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# FACTORS TO BE CONSIDERED IN THE INTERPRETATIONS OF INJECTIVITY PROFILES

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## ABSTRACT

The increasing knowledge of the problems of fluid injection in secondary recovery operations has resulted in the need for improved accuracy of well profile information

As profiling techniques have been improved and well information accumulated, the importance of well conditions to the interpretation of profile surveys is becoming more apparant. Conditions such as changes in tubing or casing sizes, variations in open hole diameter, paraffin or scale deposits, and vertical fractures are some of the factors that cause errors in interpretation.

The mechanical and chemical conditions, as well as the human factor, are covered in this paper to provide the engineer with information needed and the proper procedure to use to obtain more efficient profiles.

## INTRODUCTION

Fluid movement surveys, or profiles are "coming of age" in the field of analysis. These surveys, no longer just logs with a rather nebulous meaning, are being used to detect reservoir behavior heretofore only suspected. The interest evidenced by the use of this "new" evaluation technique indicates that it should be placed in its proper perspective as a highly informative survey. The information can only be obtained, however, if the survey is properly executed and analyzed.

The profile log is derived from observing dynamic, or constantly changing conditions downhole by means of one or more tools and methods. The interpretation technique, therefore, must also be dynamic in its approach. A thorough understanding of tools, their reactions, and the conditions that cause these reactions is essential to conclusive analysis.

The tools, applications and operations have been discussed in detail in several other publications, so only primary identification is presented here. The basic "tools of the trade" fall into these categories:

1. Mechanical - Metering Devices, Flowmeters, Spinners
2. Radiation Detectors - Gamma Tools and Ejectors
3. Associated Tools - Borehole Fluid Analyzers, Samplers, Manometers, Temperature, Calipers, etc.

## MECHANICAL TOOLS

Assuming absolute or ideal conditions, the mechanical tools probably present fewer problems in interpreting since the signals are usually presented as a direct readout, and can be calibrated for accurate quantitative results. Interpretation of the results falls into the realm of placement technique and controlled conditions rather than of the actual readings. For example: (Figure 1) This well in a Yates Sand Flood showed good distribution into the upper zones at 400 BWPD and 540 psi surface injection pressures. The survey was run under stabilized conditions and found to repeat over a period of several hours. Initial stabilization occurred in approximately 4-1/2 hours and the resultant survey showed that 77% of the additional 180 BWPD was being distributed rather equally over a 15 foot interval of the lower end. Three (3) hours later, however, a slight increase in pressure (20 pounds) and a rate decrease to 520 BWPD prompted another profile run. The results showed that now only one foot (or less) of the lower pay was accepting water, and the upper zone was actually accepting less than at the original rates and pressures. This condition continued for approximately 2 hours, after which time the survey was terminated. Interpretation of results seems to indicate that exceeding the initial rates and pressures did not result in better distribution, but poorer results, and that both zones could not be flooded simultaneously without additional preparation or equipment. The lower zone appeared to accept fluid only so fast (or only a small volume) and the thin section in the lower zone broke down when pressures exceeded 650 pounds. This information is supported by the history of numerous premature breakthroughs in this area.

Results are not always so concrete, however, and the reasons are sometimes operational in nature. The spinner and flowmeter both have similar shortcomings in accuracy.

Fluid Bypass - the reaction of the tools depends upon fluid impressed across the turbine or spinner (Figure 2). As the blades are energized, a pressure differential is formed across them. The differential, though slight, is sufficient to force an increment of fluid past the tool outside the perimeter of the spinner, if the space is not completely sealed. This amount could be calculated if the exact bypass and precise rate at that point were known, but in actual operation these are some of the variables to be determined. The percentage bypassing the spinner would change with every rate or borehole change, and since the survey is attempting to determine the rates at different depths, this parameter is not available to "plug in" to formulation. Moving the spinner, as in the continuous log, serves to increase the probable error, reducing the survey to only a relative pattern of injection.

The packer type flowmeter (Figure 3) fares only slightly better under bypass conditions. The caliper cannot serve as a guideline since, presumably, the bypass area is sealed by the packer. A small bypass area outside the perimeter of the borehole or casing would result in a small increment of fluid passing undetected, while a larger one would result in greater error at the same injection rates. The chart of differential pressures vs operating capacity calls attention to the lower two-thirds of the capacity.

production rates were determined by examining the profile results and the stimulation results were judged inadequate. Subsequent re-treatment resulted in increased production. A point to remember when evaluating flowmeter production logs is the calibration system used for the tools. Most surface conditions dictate the calibration curves be derived with a constant medium such as water or refined oil. The volumes are usually expressed in BWPD.

When calculating downhole flowing volumes of oil and gas, the results must be reconciled and corrected to the calibration medium. GOR's, pressures shrinkage, etc. must be considered to reduce the indicated downhole volumes to the actual calibration volumes before the true profile can be determined. The proper values for these corrections should be determined by a production test <u>during</u> the survey, since a previous test is not necessarily indicative of constant or current conditions.

Total equivalent volumes downhole (gas, oil & water) cannot exceed the volume capacity of the flowmeter tools. The packing element begins to bypass fluid and be "swept away" from the sides of the hole at approximately 12-14 # differential and above this point the element will burst or the tool forced up hole. Always check with the service company's operating engineer for the limitations of each tool and well set up.

Debris (sand, scale, algea, paraffin and precipitates, etc.) also cause operational problems (Reference 1 ) due to the precise construction of the tools. The conditions are often severe enough to make logging impractical by this method. There are no operating techniques or methods available for correction when this occurs and another method of surveying should be investigated. Temperature in producing wells becomes a problem since the materials used in the packing element become permeable to gas at $180^{\circ}$ or above and lose elasticity and tensil strength.

## RADIATION DETECTORS

Profiles obtained using tracer ejectors and multiple radiation detectors provide a combination of methods to measure fluid movement in the borehole and behind the tubing or casing. The use of solution tracers have been found to provide more reliable interpretations than the earlier activated solids. (Ref. 4)

The velocity type survey utilizing the dual detector system has eliminated the human error present in the single detector tools. The interpretation of the information obtained requires a knowledge of the fluid flow types and the borehole mechanical conditions.

## FLUID FLOW CONSIDERATIONS

The interpretation of time readings has customarily been made on the basis of piston type displacement between the two detectors and utilizing the calipered hole diameter over the interval to determine the volume rate of

flow. (Ref. 5) It is possible that in some cases such interpretations could be correct, but quite clearly it would only be happenstance, and could be in error by 20 to 100%.

The reasons for such large errors can be described as follows. The initial discussion is based on fluid flow in a round circular pipe without a logging tool being present. When a fluid flows in a pipe, there exists a continuous increase in velocity from the wall to the center of the pipe. At the wall of the pipe the water velocity is zero and increases to a maximum velocity at the center of the pipe. The maximum water velocity in the center may range from 20 percent to 100 percent greater than the average water velocity. This large difference between the average and maximum water velocity depends primarily on the Reynolds number of the fluid. Figure 8 shows a plot of the daily injection rate in barrels/day versus Reynolds number, $DV_p/u$ for various pipe sizes. This chart was constructed for a salt water of 64.7 lbs./cu. ft. density and temperature of 90°F., which is believed to be sufficiently representative to have fairly general application of water injection service.

The interpretation of the transit times on the dual gamma ray tool should consider three flow regimes. (Turbulent, Transition, and Streamline)

Turbulent Flow:

Turbulent flow of water occurs when the Reynolds number exceeds 2,850. This number represents an average value and can vary. Reviewing Figure 8, it will be seen that turbulent flow will occur in the tubing and for a considerable distance into the open hole for most all water injection wells serviced thus far. Turbulent flow provides for mixing inside of the fluid, but the average fluid velocity will range from about 0.72 to 0.82 of the fastest streamline measured in the center of the hole. If the water injection rate is 1,000 barrels of water per day through 2" tubing, Figure 8 shows that this corresponds to a Reynolds number of 50,000. For this case, the average water velocity is only 0.805 of the maximum water velocity.

