APPENDIX C

NATURAL GAS PIPELINE
LEAK DETECTION SYSTEM

PROPOSED GAS PIPELINE LEAK DETECTION SYSTEM
CONSUMERS POWER COMPANY- MIDLAND POWER PLANT

by

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INTRODUCTION

The Midland Nuclear Power Plant owned by Consumers Power Company has five boilers that use natural gas as their fuel. These boilers are fed from a Consumers Power Company gas transmission line through the Stewart Road Regulator, which is approximately two miles West of the Midland plant site. Gas is delivered to the North side of the Midland plant site through approximately 2 1/2 miles of six-inch and eight-inch pipeline that is operated at 350 to 400 PSIG. The total connected load of all five boilers is approximately one million cubic feet per hour.

It has been determined that it would be undesirable to have natural gas contaminate the air supply used for various purposes at the Midland plant. Consumers Power Company has retained Stoner Associates, Inc. to recommend a procedure for detecting leaks and preventing the escape to the atmosphere of large quantitiies of natural gas.

The proposed leak detection procedure, outlined in the body of this report, uses a combination of pressure and flow measurements taken on a short time interval, a digital computer based pipeline pressure flow model, and a fail-close shutoff valve at the Stewart Road Regulator Station. These combine to form a high quality leak detection procedure that should be able to detect leaks in the order of 10 to 20 MCFH in a lapsed time of one to two minutes and close the shutoff valve.

GENERAL OVERVIEW

There are several methods of detecting leaks on pressurized piping systems, all having different methods of accuracy and detection times. Detection time as used here indicates the elapsed time between inception and detection. There are two techniques in use today which provide relatively short detection times. These are the acoustic leak detection procedure, which "listens for" leaks and computer-based modeling approaches which simulate the pressure-flow response of the system, and compare it with actual measurements. The method proposed is a computer-based system.

The key components of this computer based system are as follows:

1. Measurements of pressure, flow, and temperature (P, Q, T) taken at approximately 5 second intervals. For the concept to work, all flow into and out of the system must be measured.

2. A model which uses some of the (P, Q, T) measured values as boundary conditions to predict values for the remaining (P, Q, T) variables which can be compared with other measurements.

3. A computer which performs the task of collecting the measurements, executing the model calculations, performing comparisons for leak criteria evaluation, and issuing instructions to shut off the flow to the system, and alarm the operator should an abnormality (leak) exist on the system.

This leak detection procedure has been applied previously to a crude oil pipeline running through the environmentally sensitive Gulf of Mexico. The pipeline is owned by the Chevron Oil Company and transports crude oil from Empire, Mississippi to Pascagoula, Louisiana. The distance is approximately 100 miles. The design flow rate is 160 barrels per minute. The present two minute leak criteria is approximately five barrels, which represents a 2 percent leak. A comparison of measured flows and calculated flows for this system can be found on page 202 of Reference 1.

DESCRIPTION OF THE SYSTEM

Figure 1 shows that portion of the Consumers Power Company Distribution System that supplies natural gas to the two auxiliary boilers and three HP boilers at the Midland Nuclear Power Plant. The system is approximately 2-1/2 miles in length and consists of 8-inch and 6-inch pipes. The key components, or locations, have been identified on Figure 1, and are described below.

Point A is the Stewart Rd. Gate Station which receives flow from the Consumers Power Transmission Line and regulates the pressure to approximately 350-400 PSIG. This station will be modified to include an automatic shut off valve that will be programmed to fail closed. The pipeline between Stewart Rd. and Point B is approximately 0.80 miles of 8-inch line.

Point B is a junction where the pipeline size reduces to six inches. No flow leaves the system at this point. From Point B to Point C, the pipeline is 6-inches in diameter and approximately 0.79 miles in length.

Point C is the location where gas is removed from the system to supply a small load (2 MCFH) in the outage building. From Point C to the Midland Plant boilers is approximately 0.84 miles of six-inch line.

Point D is a representation of the boiler loads at the Midland Plant. There are five separate boilers, any or all of which can be operating. The total connected load of all five boilers is approximately one million cubic feet per hour. The following measurements will be required at the locations given.

