272.5	FIPK FIPK	C C	20° 20°	1 2									
275		>95	80	275-	FIPK	C	30°	1-3					~12 FRACS 275-285 OIL STAINED FRAC AT 283.5' (FRACS OCCUR ALONG SHALY PARTINGS)				
		>95	80										~12 FRACS 285-295.5				
300		>95	90		FIPK	C	20°	1-2					~6 FRACS 295.5-306				
		>95	85										~8 FRACS 306-316.5				
325		>95	90										~6 FRACS 316.5-327				
		>95	95		FIPK	C	20°	1					~4 FRACS 327-338				
		>95	85		FIPK	C	25°	1-2					~8 FRACS 338-349 352 - REGULARLY INTERBEDDED LT GREY MED GR LIMESTONE W. CALCITE FILLED BURROWS & CALCITE STRINGERS ALONG BEDDING PLANES (BED THICKNESS ~20 CM) AND DARK GREY SHALY MICRITE (BED THICKNESS ~5 CM)				
350		>95	95		FIPK	C	20°	0-1									
		>95	>95					0					~3 FRACS 349-359.5 362.5 DUSKY RED CALC. SHALE 85% & LT GREY F-MED GR LIMESTONE 15%				
375																	

NOTES:

SCALE: 1 DIVISION= FEET

DATE LOGGED BY *AES*

Golder Associates

PROJECT Martin Marietta / Groundwater / Oak Ridge	JOB NO. 863 5386	BORING NO. CH5 DATE	SHEET 4 OF 4
BORING BEGAN –	BORING COMPLETED –	CORE HOLE LOCATION –	
METHOD OF CORING –	DRILLING FLUID –	GR.ELEV. – WEATHER –	
CASING USED – SIZE –		INSPECT OPERAT. –	WATER LEVEL, TIME, DATE –

DEPTH (FT.)	RUN NUMBER	RECOVERY	RQD	DISCONTINUITIES DEPTH	TYPE	INFILLING	ANGLE W/AXIS	FREQUENCY	LITHOLOGY	COLOR	TEXTURE	WEATHERING	DESCRIPTION	POINT LOAD TEST	HARDNESS	SAMPLES-LABORATORY TESTS	DRILLING RATE MIN./FT.
375		>95	>95		FIPK	C	20°	0 / 1					375-378 LIGHT GREY MEDIUM GRAINED LIMESTONE WITH CONTORTED SHALE PARTINGS				
		>95	>95					0					378-391 DUSKY RED CALC SHALE 60%, LIMESTONE (AS ABOVE) 40%. 391- LIGHT-MED GREY FN-MED LIMESTONE WITH SHALY MICRITE LAMINA				
		>95	90		FIPR / FIPK	BRECCIA / C	20° / 20°	1 / 0-1					PCM BROKEN ZONE @ 395'. W. CONTORTED SHALY PARTINGS ~4 SLICKENSIDED FRACS 391-401.5				
400		>95	95		FIPK	C	20°						~4 FRACS 401.5-413. ~410 - LIGHT GRAY MED-GRAINED LIMESTONE SOME CONT. SHALY PARTINGS & LAMINAE SOME PELLET & CLAST BEDS				
		>95	95		FIPK	C	20°	0-1					~4 FRACS 401.5-413				
425		>95	90	431-431.5	FIPR / FIPK	MYLONITE / C	20° / 20°	4					~6 FRACS 424-434				
		>95	90										W. STYLOLITES 434-. ~6 FRACS 434-446.41				
													TD CORED = 446.41'				

NOTES:

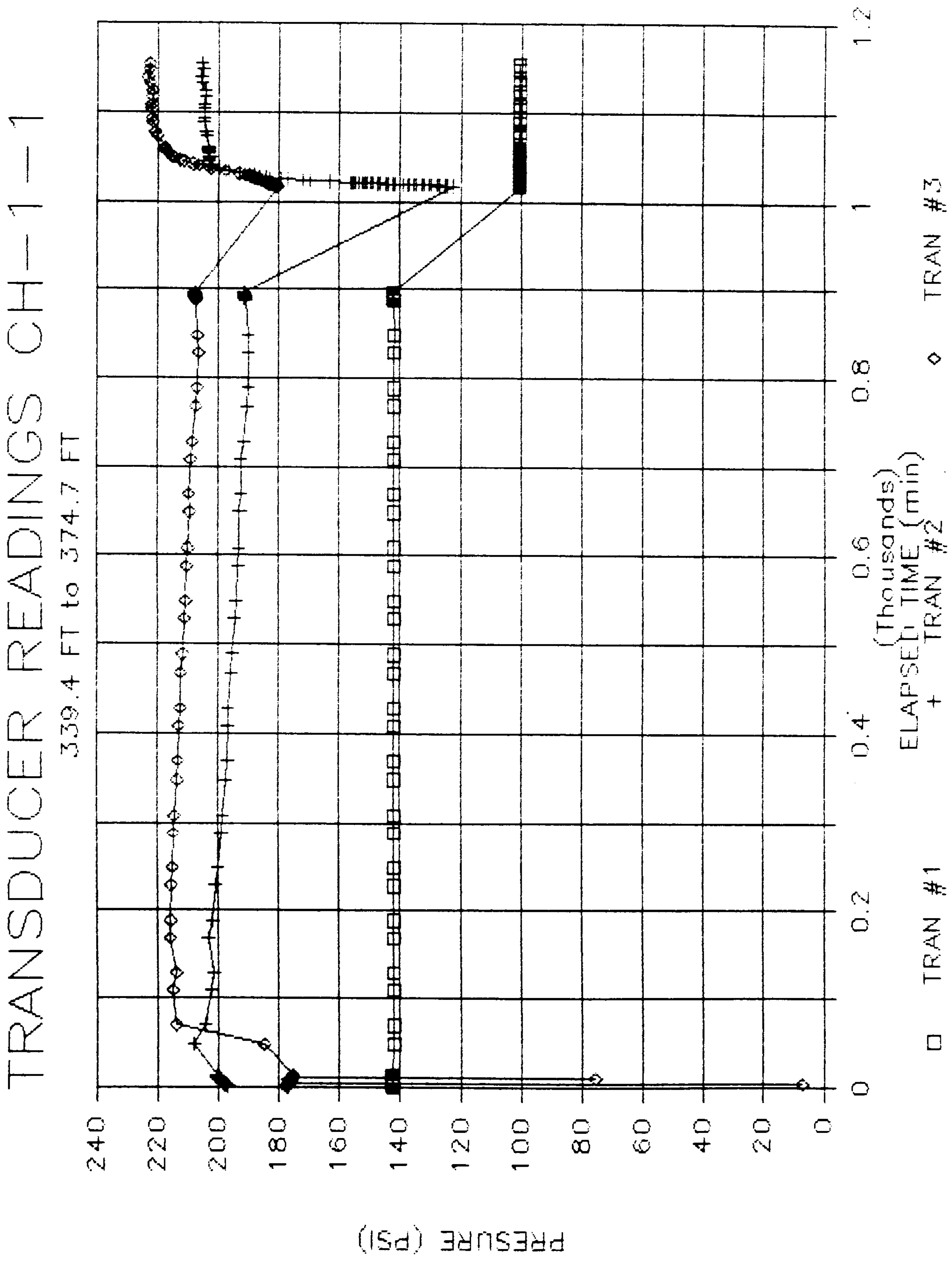
SCALE: 1 DIVISION = FEET

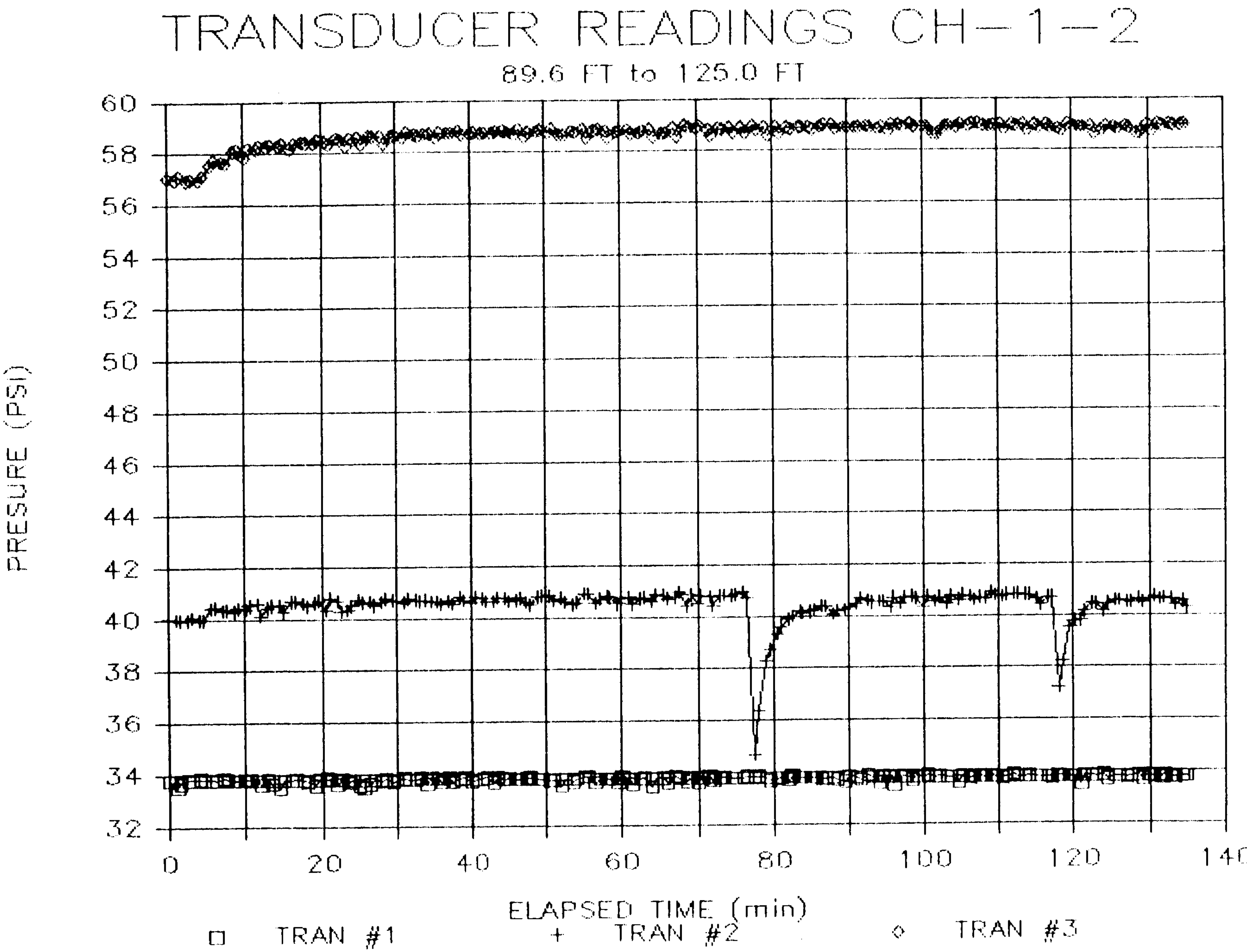
DATE LOGGED BY

Golder Associates

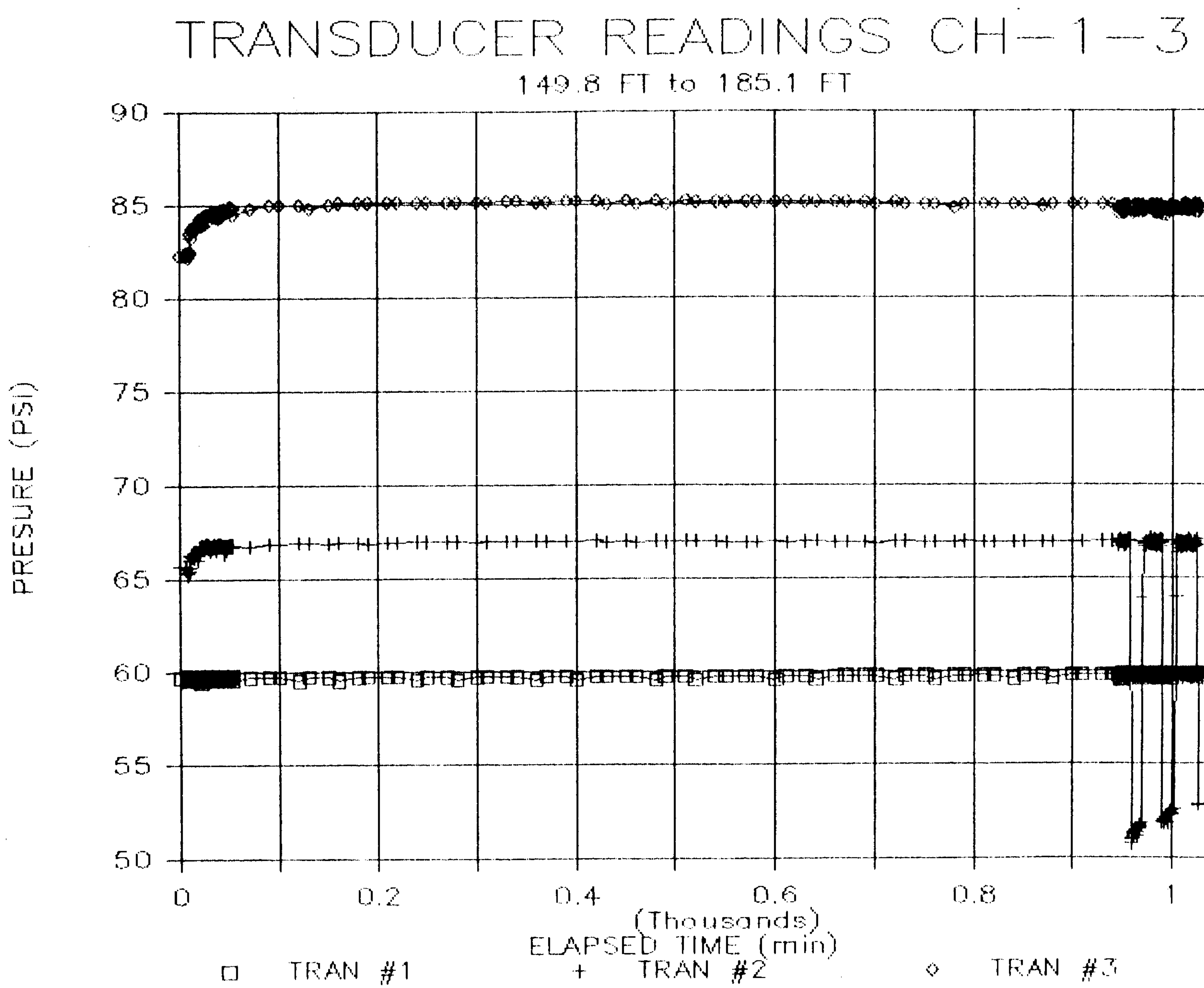
APPENDIX B

ARITHMETIC PLOTS OF TRANSDUCER READINGS

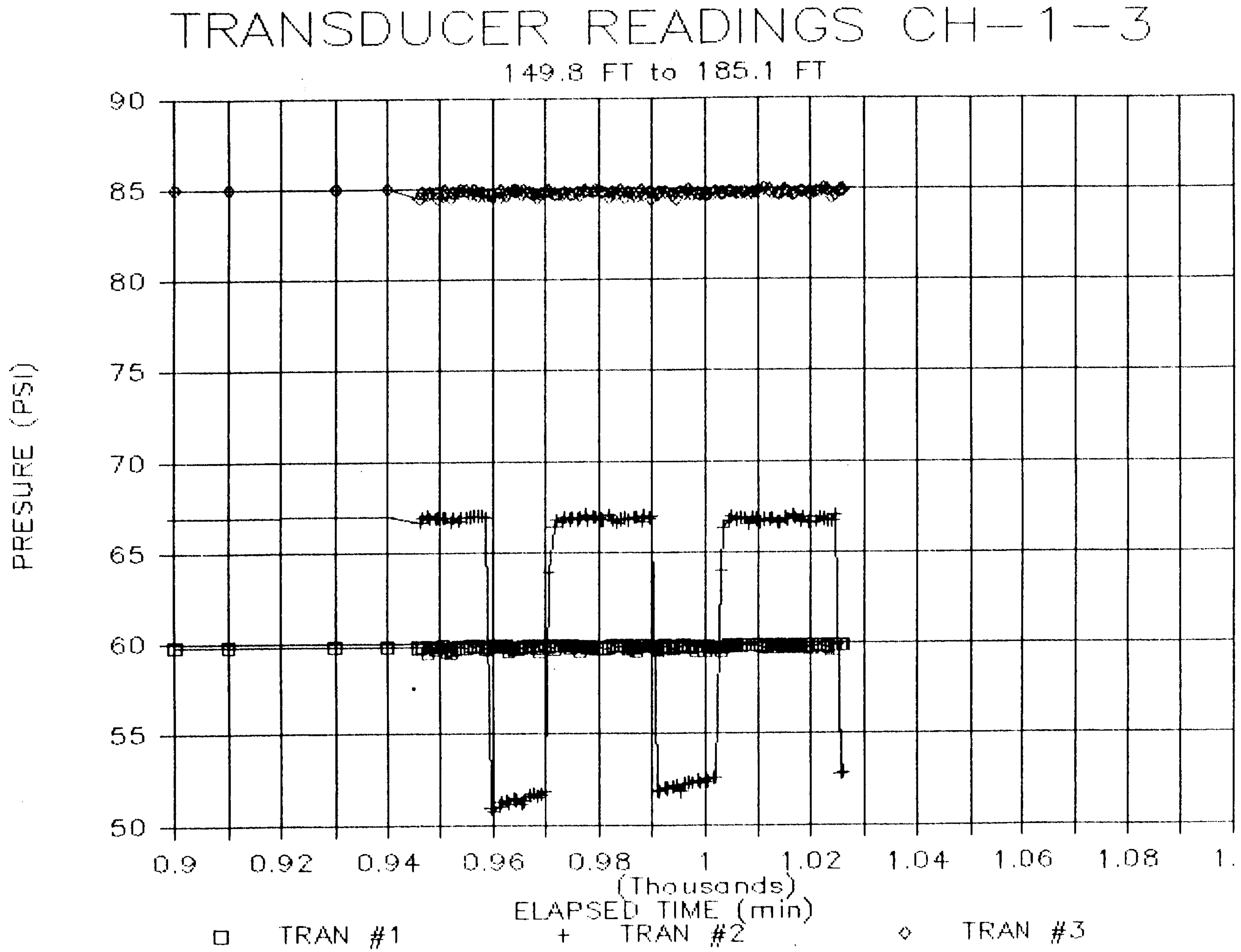

TRANSDUCER READINGS CH—1—1
339.4 FT to 374.7 FT
PRESSURE (PSI)
0
20
40
60
80
100
120
140
160
180
200
220
240
0
0.2
0.4
0.6
0.8
1
1.2
(Thousands)
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3



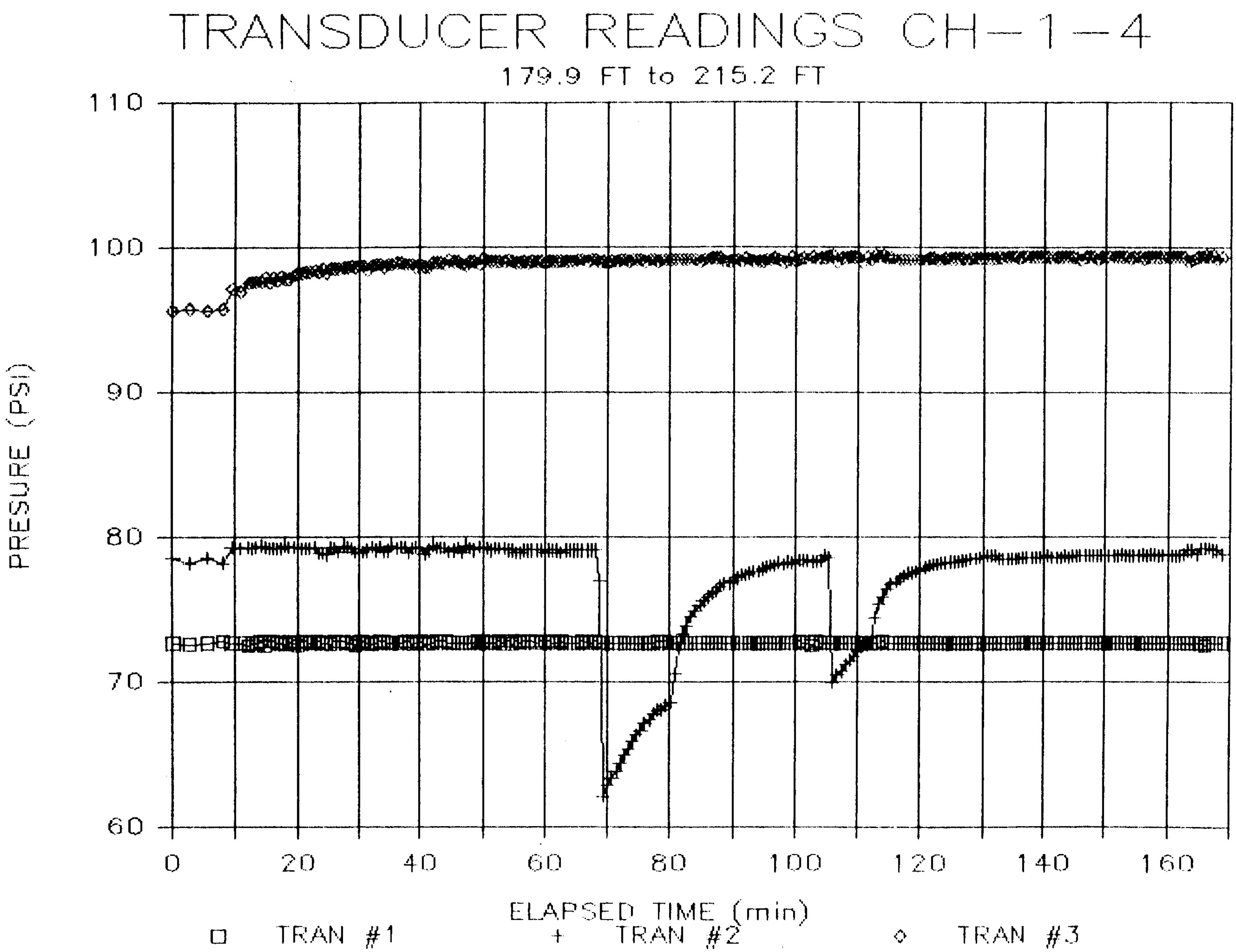
TRANSDUCER READINGS CH-1-2
89.6 FT to 125.0 FT
PRESURE (PSI)
60
58
56
54
52
50
48
46
44
42
40
38
36
34
32
0
20
40
60
80
100
120
140
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3



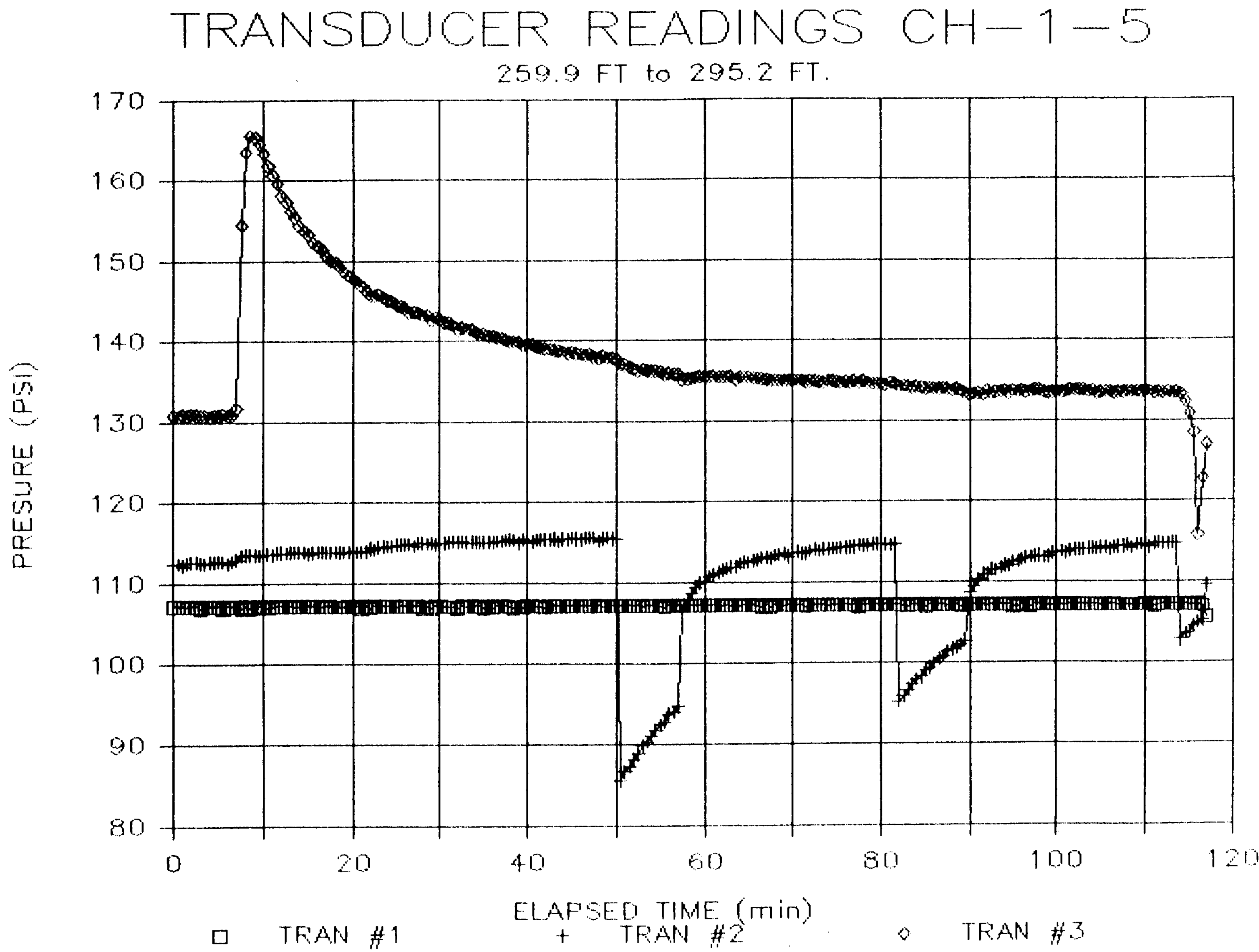
TRANSDUCER READINGS CH-1-3
149.8 FT to 185.1 FT
PRESURE (PSI)
90
85
80
75
70
65
60
55
50
0
0.2
0.4
0.6
0.8
1
(Thousands)
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3