Transition Zone:

The flow regime changes from turbulent to streamline as the Reynolds number decreases from 2,850 to 2,100. Referring to Figure 8, it is seen that a flow of 200 barrels/day in 9" open hole results in a Reynolds number of 2,500. This is in the transition region and the average velocity may range from 0.5 to 0.72 times the maximum velocity. This is based on circular hole without the tool present. The transition zone should be studied carefully. Since this is a region of uncertainty, it is suggested that the remainder of the interpretation start at the bottom of the hole and work up.

Streamline Flow Zone:

For an injection profile, the flow will always be streamline at the bottom of the hole as the water rate is near zero. In the streamline region, the average water velocity is one-half the maximum water velocity. This value of 0.5 was developed for circular pipe without a logging tool present.

The transition to turbulent flow occurs as follows:

| Hole Size | Transition Water Rate, bbls/day |
|---|---|
| 5 in. pipe | 80 |
| 6-5/8 in. pipe | 115 |
| 9-5/8 in. pipe | 170 |
| 12 in. hole size | 220 |
| 16 in. hole size | 290 |
| 20 in. hole size | 370 |
| 28 in. hole size | 510 |

From the above table,it is seen that for a water injection rate of 1,000 barrels of water per day, 80 to 90 percent of the injected water will be calculated as a turbulent flow problem. Only the lower 100 to 200 bbls. a day rate will be in the streamline region for holes of 6-5/8" to 12" diameter.

In the streamline region the velocity ration is constant as 0.5. There is a sharp increase in average to maximum velocity in the transition region at values of the Reynolds number between 2,000 and 4,000. The velocity ration increases from 0.72 to 0.81 as the Reynolds number increases to 100,000.

It should be noted that the Reynolds number may be based on either the maximum or average water velocity. If the radioactive tracer is mixed with the water by turbulence, the velocity of the fastest streamlines will be represented by the first arrival times seen on the G/R detectors.

Annular Flow String

The presence of the G/R detector causes the water to flow in the annular region. In an annular region, the velocity distribution is much different than that in a round circular pipe.

Figure 9 shows the velocity distribution for streamline flow about a 1-3/8" diameter tool in a 6-3/4" from the center and the streamlines have about the same velocity for the radius 1.75 to 2.0 inches. The maximum water velocity when the 1-3/8" diameter tool is present in a 6-3/4" diameter hole was calculated to be a 1.55 times the average water velocity, or the average water velocity was 0.645 times the maximum water velocity.

It should be noted that if the radioactive material only extends 1/4" from the tool, the velocity of the streamline will be about 80 percent of the average velocity. The tracer should be at a distance of 1" from the tool to be in the fastest streamline for a 6-3/4" hole.

If the G/R tool is in a pipe smaller than 6-3/4", the average velocity increases to a maximum of 0.667 times the maximum velocity.

Turbulent Flow:

With the G/R tool in the hole, the value of the pipe diameter in the Reynolds number calculation should be represented by the effective diameter. The effective diameter is eaual to D hole - D tool) with the units on feet. This is the appropriate value when the tool is centered in the hole. It would seem likely that with turbulence being present for most of the interpretation one could feel reasonably sure that the tracer reached the fastest velocity zone. Without turbulence, the tracer should be sent out with sufficient velocity to reach the fastest streamline.

## BOREHOLE CONDITIONS

Some of the present interpretative procedures used on the dual gamma ray detector tool indicate that the flow in the hole below a particular point may be much greater than the flow above this point.

In reviewing this problem, it was found this frequently occurred where the caliper logs indicated a washout or enlarged hole diameter, Figure 10. Interpretations for this condition could be made by assuming no fluid loss and calculating the effective hole diameter for a wash-out region. Where fluid is going into the formation, the data will be wrong. Areas of abrupt hole diameter changes or restrictions could be by-passed and velocity readings made at the more uniform sections. The profile obtained would be accurate for comparisons of long intervals only. More detailed and accurate profile information can be obtained using a comparison of tracer runs. A stack plot of the tracer as shown in Figure 11, compares favorably with the velocity profile shown on the right. The tracer runs serve as an excellent check on doubtful areas indicated by a velocity profile.

An extension of the "Stack Plot" and Analytical Run Techniques now affords a method of accurate quantitative results from tracer runs. Analysis of these runs has heretofore been confined to "plate out" technique in the case of partical tracers and rate of dissipation in the instance of soluable tracers. These methods have dealt with the amounts of tracer material deposited or left behind the moving slug or burst of tracer in the fluid stream. The problems of erratic accumulation fluid traps material proximity to tool, extreme borehole diameter change, etc. (Ref. 1 & 3) all caused error in the interpretation. Measuring the radiation intensity remaining in the fluid stream and deducting this measurement from the total intensity originally introduced offers a means of comparing finite values to derive the profile.

Radioactive materials decay with a characteristic rate and intensity for each isotope. The emission from this decay can be measured and recorded by a gamma detector held in close proximity to the material. Since the confines of the borehole and/or the moving stream of injection water are small enough to hold all, or nearly all the moving material close to the tool detector, each logging run thru a moving slug of material is a graph

of activity, time and dispersal, or re-stated, the total detectable number of gamma emissions occurring in a given section of borehole at a given time. Intensity recorded varies with concentration of material, therefore, the same number of decay occasions can cause high recorder deflection when concentrated in a few feet, or lower deflections when spread over 20 to 30 feet of hole

Intensities will appear higher in tubing and very small diameters of hole due to the total emission being held very close to the detector. The very weak radiations that can be shielded by less than one inch of water are also detected in this instance. A correction factor based on absorbtion coefficient must be used in intensities in tubing are used vs those in csg or open hole.

Using a soluable tracer material, the isotope follows the water path proportionately, therefore, if 40% of the injected water enters the formation, 40% of the isotope is also lost. the isotope remaining in the borehole will reflect this loss by a proportionate loss of activity.

Calculation of the amounts is not difficult. The active limits of the moving slugof material are defined by marking the leading and trailing interfaces and the base line intensity. The triangle thus formed represents the amounts of introduced radiation remaining in the hole.

The relative number of detectable particals apparent (Self index) is determined by triangulatic . Comparison of the indices of each run reveals the percentages of fluid loss in direct ratio. Figure 12 shows the basic concept.

Run #1 in tubing - 100% of radiation
Run #2 in casing - 100% radiation, 12.4% absorbtion factor applied to Self index.(Tubing to Casing)
Run #3 in casing - 100% of radiation (3% difference in index from run #2)
Run #4 in casing past perforations - 12% loss indicated.

Explanation of the actual calculations are not presented at this time but the calcualtions have been used on over 300 logs to date, with excellent accuracy. Any profile logging runs performed properly and using soluable isotopes can be calculated by this method. The technique has the disadvantage of being less selective in depths investigated and, in some cases, several bursts must be fired and traced before sufficient breakdown of zone results. The advantages are - elemination of hydraulic diameter and shot hole error, and quantitative analysis of injection pattern when all other techniques are inadequate.

## CONCLUSION

Interpretation of fluid movement surveys (profiles) is a science which utilizes not only the recorded log, but all the knowledge of formation characteristics, hydraulics and mechanical probabilities available. The interpreter must have a good insight into tool operation and reaction, the conditions that may affect these reactions, and be able to apply this knowledge with an open mind.

Profiles properly run and analytically applied yeild a wealth of information, not only in the wells surveyed, but of the reservoir conditions therselves. The associated information obtained during profile operations can lead to better control, more efficient stimulation of primary producers in the area and assist in avoiding possible development of future problems heretofore unknown.