POINT A - The flow into the 8-inch line

The pressure on the outlet side of the regulator

The temperature on the outlet side of the regulator

The open or closed status of the shutoff valve

These items will be measured by a remote terminal unit and transmitted to a computer facility in the evaporator building control room.

POINT B - No measurements are required at Point B; however, the model will perform computations at this point due to the diameter change.

POINT C - The flow consumed at the Outage Building

The pressure

The temperature

POINT D - The ΔP across each orifice plate at each of the five boilers

The temperature at each of the five orifice measurements to the boilers.

The static pressure upstream of the orifice plate

The status of ignition of each of the five boilers

The pressure of gas in the pipeline upstream of the regulator at the Midland Plant

The temperature of the gas in the pipeline upstream of the regulator

The measurements will be made on approximately a five-second scan time. Measurements at Point A and Point C will be made by Remote Terminal Units (RTU's) and transmitted over leased telephone lines to a receiving unit at the computer located in the boiler building. Measurements of the inputs at Point D will be hard wired to the computer.

MODELING PROCESS

The flow of natural gas in a piping system such as that described above can be modeled with considerable accuracy using a mathematical description of the continuity, momentum, and energy relationships pertaining to the flow of fluids in closed conduits. One such model is detailed on Pages 321 - 325 of Wylie and Streeter (Reference 1). These equations have been programmed in a general purpose model called GASTHERM (Reference 2). A forerunner of the GASTHERM model was used to validate the use of GASUS for the research work done by Mechanics Research, Inc. entitled "Nuclear Power Plant Risks From a Natural Gas Pipeline" as it related to the Hartsville Nuclear Power Plant, Hartsville, TN. GASTHERM was developed as a general purpose model in 1979 for modeling unsteady pressure flow and temperature in the Northwest Alaskan Gas Pipeline. This model has been used on various projects over the last three years. The calculation procedure for this model results from applying the method of characteristics to the three partial differential equations mentioned above, which produces model equations with independent variables, X, t (distance along the pipeline, and time) and with dependent variables, P, Q and T (pressure, flow, and temperature).

Figure 2 shows an X-t diagram for the P, Q, T model. Assume for the moment a simplified pipeline with upstream end at A, and downstream end at D. A typical solution of the model would be to calculate the predicted flow at the upstream end, Q_{AC} at time $t + \Delta t$, knowing the pressure and temperature (P_A T_A) at a given time, and to calculate the downstream pressure and temperature (P_D T_D) at t + Δt, knowing the downstream flow, Q_D at t. This procedure can be repeated for time t + 2 Δt in a like manner as long as values of P_A, T_A, and Q_D are available at the new time. The procedure for using these calculated variables in a leak detection sense is described in a later section of this report.

The items that must be assumed to provide enough information for the model to function include the gas properties, the friction parameters for the pipeline, and an estimate of ground temperature.

It is proposed to use the pipeline calculation algorithm from GASTHERM as the model in this leak detection process. The equations, as they are solved in GASTHERM using the method of characteristics, have been verified by comparison with a closed form analytical model. The comparison can be seen on the attached figures, taken from the abstract of a paper by Dr. C. P. Liou, Ph.D., of Stoner Associates, Inc. and Professor E. B. Wylie of the University of Michigan entitled "One Dimensional Transient Gas Flow With Internal Heating", a copy of which is attached to this report. The comparison is performed for an internal heating process in a pipeline. The agreement between GASTHERM and the closed form analytical solution is very good.

An isothermal model for unsteady flow in gas systems would probably be quite adequate for the purposes intended as temperature effects in a gas distribution system are usually of second order importance. Reference 3, page 52, shows a comparison of pressures recorded versus those calculated for a natural gas pipeline having the same approximate flowrates and pressure drops as encountered in the Midland Pipeline System. The proposed GASTHERM calculation algorithm is expected to be more rigorous as temperature effects are considered.