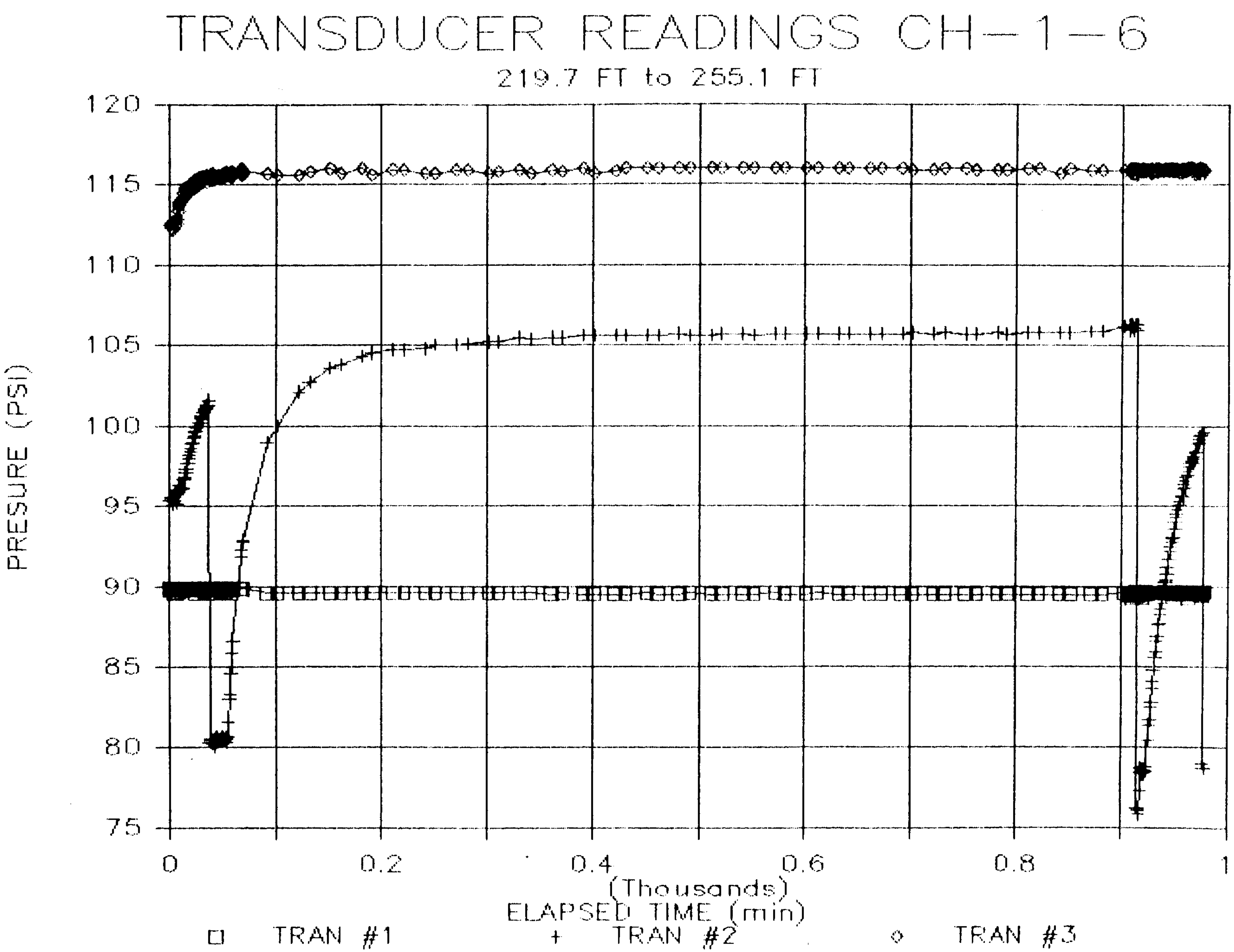
TRANSDUCER READINGS CH-1-3
149.8 FT to 185.1 FT
PRESURE (PSI)
90
85
80
75
70
65
60
55
50
0.9
0.92
0.94
0.96
0.98
1
1.02
1.04
1.06
1.08
1.1
(Thousands)
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3

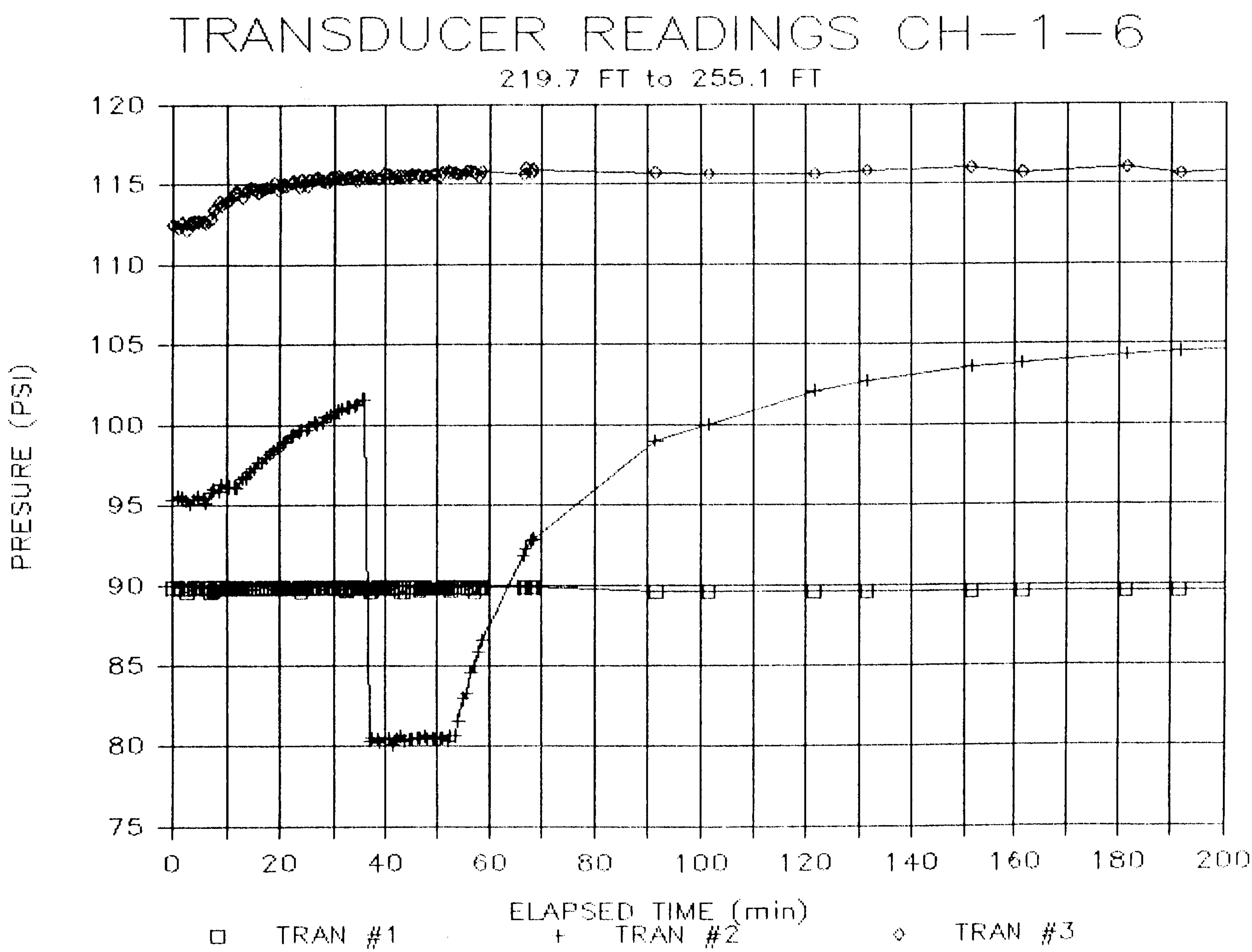


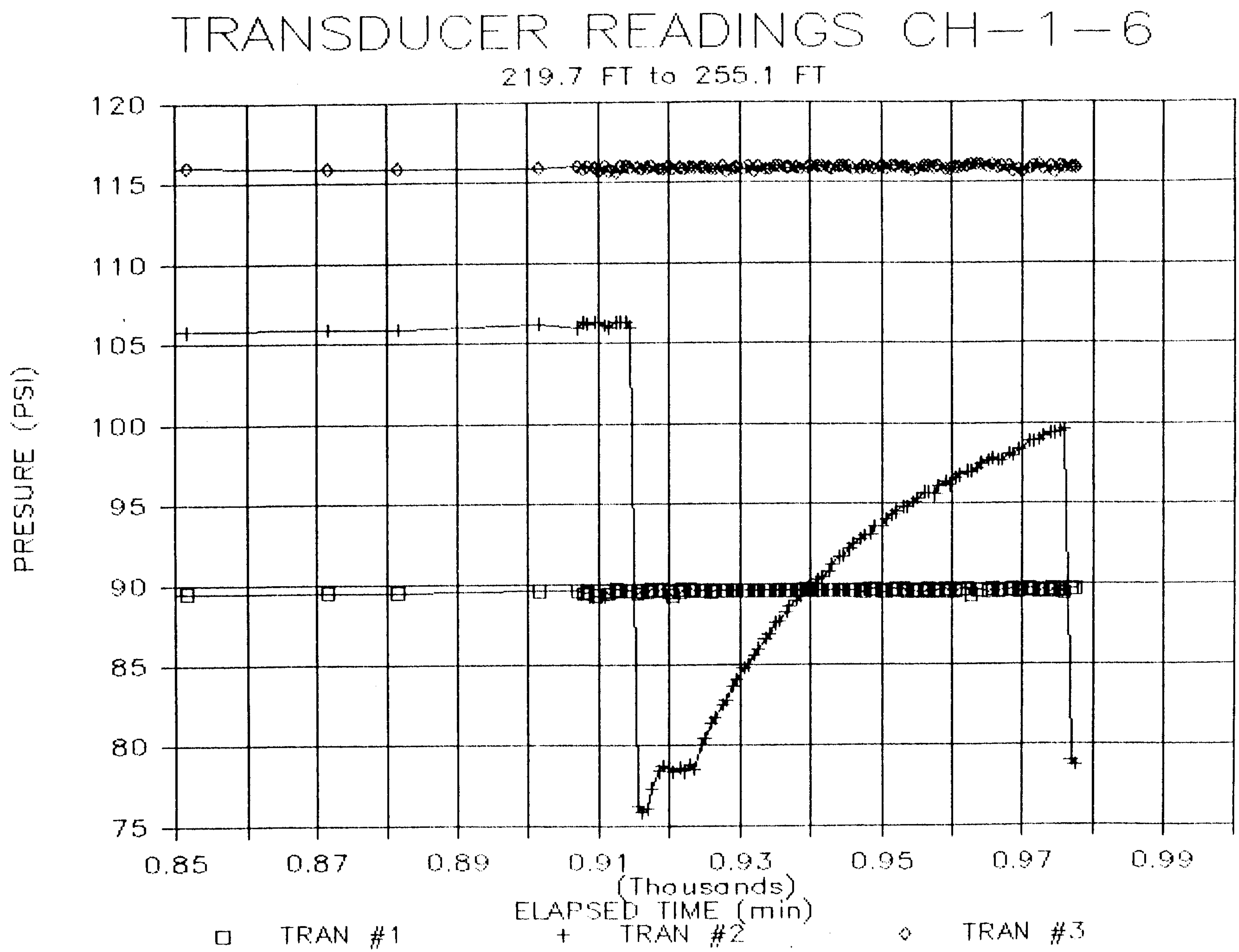
TRANSDUCER READINGS CH-1-4
179.9 FT to 215.2 FT
110
100
90
80
70
60
PRESURE (PSI)
0
20
40
60
80
100
120
140
160
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3



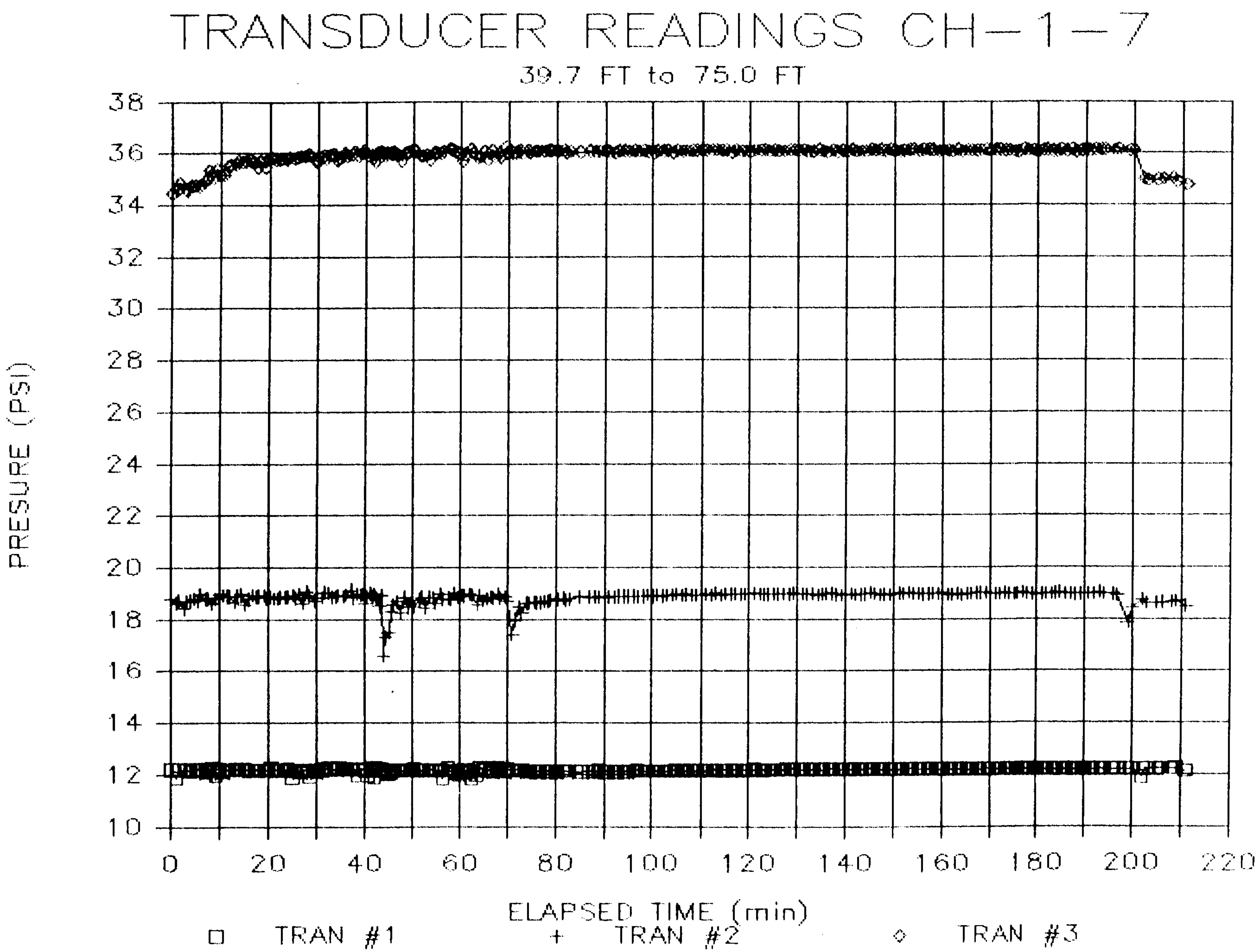
TRANSDUCER READINGS CH-1-5
259.9 FT to 295.2 FT.
PRESURE (PSI)
170
160
150
140
130
120
110
100
90
80
0
20
40
60
80
100
120
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3

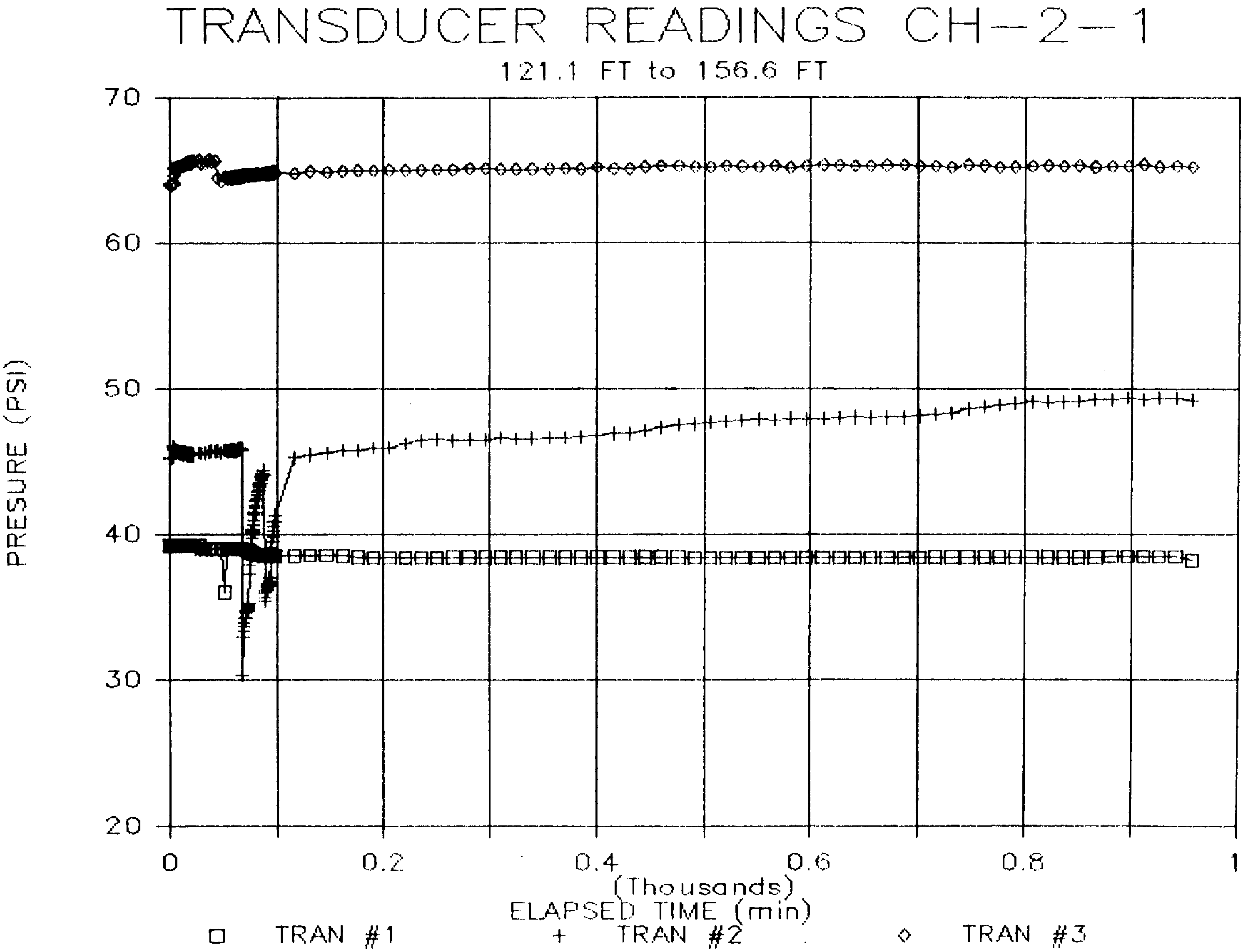

TRANSDUCER READINGS CH-1-6
219.7 FT to 255.1 FT
PRESURE (PSI)
120
115
110
105
100
95
90
85
80
75
0
0.2
0.4
0.6
0.8
1
(Thousands)
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3


TRANSDUCER READINGS CH-1-6
219.7 FT to 255.1 FT
PRESURE (PSI)
120
115
110
105
100
95
90
85
80
75
0
20
40
60
80
100
120
140
160
180
200
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3

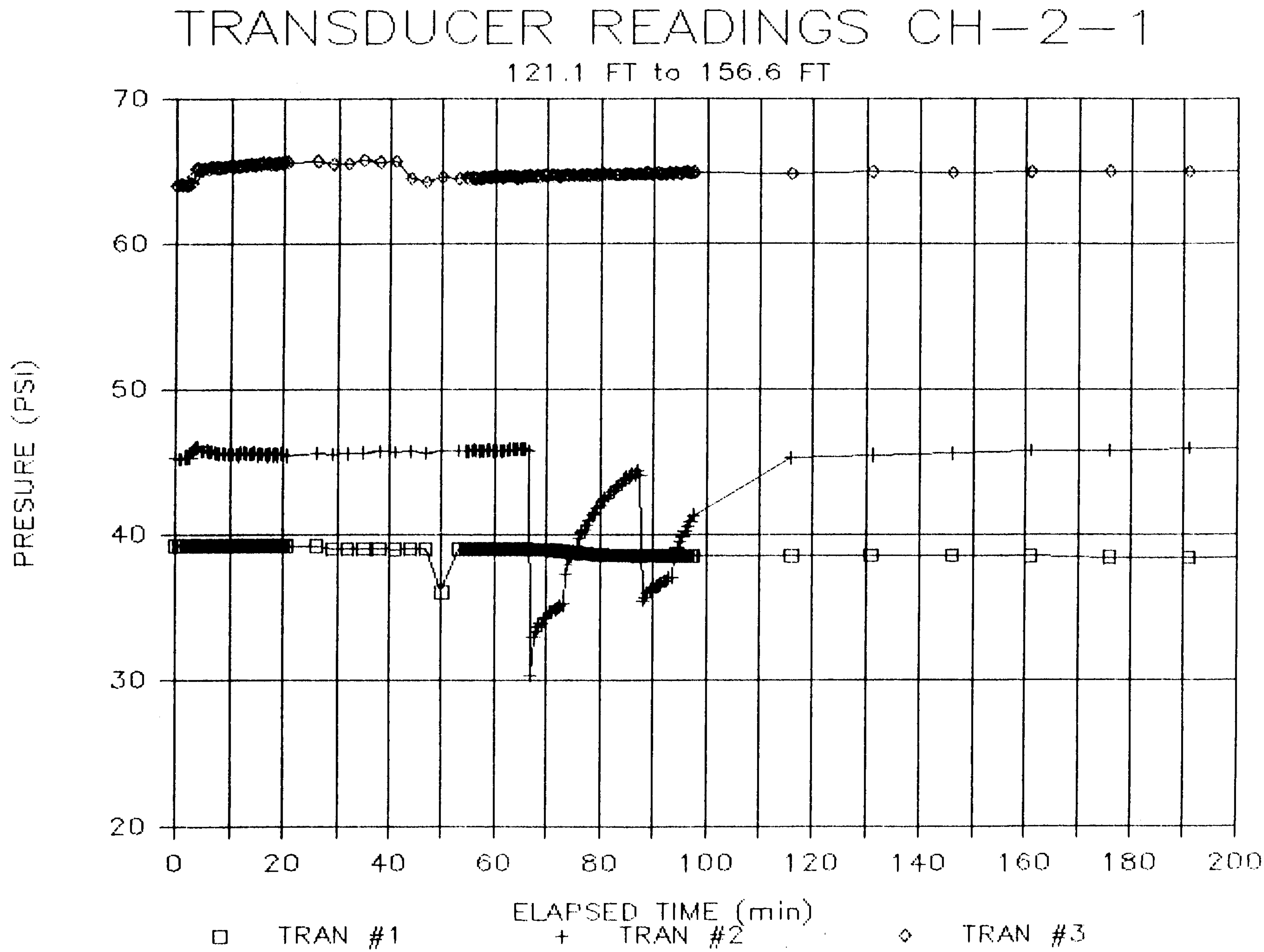


TRANSDUCER READINGS CH-1-6
219.7 FT to 255.1 FT
PRESURE (PSI)
120
115
110
105
100
95
90
85
80
75
0.85
0.87
0.89
0.91
0.93
0.95
0.97
0.99
(Thousands)
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3


TRANSDUCER READINGS CH-1-7
39.7 FT to 75.0 FT
PRESURE (PSI)
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
0
20
40
60
80
100
120
140
160
180
200
220
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3