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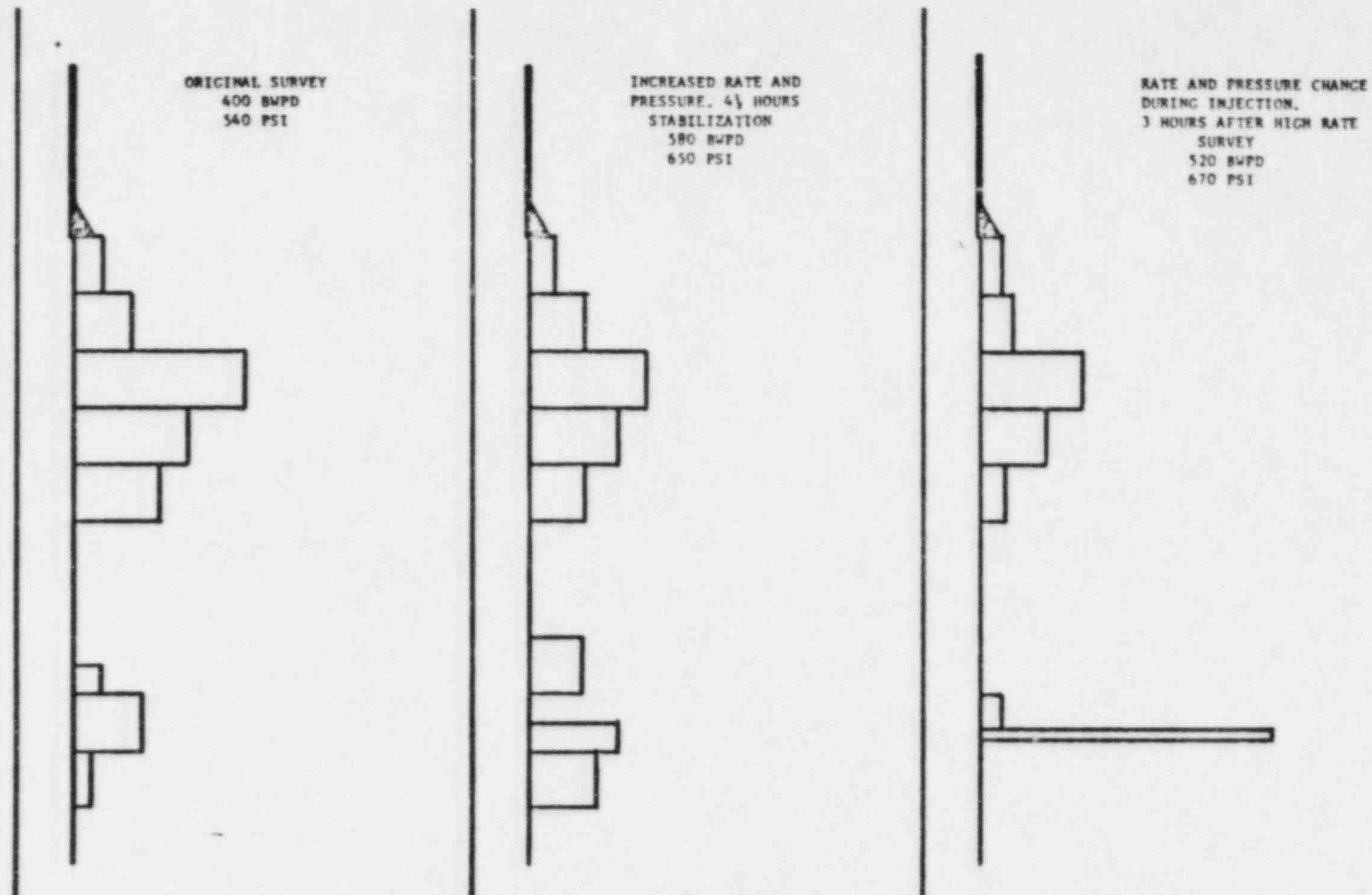
3. Johnson, Wallace and Morris, Billy P., "Review of Tracer Surveys", presented at the Southwestern District, Division of Production, API, March 18-20 , 1964

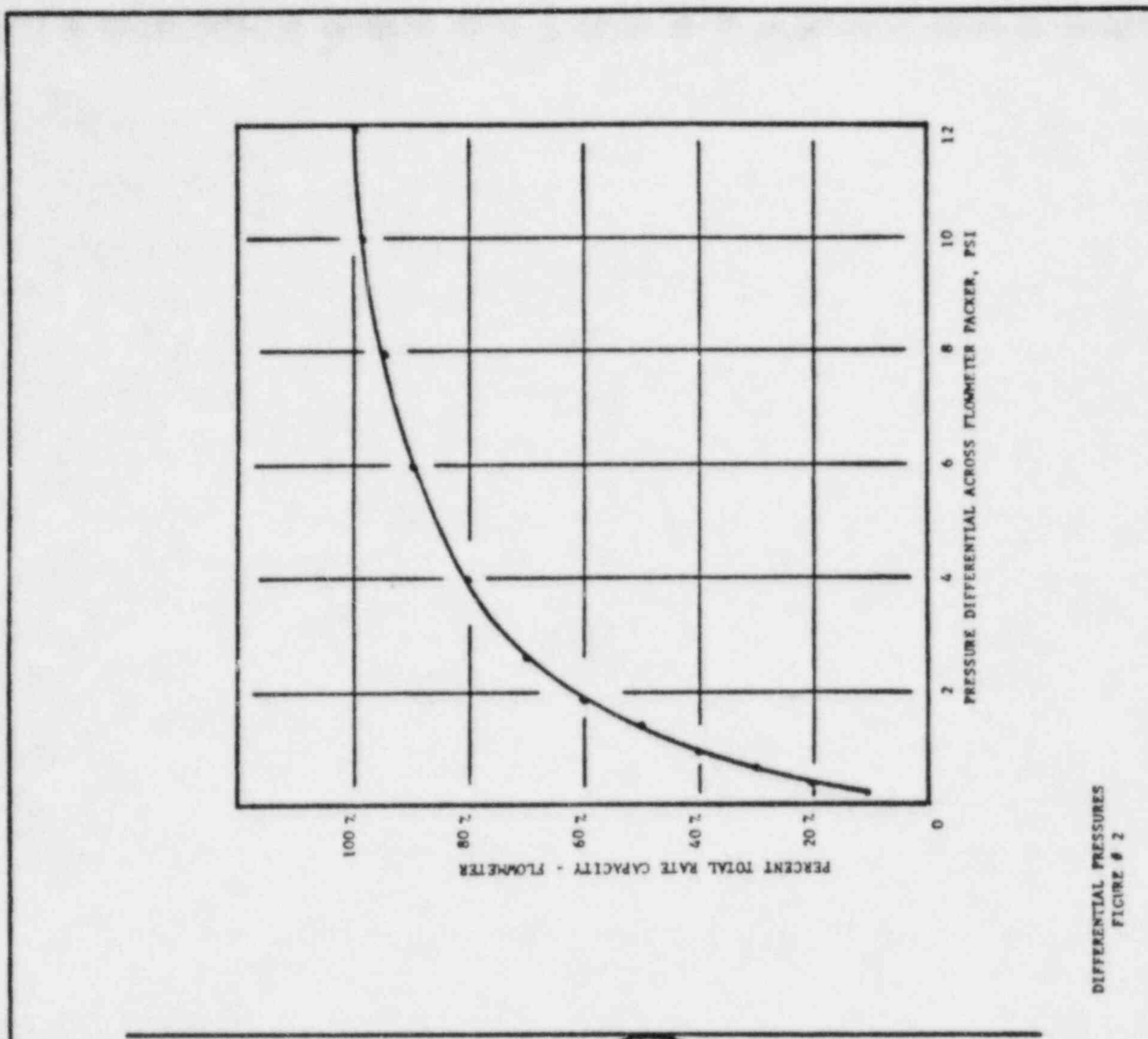
4. Alberts, A. A. and Cocanower, R. D. "Application of Radioisotopes to Sub Surface Surveys", Paper No. 389-G, presented at AIME Annual Meeting San Antonio, Texas, Oct, 1954

