UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

JUN 2 1978

MEMORANDUM FOR: Edson G. Case, Acting Director
Office of Nuclear Reactor Regulation

FROM: Saul Levine, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER - #27 - BEACON/MOD 2

1.0 INTRODUCTION

1.1 Identification of the Completed Research

This Research Information Letter transmits the BEACON/MOD 2 computer code manual, describes its field of application and discusses the code's strengths and limitations.

BEACON/MOD 2 is an advanced, best estimate computer code intended for evaluation of short term thermohydraulic conditions within "dry" (full pressure) multicompartment containments, or within certain regions of the "pressure suppression" containment drywell.

Developed by Idaho National Engineering Laboratory, this code was completed, documented and transmitted to the Argonne Code Center at the end of December 1977. The code Users Manual is given in Enclosure 2.

1.2 Relation of this Research to Regulatory Needs

This particular research was initiated by RES, about three years ago, as a result of its survey of the existing containment codes and identification of the problem areas in need of important modeling improvements for Best Estimate analyses. Hence, this research was undertaken in anticipation of future NRR needs, rather than in response to a specific NRR Research Request.

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The areas identified by RES to require better resolution, especially for determination of the margin of safety, involved the evaluation of hydraulic loads on the walls, barriers, and system components located either within the break compartment or in the adjacent compartments of a full pressure (dry) containment. Some regions of the pressure suppression (PS) containment drywell also require a detailed examination of hydraulic loads and could be analyzed in the same fashion.

Those hydraulic loads are caused either by the direct impact of the fluid discharging from the postulated break, or by the creation of significant differences in fluid pressure in the compartments divided by the internal walls or barriers. Such loads reach their peaks within a relatively short time following the initiation of LOCA.

2.0 DISCUSSION

2.1 Modeling Requirements for Best Estimate Analysis of Hydraulic Loads

The requirements listed below pertain to the locations in the dry and PS containments described above and to the early period of LOCA.

(a) The ability to treat thermal and mechanical nonequilibrium is required. Thermal nonequilibrium constrains the rate of phase change, hence density change, and thereby greatly influences the magnitude of the local impact load of a flashing jet. It also affects the rate of pressurization within the compartment receiving the discharging fluid. Thermal nonequilibrium implies that the liquid and the gaseous phases (vapor and air) do not have to be at the same temperature.

Mechanical nonequilibrium implies that the fluid components need not be intimately mixed and could be traveling with different velocities.

(b) Multidimensional analysis capability is essential for description of the evolution of a flashing jet and its impact load; for tracking of the propagation of pressure waves within the confined regions containing the ruptured pipe (such as a reactor cavity); and for determination of the manner in which the discharging fluid mixes with air. For example, pockets of the slowly circulating air could be formed, greatly affecting the composition of the fluid flowing through apertures between adjacent subcompartments. Fluid composition influences the rate of flow through such apertures and, therefore, the buildup of pressure differentials between subcompartments.

(c) The ability to describe the containment with a computing mesh consisting of multidimensional, one-dimensional and zero-dimensional (or lumped parameter) zones is required. This allows the opportunity to place the emphasis on the computational details where they are needed.

None of the codes reviewed prior to initiation of this research effort had the above listed capabilities.

2.2 Analytical Techniques Employed in BEACON/MOD 2

The fluid flow solution routines are based on the first version of K-FIX code developed at the Los Alamos Scientific Laboratory. That version of K-FIX solves the conservation equations for water, water vapor, and air in two dimensions (axisymmetrical). In BEACON/MOD 2 the computational mesh was extended to include the two-dimensional cartesian mesh, a one-dimensional mesh for the description of interconnecting flow passages, and zero-dimensional (lumped parameter) zones for description of those regions of the containment which do not require the resolution of flow momentum. In addition, BEACON/MOD 2 includes the capability to consider "obstacle cells," within the multidimensional zones, to model internal flow barriers or system components experiencing hydraulic loads. Sources of mass, momentum, and energy can be prescribed for any cell. This feature allows, among others, consideration of the primary coolant system break flow. By sharing the momentum flux over different cell faces, the jet of fluid discharging from the break could be aimed in any desired direction to explore the consequences of jet impact loads.

Multiphase, multicomponent description of thermal hydraulics allows for relative motion between liquid (droplets) and the gaseous phase (vapor and air) and for unequal temperatures. Consequently, both the mechanical and thermal nonequilibrium are allowed. The numerical technique of K-FIX is based on a Fully Implicit Exchange of mass and energy between the liquid and the vapor phases.

2.3 Evaluation of Strengths and Limitations

BEACON/MOD 2 offers considerable advantages over the existing containment codes for best estimate evaluation of hydraulic loads in multicompartment PWR type containments. It is particularly suitable for evaluation of the reactor cavity loads (for postulated breaks between the reactor vessel and the biological shield) in both PWR and BWR containments. Sample results of such an analysis are given in Enclosure 1.

The code has also shown a capability to describe the evolution of a two-phase (flashing) jet and the resulting pressure loads on the impacted barrier. This capability was studied by modeling two jet impact experiments - one featuring a very small, 10 mm diameter jet; the other featuring a 100 mm diameter jet. The tests were performed by KWU and Battelle Frankfurt, respectively.

As shown in Enclosure 1, good agreements with test data were obtained by suitably adjusting the mass exchange (Γ_e) and the momentum exchange (K_D) coefficients. Although the same values of Γ_e and K_D gave good agreements with test data, it is clear that a purely predictive capability was not demonstrated but, rather, the capability to handle the situation when certain basic physical models are empirically normalized.

The interphase heat transfer in BEACON/MOD 2 is the product of an interphase heat transfer coefficient, an input constant selected by the user, and the differential temperature between the two phases.

There are several interphase mass transfer options available in BEACON which are formulated for various flow regimes such as dispersed, bubbly, slug, etc. However, the MOD 2 version does not yet contain the logic to determine the type of flow and to choose the proper formulation. The user may select the desired flow regime modeling as input; however, once selected, the flow regime is fixed for the remainder of the problem.

The momentum exchange between phases is the product of a momentum exchange coefficient and the velocity difference between the two phases. The modeling options currently available for computing the interphase momentum exchange coefficient are:

(1) Input constant, selected by the user

(2) Dispersed flow momentum exchange assuming a constant bubble/droplet size

(3) Dispersed flow momentum exchange assuming a constant bubble/droplet number density.

The above brief description of the techniques employed in BEACON/MOD 2 to model the interphase exchange of mass, momentum, and energy illustrates some limitations in the present version of the code. Such exchange processes must be described with more physical models and without the User intervention. The ongoing work is aimed at removing these limitations.

Additional limitations involve (a) inability to consider de-entrainment of liquid droplets due to wall impingement; and (b) inability to consider wall heat transfer. Both of these limitations are being removed during the calendar year of 1978. Liquid droplets that impinge on walls or obstacles form falling liquid films which not only change the moisture content in the flowing stream - and thereby affect pressure drops between compartments - but also affect the wall heat transfer.

3.0 RESULTS

The product of this research is a computer code, hereby transmitted. Results of some of its applications are found in Enclosure 1.

4.0 RECOMMENDATIONS

It is recognized that the code must be more extensively tested against experimental data. Nevertheless, the BEACON/MOD 2 code is recommended for calculations of the reactor cavity loads, for both PWR and BWR installations, and for evaluation of jet impact loads. This recommendation stems from the fact that this code, due to its advanced thermal hydraulics modeling, does present very significant improvements over the presently available analysis tools. Further testing of this code will proceed as new (presently planned) test data sources yield additional information.

This code version is not recommended for evaluation of inter-compartment pressure differentials because it does not handle wall heat transfer. However, BEACON/MOD 2A, scheduled for release to NRC the end of December 1978, will meet these requirements.

Saul Levine

Saul Levine, Director
Office of Nuclear Regulatory Research

Enclosures:

Enclosure 1 - BEACON/MOD 2 Developmental Verification

Enclosure 2 - C. R. Broadus, S. W. James, W. H. Lee, J. F. Lime and R. A. Pate, "BEACON/MOD 2, A CDC 7600 Computer Program for Analyzing the Flow of Mixed Air, Steam, and Water in a Containment System - Users Manual," December 1977, CDAP TR 002

See cc next page

ENCLOSURE 1

BEACON/MOD 2 Developmental Verification

The MOD 2 version of BEACON is applicable only to examination of the PWR and BWR reactor cavity loads and of the jet impingement loads.

There is no test data source available as of now to verify the code's ability to correctly calculate the reactor cavity loads. However, LASL's K-FIX code on which BEACON/MOD 2 is based has shown the capability to properly track shock waves propagating through two-phase fluids, to calculate break discharge flow, and the PWR downcomer transients.