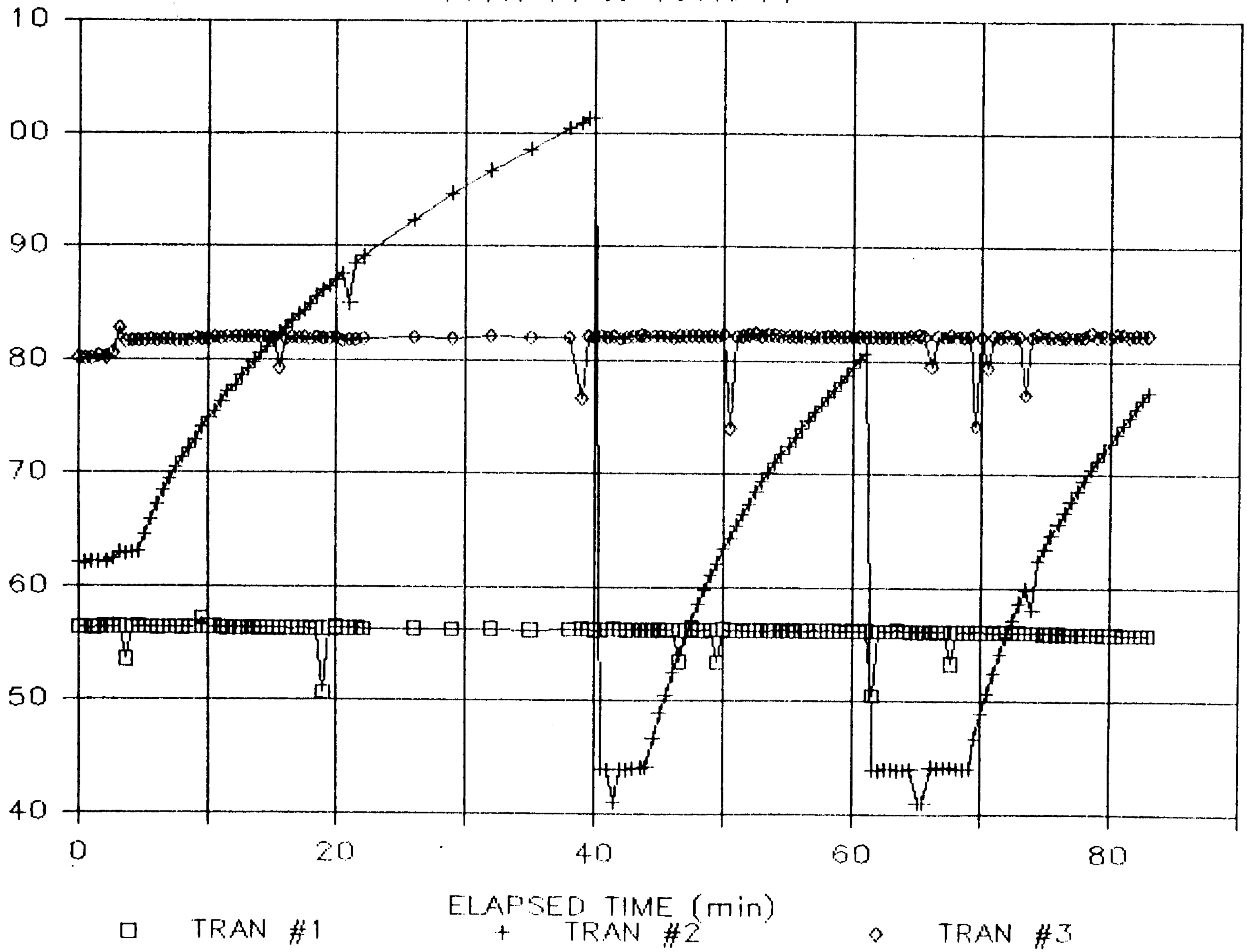


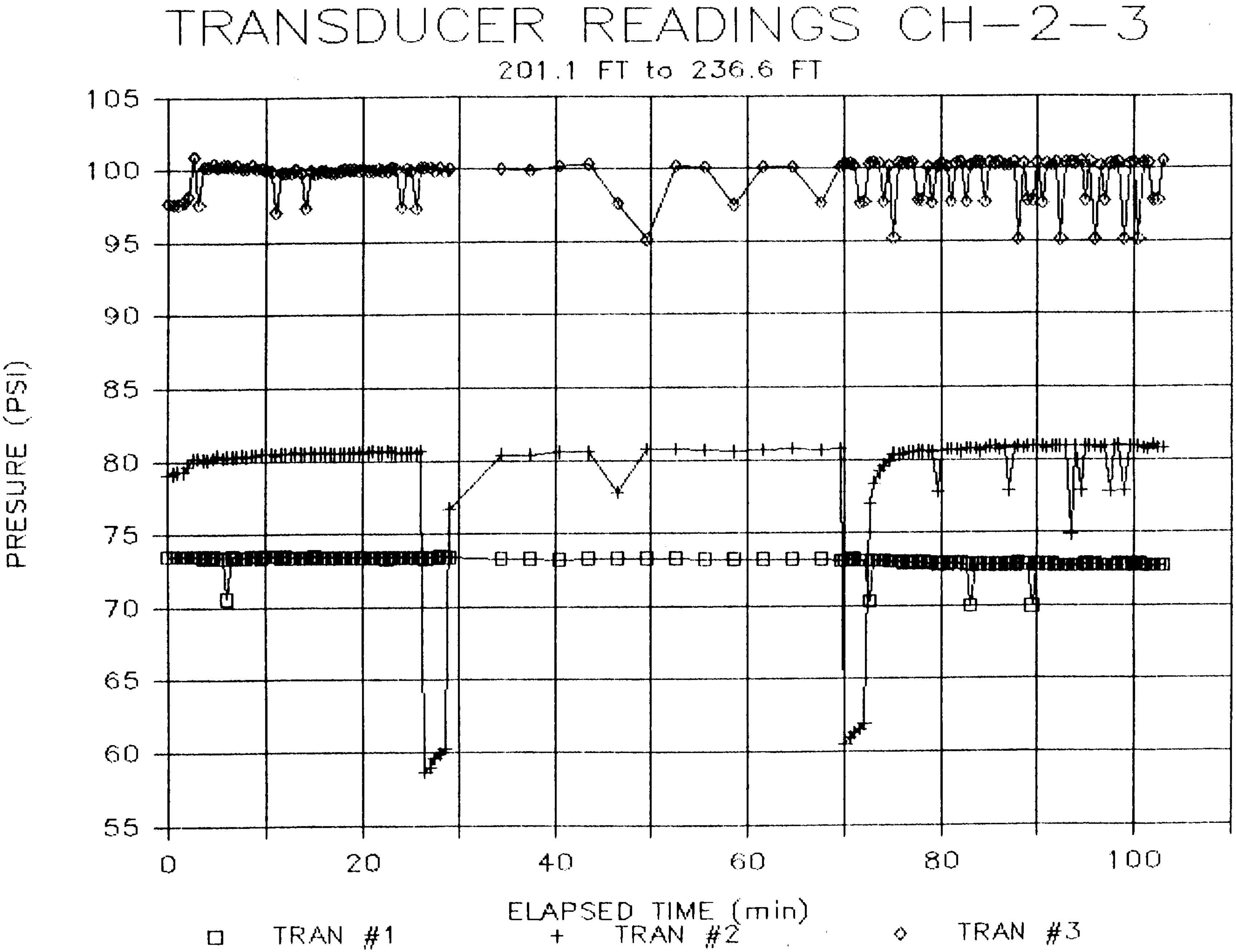
TRANSDUCER READINGS CH-2-1
121.1 FT to 156.6 FT
PRESURE (PSI)
70
60
50
40
30
20
0
0.2
0.4
0.6
0.8
1
(Thousands)
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3


TRANSDUCER READINGS CH-2-1
121.1 FT to 156.6 FT
PRESURE (PSI)
70
60
50
40
30
20
0
20
40
60
80
100
120
140
160
180
200
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3

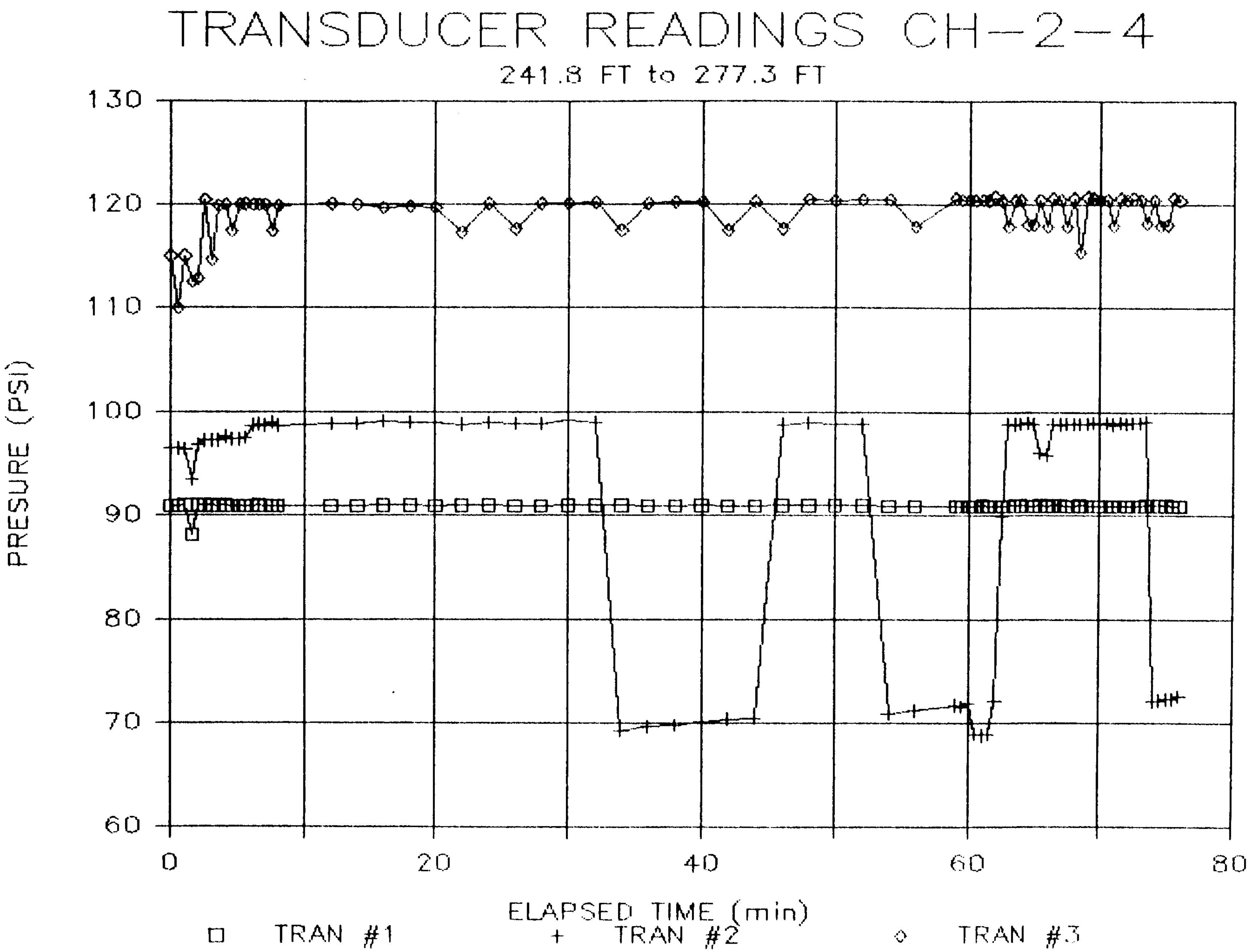
TRANSDUCER READINGS CH-2-2

161.1 FT to 196.6 FT



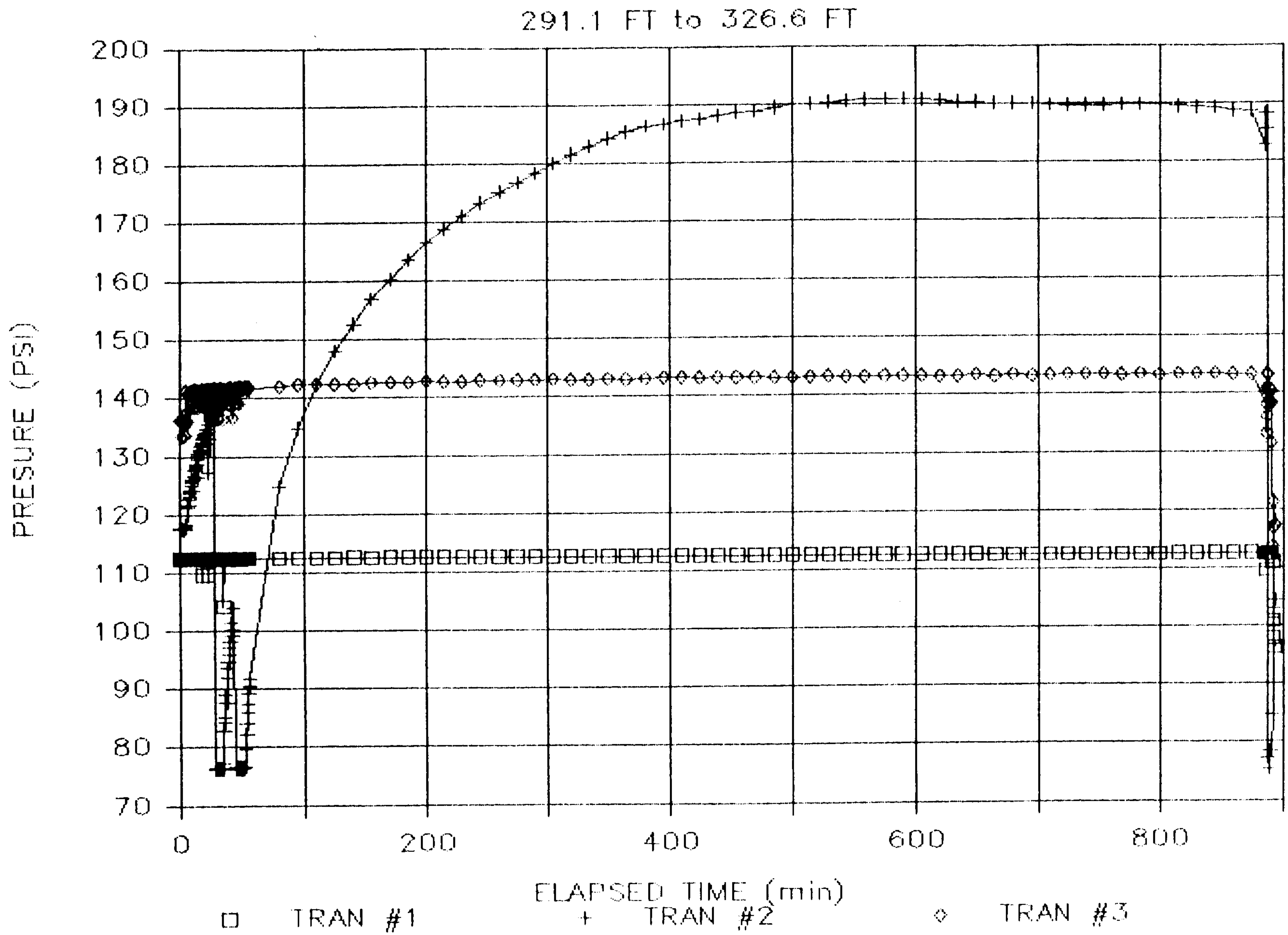


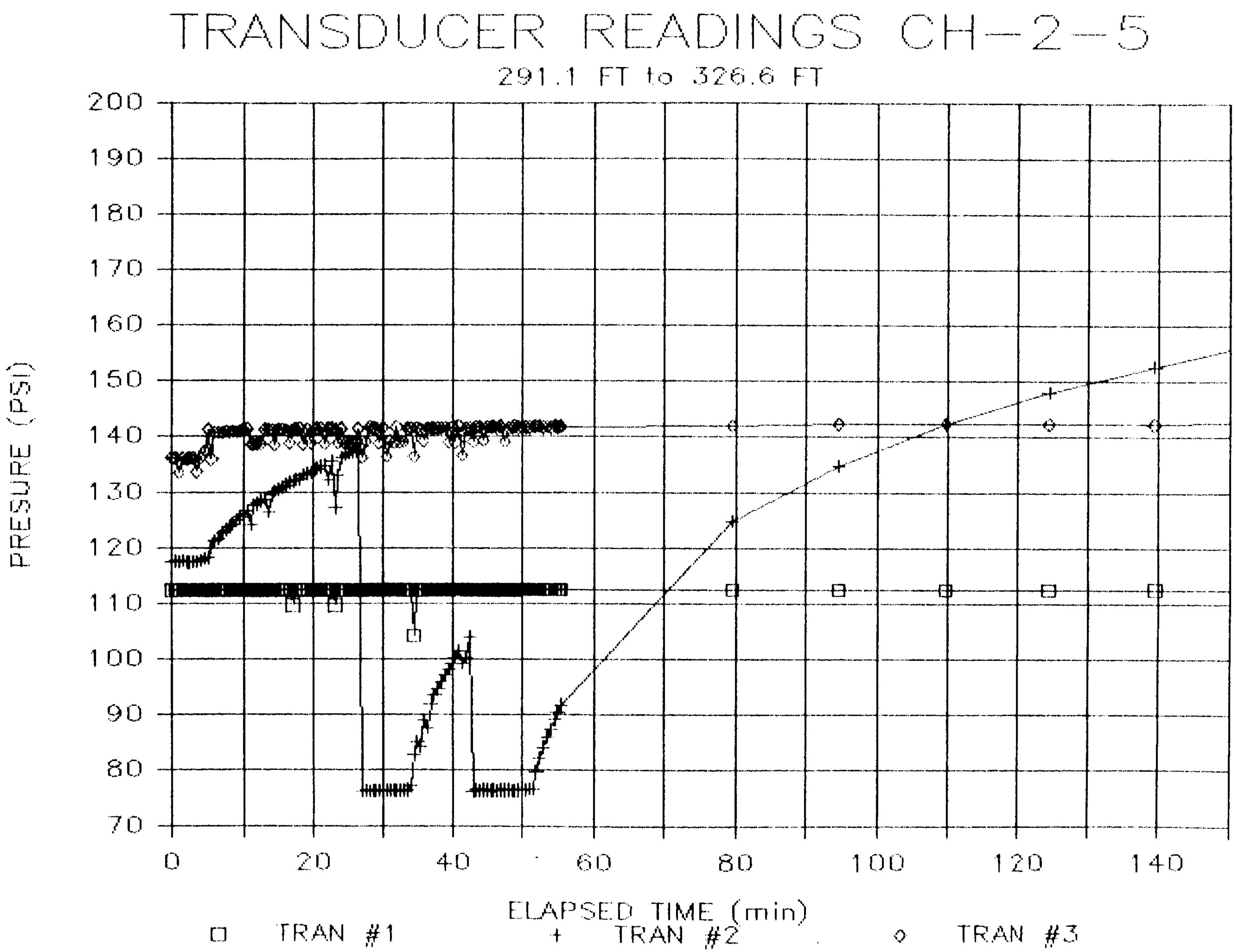
TRANSDUCER READINGS CH-2-3
201.1 FT to 236.6 FT
PRESURE (PSI)
105
100
95
90
85
80
75
70
65
60
55
0
20
40
60
80
100
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3



TRANSDUCER READINGS CH-2-4
241.8 FT to 277.3 FT
PRESURE (PSi)
130
120
110
100
90
80
70
60
0
20
40
60
80
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3

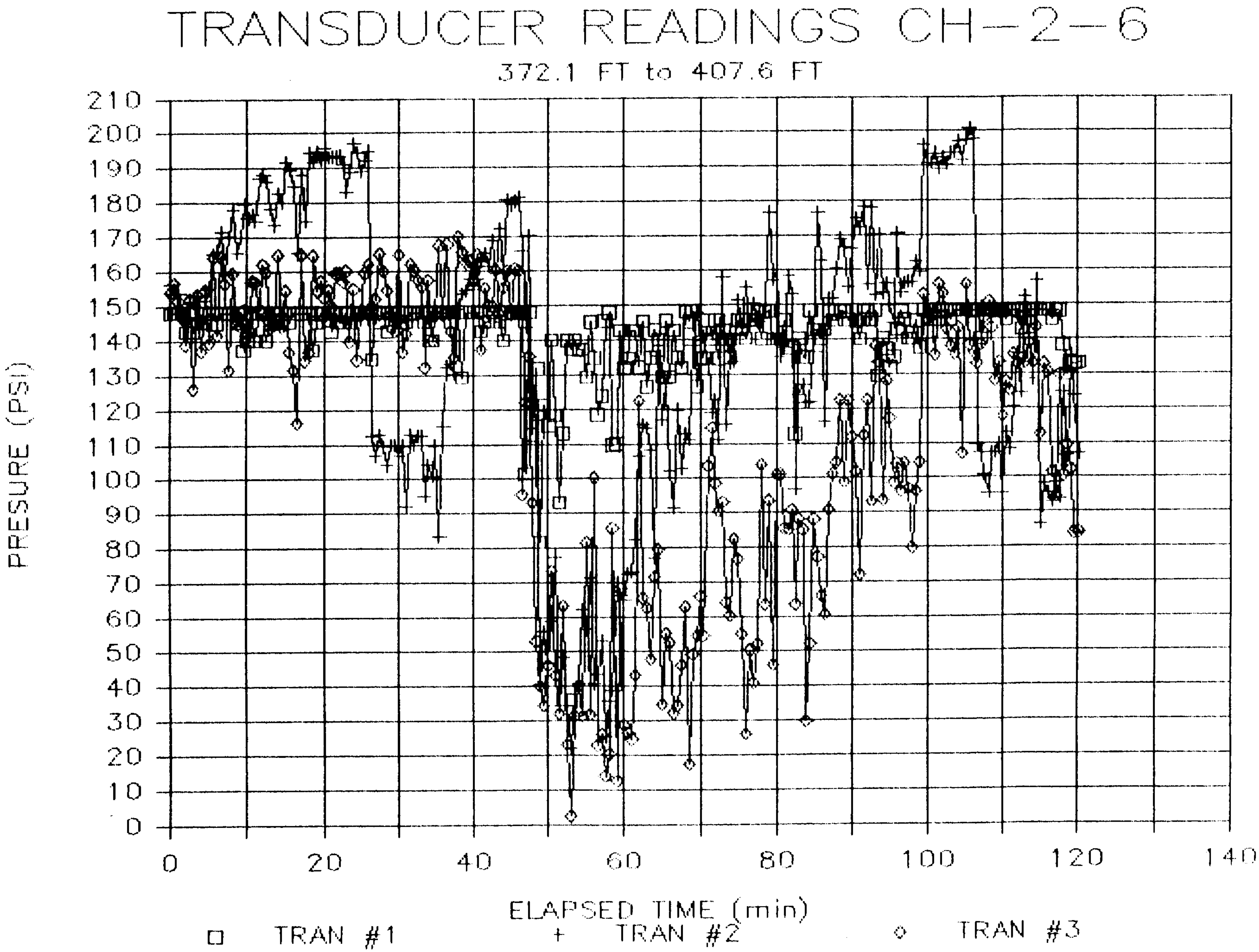
TRANSDUCER READINGS CH-2-5



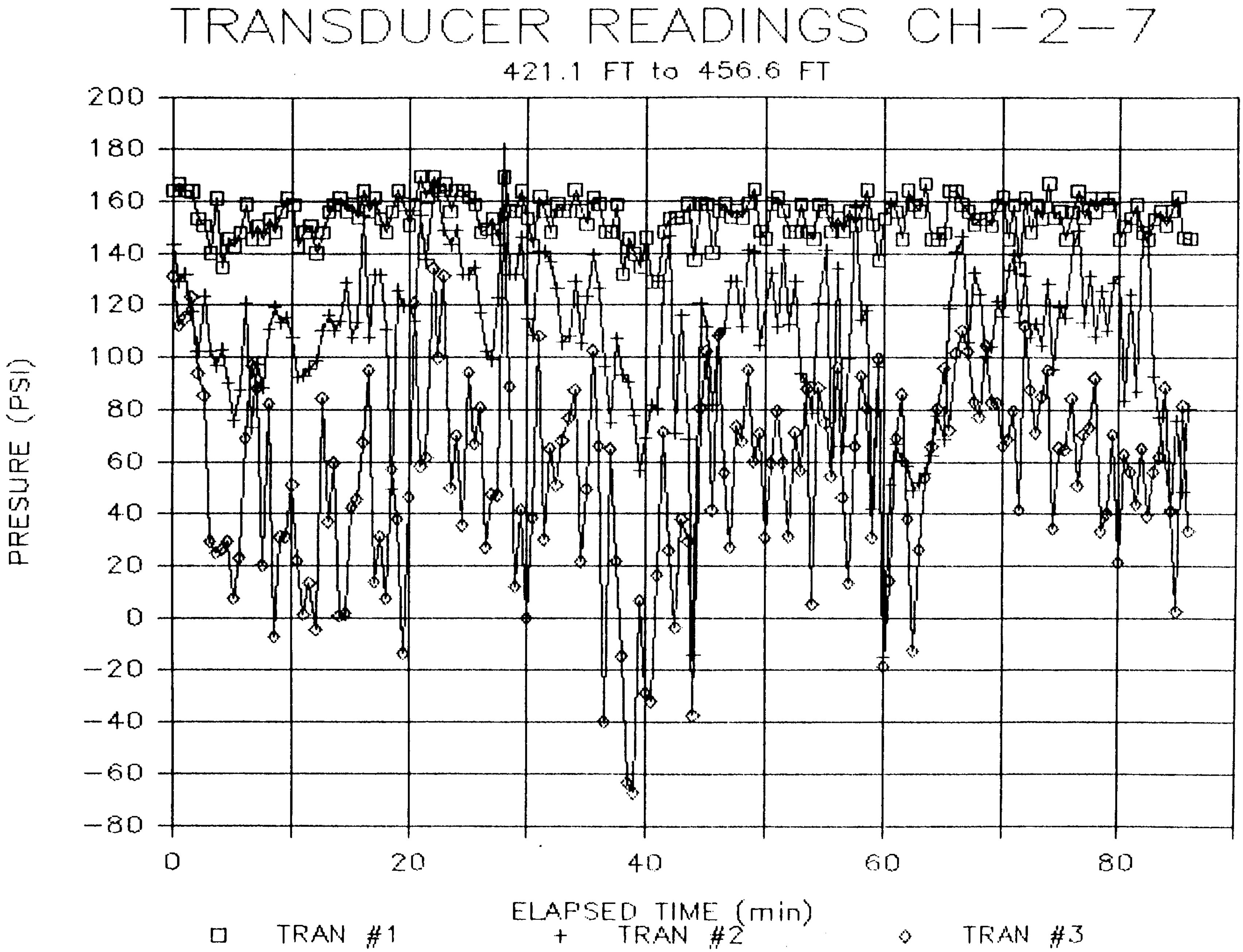


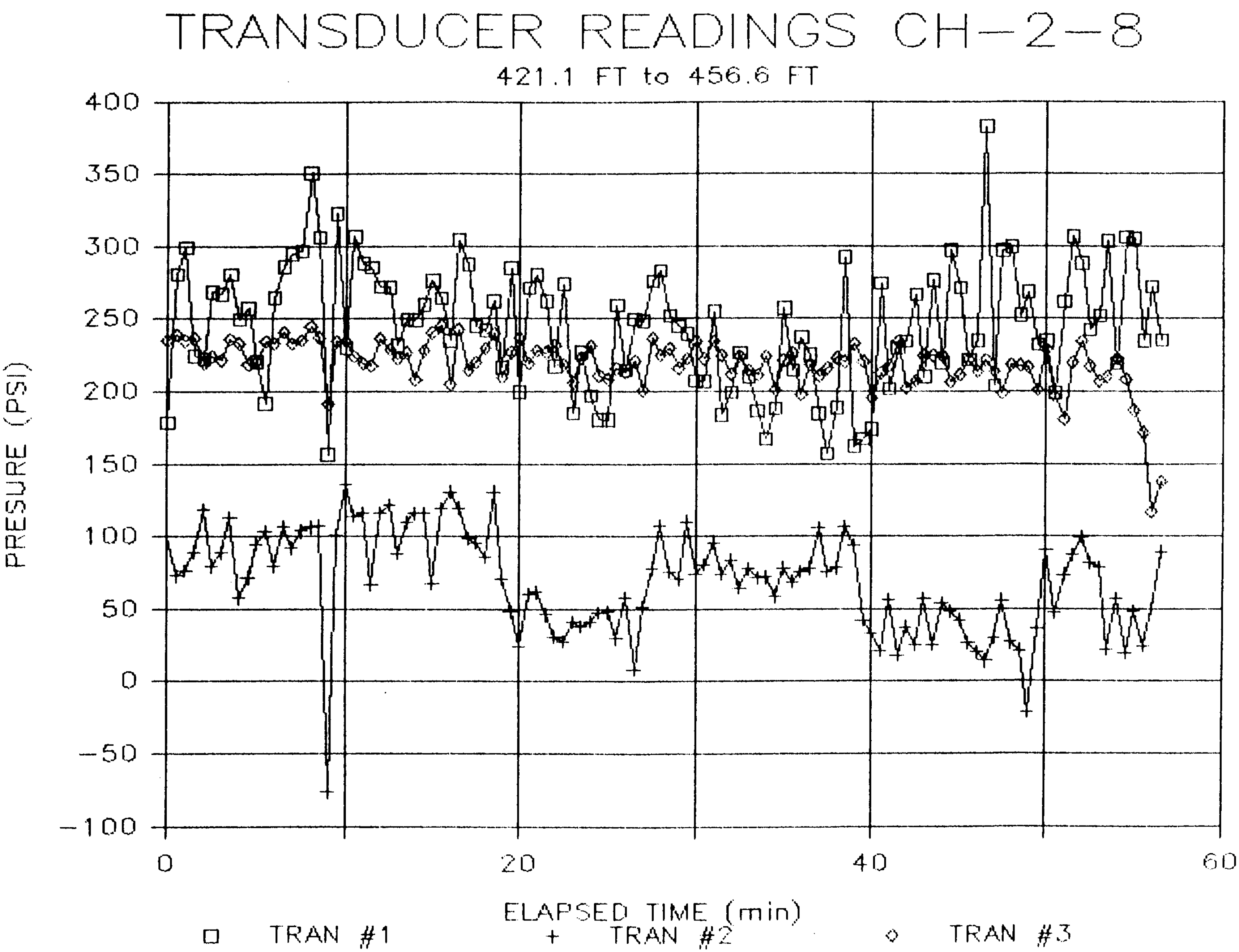
TRANSDUCER READINGS CH-2-5
291.1 FT to 326.6 FT
PRESURE (PSI)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
0
20
40
60
80
100
120
140
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3