5. Figure 16, Journal of Petroleum Technology, Page 856, August, 1964.

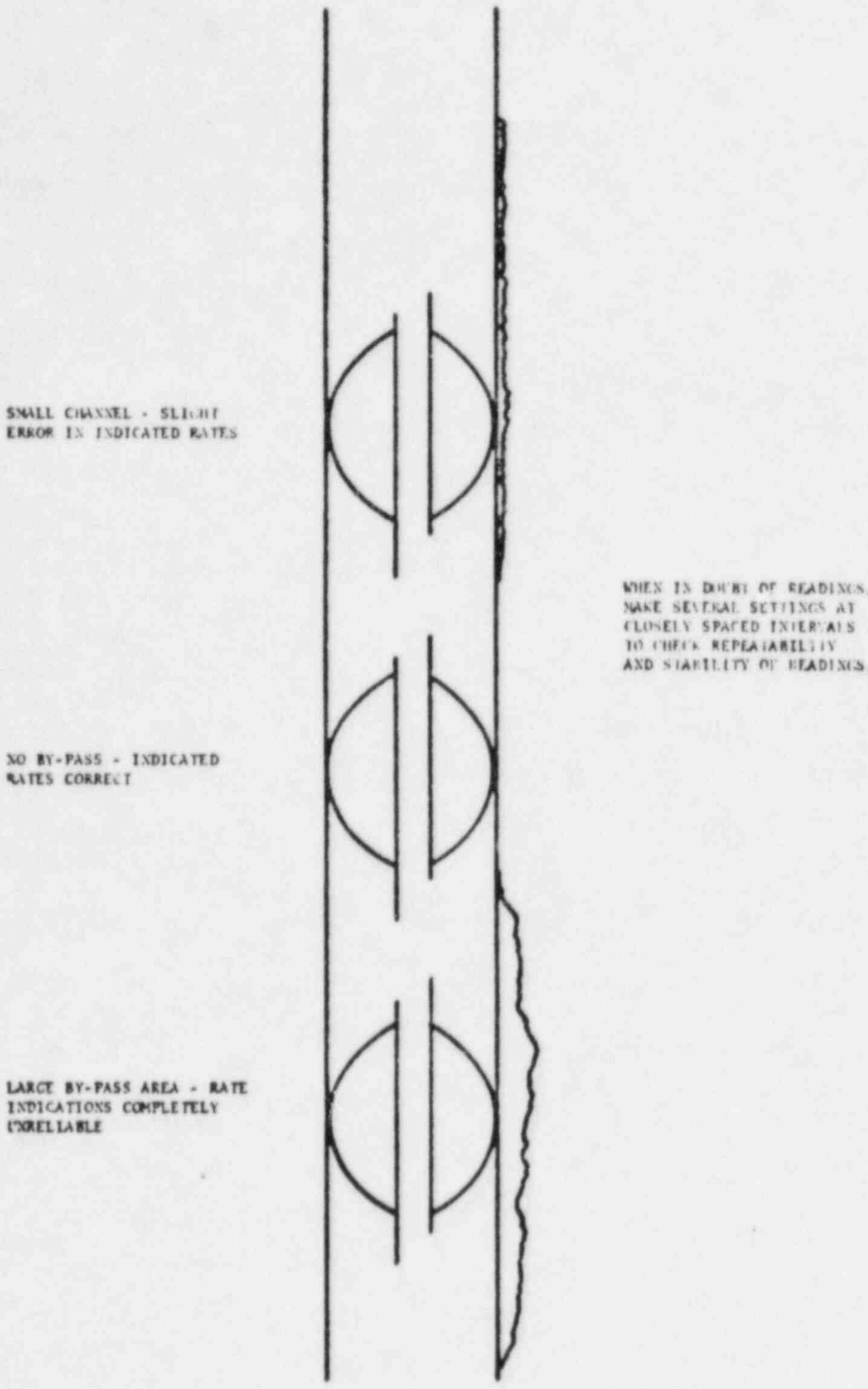



CHANGE OF PROFILE, RATE AND PRESSURE SHANCE (YATES )