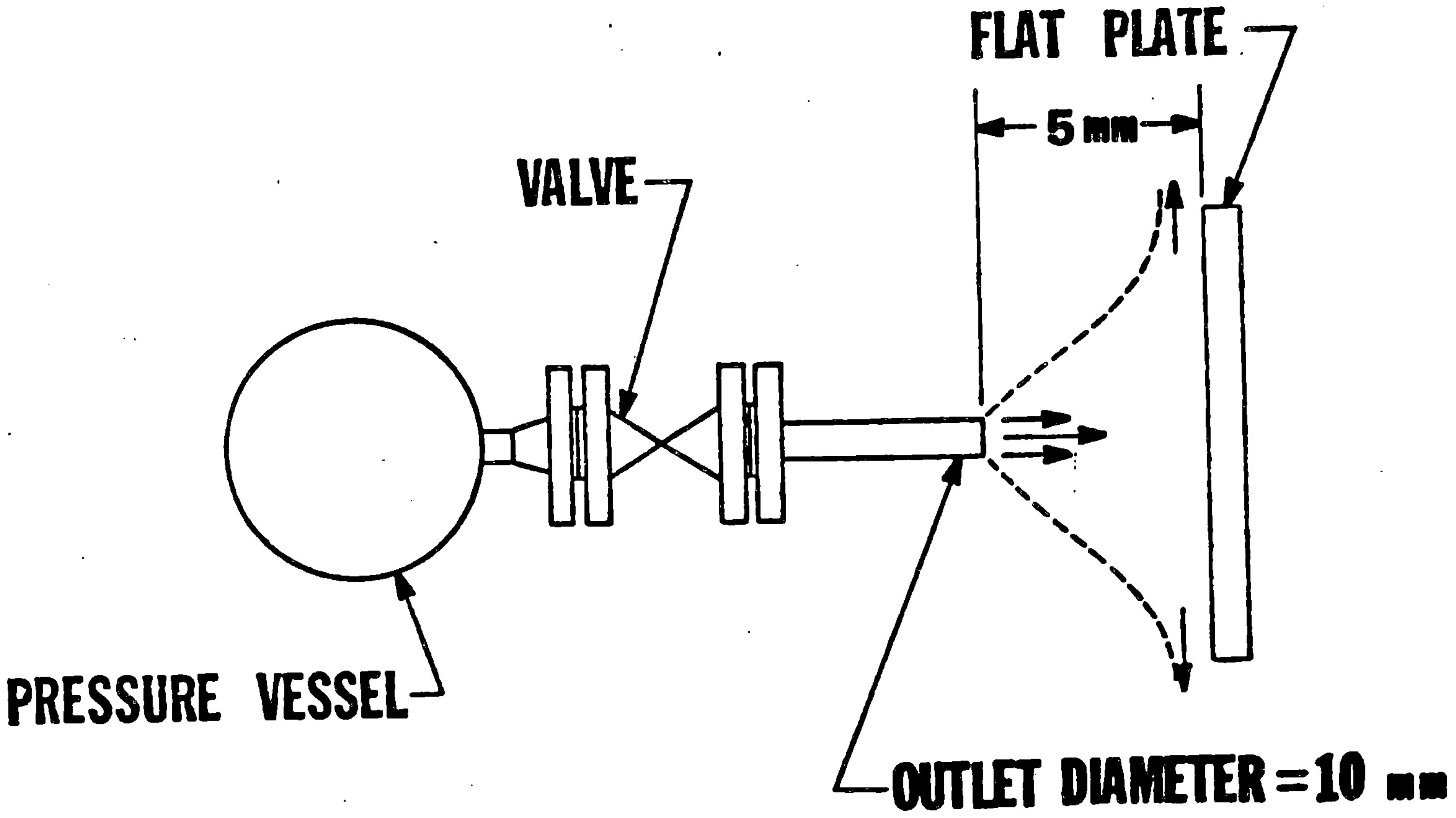
There were only two test data sources available for testing the code's ability to calculate jet impingement loads.

Kraftwerk Union (KWU) has published test data on a small scale, two-phase jet impinging on a flat plate. This test was simulated with the BEACON code for a range of K_D, the drag coefficient between the liquid and vapor phase and Γ_e and Γ_c, the scaling factors relating the evaporation or condensation rate and the amount of superheating of the liquid phase or subcooling of the vapor phase. Because there was little flashing in this test, information could not be obtained about Γ_e or Γ_c. But stagnation pressure was found to be a definite function of the K_D and indicated a high degree of coupling between the phases.

Another test on a somewhat larger (100-mm diameter) jet impinging on a flat plate was made by Battelle-Frankfurt in their test Program RS-50, Experiment C-12. As with the KWU test, simulation runs were made and the results were compared with the measured pressure distribution on the plate. From these simulations, a reasonable value of the Γ_e was obtained and the previously obtained value of K_D was verified.

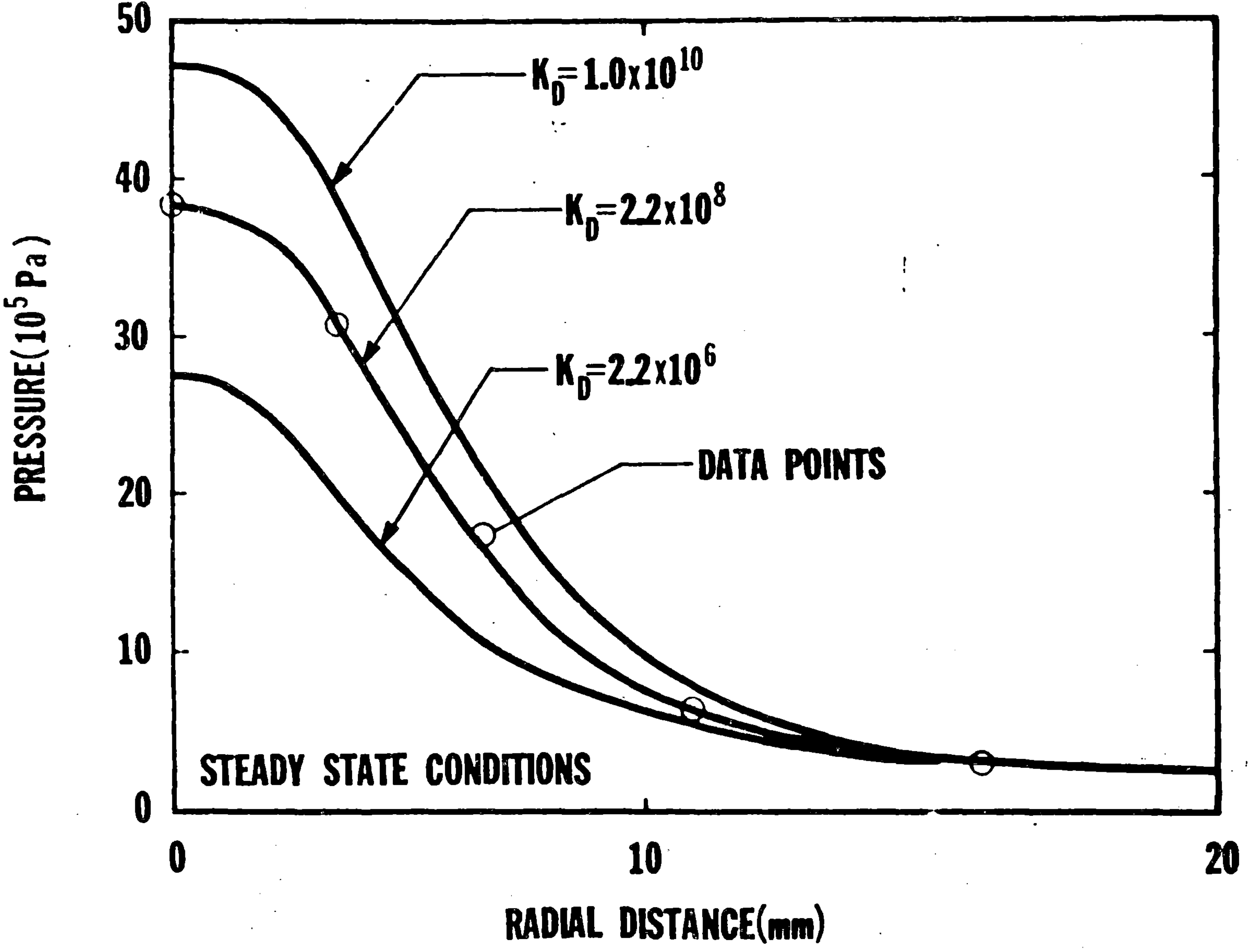
To match both tests, a high value of interphase heat transfer coefficient was used.

