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INTERNAL TECHNICAL REPORT

TRAC-BWR COMPLETION REPORT
ADAPTATION OF ANDERSEN/ISHII INTERFACIAL
SHEAR PACKAGE FOR TRAC-BD1/MOD1

CODE DEVELOPMENT DIVISION

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ADAPTATION OF ANDERSEN/ISHII INTERFACIAL SHEAR PACKAGE FOR TRAC-BD1/MOD1

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This model was developed and coded for TRAC-BD1 by Jens G. Munthe Andersen of the General Electric Company.

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ADAPTATION OF ANDERSEN-ISHII INTERFACIAL SHEAR PACKAGE FOR TRAC-BD1/MOD1

1. MODEL REQUIREMENTS

This model was incorporated into TRAC-BD1 in order to improve code performance in a number of data comparisons with separate-effects void fraction tests. In particular, the void distribution predicted for the General Electric Large Vessel Level Swell Tests was significantly improved by this model. The model uses the drift-flux correlations developed by M. Ishii[1] and recasts them into a form suitable for two-fluid momentum calculations. The same formulation is used in both 3-D and 1-D calculations. In addition, a recent improvement in entrainment modeling, also developed by Ishii[2], has been incorporated.

2. FINAL MODEL DESIGN

2.1 Model Description

In the drift-flux formulation for 2-phase flow, the individual phase motions can be related by[3]

$$\langle j_g \rangle = C_o \langle j \rangle \langle \alpha \rangle + \langle V_{gj}\ \alpha \rangle \qquad (1)$$

where

j = local volumetric flux (m/s)

j_g = local vapor volumetric flux (m/s)

α = void fraction (-)

C_o = concentration parameter $\frac{\langle \alpha\ j \rangle}{\langle \alpha \rangle \langle j \rangle}$

V_{gj} = drift velocity (m/s), $\langle (\text{vapor velocity} - j)\alpha \rangle / \langle \alpha \rangle$

and "<>" indicates an average over the flow cross section. Ishii (see Reference 1) has compiled void fraction and flow data for numerous 2-phase flow experiments and has derived correlations for C_o and V_{gj} for each of several flow regimes.

Since this model is directly applicable only to a drift-flux flow formulation, it must be altered in order to be used in a 2-fluid model. This has been done by J.G.M. Andersen of the General Electric Company (GE). The phases are coupled through interfacial drag, and Andersen has shown that for appropriate partitioning of wall drag force, the interfacial force coefficient can be expressed as

$$\bar{C}_i = \frac{\Delta\rho\ g\ \alpha<1-\alpha>}{|\bar{V}_{gj}|\ \bar{V}_{gj}} \qquad (2)$$

where

$$\bar{V}_{gj} = (1 - C_o <\alpha>)\ \bar{V}_g - <1-\alpha>\ C_o \bar{V}_\ell .$$

The drag coefficient used by TRAC, C_D, is related to $\bar{C}_i$ by

$$\bar{C}_i = \frac{1}{8} \frac{C_D}{d_h} \rho_c \qquad (3)$$

where

d_h = the hydraulic diameter of bubbles or drops

ρ_c = the density of the continuous phase.

Equations (2) and (3) must be applied to each flow regime being considered. These are:

1. Bubbly/Churn Flow (continuous liquid phase)

   The hydraulic diameter is based on bubble size as determined by the critical Weber number [$We = \frac{G^2 d_h}{g_c \rho_g \sigma}$; where $G = \alpha\rho_g (v_v - v_\ell)$]

$$\frac{1}{d_h} = 6 <\alpha> \frac{\rho_\ell \bar{V}_{gj}^2}{\sigma We_c <1-\alpha>^2} \qquad (4)$$

For this flow regime Ishii correlates $\overline{V}_{gj}$ as

$$V_{gj} = \sqrt{2}\ [\frac{\Delta\rho g\sigma}{\rho_\ell}]^{1/4} \tag{5}$$

Using Equation (5), the drag coefficient may be derived from Equations (2) and (4) as

$$C_D = \frac{We_\ell <1-\alpha>^5}{3} \tag{6}$$

Finally, the distribution parameter, C_o, may be expressed as

$$C_o = C_\infty - (C_\infty - 1)\sqrt{\frac{\rho_g}{\rho_f}} \tag{7}$$

where $C_\infty = 1.393 - 0.0155\ \ell n\ (\frac{GD_H}{\mu_\ell})$

[The expression for C_∞ is due to Nikuradse].[4] Equation (7) gives the appropriate high pressure limit on C_o.