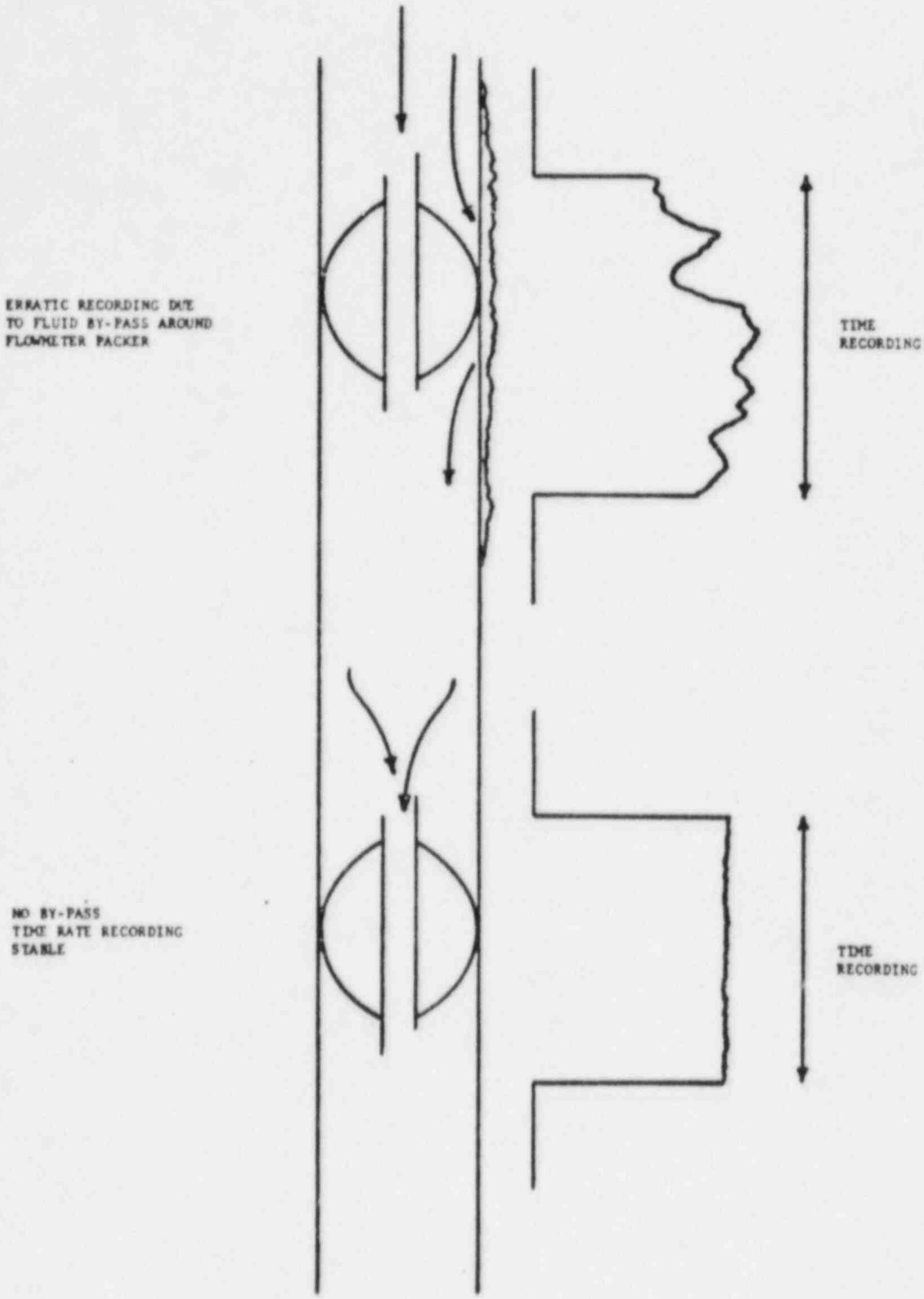
FIGURE # 1




DIFFERENTIAL PRESSURES
FIGURE # 2

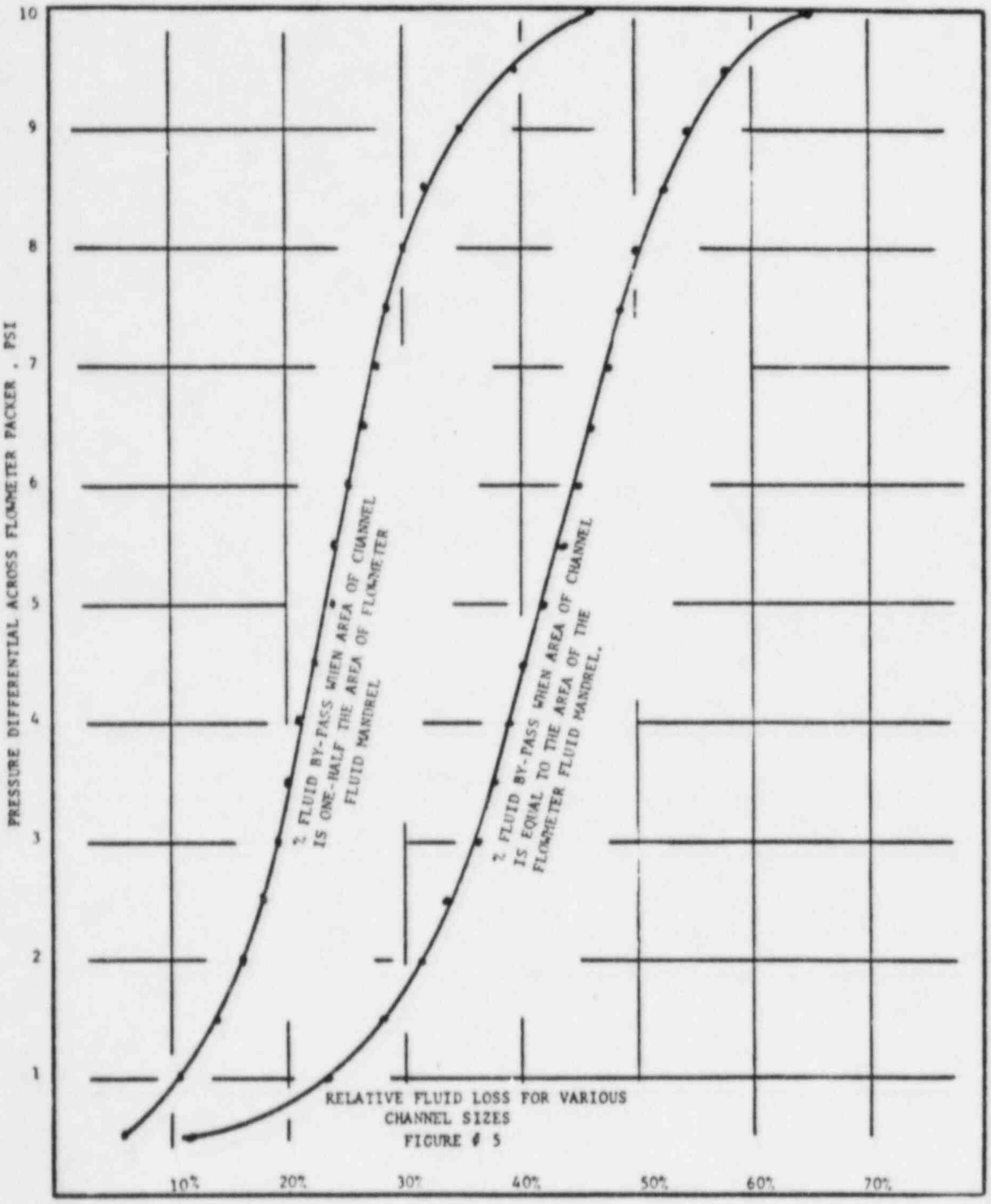



FLUID BY-PASS FIGURE #3

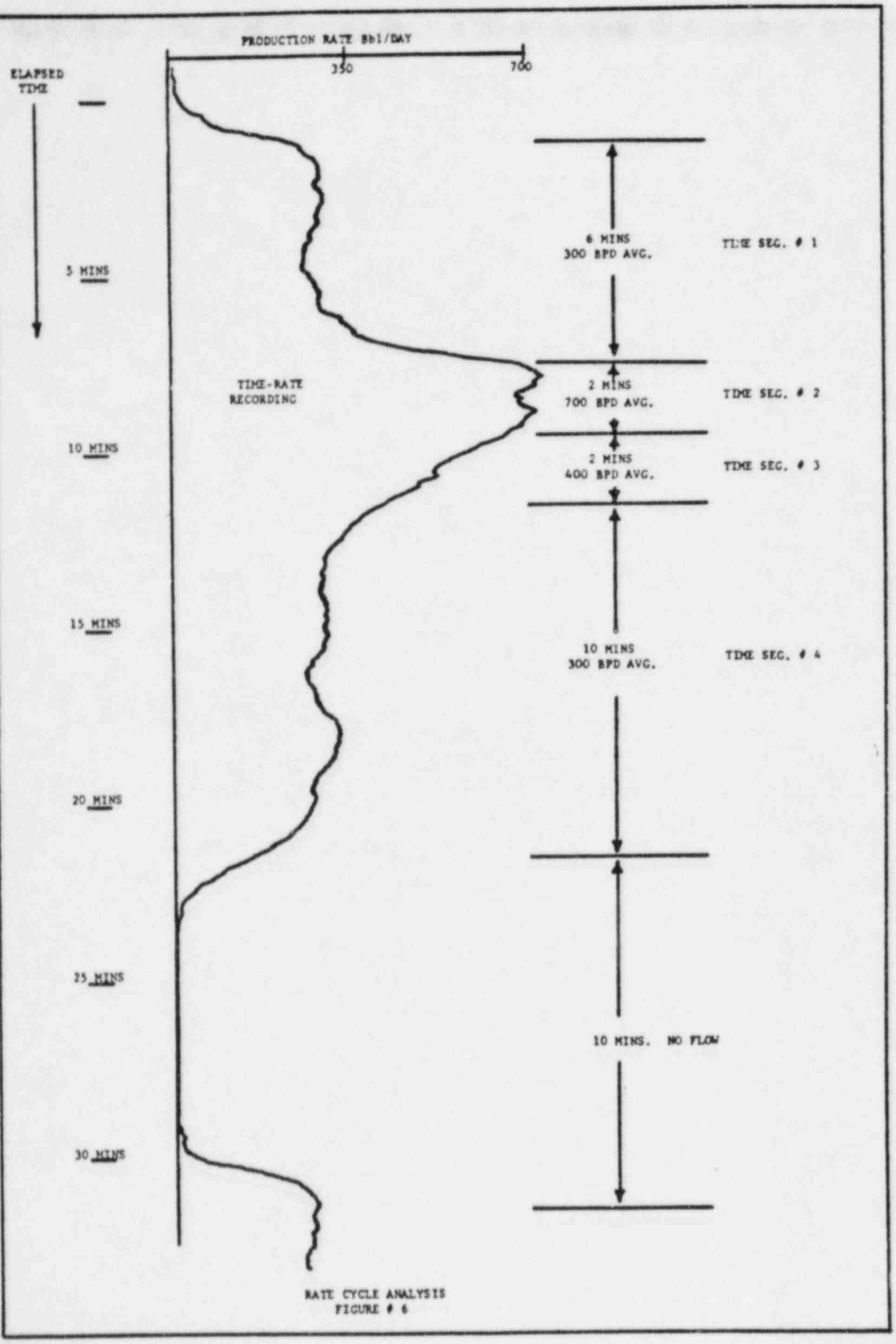



STABLE V.S. ERRATIC RATE
RECORDINGS