B-19

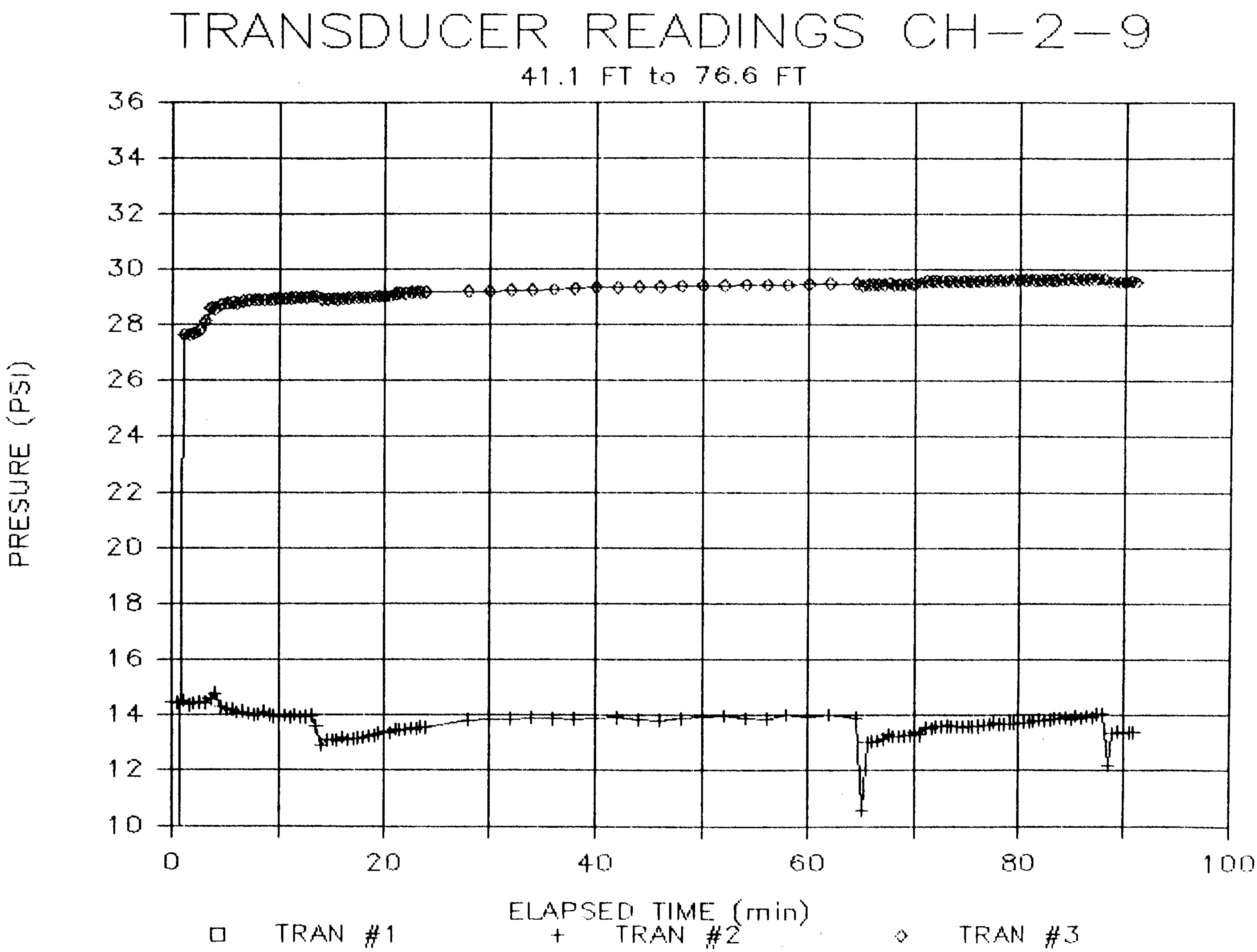


TRANSDUCER READINGS CH-2-6
372.1 FT to 407.6 FT
PRESURE (PSI)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3


TRANSDUCER READINGS CH-2-7
421.1 FT to 456.6 FT
PRESURE (PSI)
200
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
0
20
40
60
80
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3


TRANSDUCER READINGS CH-2-8
421.1 FT to 456.6 FT
PRESURE (PSI)
400
350
300
250
200
150
100
50
0
-50
-100
0
20
40
60
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3

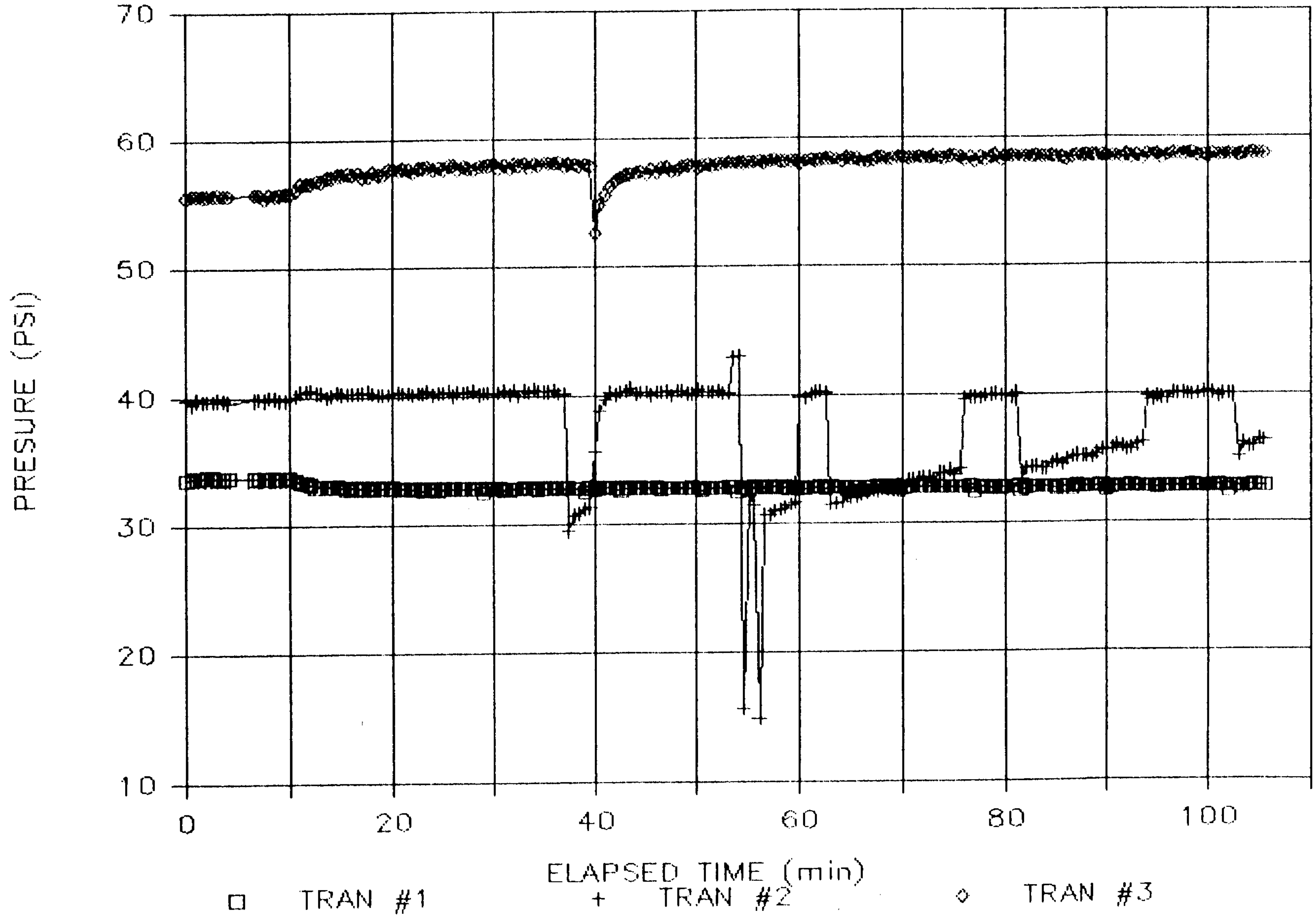
B-22

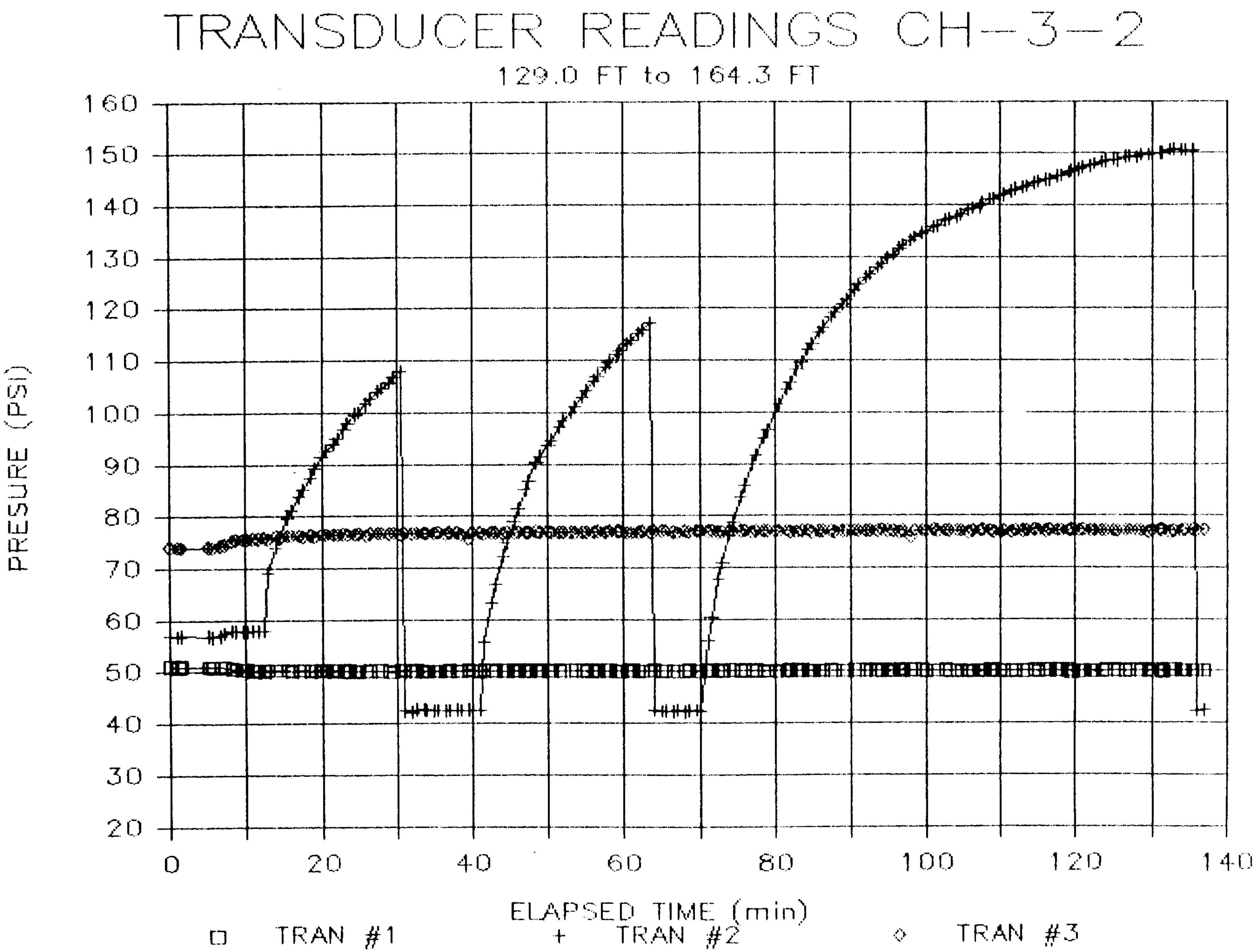


TRANSDUCER READINGS CH-2-9
41.1 FT to 76.6 FT
PRESURE (PSI)
36
34
32
30
28
26
24
22
20
18
16
14
12
10
0
20
40
60
80
100
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3

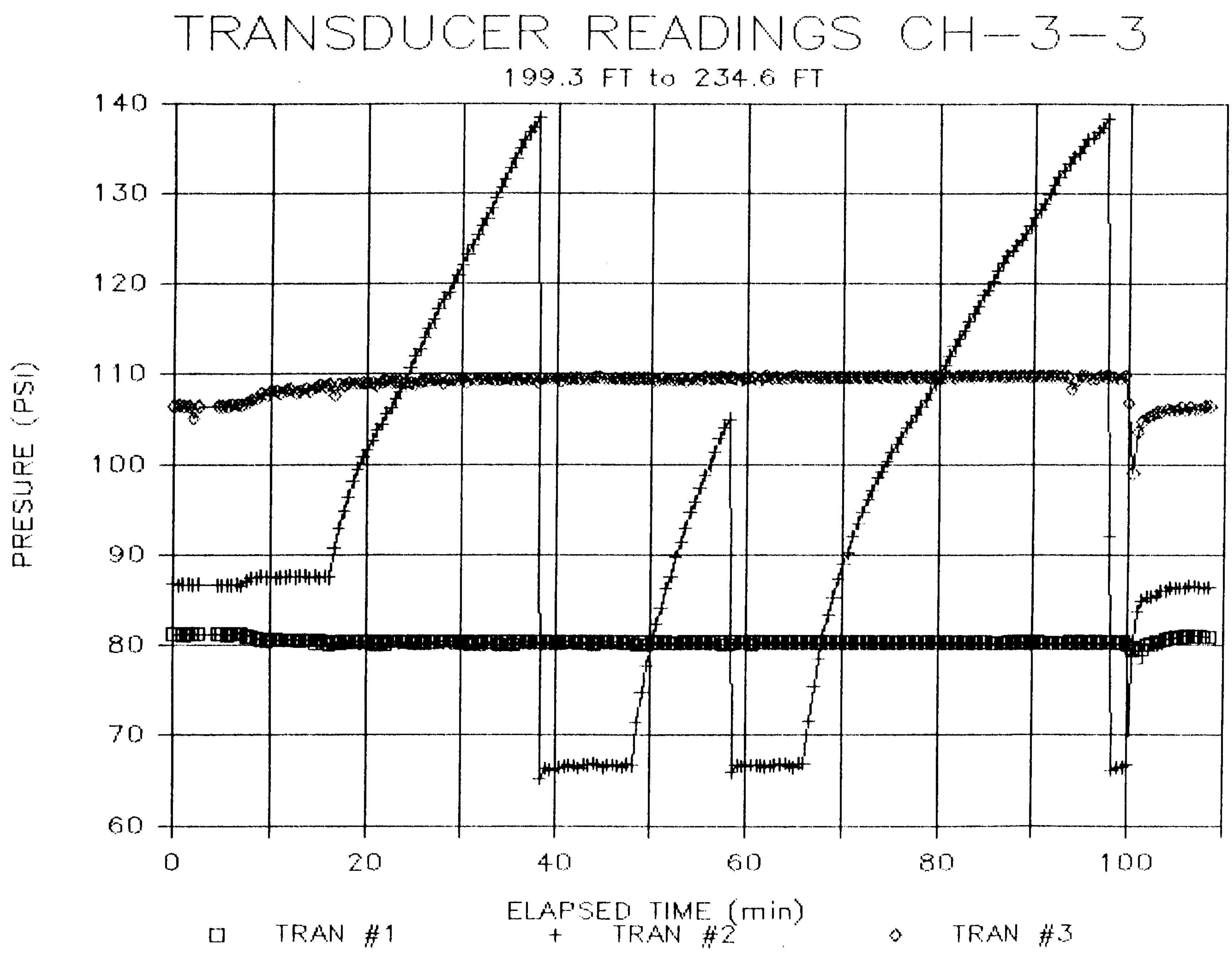
TRANSDUCER READINGS CH-3-1

89.3 FT to 124.6 FT



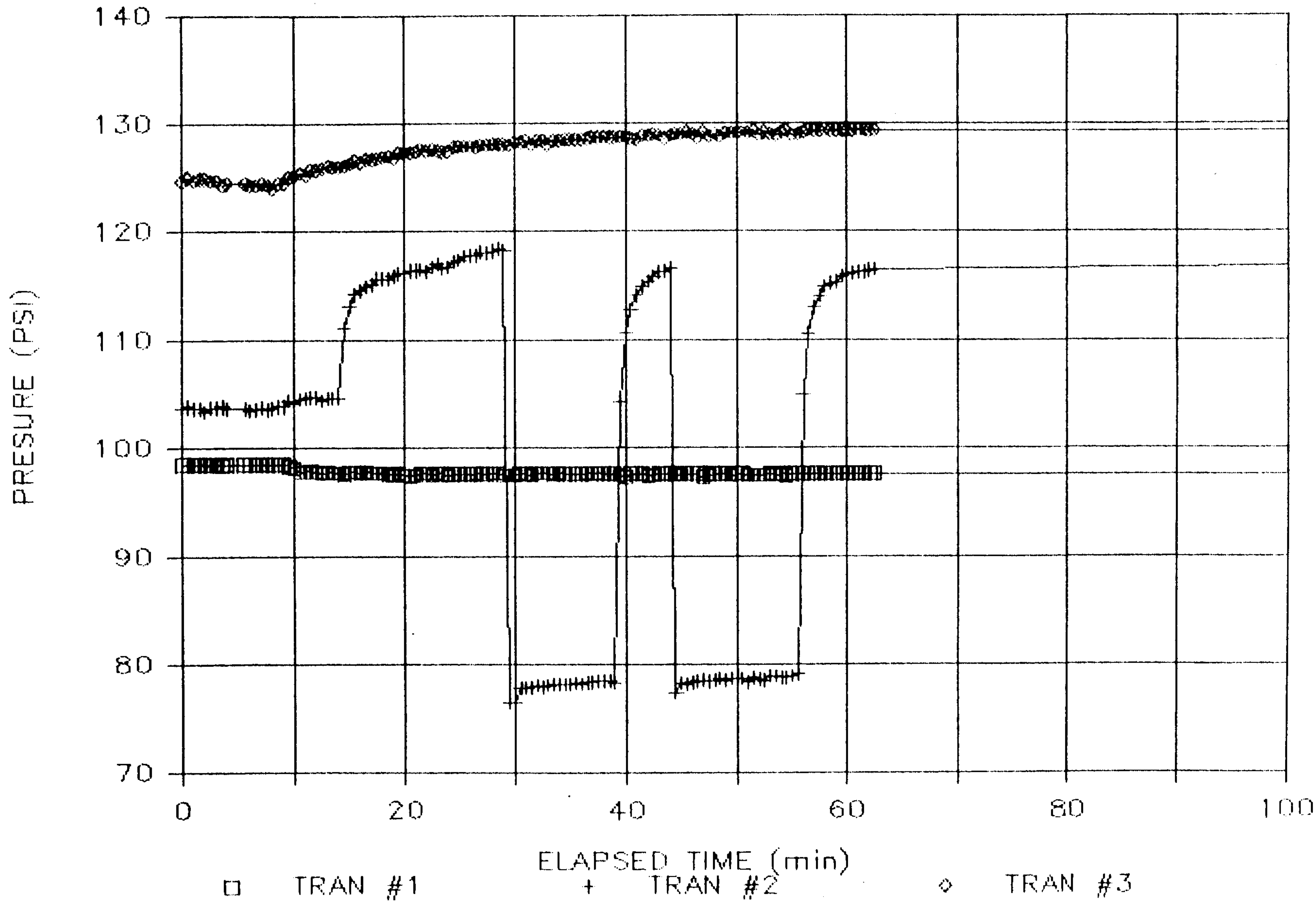


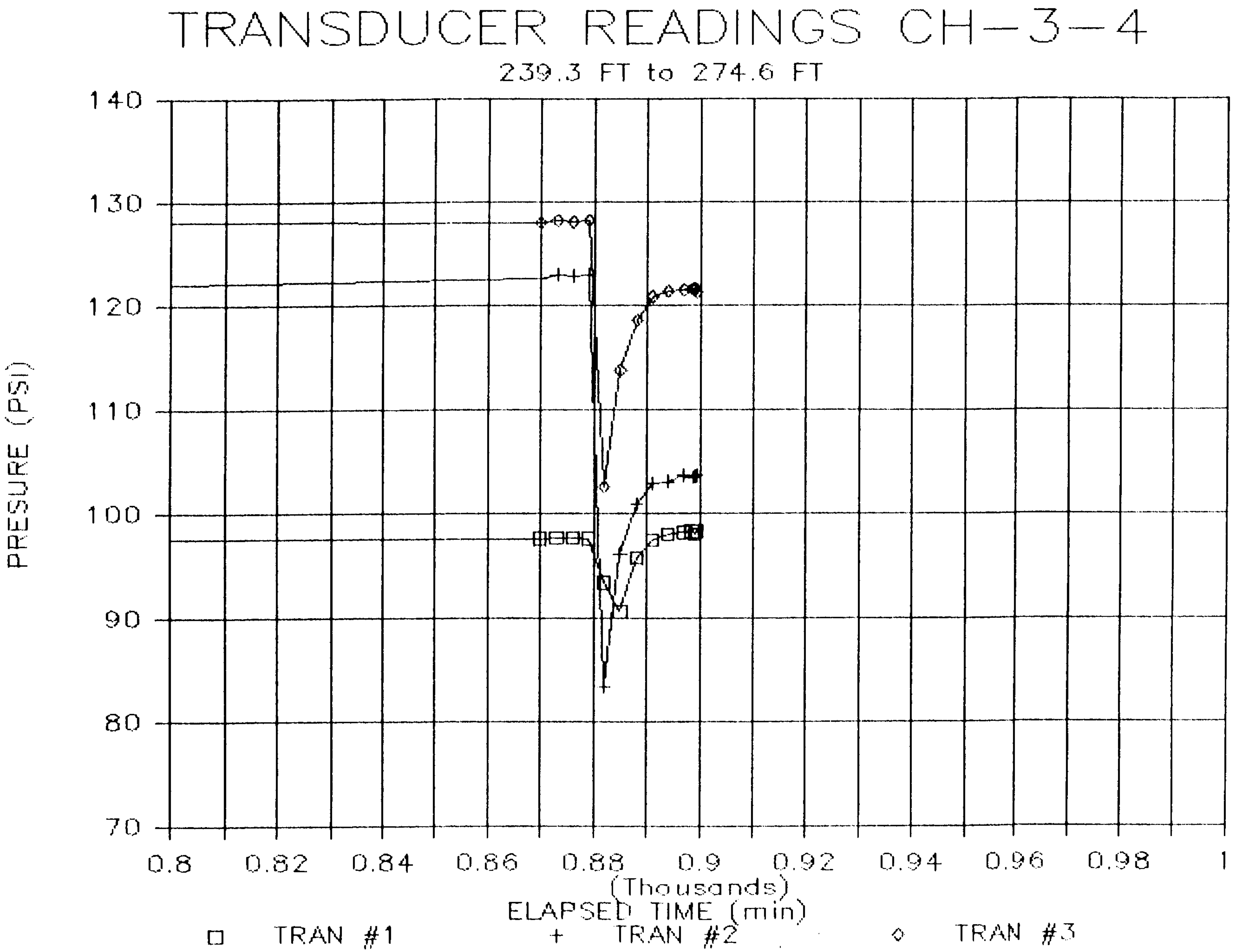
TRANSDUCER READINGS CH-3-2
129.0 FT to 164.3 FT
PRESURE (PSI)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
0
20
40
60
80
100
120
140
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3