MONITORING SYSTEM

The complete monitoring system for the proposed leak detection application is shown in a simplified form in Figure 3. Measurements will be taken at Points A, C, and D, on approximately a five-second interval. The model will use some of these measurements as driving conditions and will calculate the remaining variables. Specifically, the flow at Point A will be calculated and the pressure and temperature at Point D will be calculated. The flow at Point C will be specified and the temperature and pressure will be calculated.

Figure 4 shows this process in some detail and shows the relationship between the model calculation time, which will be on a fixed timestep (Δt) and the non-uniform interval between measurements brought back from the RTU's. The Δt of the calculation procedure will be either 1.6 or 3.2 seconds. The elapsed time between measurements will be on the order of five seconds. Straight line interpolation is used to obtain estimated values of measurements in between two actual measurement points.

Figure 5 shows the flow at Point A as a function of time. Indicated on the graph are both the measured flow, Q_{AM} and the calculated flow Q_{AC}. As long as the calculated and the measured values agree to within some small tolerance, the integrity of the system is assumed. This is depicted by the close comparison of the two flows up to time, t. If a leak or other abnormality develops on the system, the difference between measured and calculated values of flow will increase, indicating that a problem exists.

The primary leak detection criteria will be based on a comparison of the measured flow and calculated flow at Point A (Stewart Rd.). Various characteristics of the metering system affect the point comparison of calculated versus measured values in such a way as it has been beneficial to have several different comparison criteria. Stated another way, given a level of certainty, large leaks can be detected in a short period of time, whereas smaller leaks will take longer to detect. This leads to the concept shown in Figure 6 of having different volume integration windows. For instance, the accumulated flow error indicated as AFE_1 is the summation of measured versus calculated flow difference times Δt for the number of calculations performed during the window interval, W_1. When a new calculation is available at, for instance, $t + \Delta t$, the new value is added into the summation and the oldest value is dropped. For the proposed system, four windows would be used, noteably a single point in time comparison (zero window length), a thirty-second window (about 6 measured point comparisons), a two-minute window, and a 10-minute window. An instantaneous comparison would also be made between each of the calculated and measured pressures at Point C and Point D.

As mentioned above, smaller leaks take a longer time to detect. This is shown graphically in Figure 7 which shows the relationship between the accumulated flow error expressed as an average flow rate, and the window interval time. It is expected that the real leak limits can be on the order of two percent of maximum throughput flow (approximately 20 MCFH) for the 30 second window and one percent (10 MCFH) for the two-minute window. This translates into leak volume limits of approximately 150 SCF for 30 seconds and 300 SCF for two minutes leak duration.

Figure 7 also shows the use of the pseudo leak limit. The monitoring system is designed such that, as operating experience is gained, the leak limits can be adjusted. The pseudo limits provide this capability in that they allow a tighter leak detection limit that generates leak reports internally for a systems analyst, but does not alarm the operator. The system will save the last 30 minutes of operation information thereby allowing an analyst to tune the system, and investigate any problems that arise in the operation of the system. As the system is tuned, and the tolerances tightened, the real leak limits should be set such that they generate no more than approximately one false alarm per year.

When the system determines that the real leak limit has been exceeded, it will initiate the closing of the shutoff valve at Stewart Rd. and will notify the operator.

The system will also provide operator display and test functions.

OPERATION OF SHUTOFF VALVE AT STEWART RD.

Since the shutoff valve at Stewart Rd. is the major device to deny flow to a potential line break, it is proposed that this valve have a fail- closed mode of operation. It should operate in such a way that it must receive a positive signal from the monitoring system, to open or to stay open. The conditions under which it would close would be the following:

1. An interruption in electric power would fail to hold it open, and it would close either under the force of gravity or under pneumatic power.

2. If the signal holding it open is interrupted it will initiate closure.

3. If the valve does not receive a positive signal from the computer based monitoring system every ten seconds, it will initiate closure. For the monitoring system to function, it will have to be receiving data from the RTUs on every scan which means that the data acquisition system will have to be operating properly for a positive signal to be sent to the valve.

4. It will initiate closure immediately if it receives a signal from the monitoring system to close. The monitoring system will be programmed such that the leak detection procedure must be operating for it to send a positive signal to the valve which will allow the shutoff valve to open.