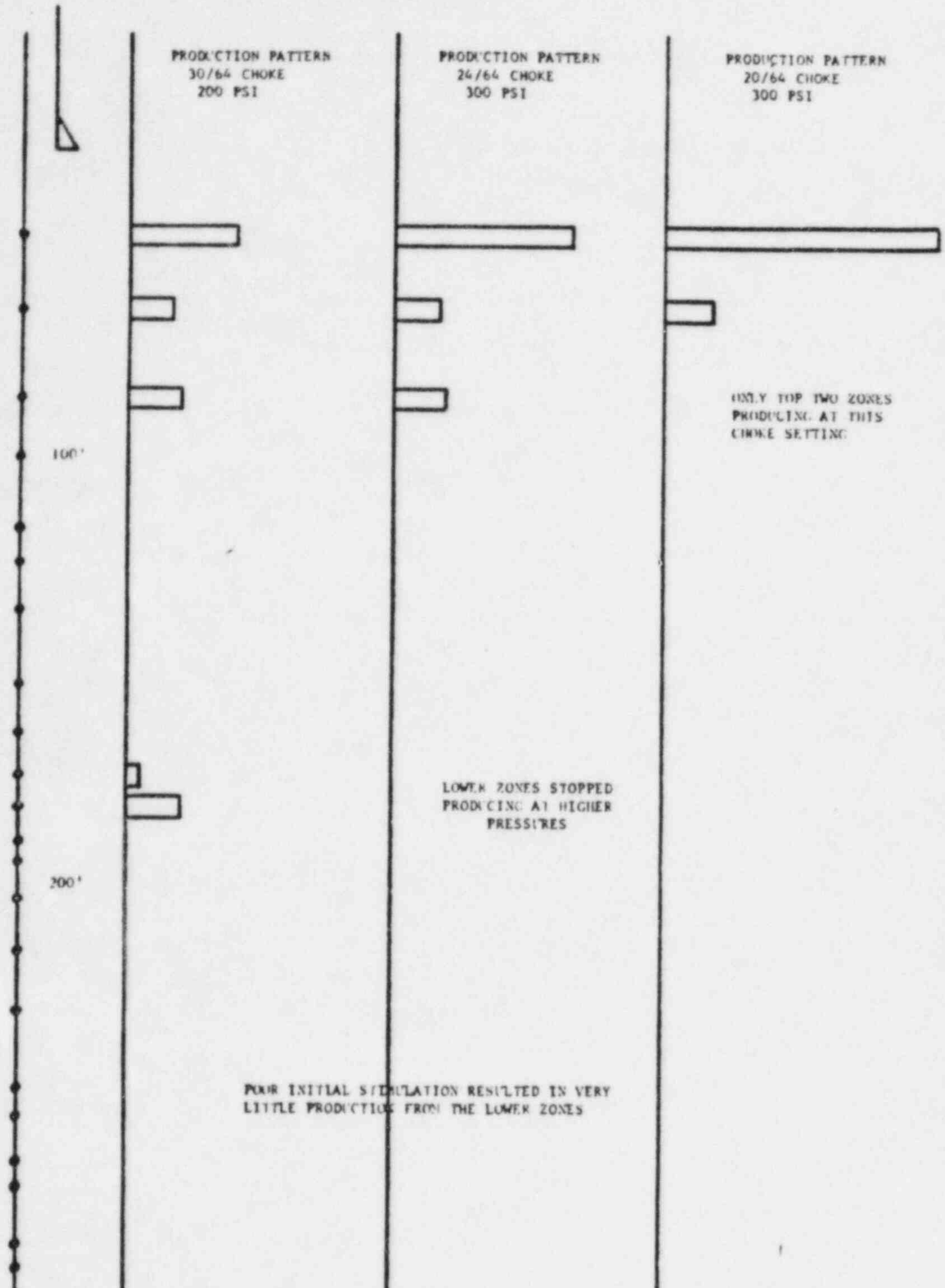
FIGURE # 4




RELATIVE FLUID LOSS FOR VARIOUS CHANNEL SIZES
FIGURE # 5




RATE CYCLE ANALYSIS
FIGURE # 6




TREATMENT EVALUATION
FIGURE # 7

REYNOLDS NUMBER AS A FUNCTION OF
WATER RATE AND PIPE SIZE
(No tool in hole)