TRANSDUCER READINGS CH-3-3
199.3 FT to 234.6 FT
PRESURE (PSI)
140
130
120
110
100
90
80
70
60
0
20
40
60
80
100
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3

TRANSDUCER READINGS CH-3-4

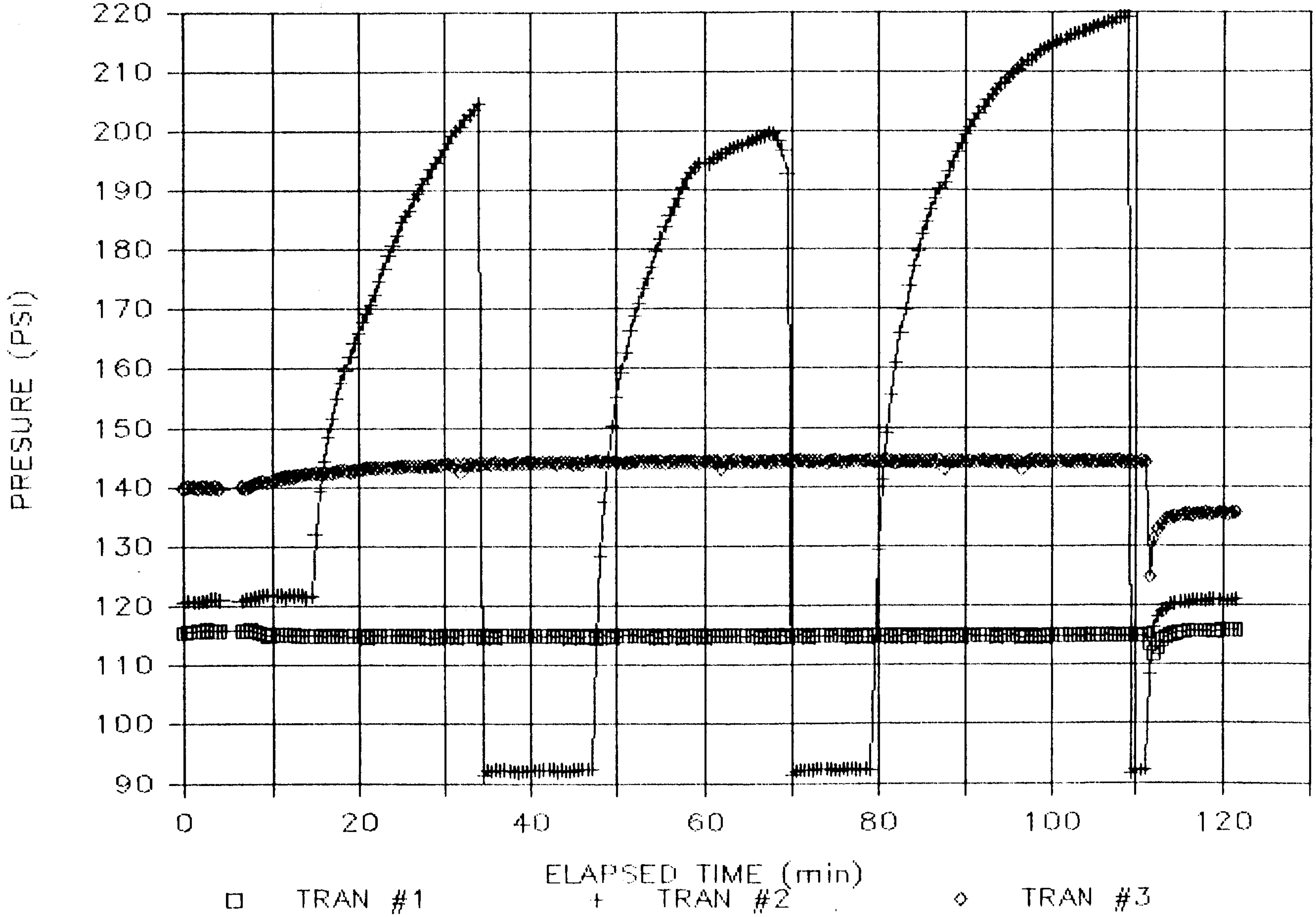
239.3 FT to 274.6 FT

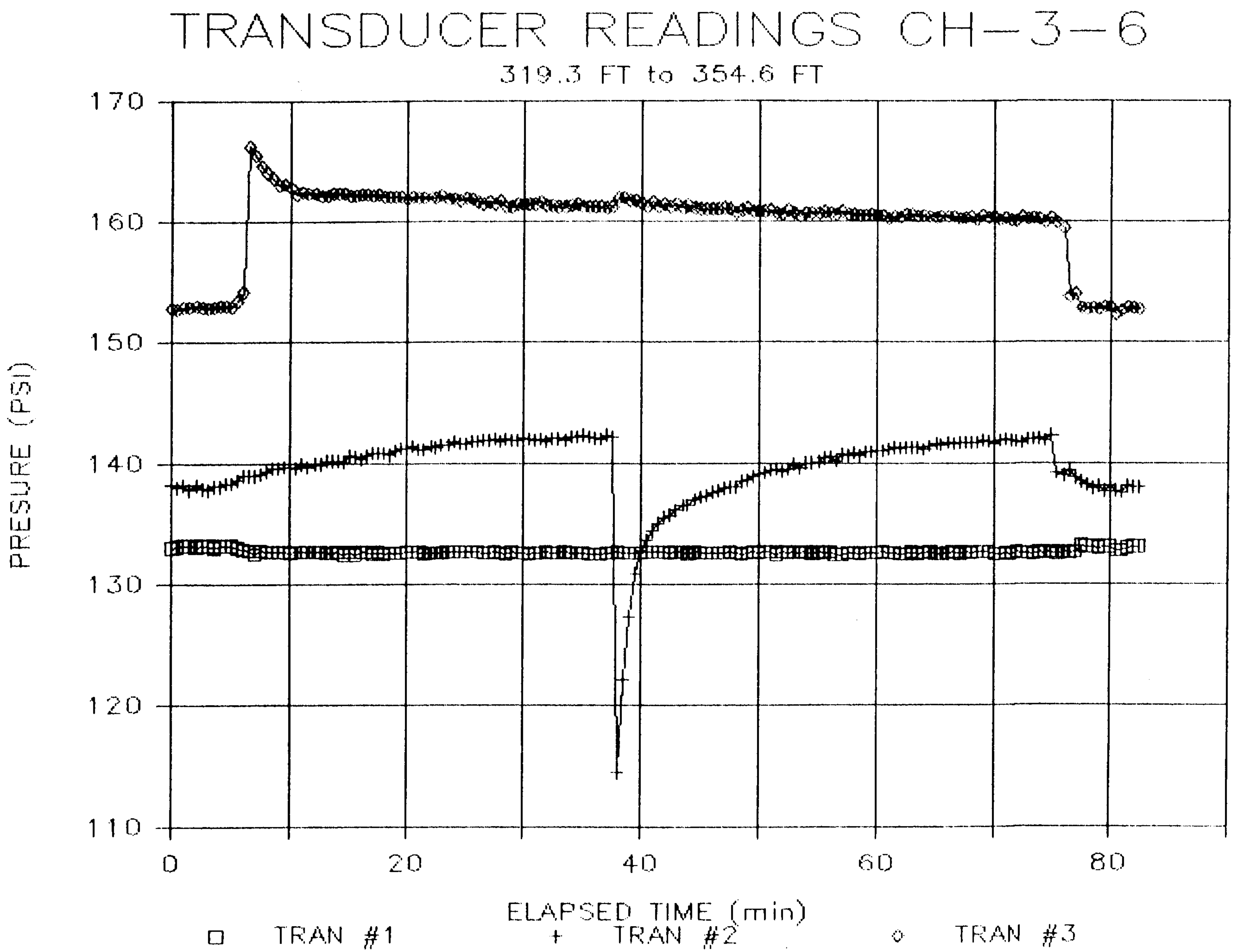



TRANSDUCER READINGS CH-3-4
239.3 FT to 274.6 FT
140
130
120
110
100
90
80
70
PRESURE (PSI)
0.8
0.82
0.84
0.86
0.88
0.9
0.92
0.94
0.96
0.98
1
(Thousands)
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3

TRANSDUCER READINGS CH-3-5

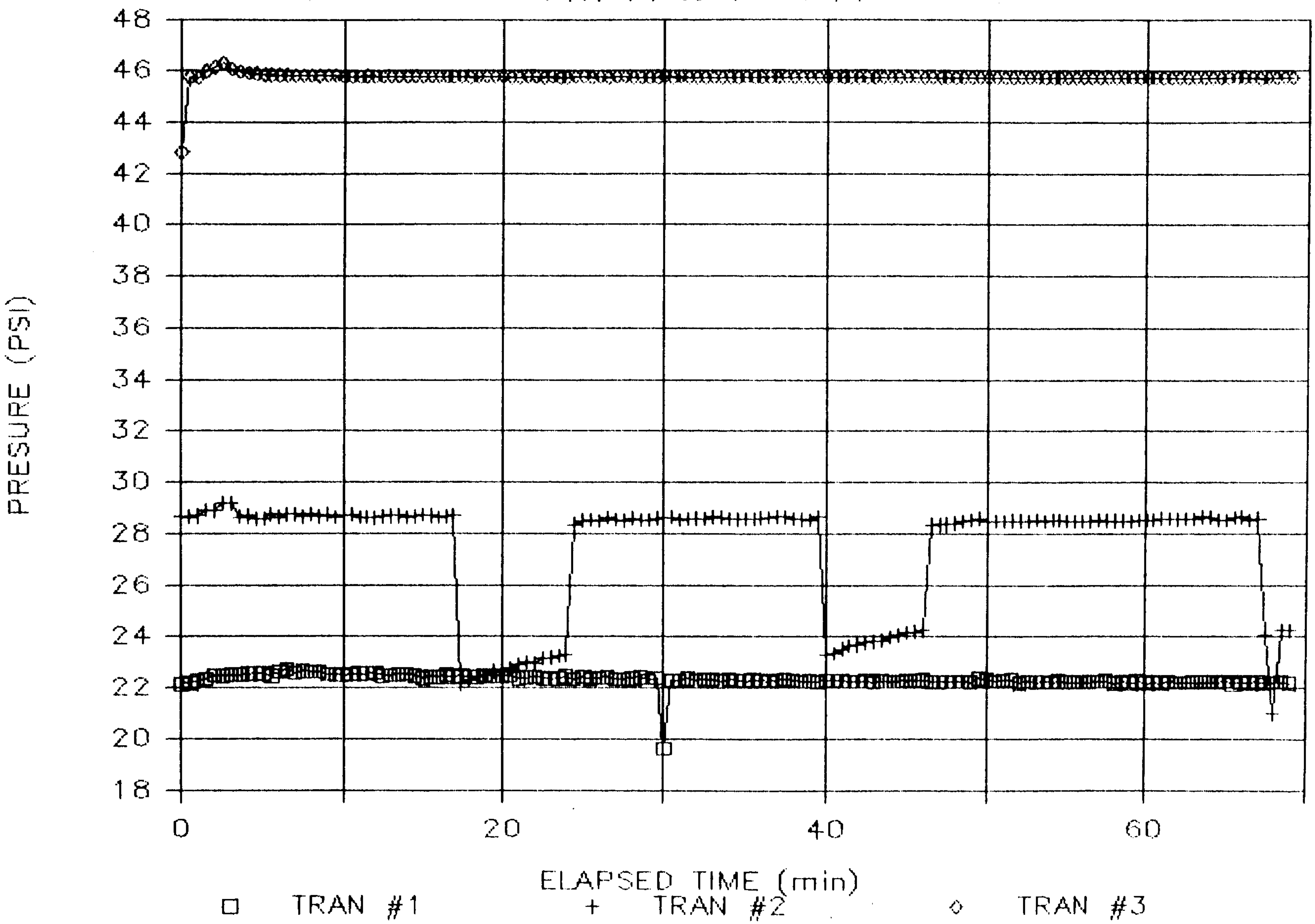
279.3 FT to 314.6 FT




TRANSDUCER READINGS CH-3-6
319.3 FT to 354.6 FT
170
160
150
140
130
120
110
PRESURE (PSI)
0
20
40
60
80
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3