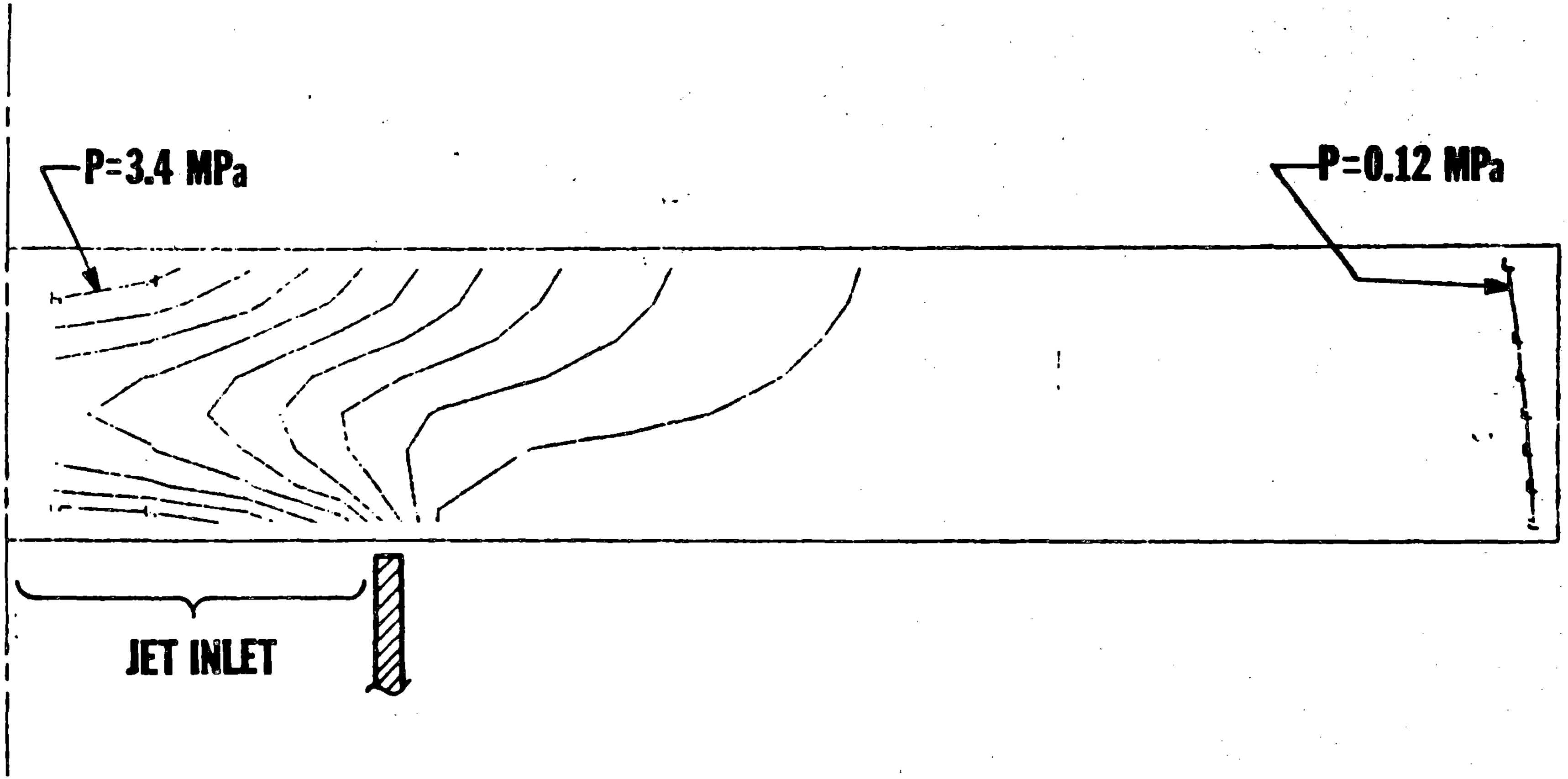
An analysis was made to determine the flow and pressure distribution in the reactor cavity following a recirculation line break in a typical BWR containment. The values derived from the jet experiments for Γ_e and K_D were used in the model. Peak pressures of slightly under 4.7×10^5 Pa were found in the cavity.



KWU SMALL JET EXPERIMENT

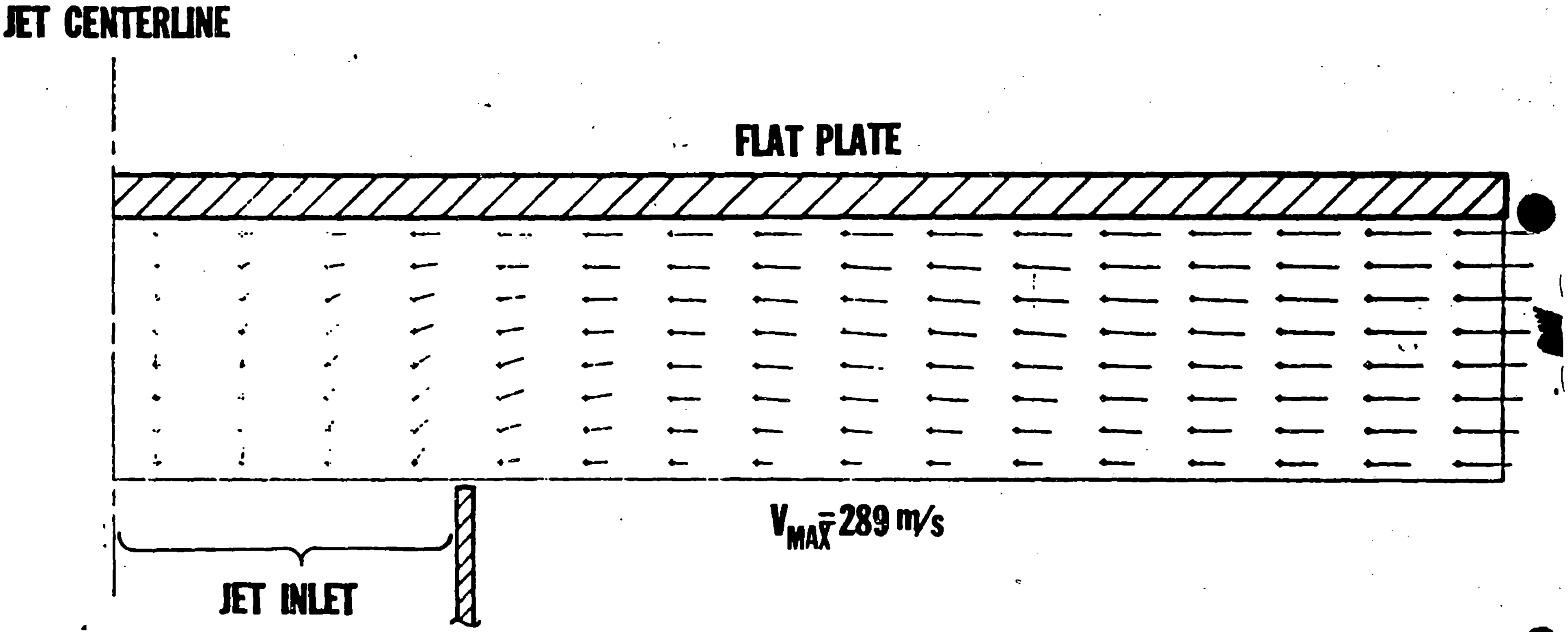
PRESSURE ON FLAT PLATE - KWU SMALL JET EXPERIMENT





STEADY STATE CONDITIONS

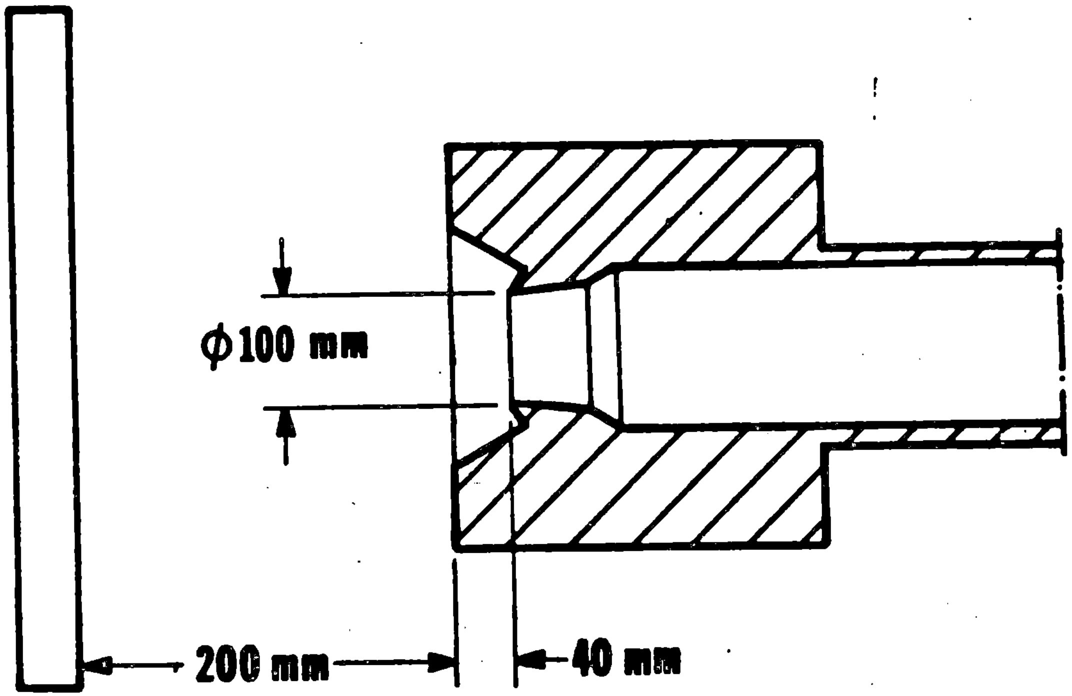
PRESSURE DISTRIBUTION
KWU SMALL JET EXPERIMENT