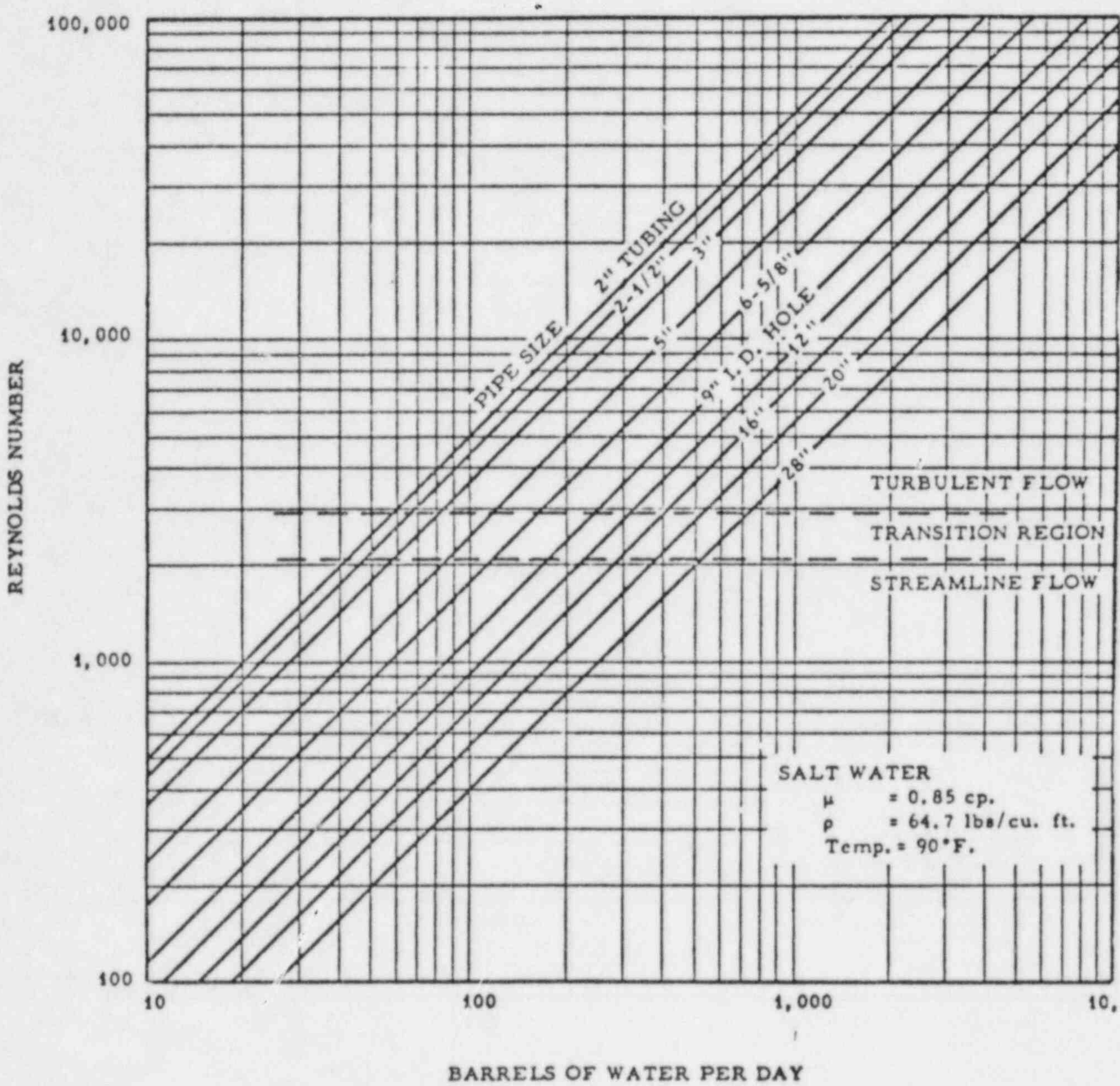



FIGURE # 8

STREAMLINE VELOCITY DISTRIBUTION WITH GAMMA RAY TOOL IN HOLE

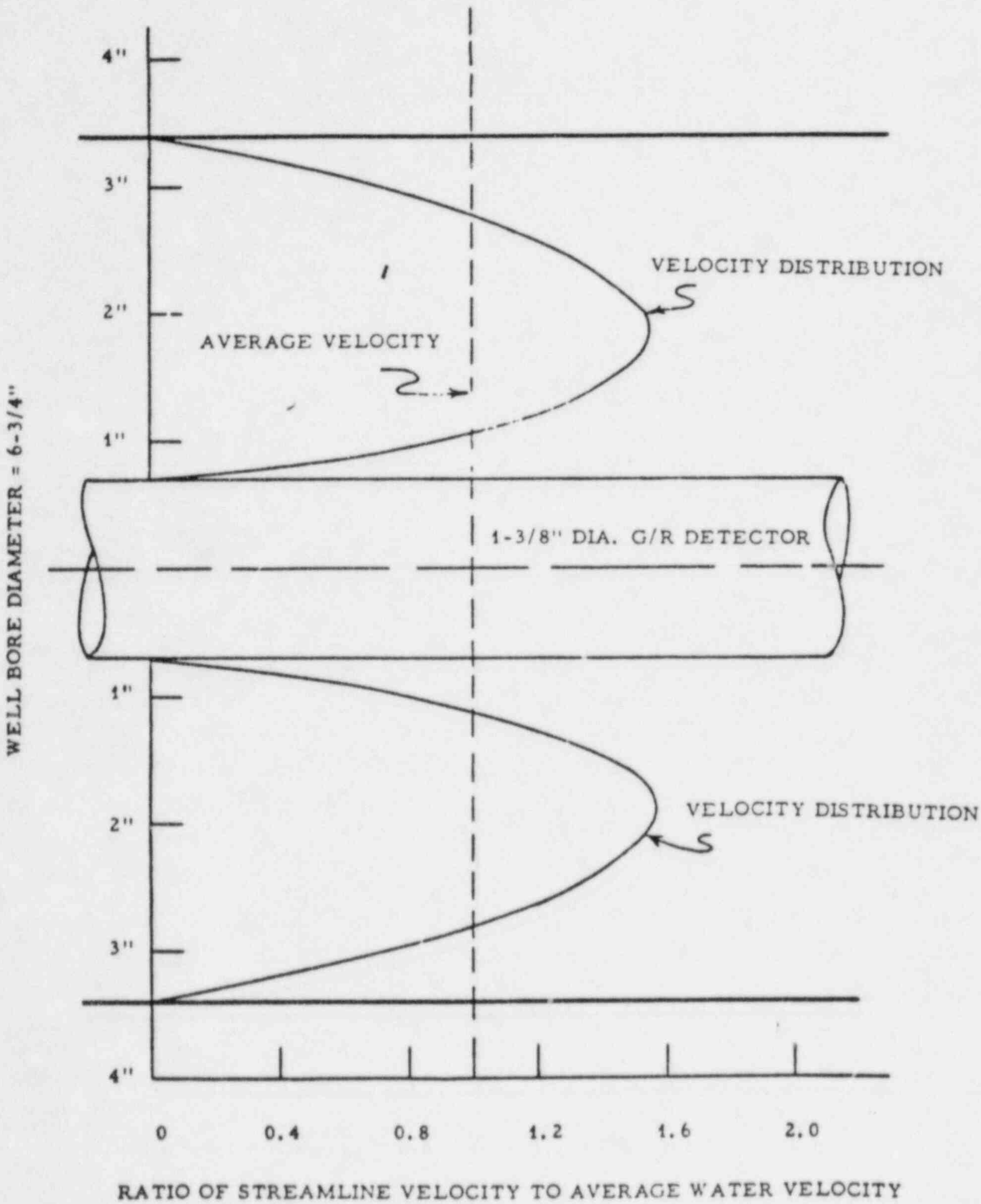
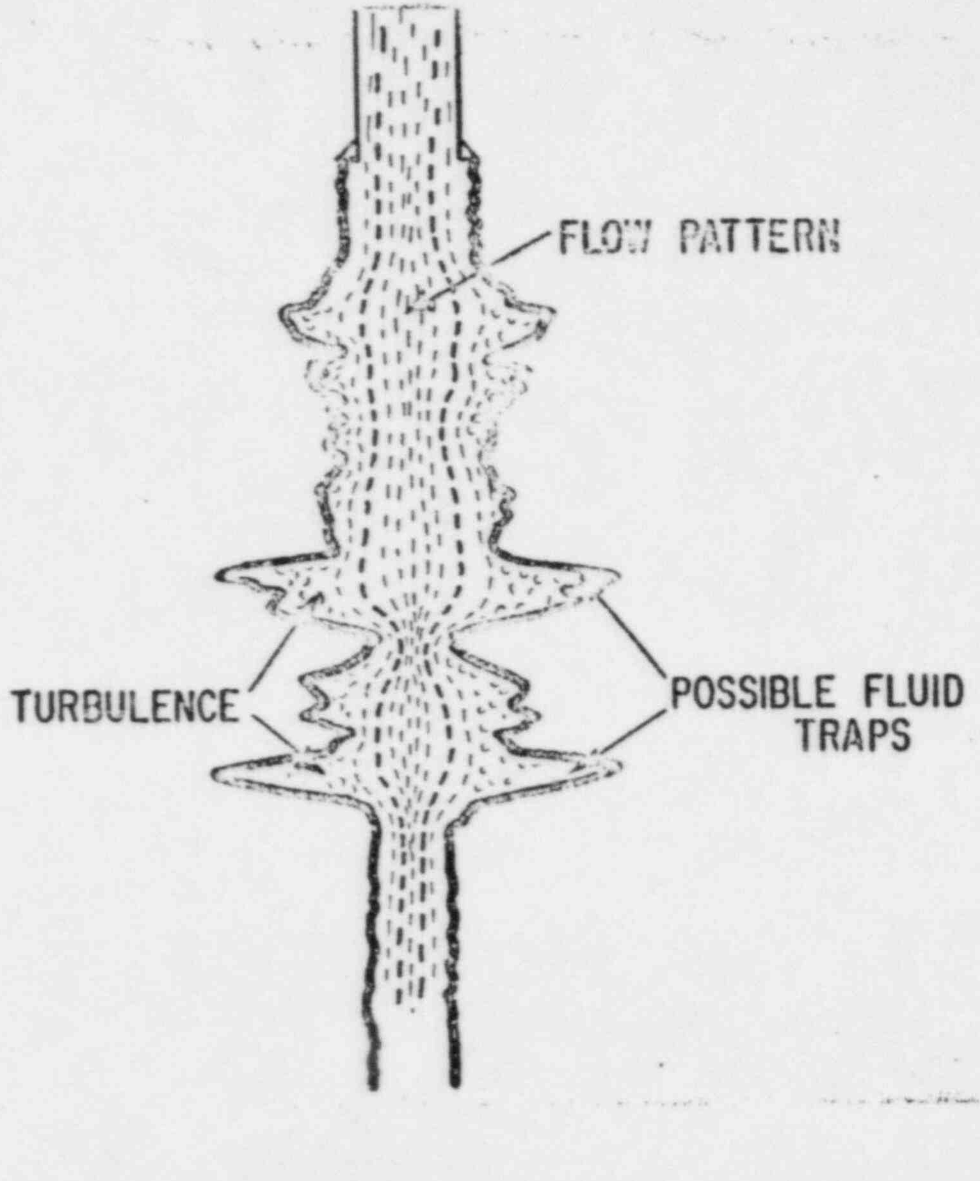
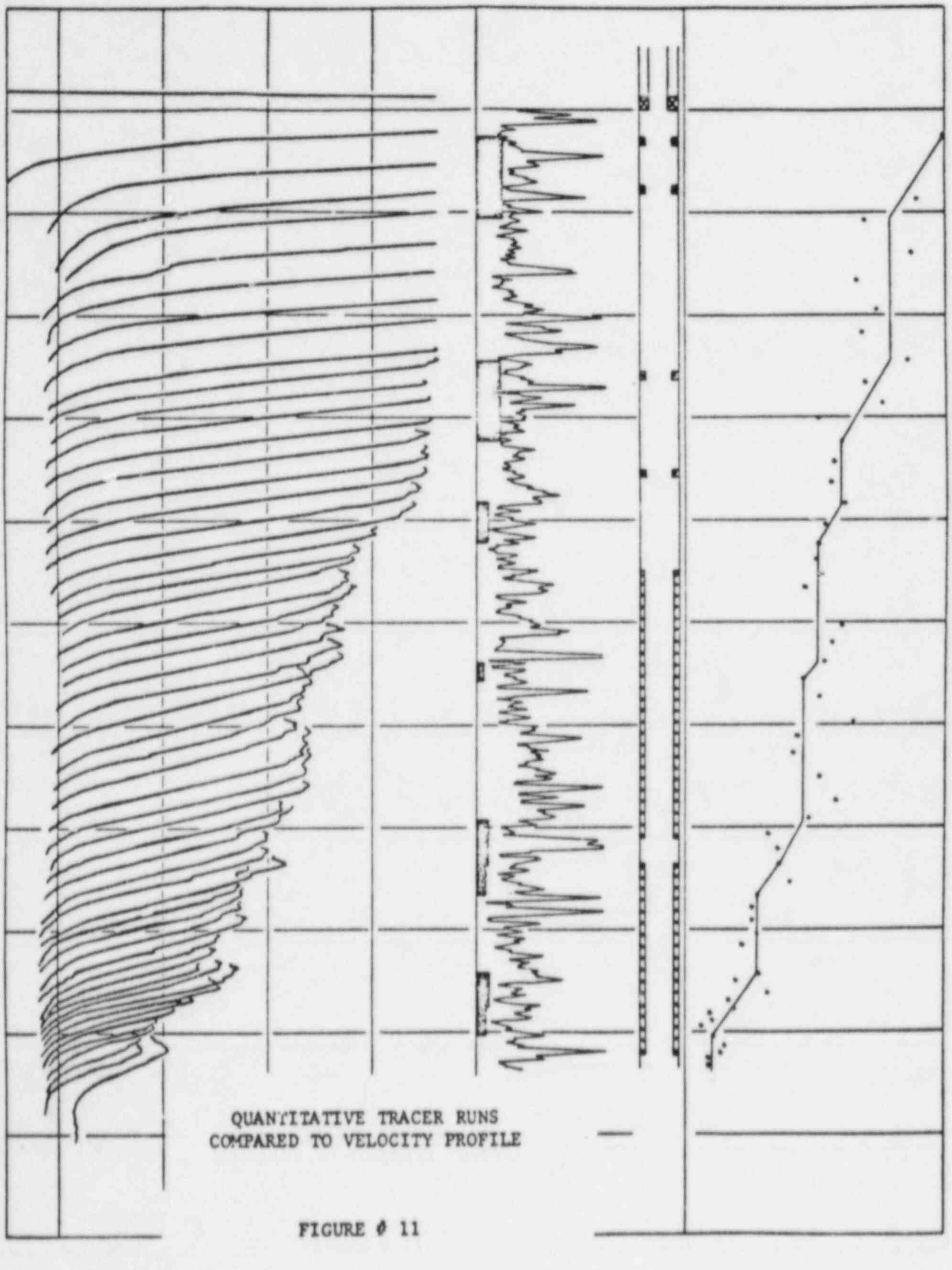