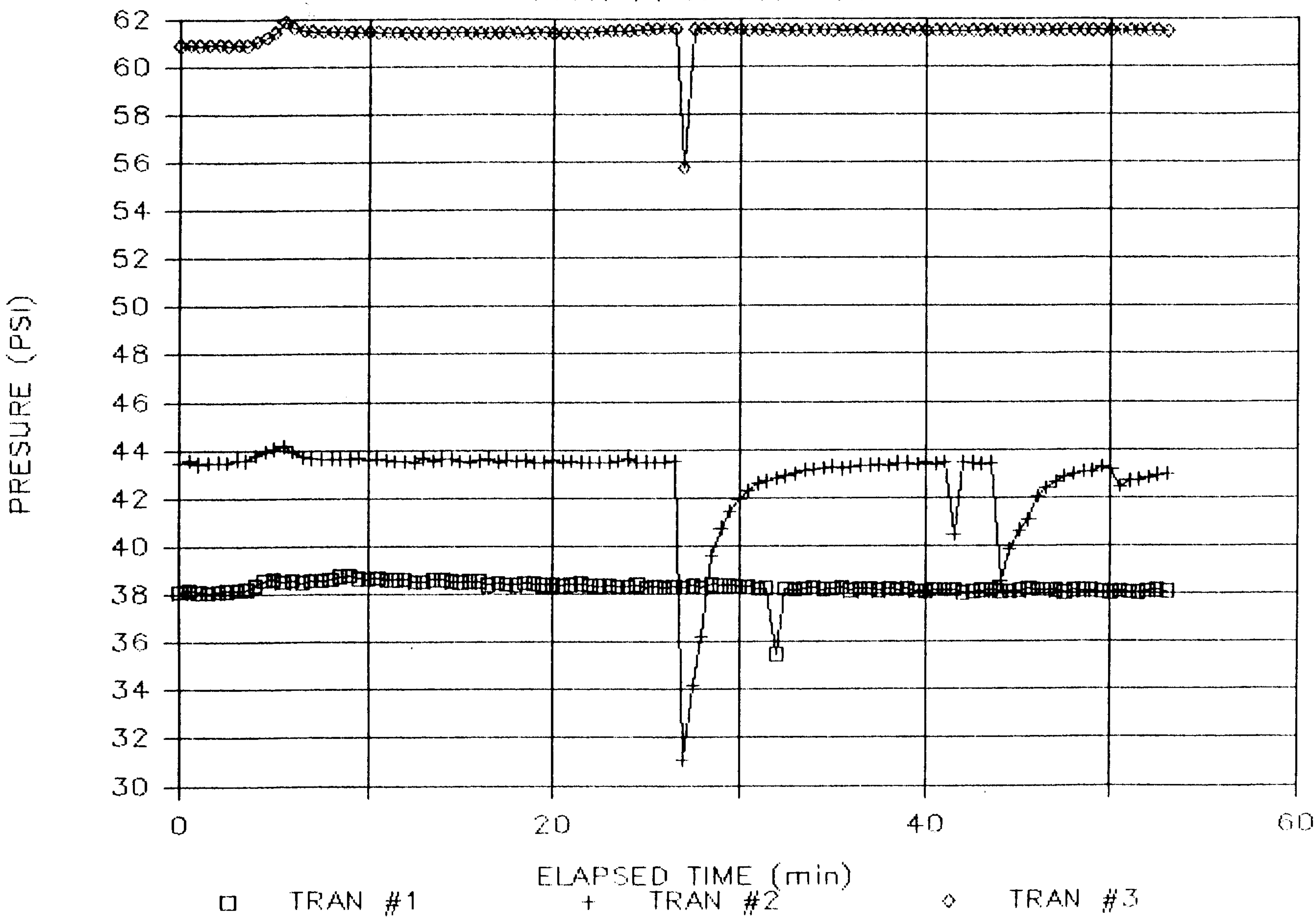
TRANSDUCER READINGS CH-4-1

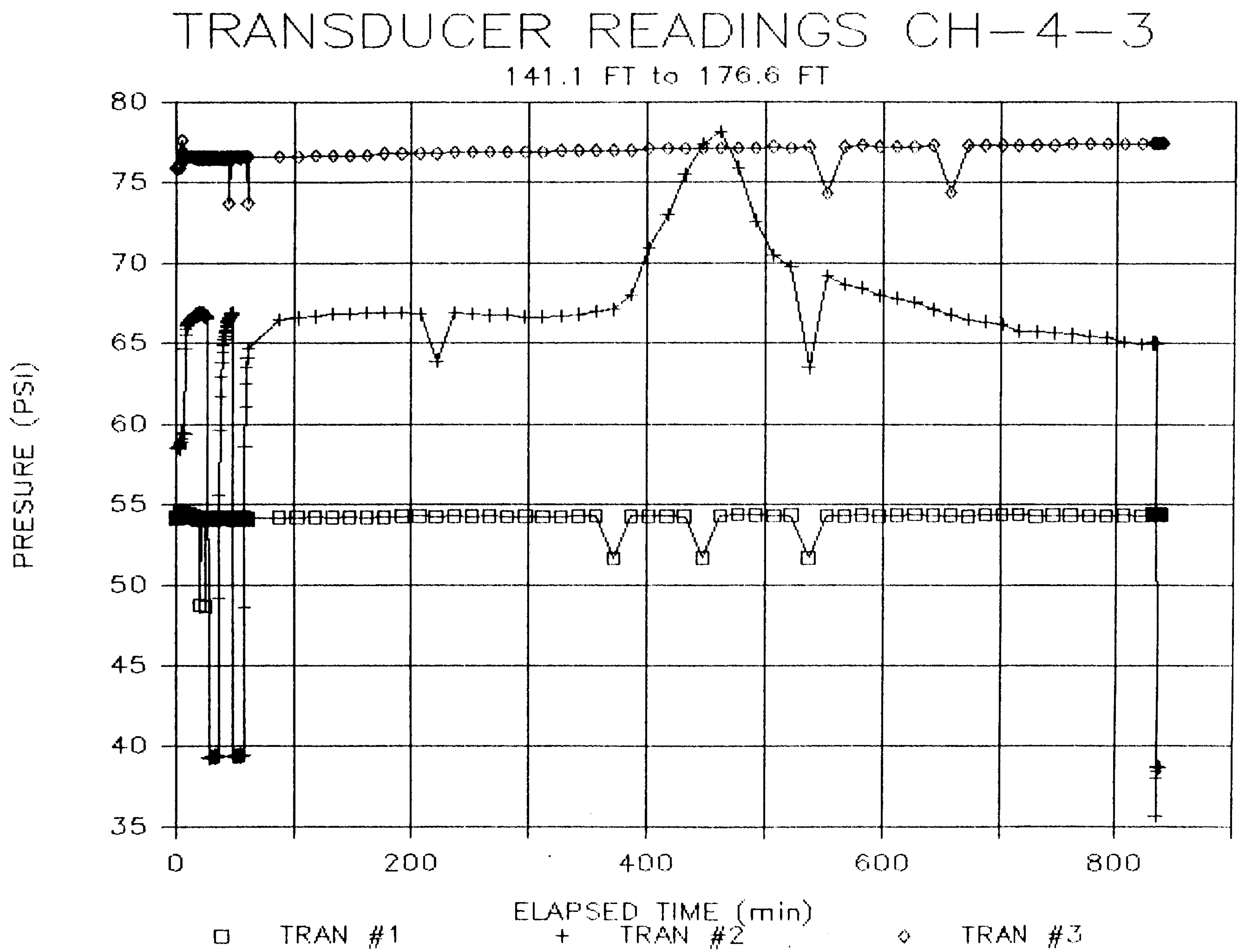
71.1 FT to 106.6 FT



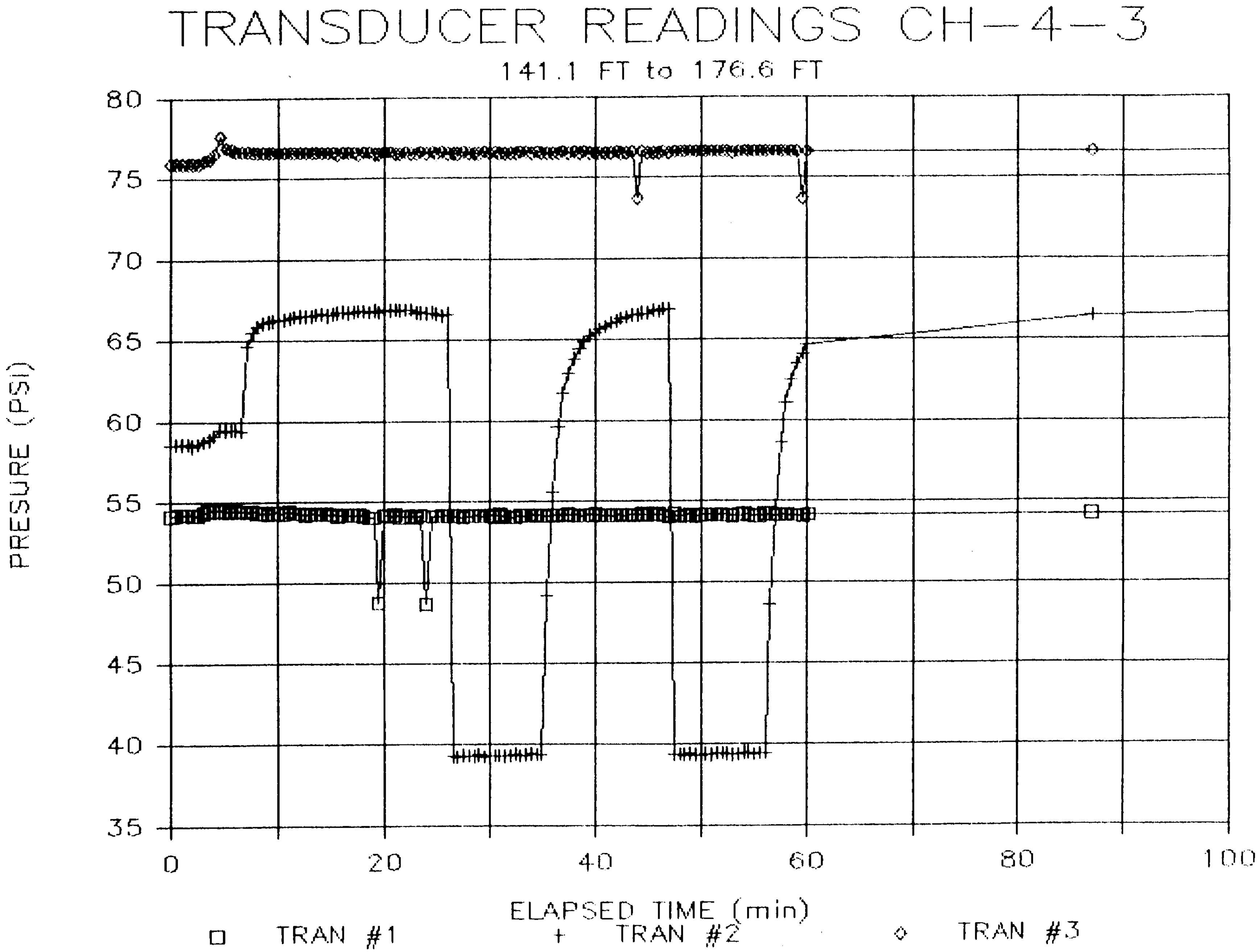
TRANSDUCER READINGS CH-4-2

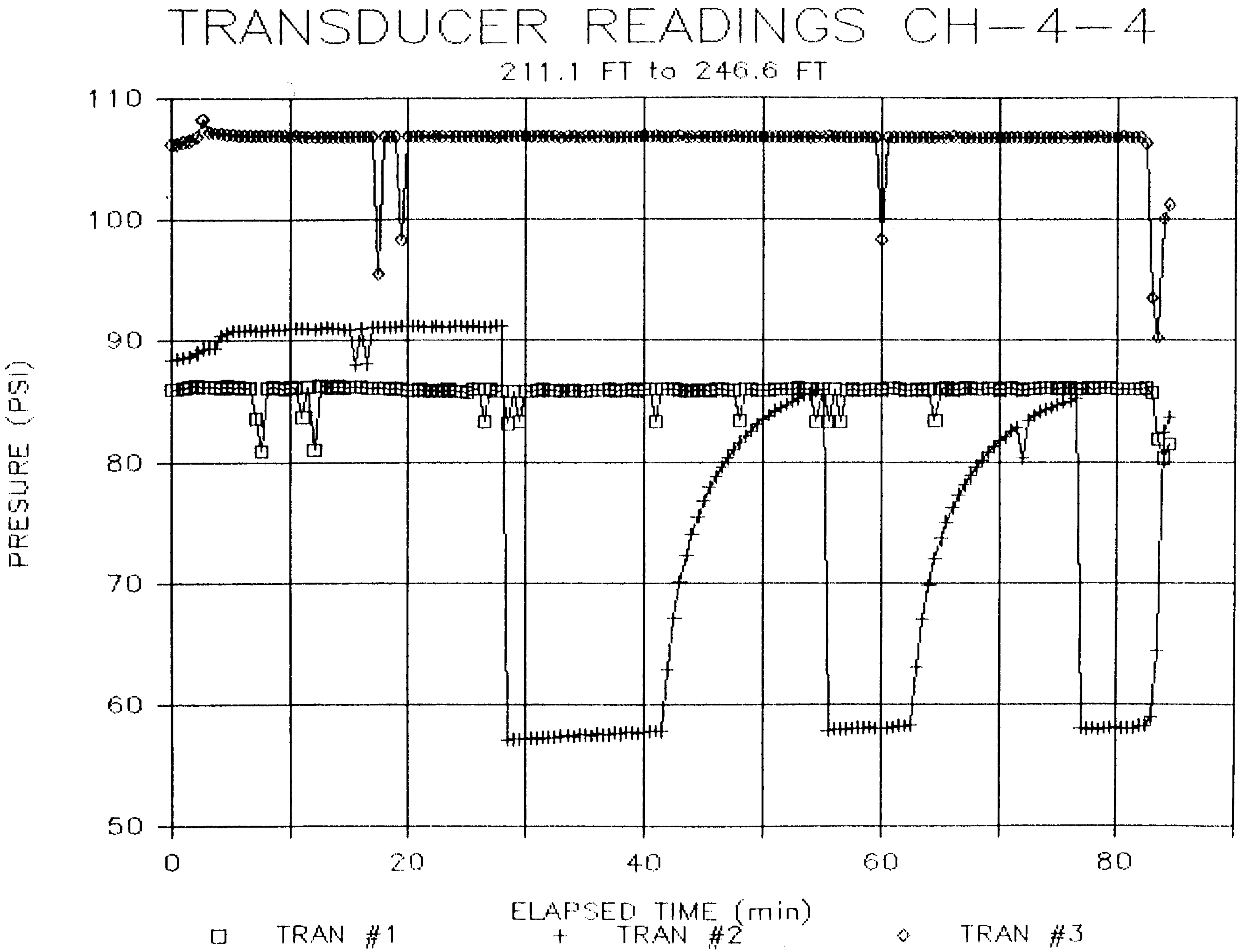
106.1 FT to 141.6 FT

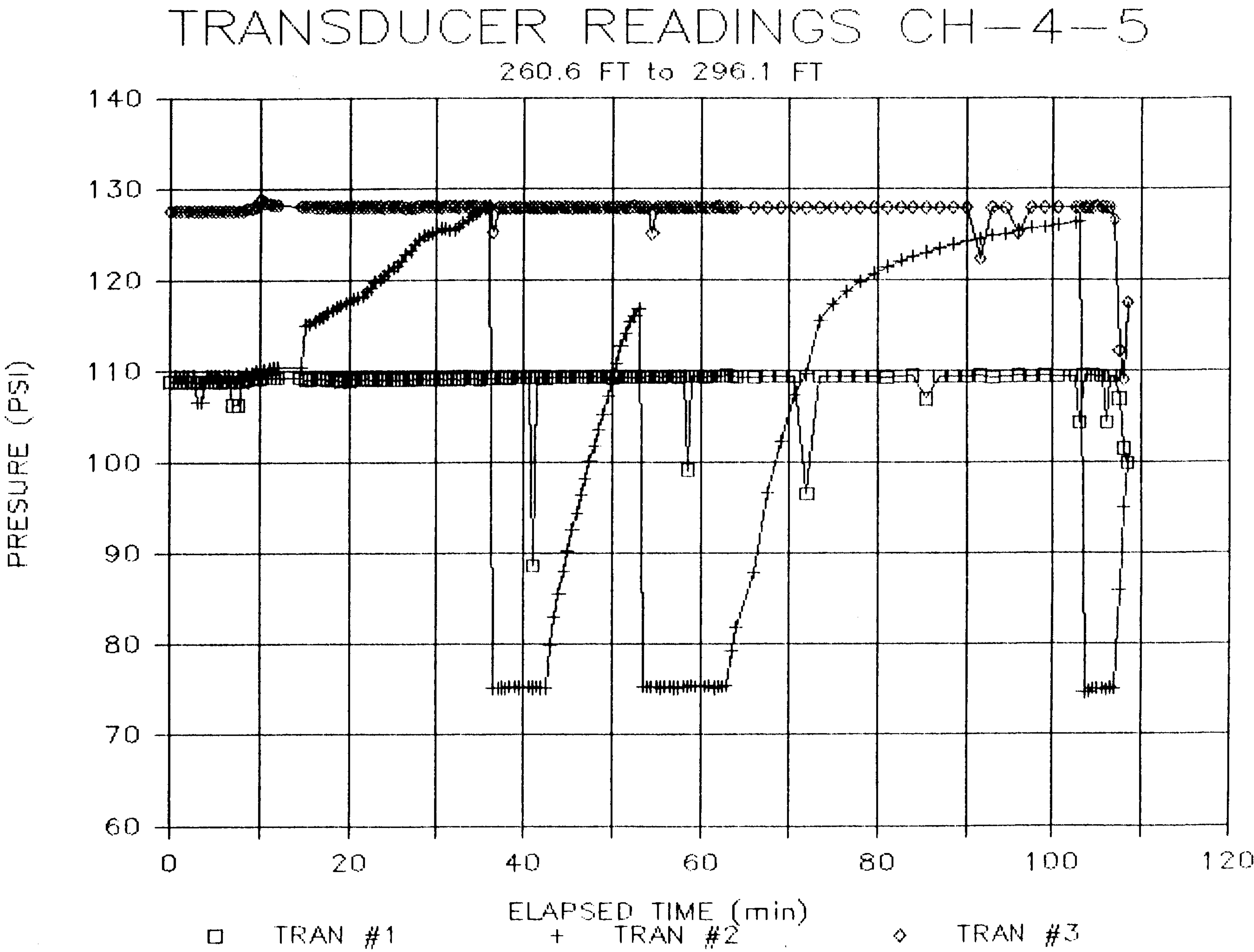


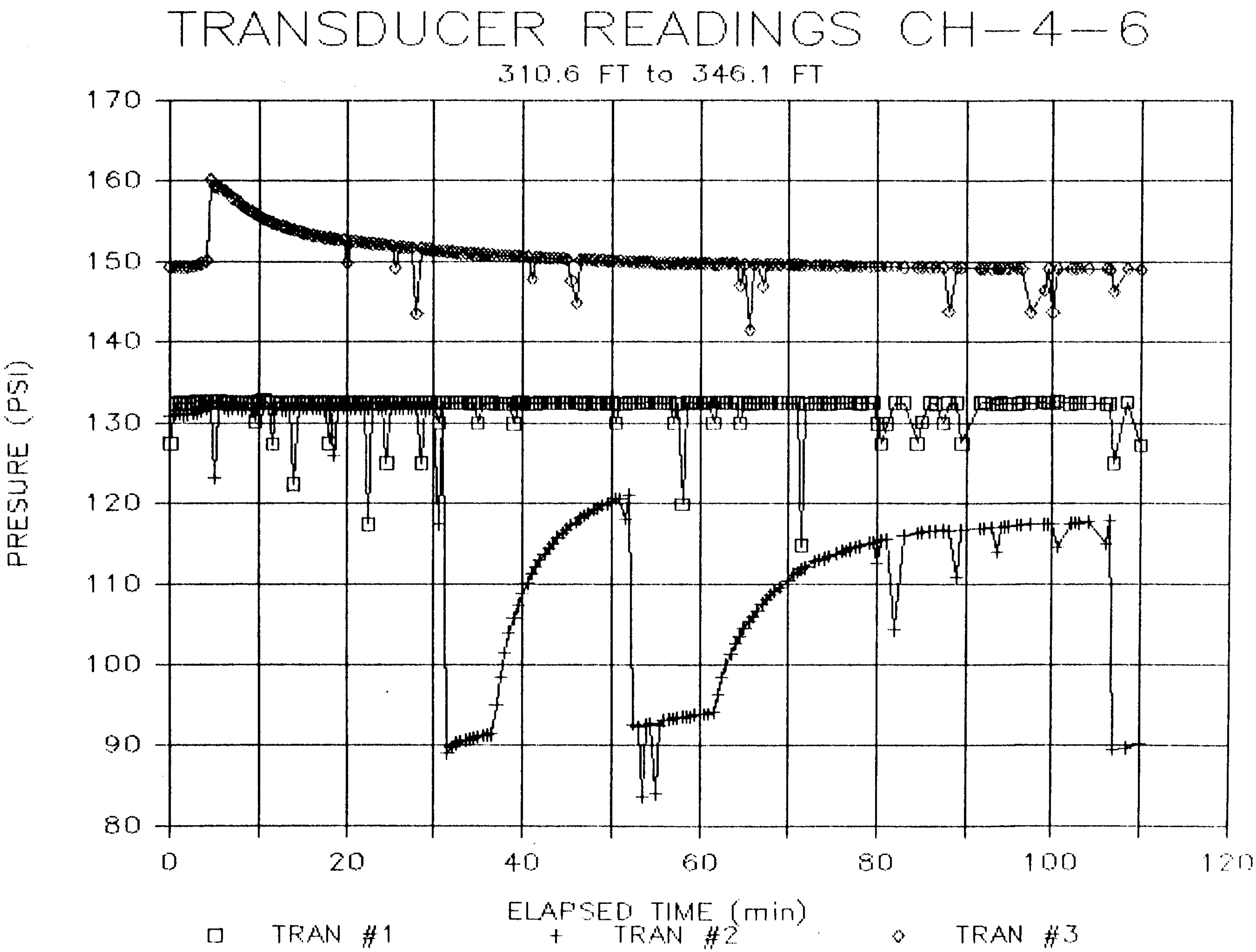


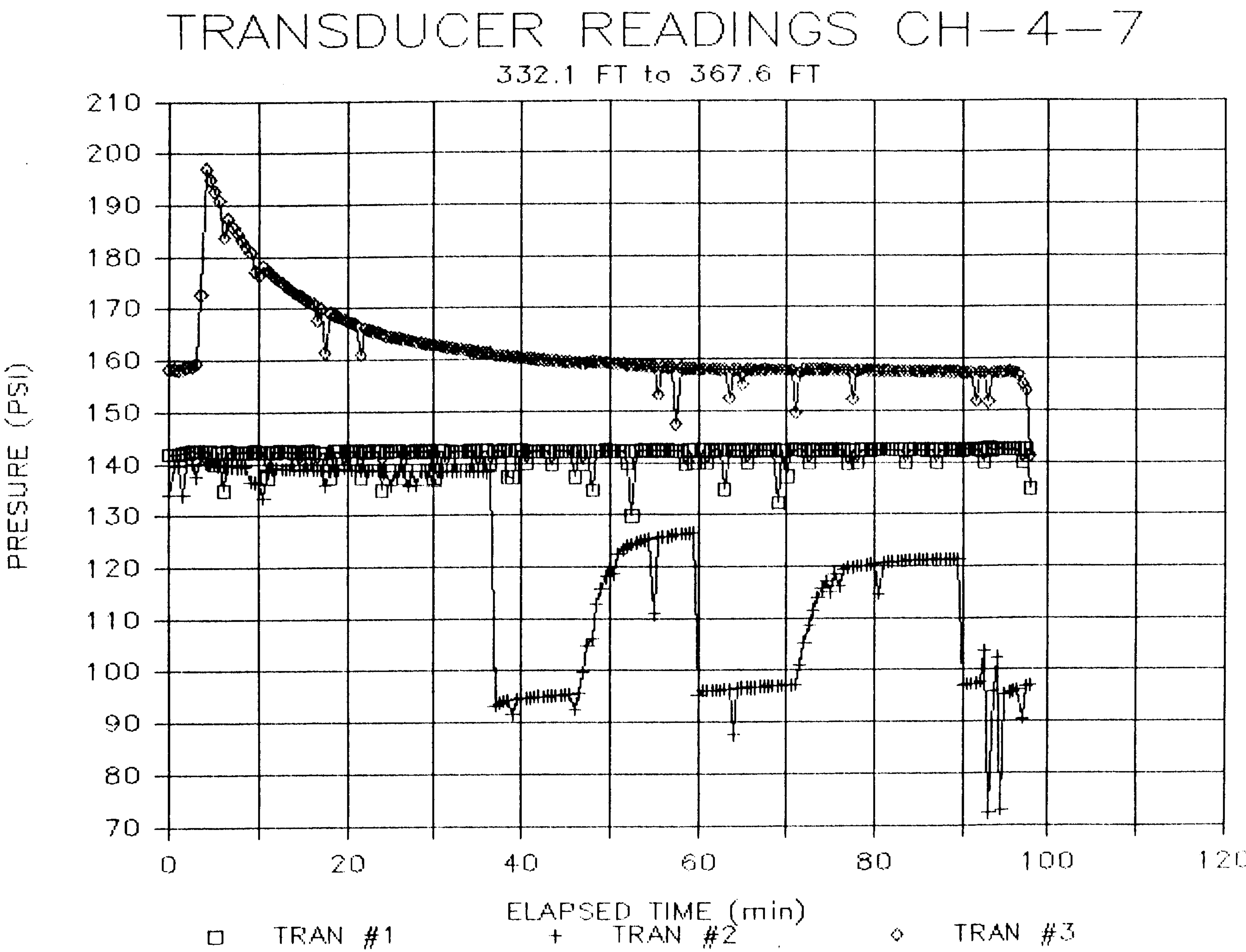
TRANSDUCER READINGS CH-4-3
141.1 FT to 176.6 FT
PRESURE (PSI)
ELAPSED TIME (min)
80
75
70
65
60
55
50
45
40
35
0
200
400
600
800
□ TRAN #1
+ TRAN #2
◇ TRAN #3


TRANSDUCER READINGS CH-4-3
141.1 FT to 176.6 FT
PRESURE (PSI)
80
75
70
65
60
55
50
45
40
35
0
20
40
60
80
100
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3


TRANSDUCER READINGS CH-4-4
211.1 FT to 246.6 FT
PRESURE (PSI)
110
100
90
80
70
60
50
0
20
40
60
80
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3

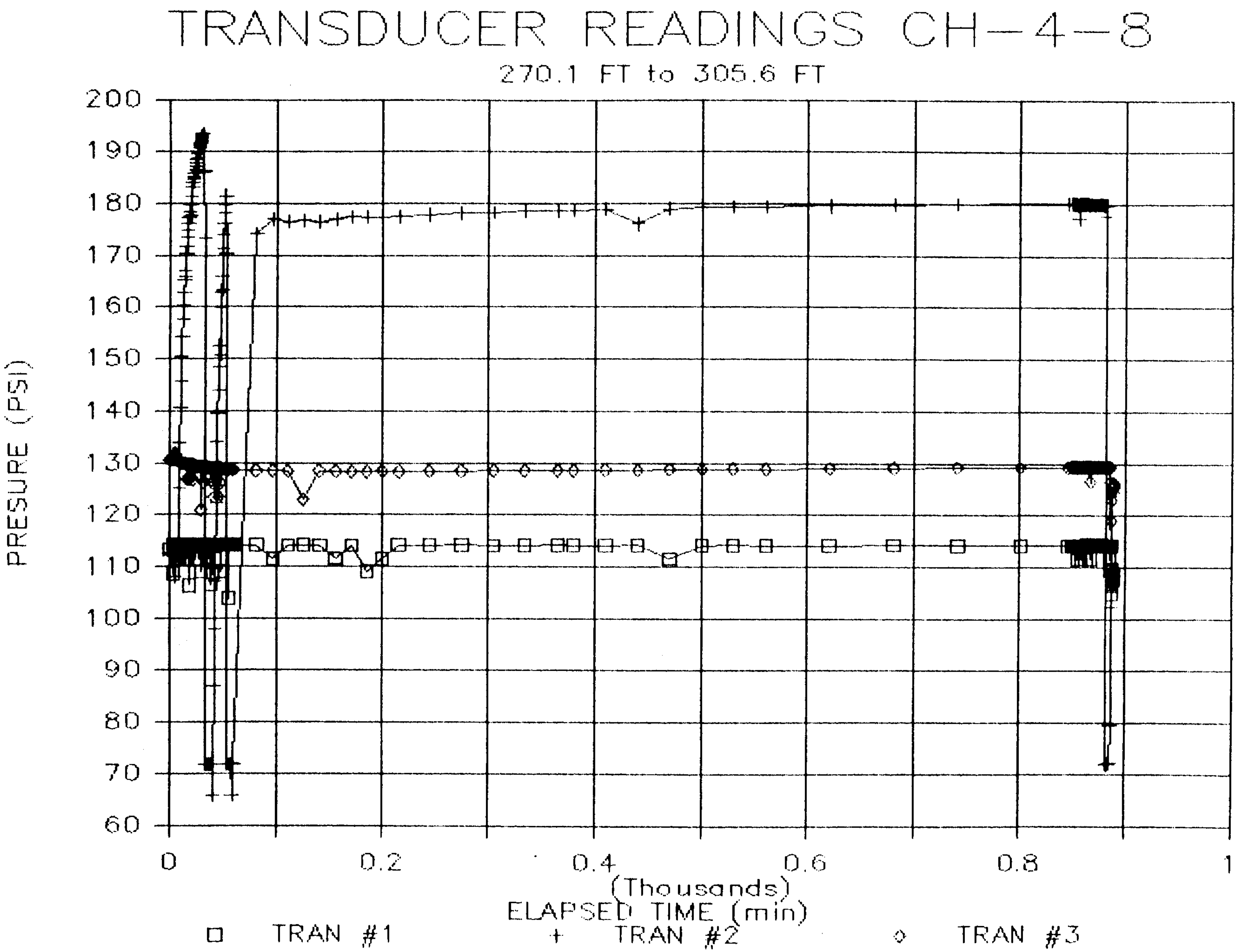

TRANSDUCER READINGS CH-4-5
260.6 FT to 296.1 FT
140
130
120
110
100
90
80
70
60
PRESURE (PSI)
0
20
40
60
80
100
120
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3


TRANSDUCER READINGS CH-4-6
310.6 FT to 346.1 FT
PRESURE (PSI)
ELAPSED TIME (min)
170
160
150
140
130
120
110
100
90
80
0
20
40
60
80
100
120
□ TRAN #1
+ TRAN #2
◇ TRAN #3



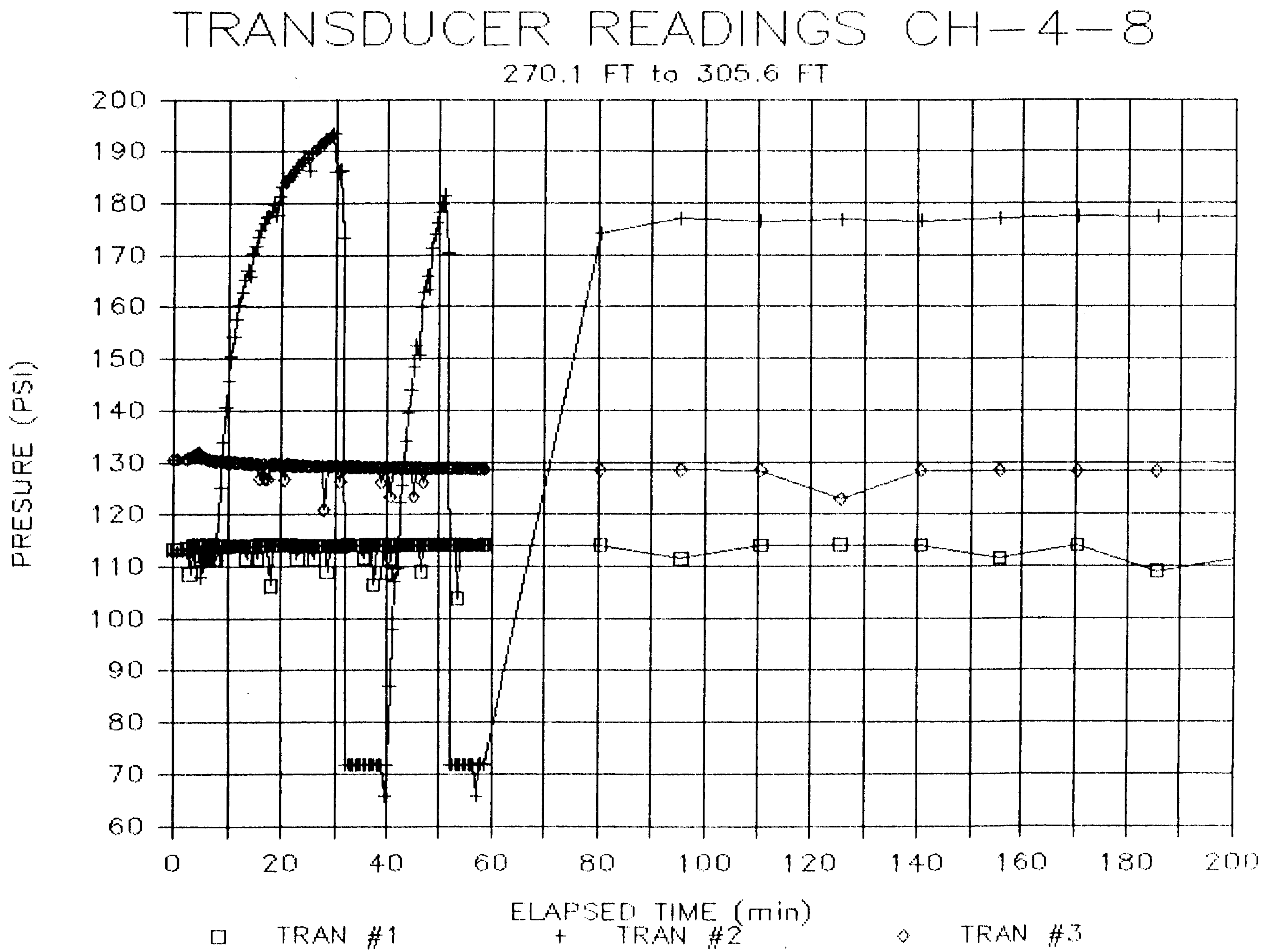
TRANSDUCER READINGS CH-4-7
332.1 FT to 367.6 FT
PRESURE (PSI)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
0
20
40
60
80
100
120
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3