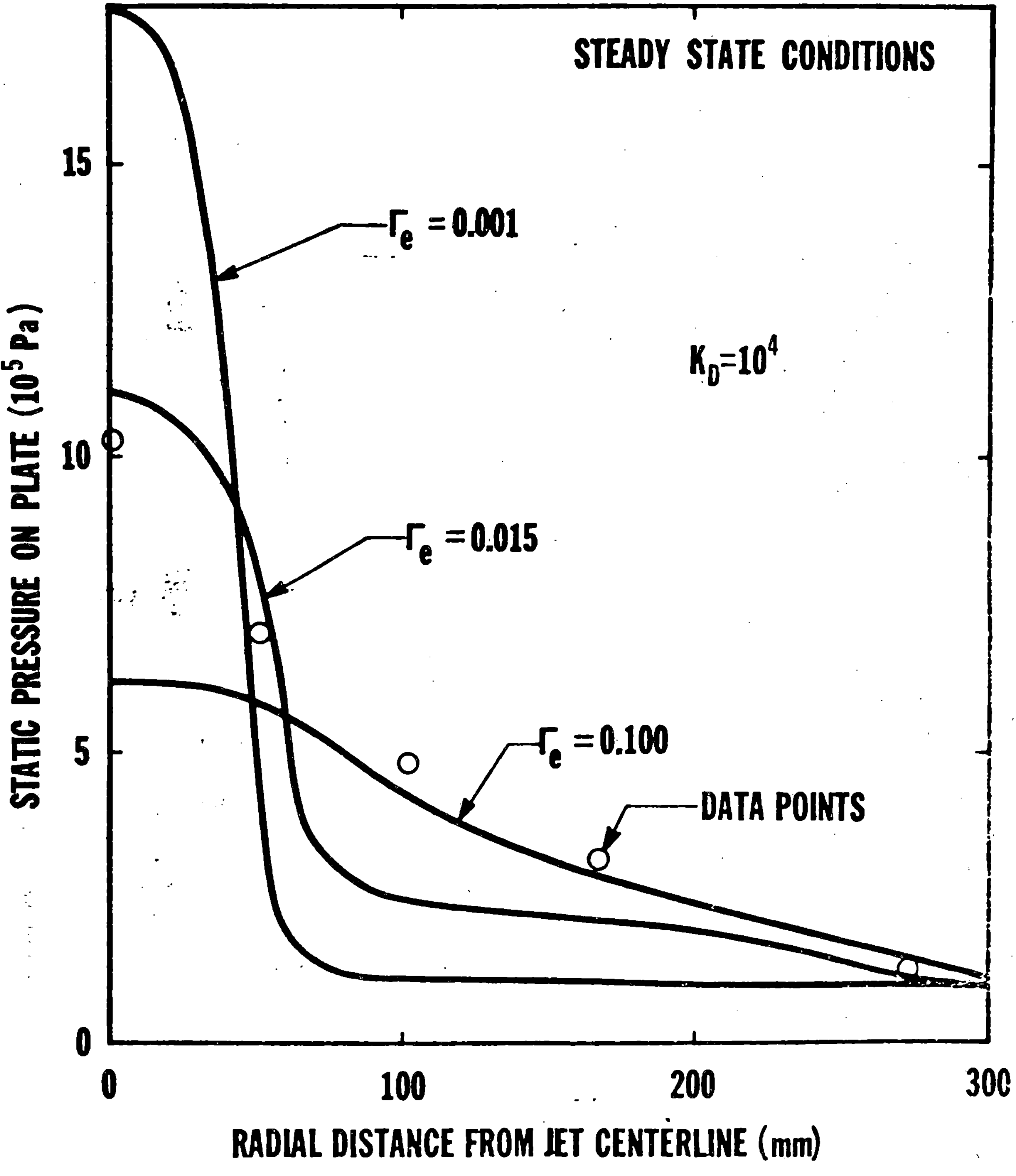
STEADY STATE CONDITIONS

VAPOR VELOCITY DISTRIBUTION
KWU SMALL JET EXPERIMENT

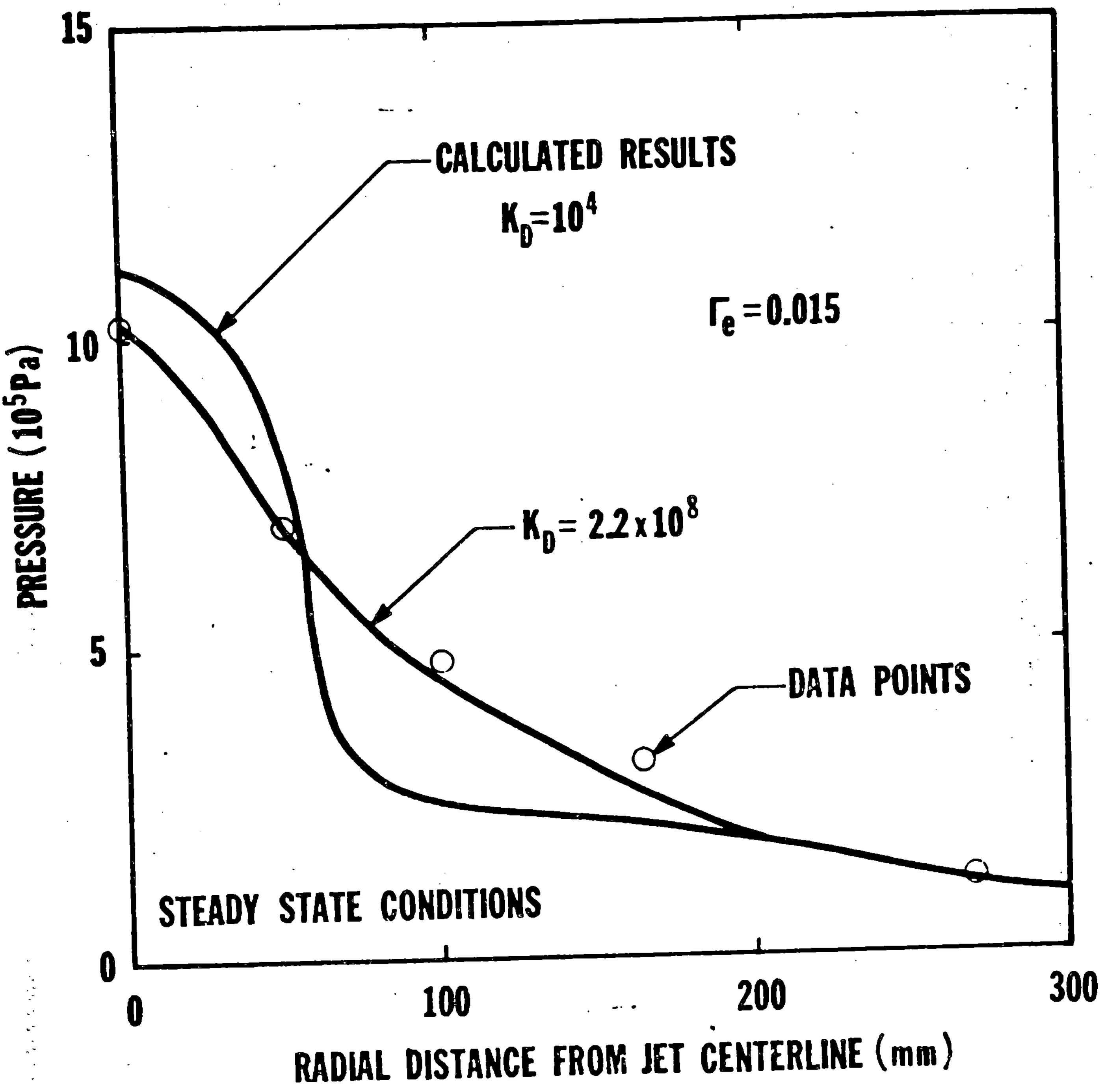
BATTELLE-FRANKFURT EXPERIMENT C-12
2-PHASE JET