2. Annular Flow (liquid assumed continuous, $\rho_c = \rho_\ell$)

The interfacial areas for completely separated annular flow leads to

$$\frac{1}{d_h} = \frac{4}{D_h}\ \sqrt{\alpha} \tag{8}$$

from Equations (2), (3) and (4) we get

$$\frac{1}{2}\ \sqrt{a}\ C_D\ \frac{\rho_\ell}{D_h}\ \frac{\overline{V}_{gj}^2}{<1-\alpha>^2} = \Delta\rho g <\alpha> <1-\alpha> \tag{9}$$

Ishii has found that for this flow regime

$$\overline{V}_{gj} = \frac{<1-\alpha>^{3/2}}{<\alpha> + a}\sqrt{\frac{\Delta\rho g D_h}{0.015\ \rho_\ell}} \tag{10}$$

where

$$a = \sqrt{\frac{1 + 75 <1-\alpha>}{a}\ \frac{\rho_v}{\rho_\ell}}\ ,$$

and

$$C_o = 1 + \frac{<1-\alpha>}{\alpha + a} \tag{11}$$

This leads to a drag coefficient of

$$C_D = 0.03 \sqrt{a}\,(\alpha + a)^2 \qquad (12)$$

3. <u>Dispersed Flow</u> (vapor in continuous phase)

Again, Equation (4) is used to get the interfacial area (or appropriate diameter), and combining Equations (2), (3) and (4)

$$\frac{3}{4} <1-\alpha> \frac{C_D}{We_c} \frac{\rho_v^2}{\sigma} \frac{\overline{V}_{gj}^{\,4}}{<1-\alpha>^4} = \Delta\rho g <\alpha> <1-\alpha> \qquad (13)$$

Ishii (see Reference 1) recommends

$$\overline{V}_{gj} = <1-\alpha> \sqrt{2} \left\{ \frac{\Delta\rho g \sigma}{\rho_v^2} \right\}^{1/4} \qquad (14)$$

which leads to

$$C_D = \frac{We_c}{3} <\alpha>. \qquad (15)$$

Due to the homogeneous mixing in turbulent droplet flow

$$C_o = 1. \qquad (16)$$

This model also treats droplets entrained from annular flow separately. The model used to determine the amount of entrained liquid is due to Ishii (see Reference 2). The fraction of liquid entrained

$$E = \text{Tanh}\,(7.25 * 10^{-7}\, j_g^{*\,2.5}\, D^{*1.25}\, Re_\ell^{0.25}) \qquad (17)$$

where

$$j_g^* = \frac{\alpha\, v_g}{\left[\frac{\sigma g \Delta\rho}{\rho_v^2} \left(\frac{\rho_v}{\Delta\rho}\right)^{2/3}\right]^{1/4}}$$

$$D^* = D_h\, \frac{g\Delta\rho}{\sigma} \qquad (D_h \text{ is the flow hydraulic diameter})$$

and

$$Re_\ell = \frac{(1-\alpha)\, v_\ell\, D_h}{\mu_\ell}.$$

Entrained droplets are considered only for sufficiently high mass flows. For

$$|G| > 1.465 \left\{ \left[\frac{\rho_v \sigma^3}{\Delta\rho g}\right]^{1/4} \cdot \frac{1}{\mu_v} \right\}^{1/6} \quad (18)$$

the droplet characteristic diameter is

$$\frac{1}{d_h} = 1/2\ (1-\alpha)\ \frac{\rho_v\ [\alpha v_v + (1-\alpha)\ v_\ell]^2}{\sigma} \quad (19)$$

and the drag coefficient becomes

$$C_D = 10.7\ \alpha\ Re_d^{-1/2} \quad (20)$$

where Re_d is the droplet Reynolds number.