B-38

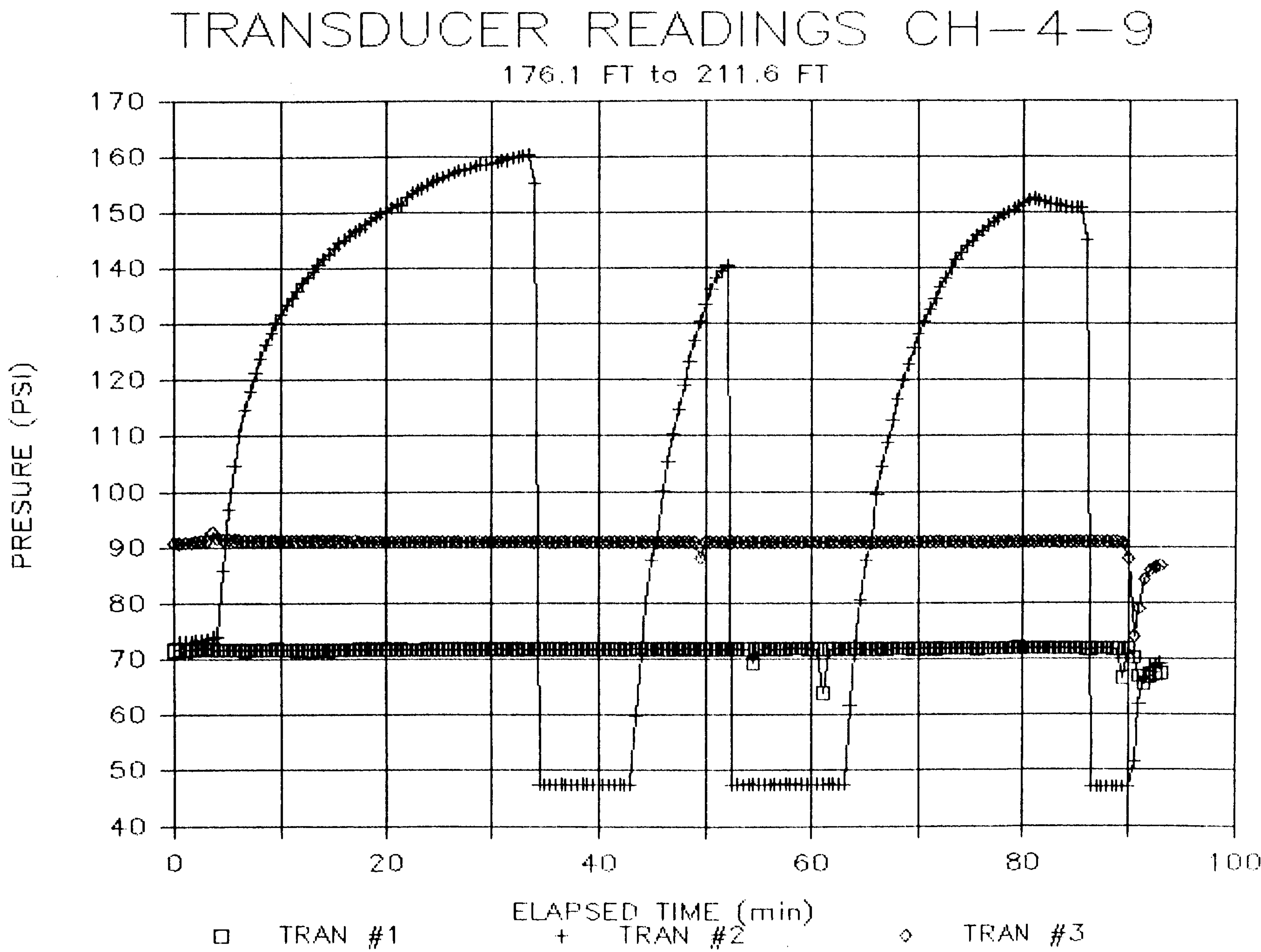


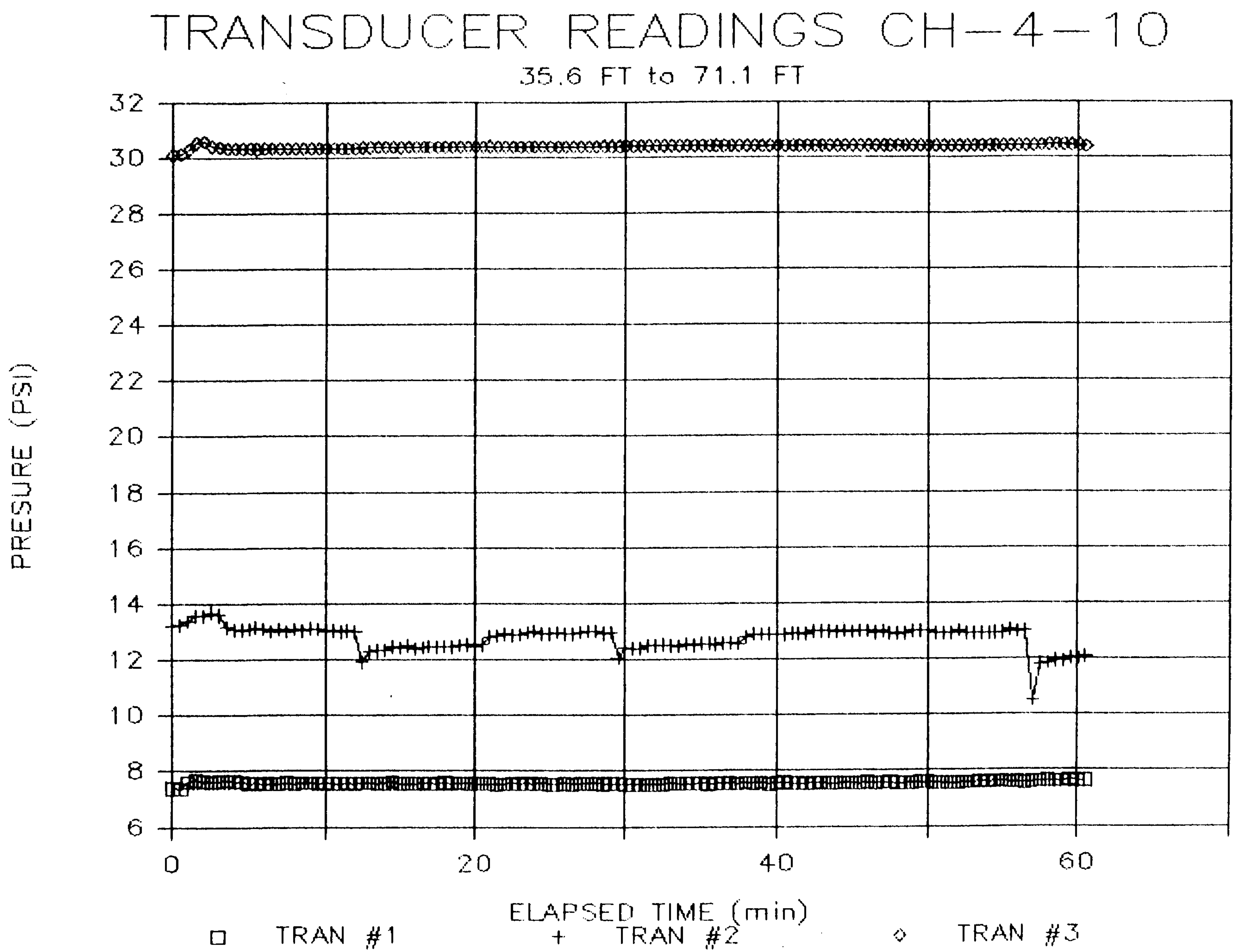
TRANSDUCER READINGS CH-4-8
270.1 FT to 305.6 FT
PRESURE (PSI)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
0
0.2
0.4
0.6
0.8
1
(Thousands)
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3

B-39

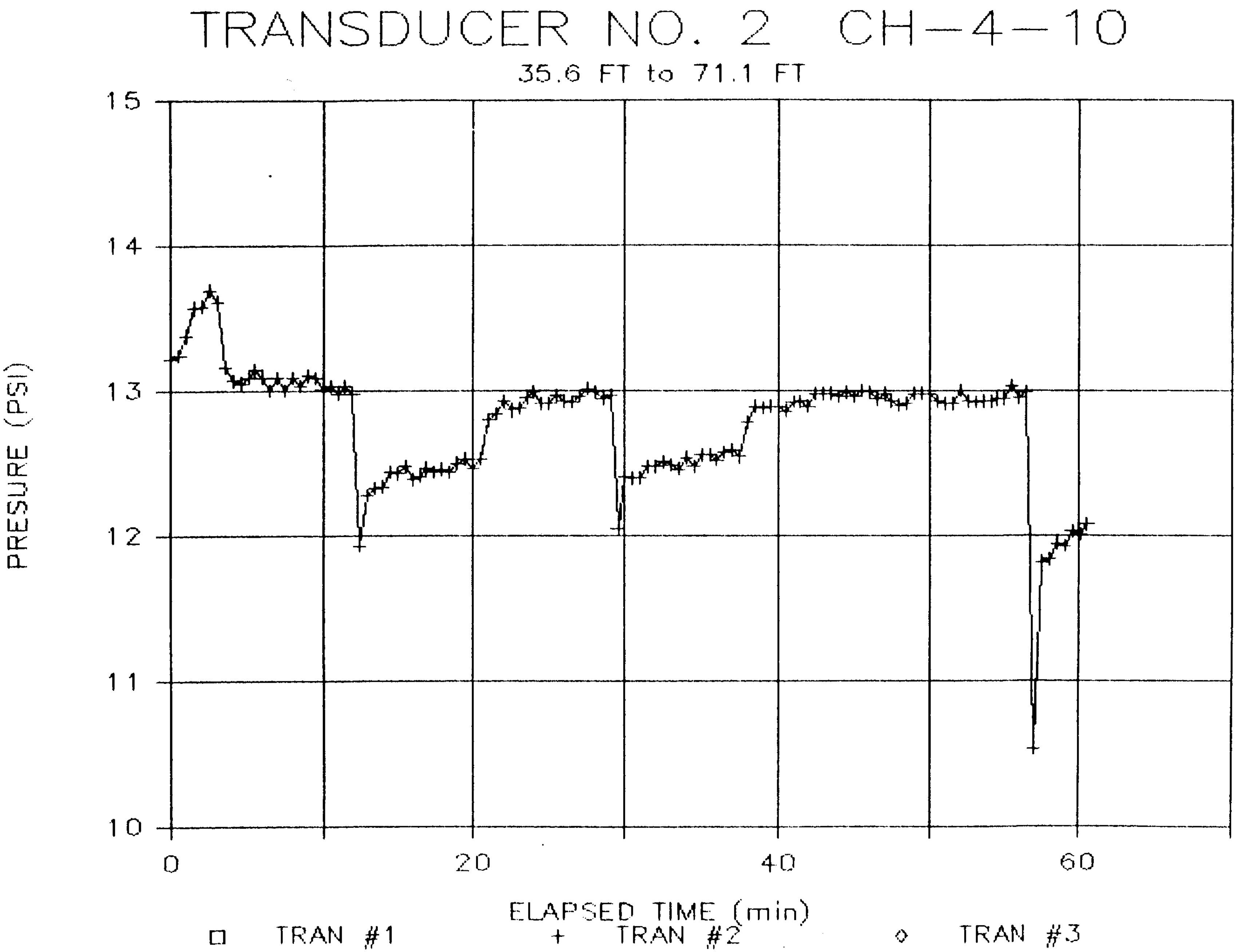


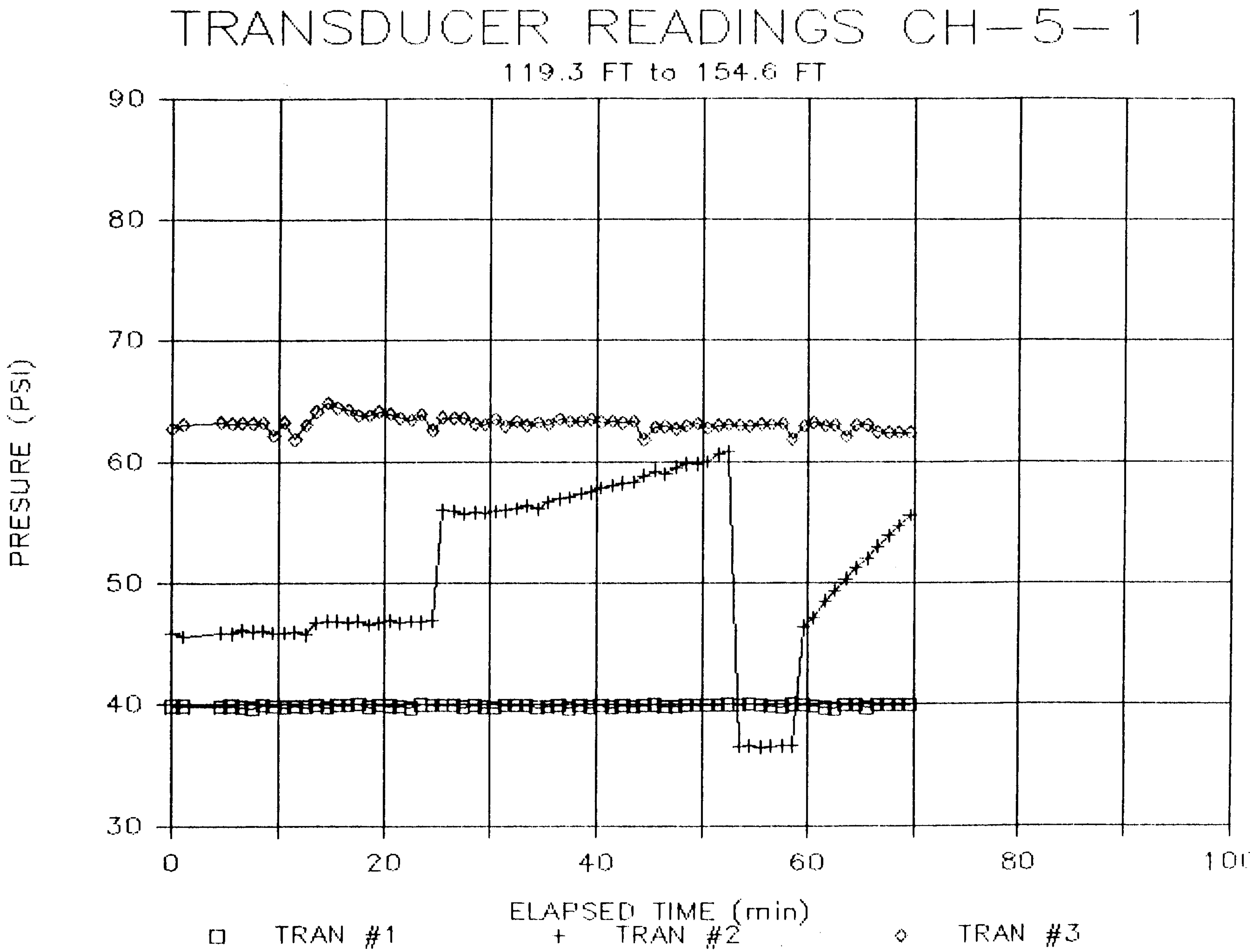
TRANSDUCER READINGS CH-4-8
270.1 FT to 305.6 FT
PRESURE (PSI)
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
0
20
40
60
80
100
120
140
160
180
200
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3


TRANSDUCER READINGS CH-4-9
176.1 FT to 211.6 FT
PRESURE (PSI)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
0
20
40
60
80
100
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3



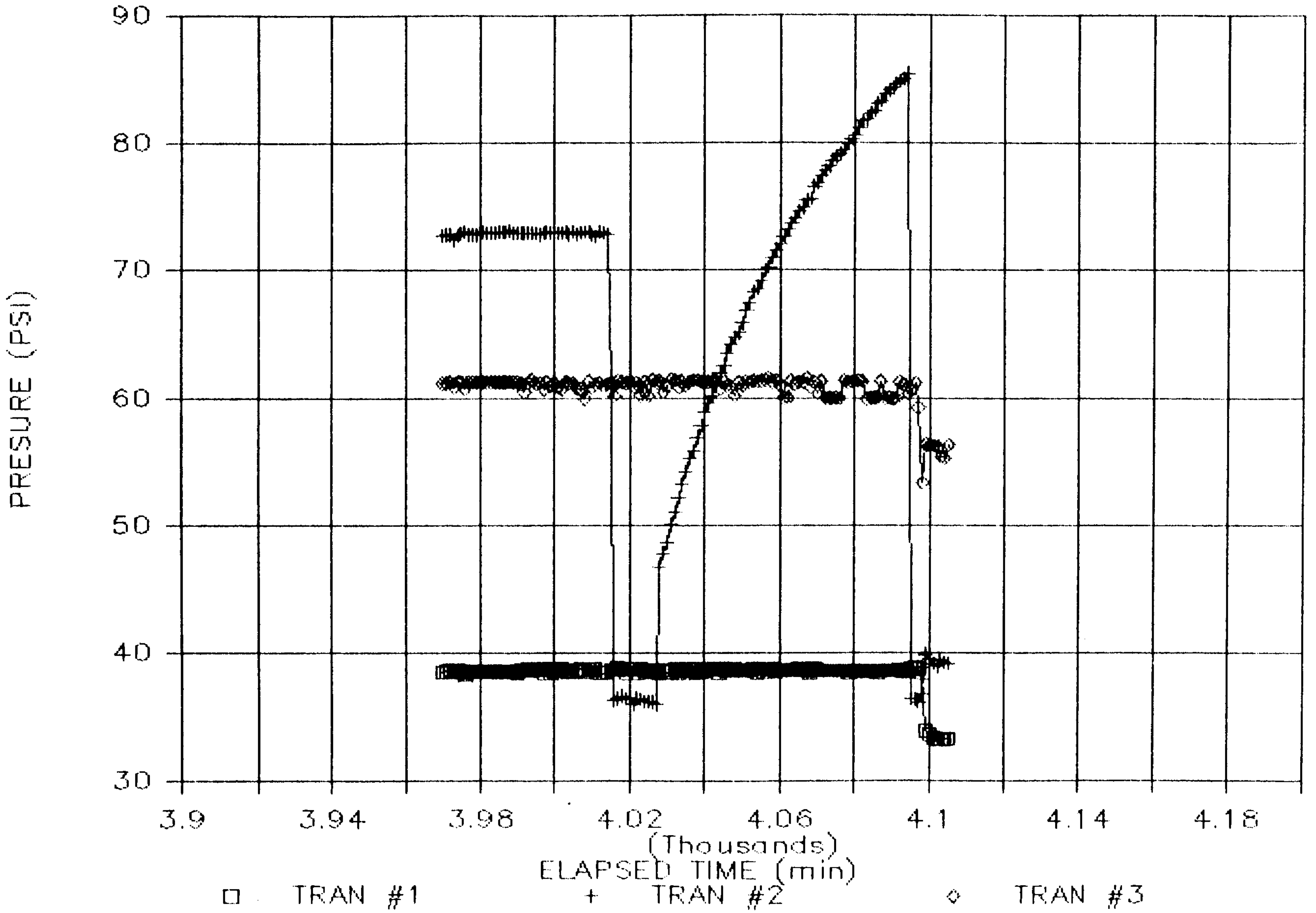
TRANSDUCER READINGS CH-4-10
35.6 FT to 71.1 FT
PRESURE (PSI)
32
30
28
26
24
22
20
18
16
14
12
10
8
6
0
20
40
60
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3

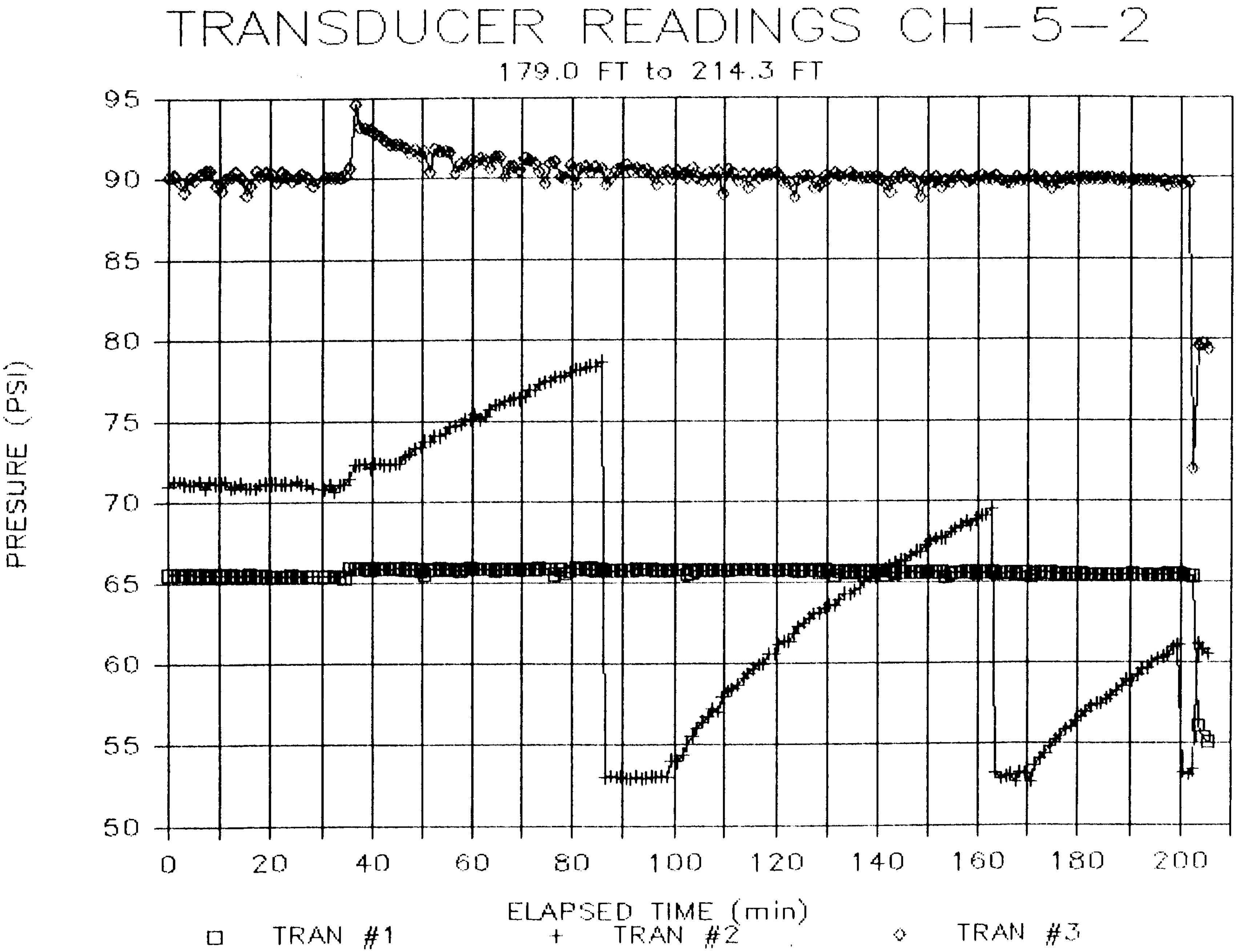

TRANSDUCER NO. 2 CH-4-10
35.6 FT to 71.1 FT
PRESURE (PSI)
15
14
13
12
11
10
0
20
40
60
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3

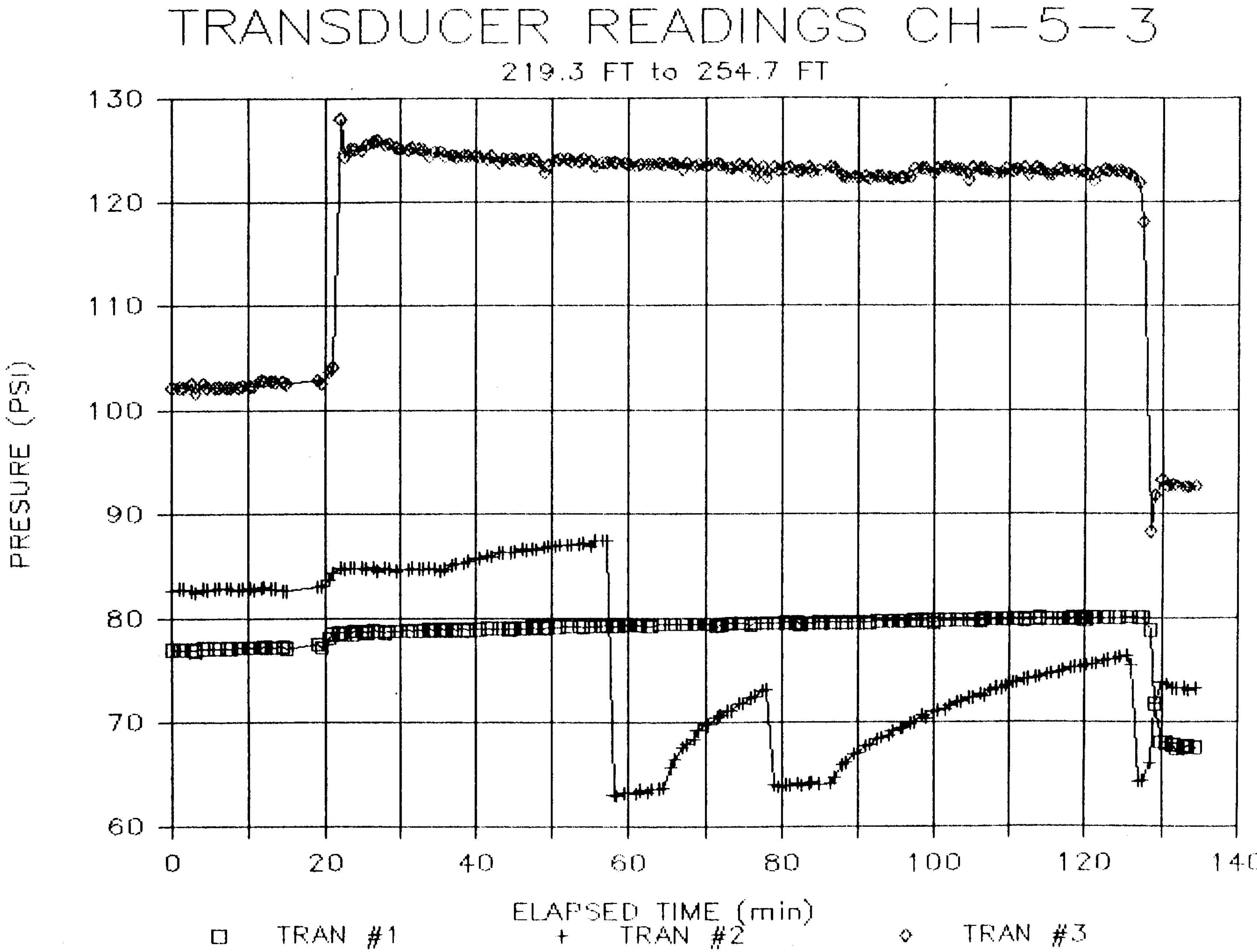

TRANSDUCER READINGS CH-5-1
119.3 FT to 154.6 FT
PRESURE (PSI)
90
80
70
60
50
40
30
0
20
40
60
80
100
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3

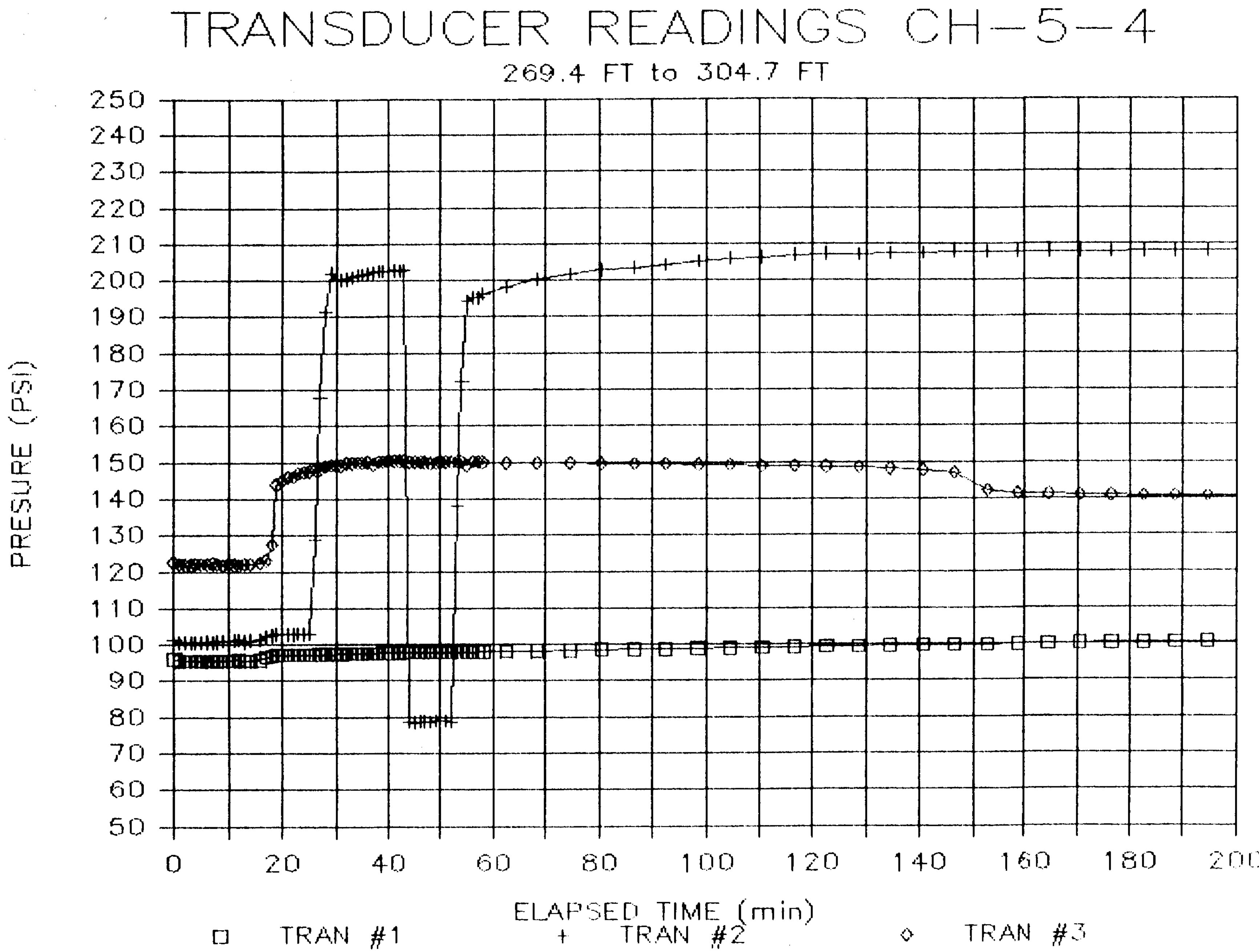
TRANSDUCER READINGS CH-5-1

119.3 FT to 154.6 FT




TRANSDUCER READINGS CH-5-2
179.0 FT to 214.3 FT
PRESURE (PSI)
95
90
85
80
75
70
65
60
55
50
0
20
40
60
80
100
120
140
160
180
200
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3