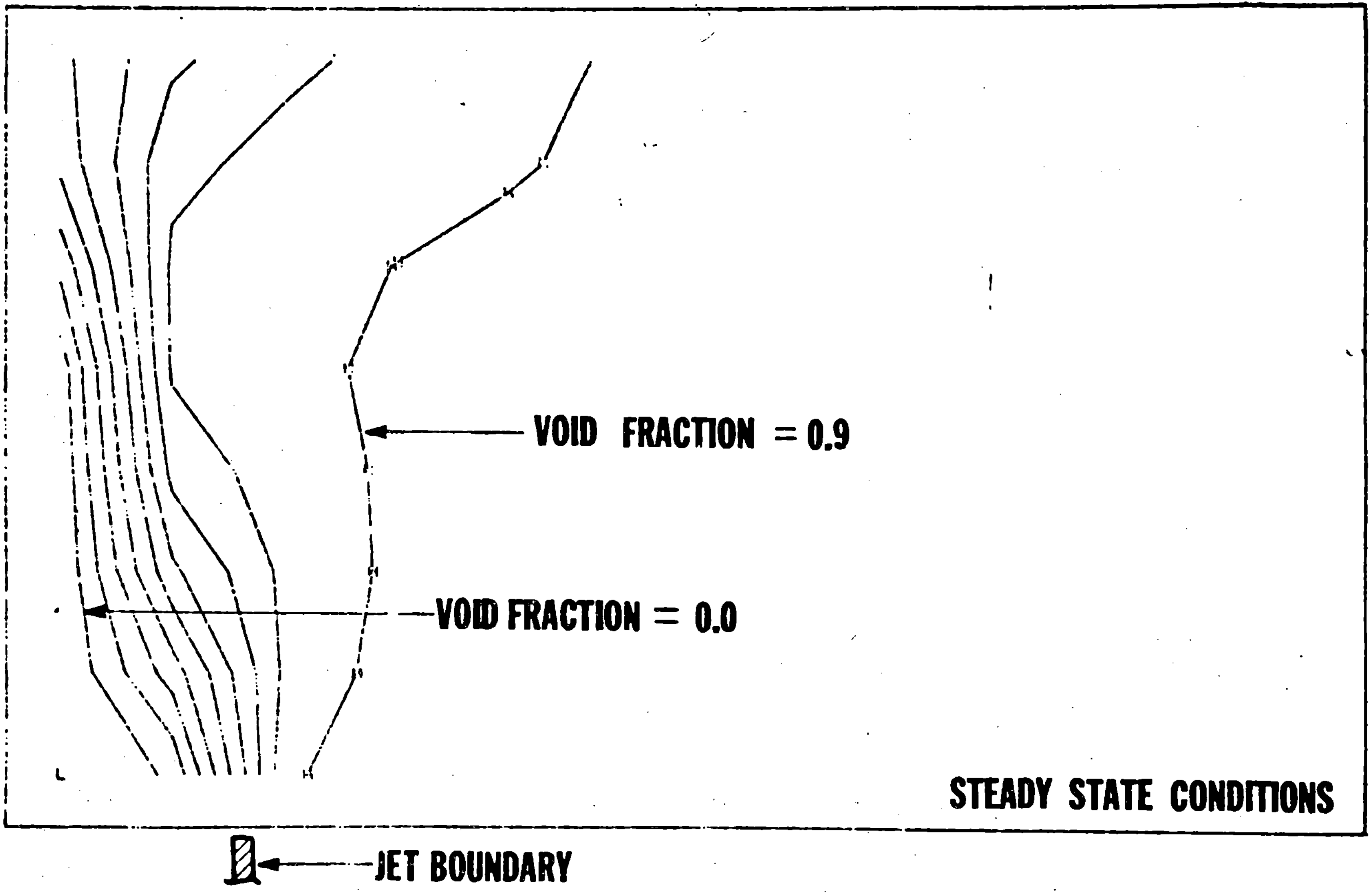
BATTELLE-FRANKFURT EXPERIMENT C-12



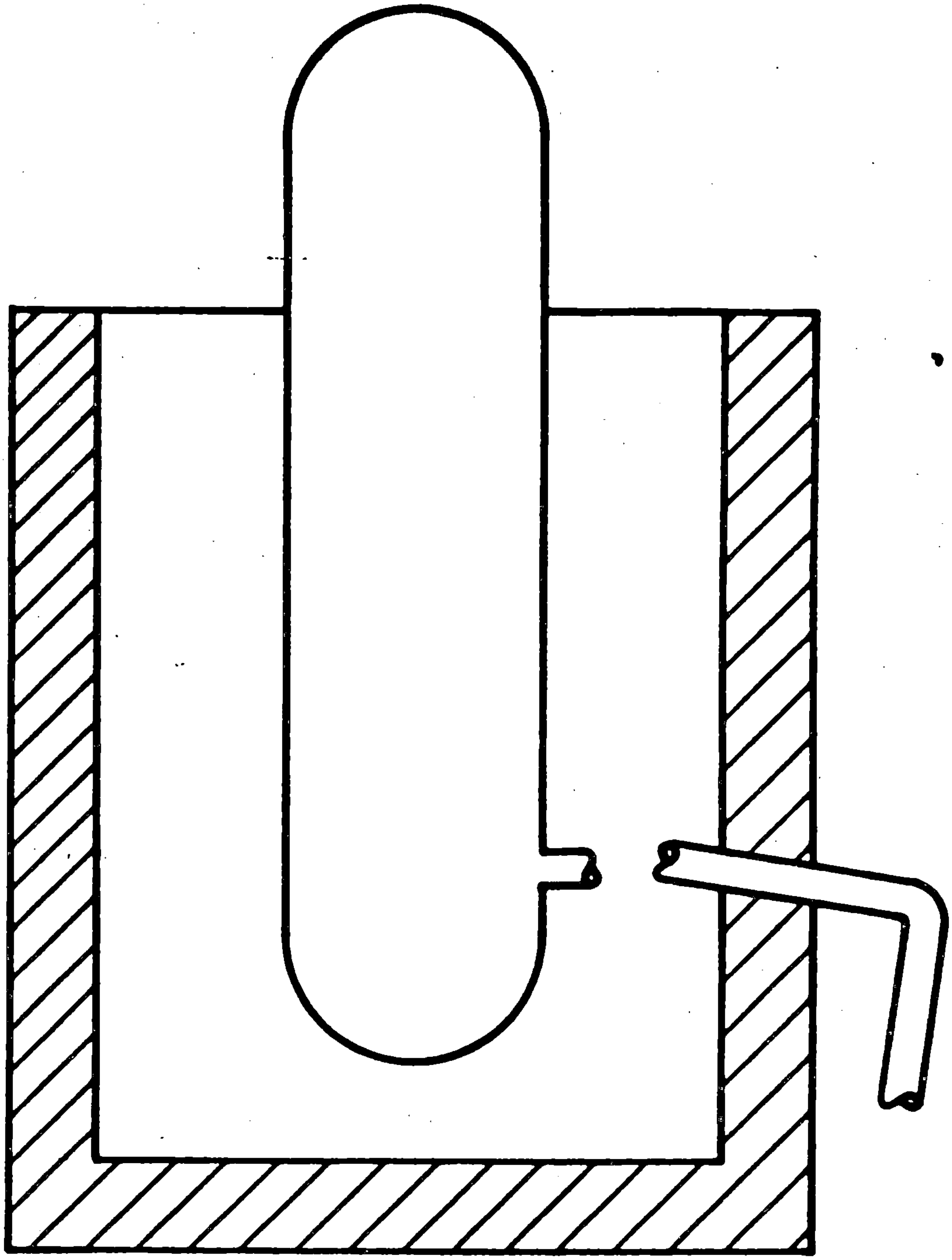
BATTELLE-FRANKFURT EXPERIMENT C-12
2-PHASE JET