In the annular (or drop/annular or dispersed) flow regime, the parameter required is a combination of annular and dispersed phase parameters weighted according to the amount of entrainment. For example, the C_o parameter becomes

$$C_o = E(C_o)_{drop} + (1-E)\ (C_o)_{annular} \quad (21)$$

E, the factor of liquid entrained, is constrained to be between 0.0 and 1.0.

There is also a transition region, which depends on void fraction, between the bubbly/churn and drop/annular flow regimes. Pure bubbly flow is taken to end at

$$\alpha_{B/C} = 4\sqrt{\frac{\rho_v}{\rho_\ell}}\ [\frac{1}{C_o} - 1] + \frac{1}{C_o} - 0.1 \quad (22)$$

The transition region is 0.10 in void fraction, so drop/annular flow is assumed to start at

$$\alpha_{D/a} = 4\sqrt{\frac{\rho_v}{\rho_\ell}}\ [1/C_o - 1] + 1/C_o\ . \quad (23)$$

$\alpha_{B/C}$ and $\alpha_{D/a}$ are constrained to be between 0.0 and 1.0. A simple linear weighting of parameters (similar to above) is also made for this flow transition region.

The actual friction force term appearing in the 1-D and 3-D momentum equations is

$$f_i = C_i \, [f(C_1 \, v_2^{n+1} - C_o \, v_\ell^{n+1}) - (f-1) \, (v_2^n - V_\ell^n)] \tag{24}$$

where $C_1 = \frac{1-C_o <\alpha>}{<1-\alpha>}$, f is a flow-regime dependent old-time/new-time weighting factor, and C_i is determined from the drag coefficient C_D using Equation (3). The four coefficients in Equation (24) are returned from the interfacial shear subroutine. This force is subtracted from the right-hand side of the vapor momentum equation and added to the liquid momentum equation. This results in modification of the right-hand side of both equations and all four coefficients in the 2x2 matrix solved for the explicit-pass velocity estimates. In the case of nearly single-phase flow ($\alpha > 0.999$ or $\alpha < 0.001$), both momentum equations are still solved (unlike in TRAC-BD1), but special coefficients are used to insure that the proper limiting relative velocity results.

2.2 Coding Changes

The coding changes used to implement this model are described below for each subroutine altered.

Subroutine FRICI

This routine was replaced by the routine developed by J.G.M. Andersen of GE. The only alterations to GE's routine are:

(1) A later version of entrainment due to Ishii[5] was included

(2) Entrainment was forced to 1.0 (total entrainment) in regions of film boiling.

Subroutines TF1DS and TF3DE

These routines were altered in order to provide the parameters required by FRICI, and to adapt the explicit velocity calculation to the new form of the interfacial shear parameters. Nearly all of this coding was taken from the GE code version. In addition, log-averaging of new and old interfacial shear coefficients was introduced in order to enhance calculational stability.

DCOMP, RECOMP, DVSSL, and REVSSL were altered in order to allow the dumping and reading of averaged drag coefficients on restart files.

2.3 Input and Output Changes

This update is transparent to the user - no input or output routines have been changed.

4. RESULTS OF ACCEPTANCE TEST CASES

This model has been tested against CISE steady state adiabatic 2-phase vertical tube flow void fraction data[6], FRIGG steady state heated bundle void distribution data[7], and a GE large-vessel transient level swell test.[8] In all cases, the use of this model improved the code simulation of these tests.

The results from three series of CISE tests are given in Figures 1, 2 and 3. The conditions for each test are stated on the figures. Results obtained with TRAC-BD1 are included for comparison, the overprediction of void fraction in TRAC-BD1 has been corrected and the code results with the new model virtually overlay the data.