FIGURE # 9

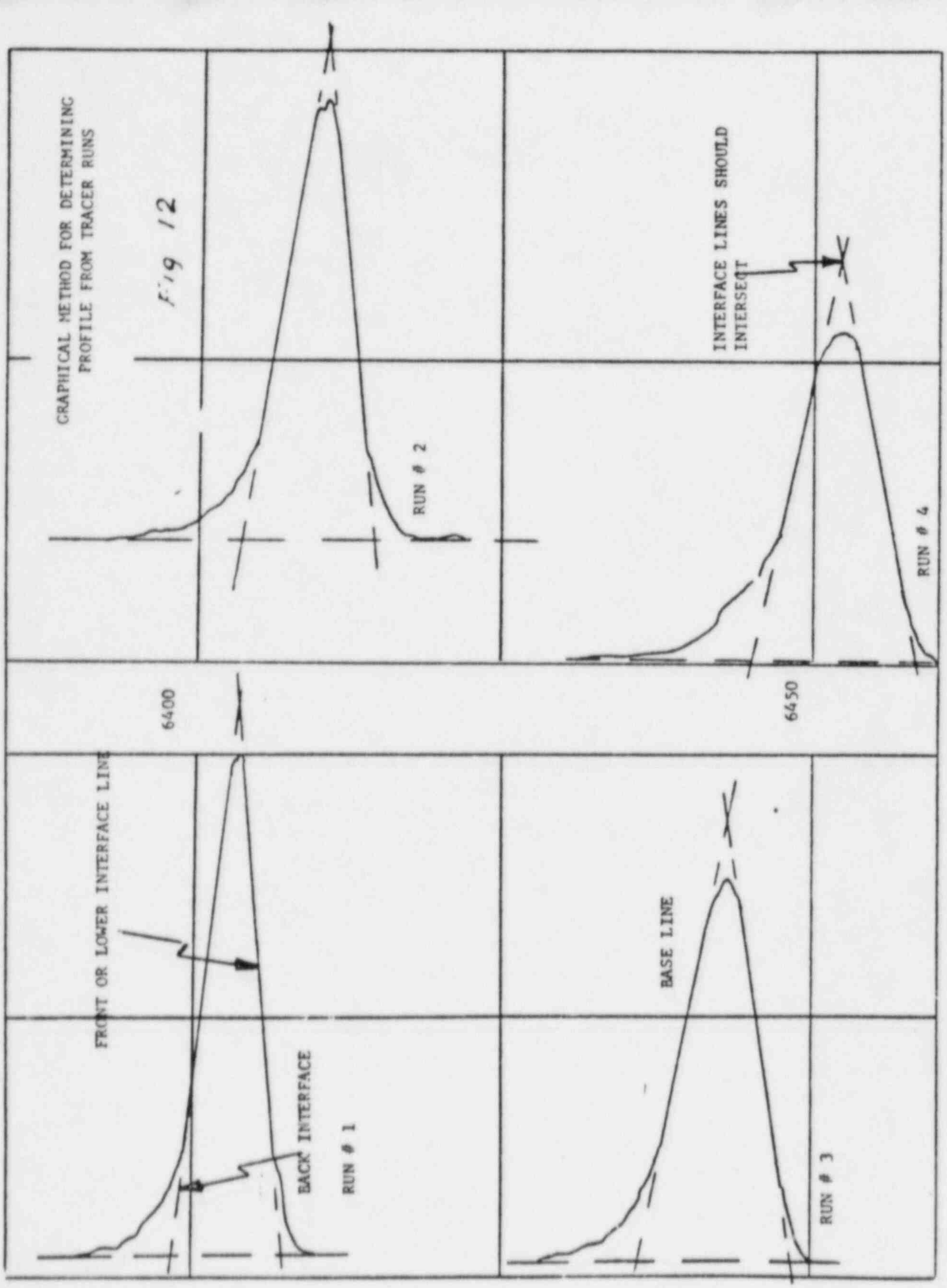
FIGURE 10





QUANTITATIVE TRACER RUNS
COMPARED TO VELOCITY PROFILE

FIGURE # 11


GRAPHICAL METHOD FOR DETERMINING
PROFILE FROM TRACER RUNS
Fig 12
RUN # 2
INTERFACE LINES SHOULD
INTERSECT
RUN # 4
6400
6450
FRONT OR LOWER INTERFACE LINE
BACK INTERFACE
RUN # 1
BASE LINE
RUN # 3