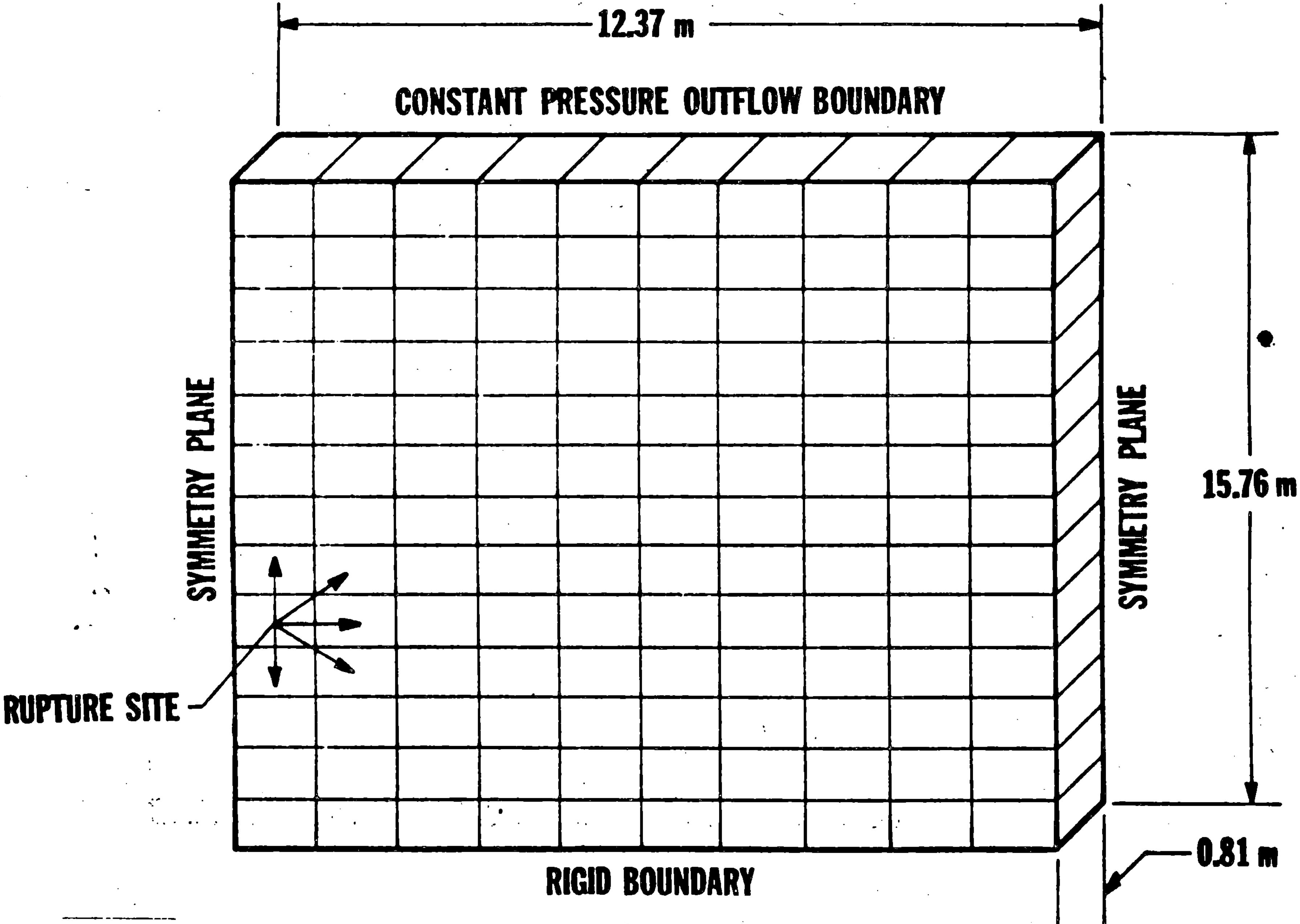


CALCULATED VOID FRACTION DISTRIBUTION
BATTELLE-FRANKFURT EXPERIMENT C-12, 2-PHASE JET



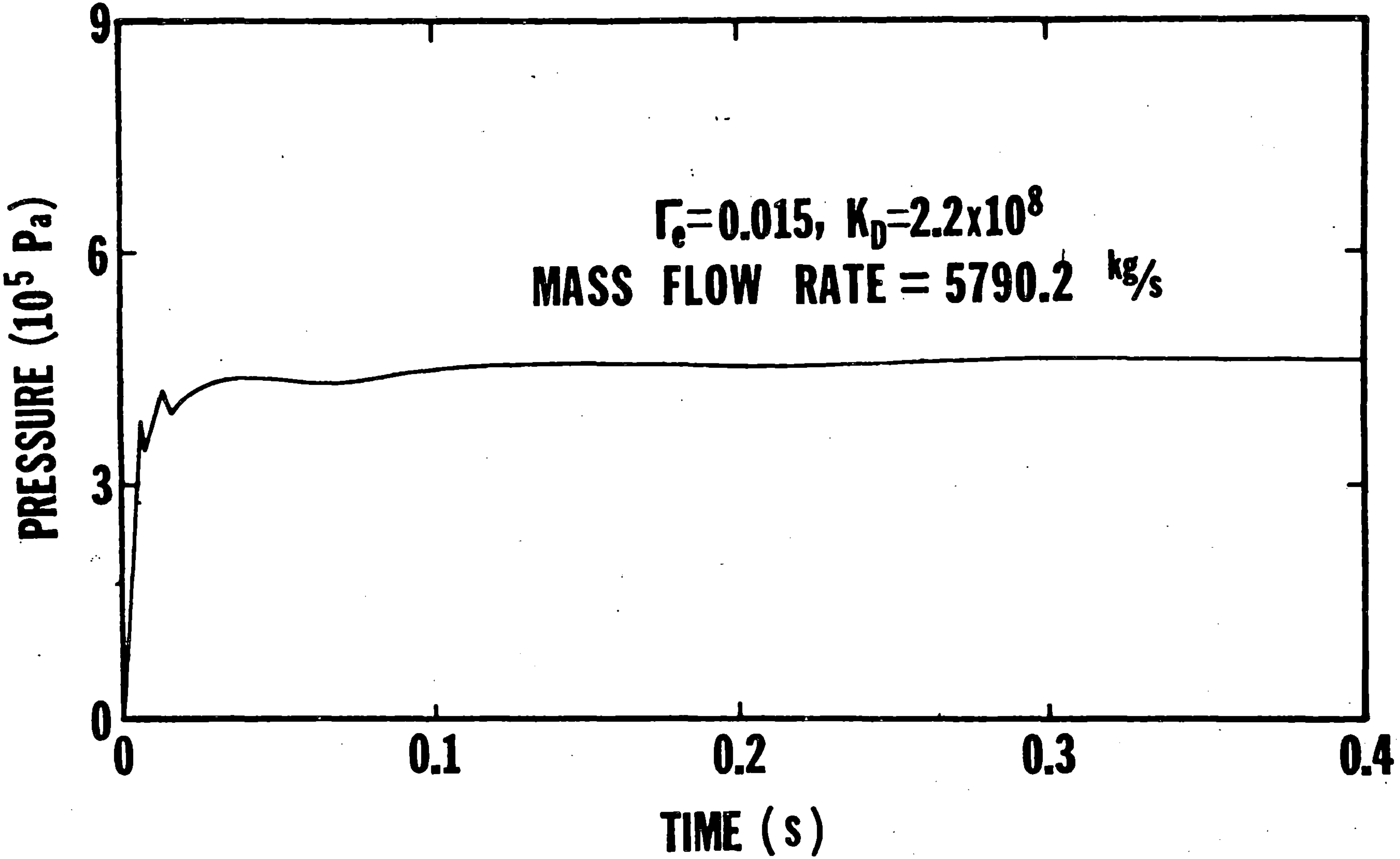
REACTOR CAVITY CONFIGURATION



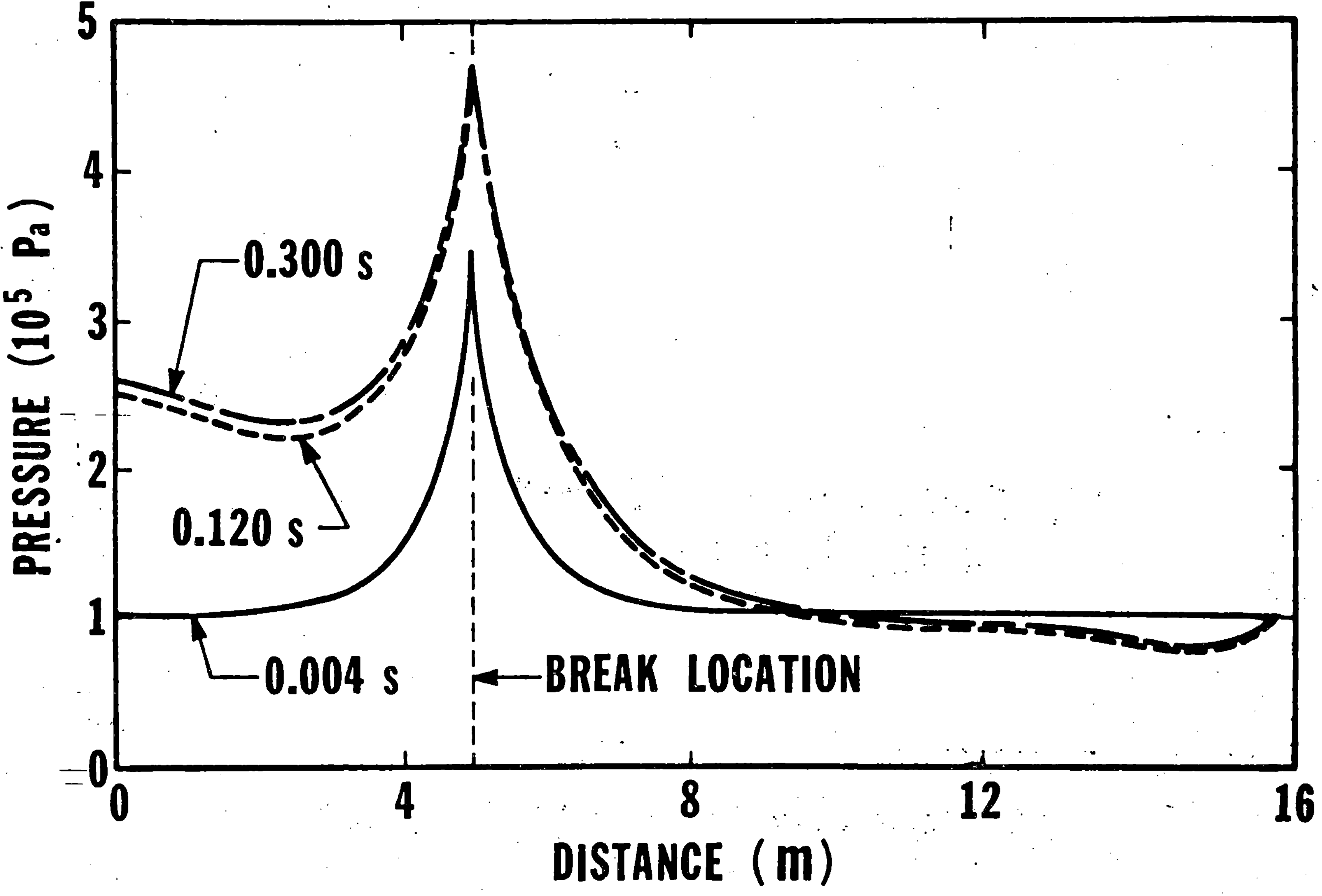


REACTOR CAVITY PROBLEM CONFIGURATION

REACTOR CAVITY BREAK NODE PRESSURE