REFERENCES

1. Wylie, E. Benjamin and Streeter, V. L: Fluid Transients, McGraw Hill, Inc., 1978.

2. GASTHERM Service User's Guide, published by Stoner Associates, Inc., Carlisle, Pennsylvania, May, 1981.

3. Stoner, M. A.: "Analysis and Control Of Unsteady Flows In Natural Gas Piping Systems", Ph.D. Thesis (Civil Engineering), University of Michigan, Ann Arbor, 1968.

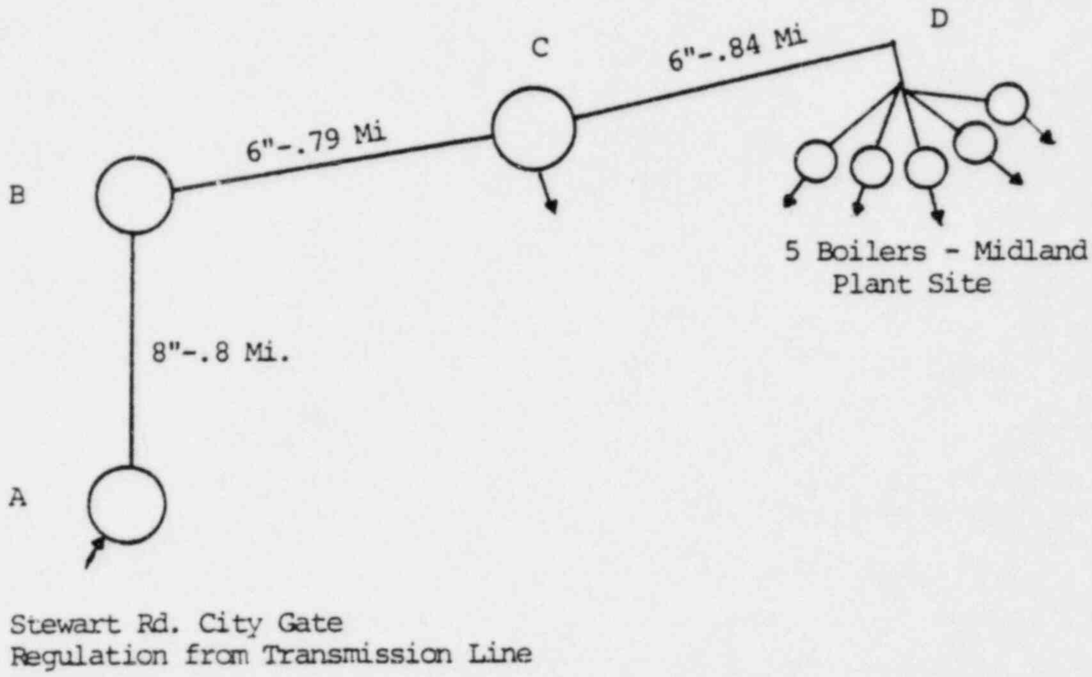


FIGURE 1

SCHEMATIC OF GAS DISTRIBUTION PIPELINE
SERVING MIDLAND POWER PLANT

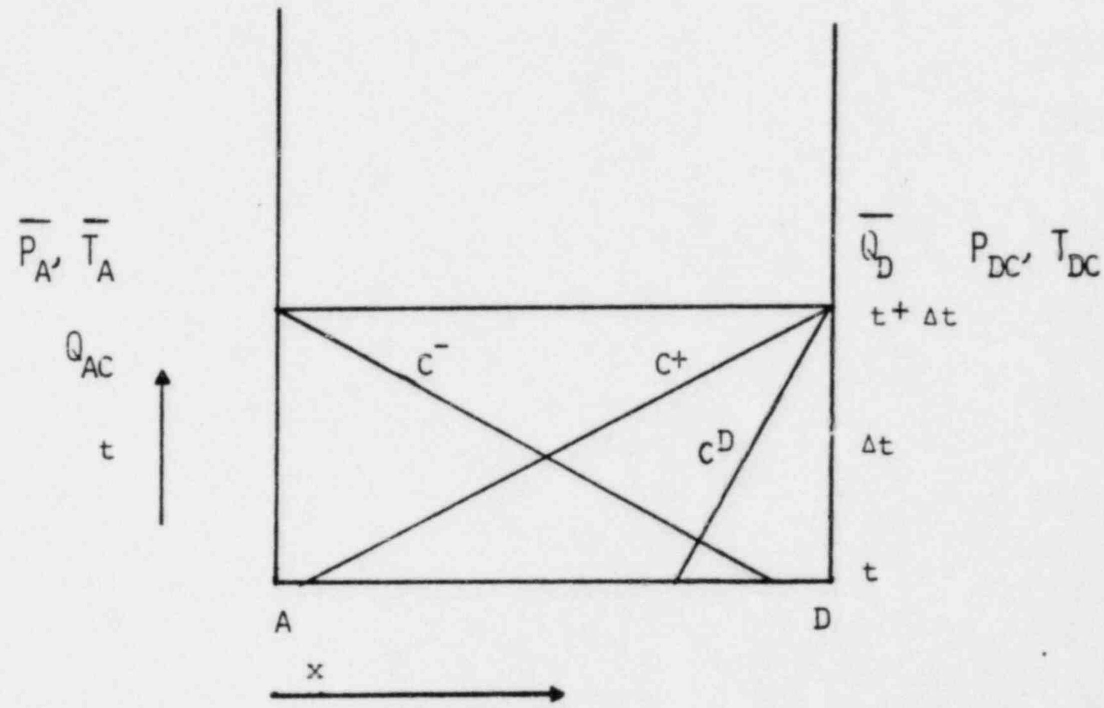
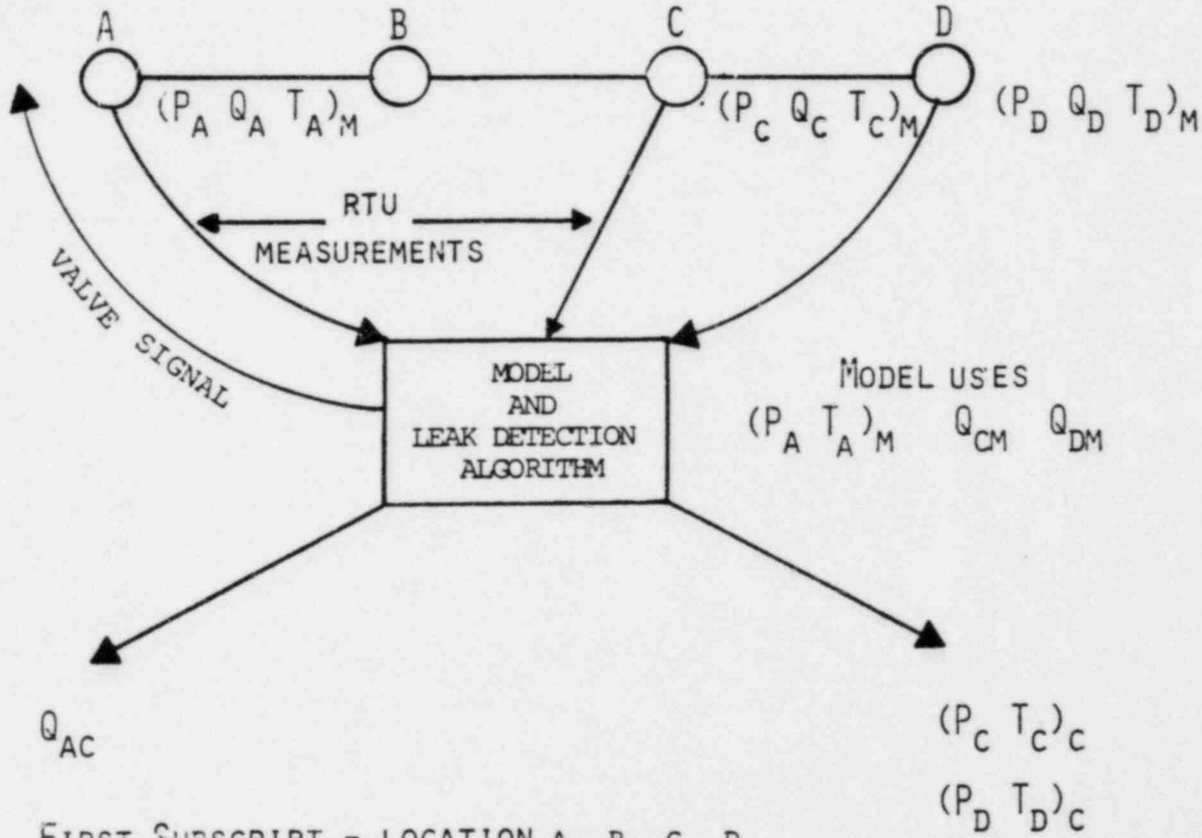