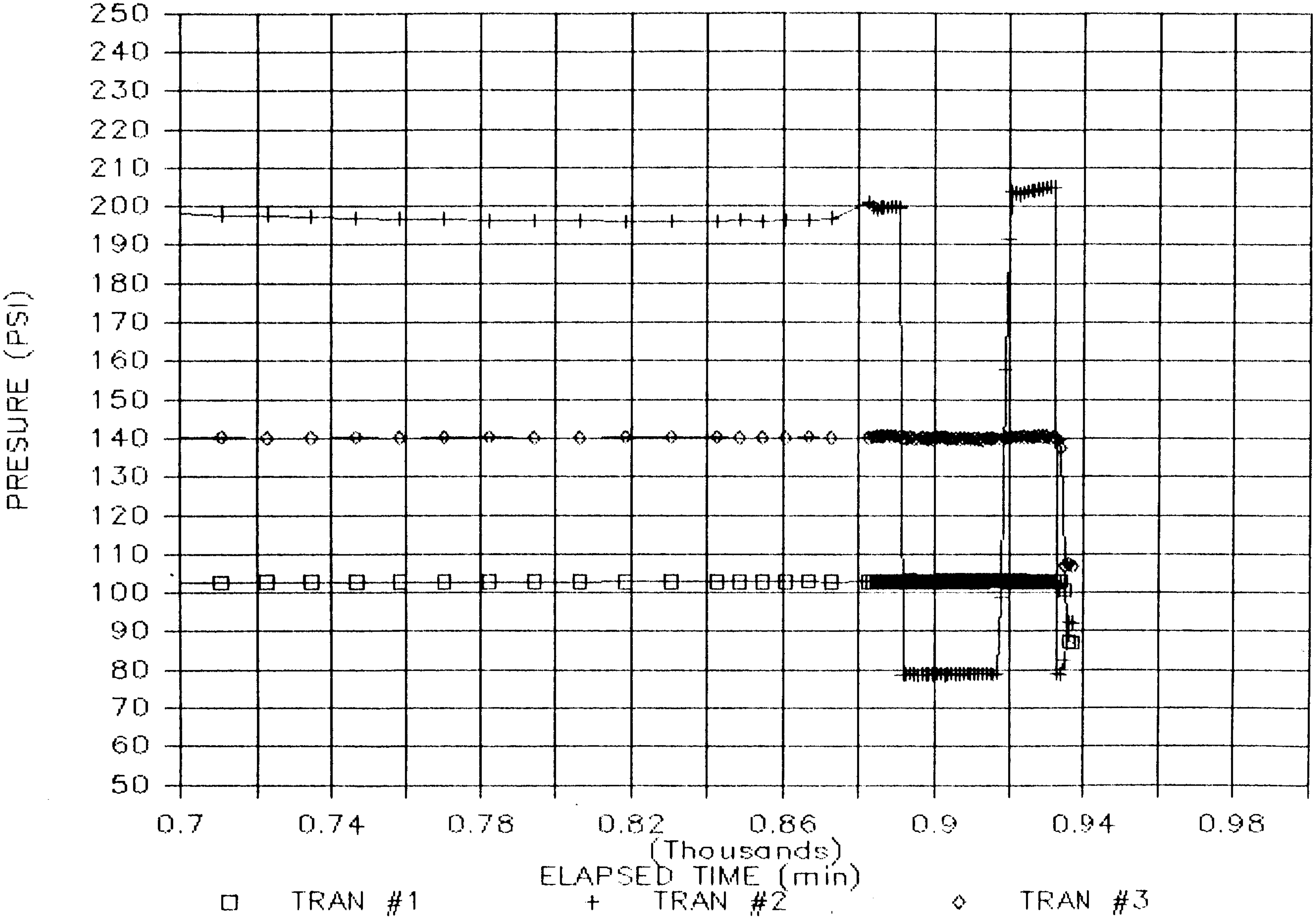

TRANSDUCER READINGS CH-5-3
219.3 FT to 254.7 FT
PRESURE (PSI)
130
120
110
100
90
80
70
60
0
20
40
60
80
100
120
140
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3

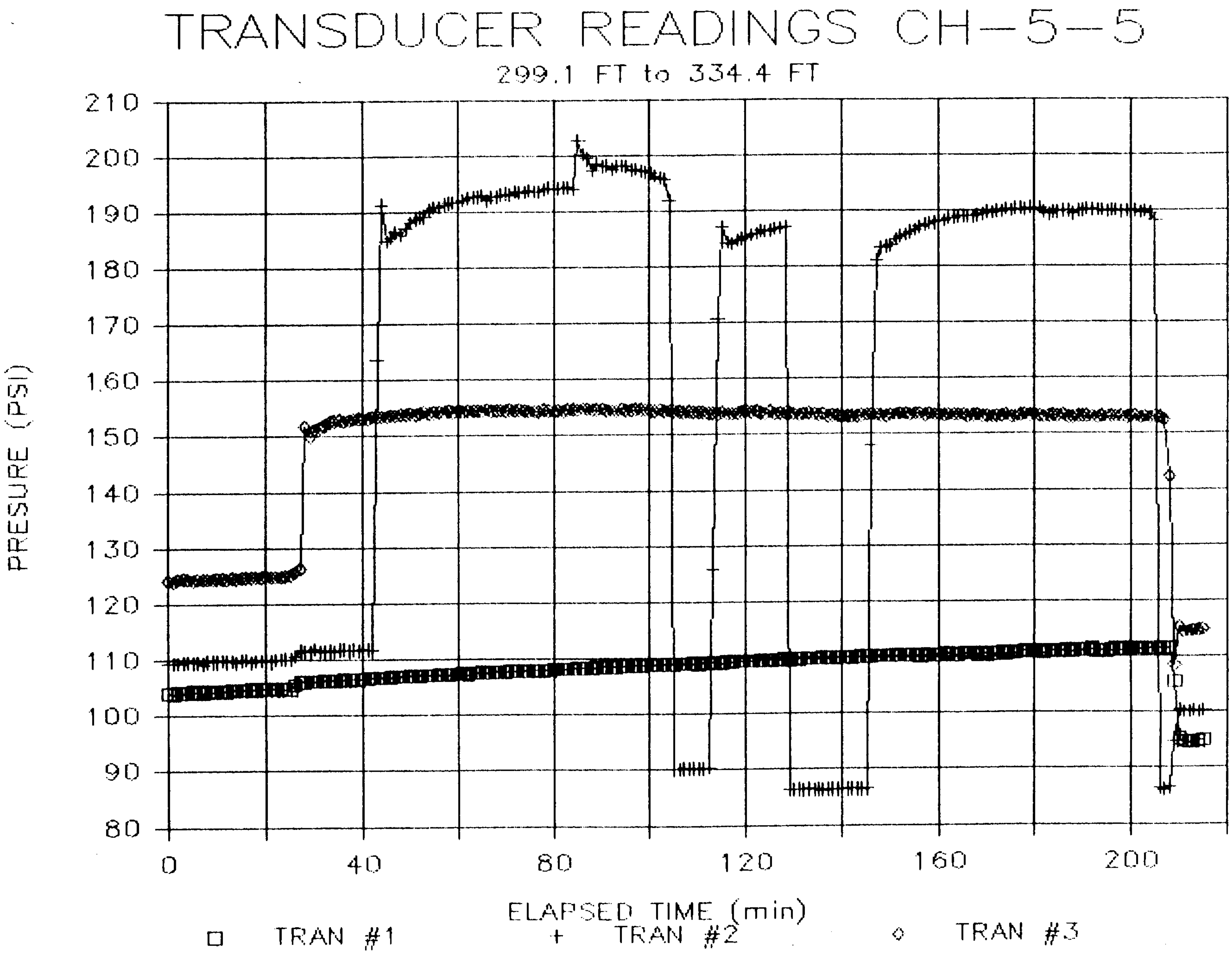


TRANSDUCER READINGS CH-5-4
269.4 FT to 304.7 FT
PRESURE (PSI)
250
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
0
20
40
60
80
100
120
140
160
180
200
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3

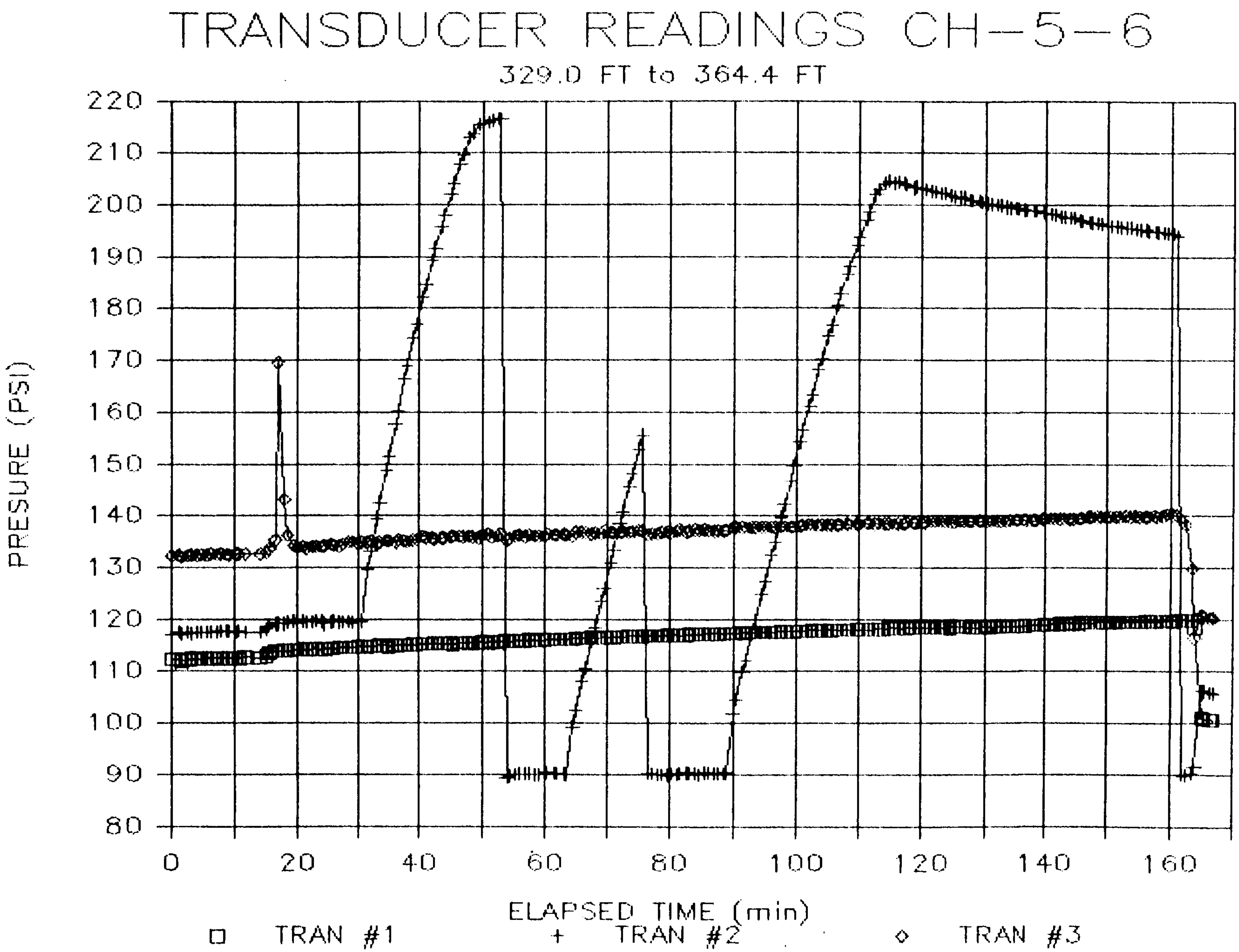
TRANSDUCER READINGS CH-5-4

269.4 FT to 304.7 FT

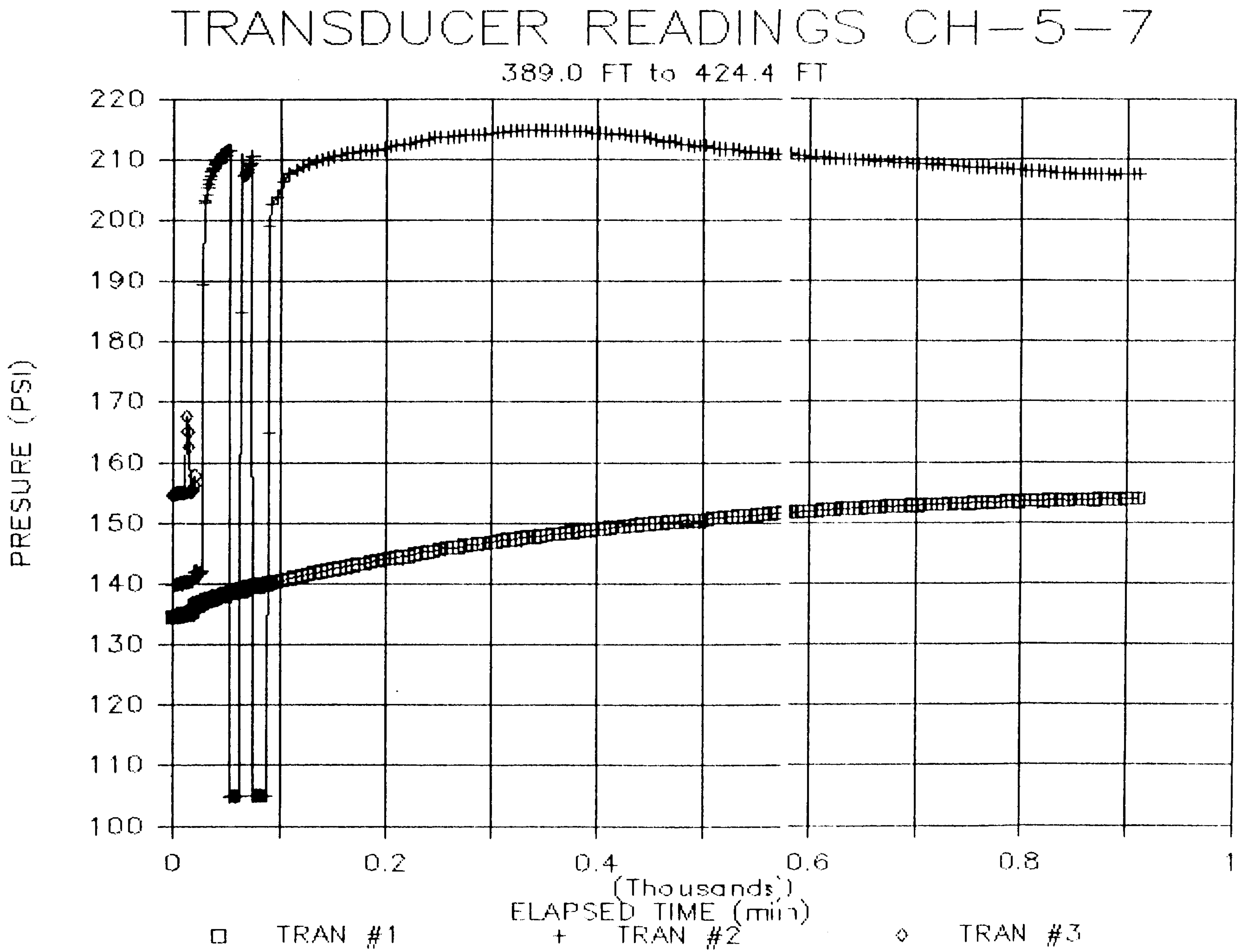




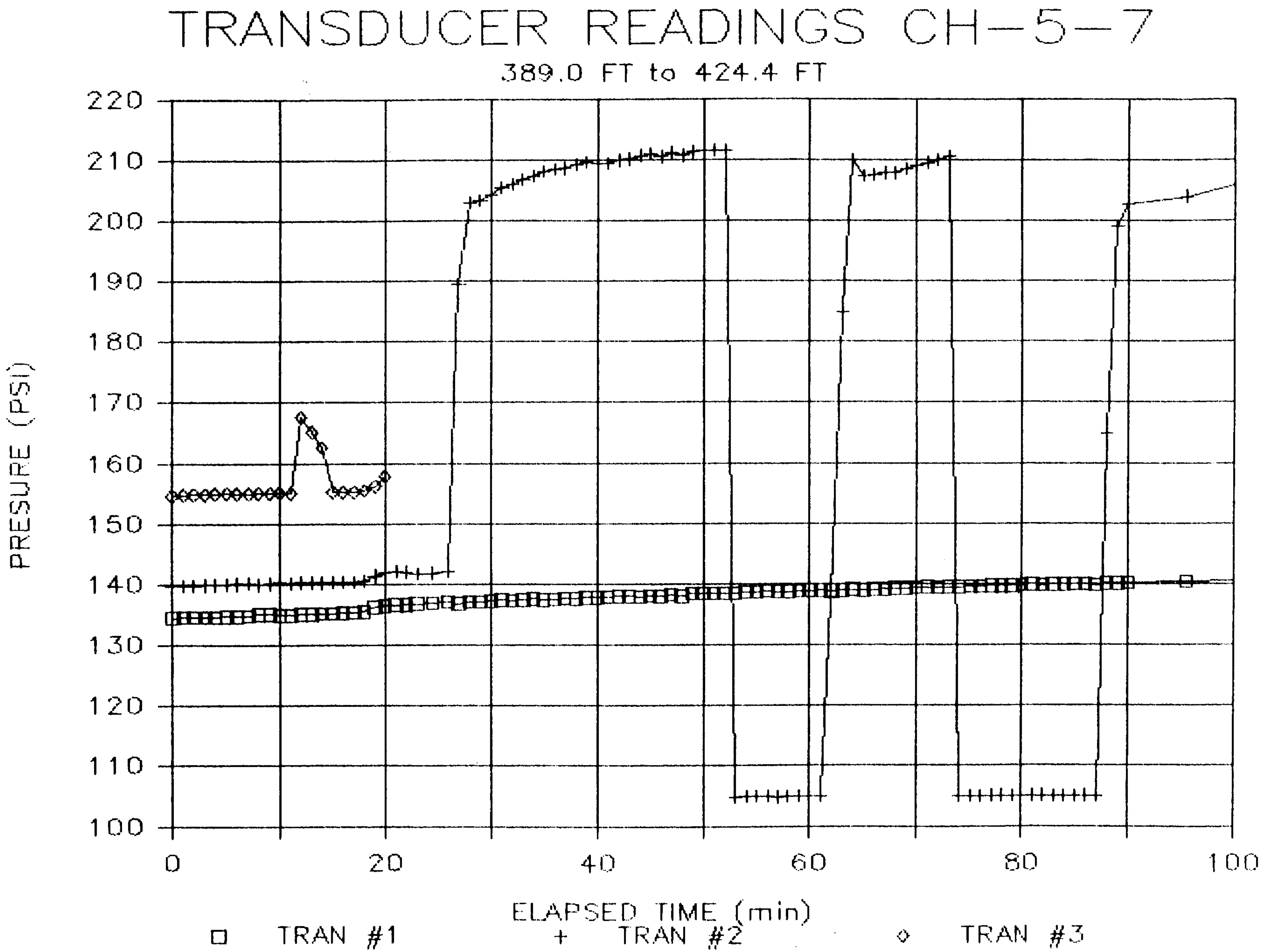
TRANSDUCER READINGS CH-5-5
299.1 FT to 334.4 FT
PRESURE (PSI)
210
200
190
180
170
160
150
140
130
120
110
100
90
80
0
40
80
120
160
200
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3



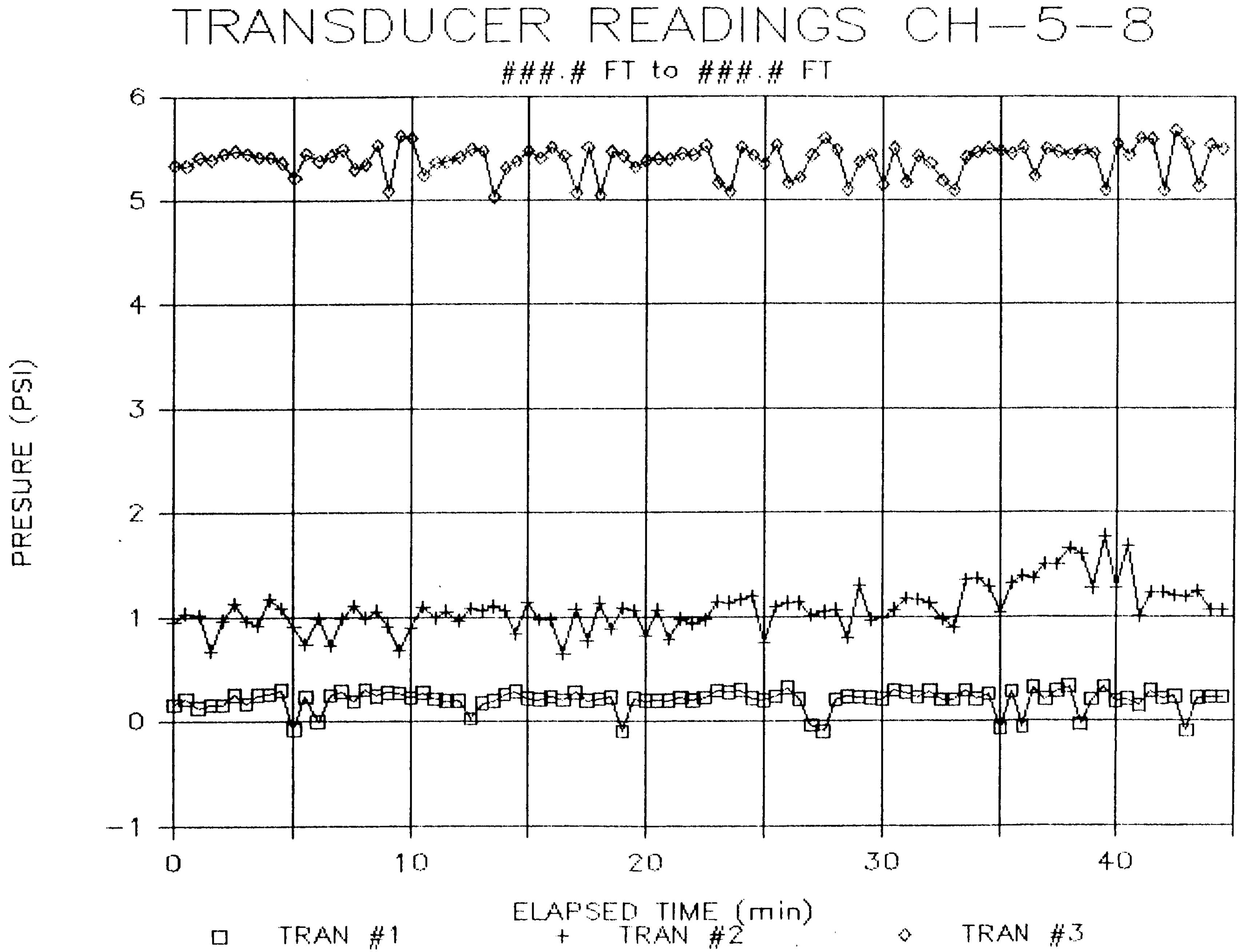
TRANSDUCER READINGS CH-5-6
329.0 FT to 364.4 FT
PRESURE (PSI)
220
210
200
190
180
170
160
150
140
130
120
110
100
90
80
0
20
40
60
80
100
120
140
160
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3



TRANSDUCER READINGS CH-5-7
389.0 FT to 424.4 FT
PRESURE (PSI)
220
210
200
190
180
170
160
150
140
130
120
110
100
0
0.2
0.4
0.6
0.8
1
(Thousands)
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3



TRANSDUCER READINGS CH-5-7
389.0 FT to 424.4 FT
PRESURE (PSI)
220
210
200
190
180
170
160
150
140
130
120
110
100
0
20
40
60
80
100
ELAPSED TIME (min)
□ TRAN #1
+ TRAN #2
◇ TRAN #3



TRANSDUCER READINGS CH-5-8
###.# FT to ###.# FT
PRESURE (PSI)
ELAPSED TIME (min)
TRAN #1
TRAN #2
TRAN #3

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