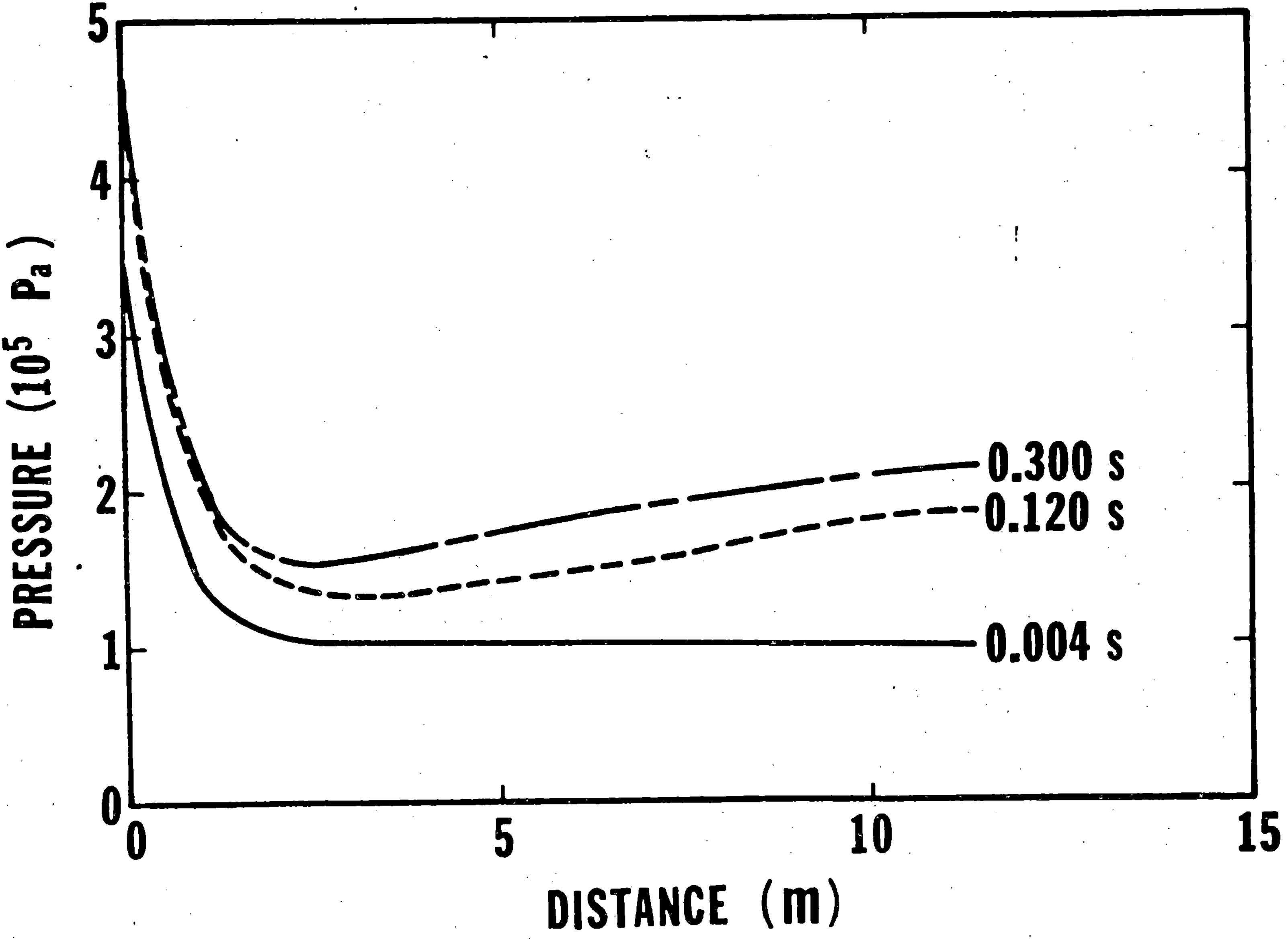


REACTOR CAVITY PROBLEM
PRESSURE VS. VERTICAL DISTANCE FROM FLOOR

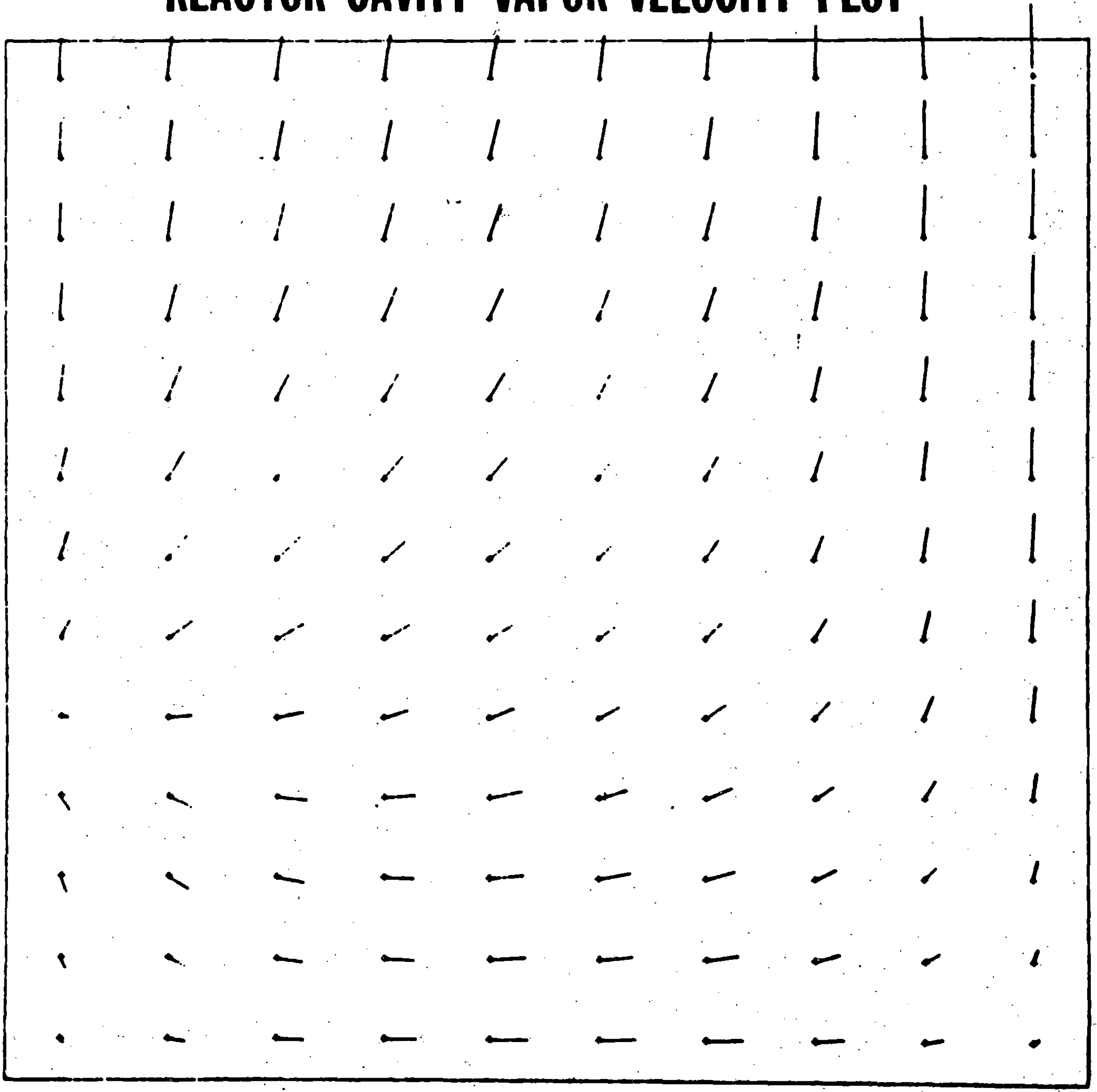


REACTOR CAVITY PROBLEM

PRESSURE VS. HORIZONTAL DISTANCE FROM BREAK

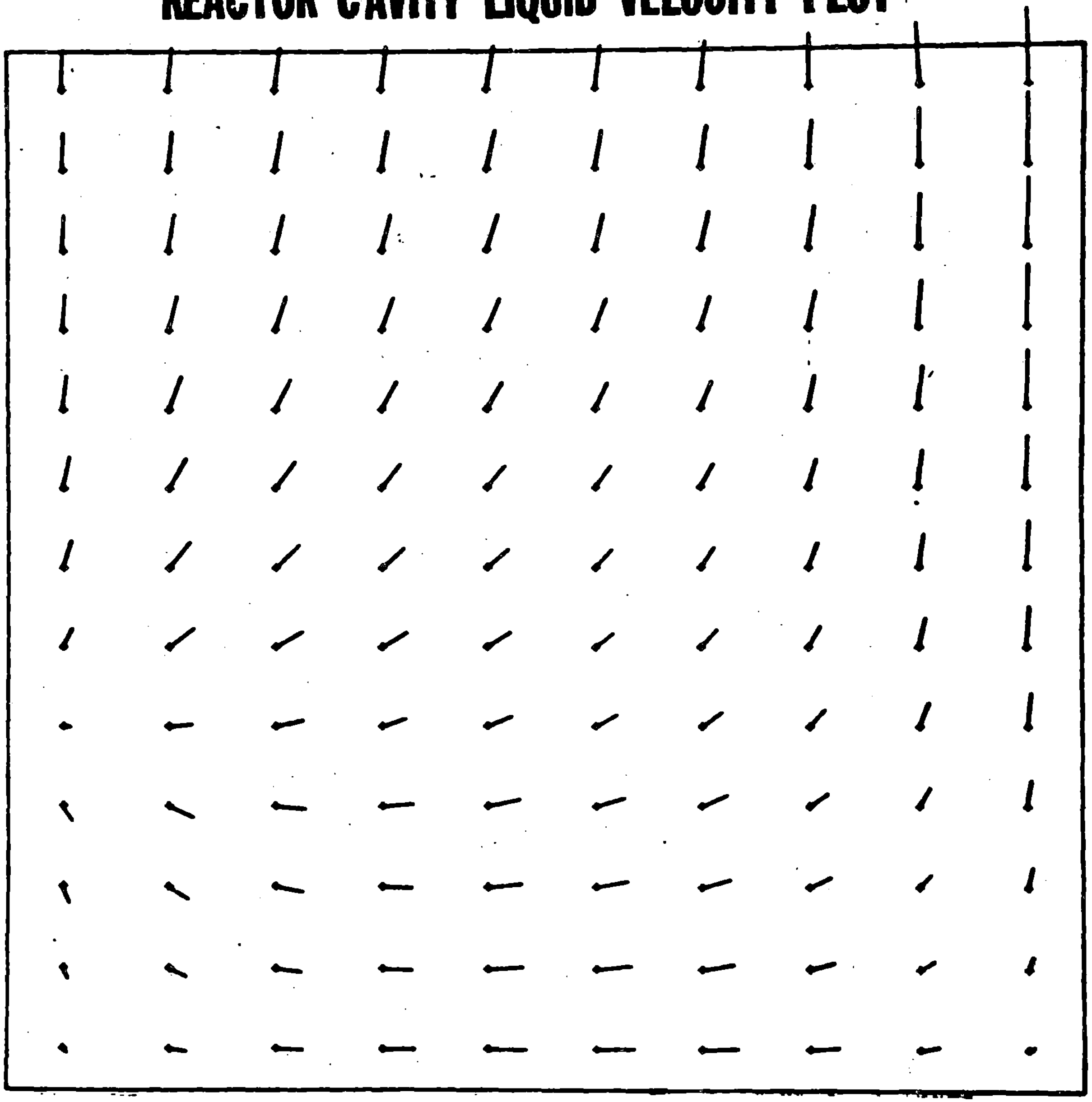


REACTOR CAVITY VAPOR VELOCITY PLOT