FIGURE 2

X-t DIAGRAM FOR MODEL SOLUTION



FIRST SUBSCRIPT - LOCATION A, B, C, D

SECOND SUBSCRIPT - M: MEASURED

C: CALCULATED

FIGURE 3

MODEL CALCULATION CONCEPT

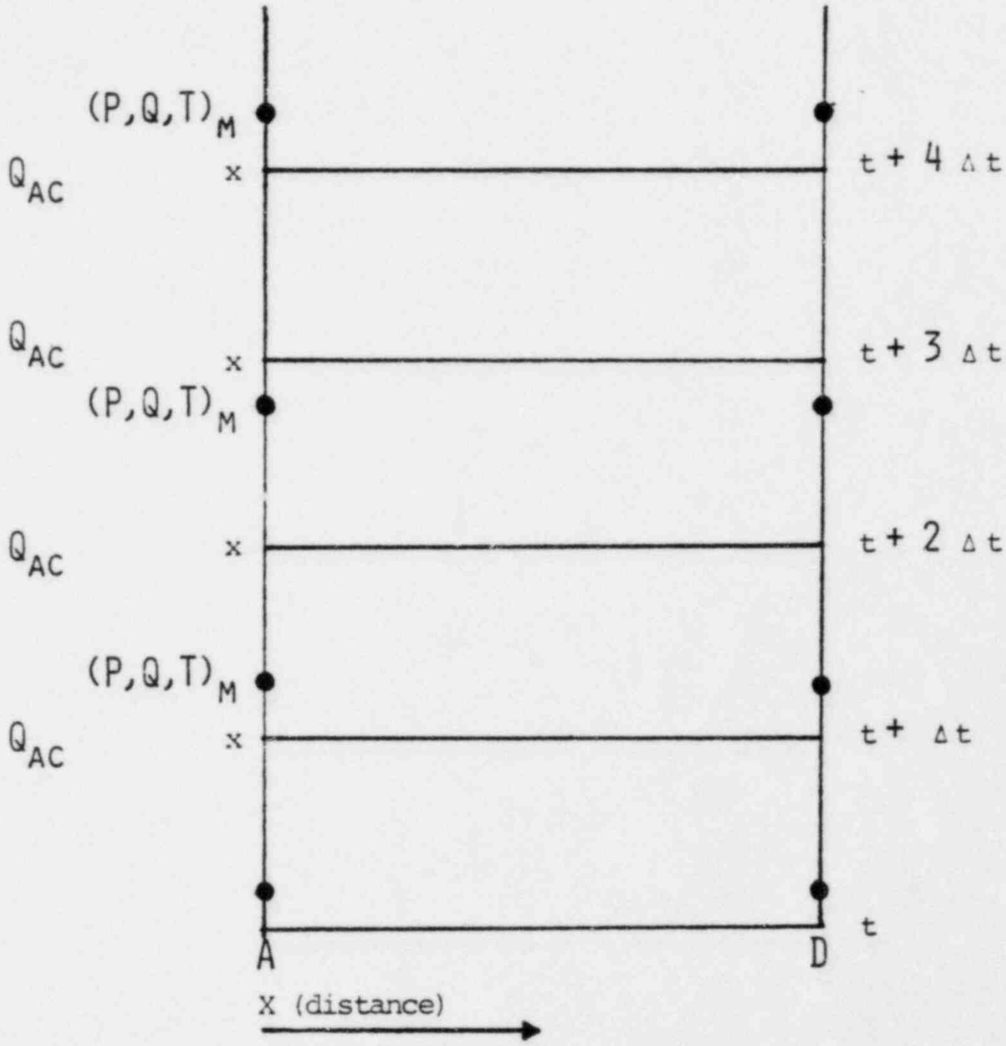


FIGURE 4

DIAGRAM SHOWING TIME RELATIONSHIP OF MEASURED AND COMPUTED VALUES

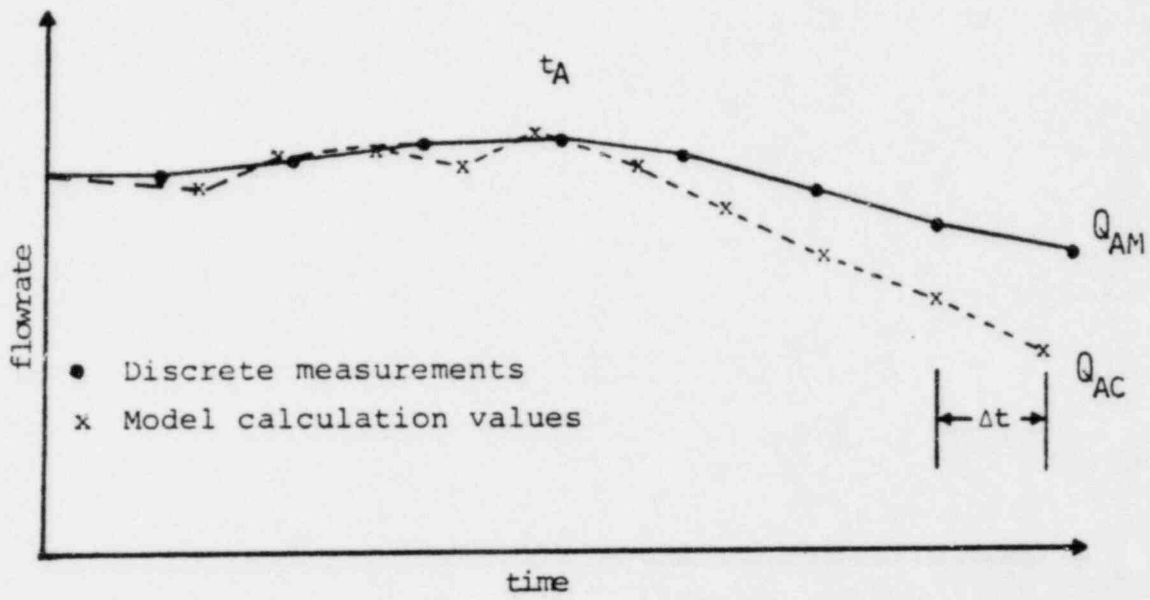
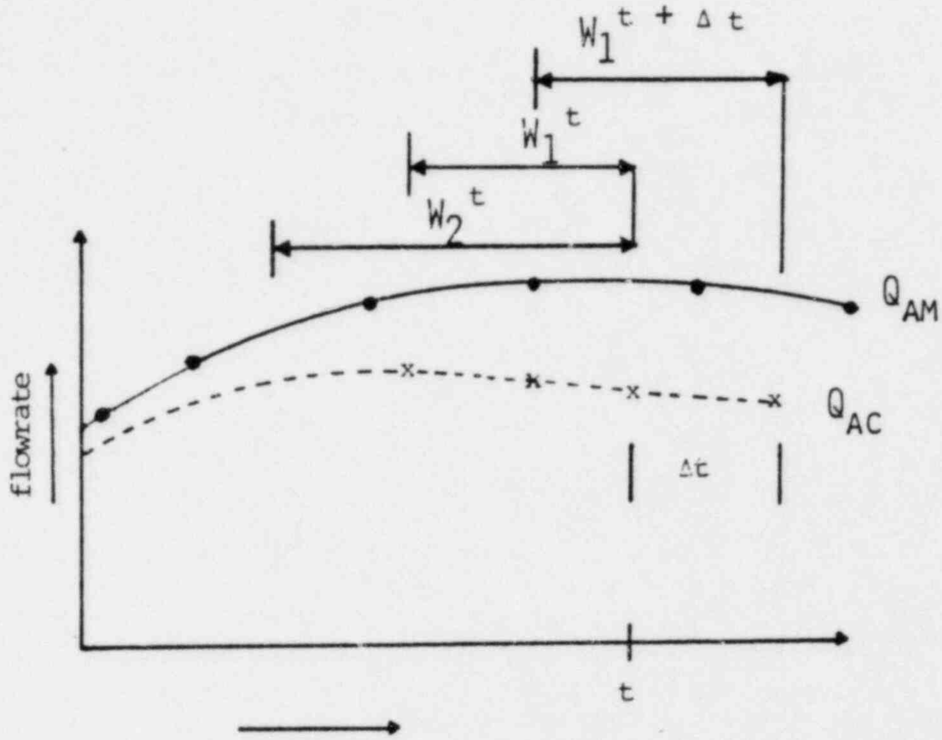