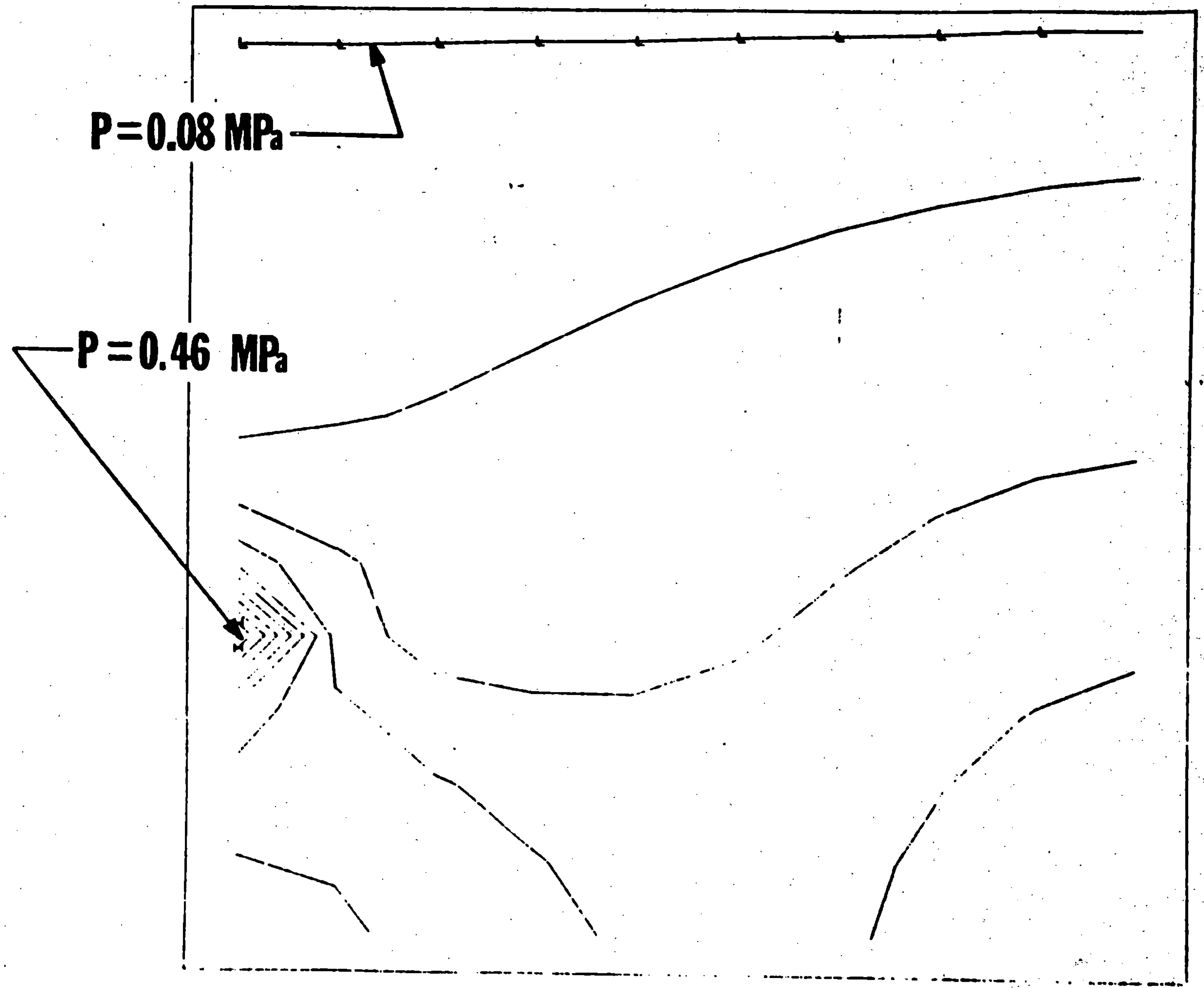
V_{MAX}=420 m/s TIME = 0.12 s

REACTOR CAVITY LIQUID VELOCITY PLOT



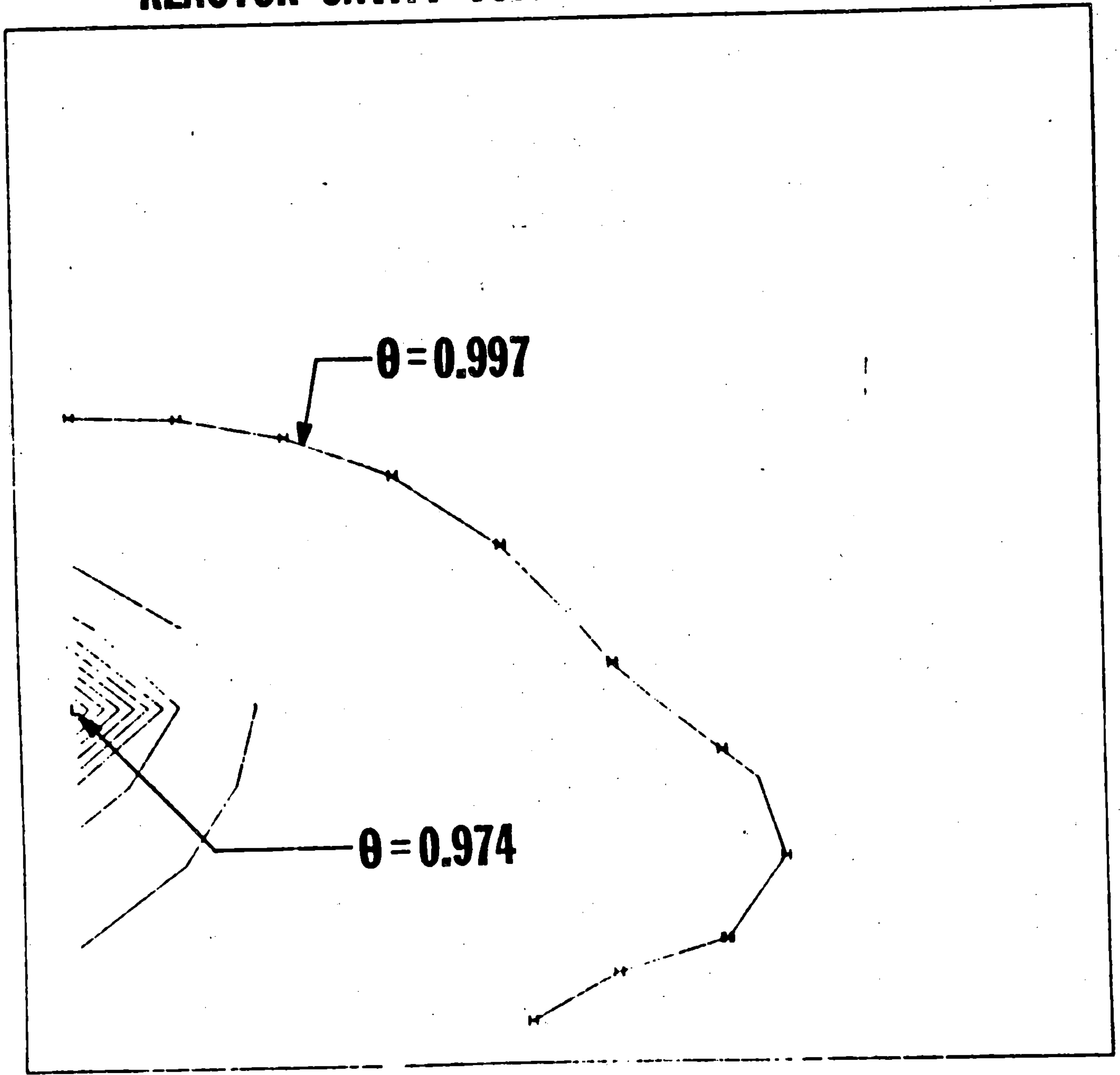
V_{MAX}=420 m/s TIME = 0.12 s

REACTOR CAVITY PRESSURE DISTRIBUTION



TIME -- 0.12 s

REACTOR CAVITY VOID FRACTION DISTRIBUTION



TIME = 0.12 s