FIGURE 5

FLOW VERSUS TIME - $Q_{measured}$ and $Q_{calculated}$



$$\text{ACCUM FLOW ERROR}_1 = \text{AFE}_1 = \sum_{t}^{t-W_1} (Q_{AC} - Q_{AM}) \times \Delta t$$

$$\text{ACCUM FLOW ERROR}_2 = \text{AFE}_2 = \sum_{t}^{t-W_2} (Q_{AC} - Q_{AM}) \times \Delta t$$

FIGURE 6

FLOW VERSUS TIME SHOWING INTEGRATION WINDOW INTERVALS

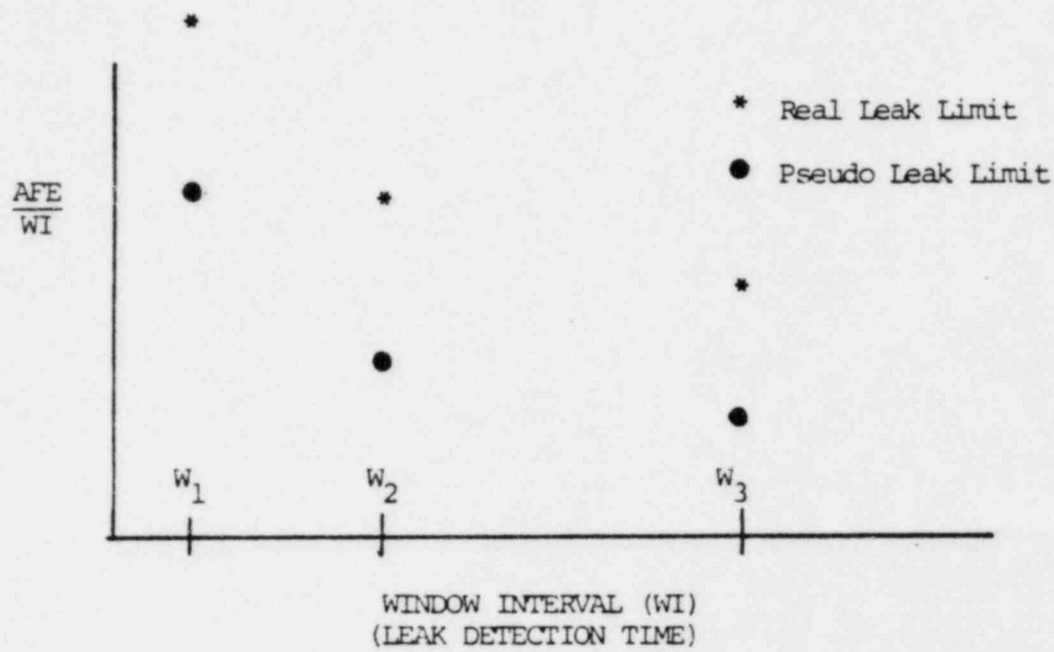


FIGURE 7

LEAK RATE LIMITS VERSUS WINDOW INTERVAL