The results from four FRIGG-1 steady state heated bundle tests are shown in Figures 4, 5, 6 and 7. Again, results obtained with TRAC-BD1 are shown for comparison. At negative qualities (subcooled liquid flow) the

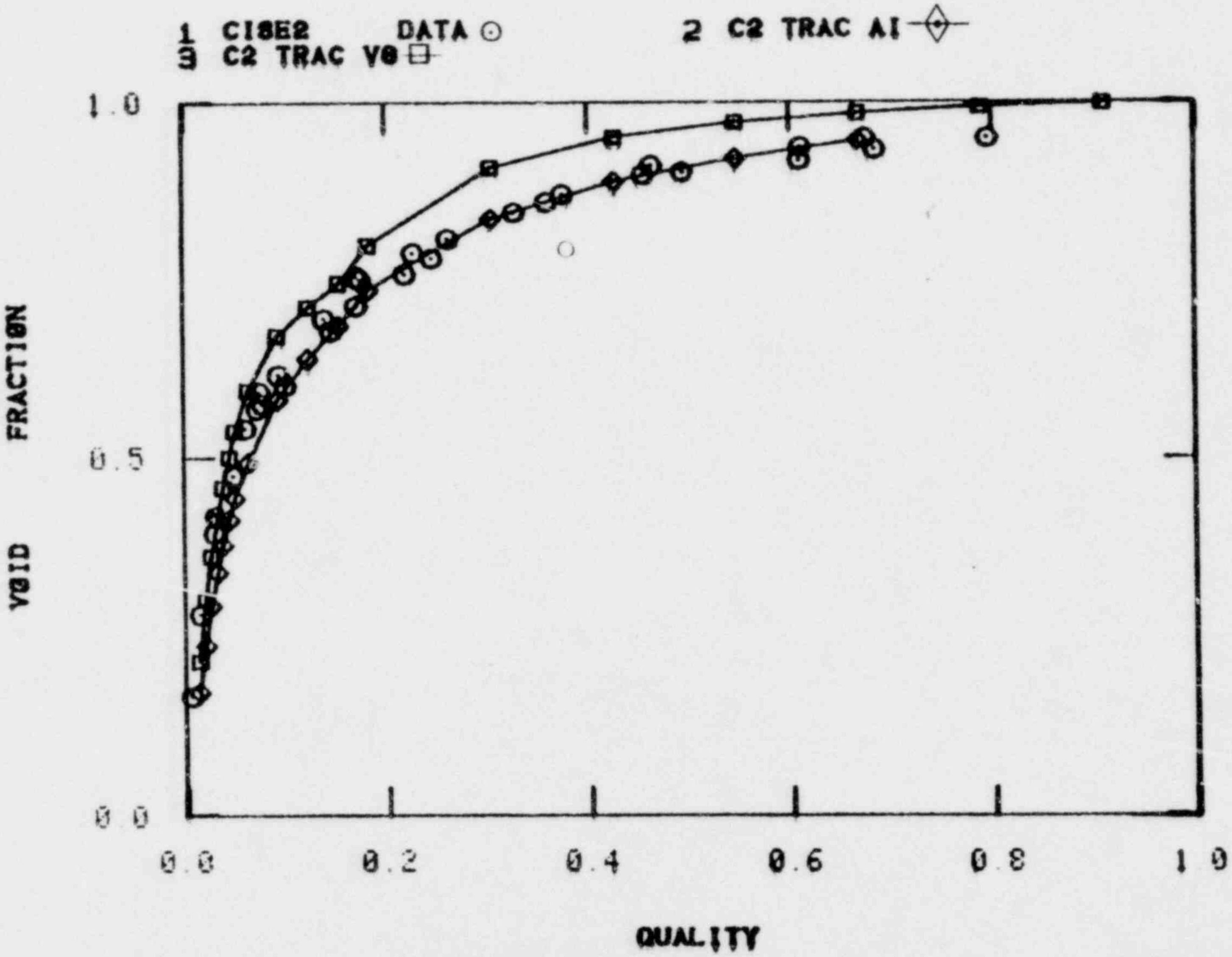

Figure 1. TRAC comparison with CISE Adiabatic tube test (Table 2).

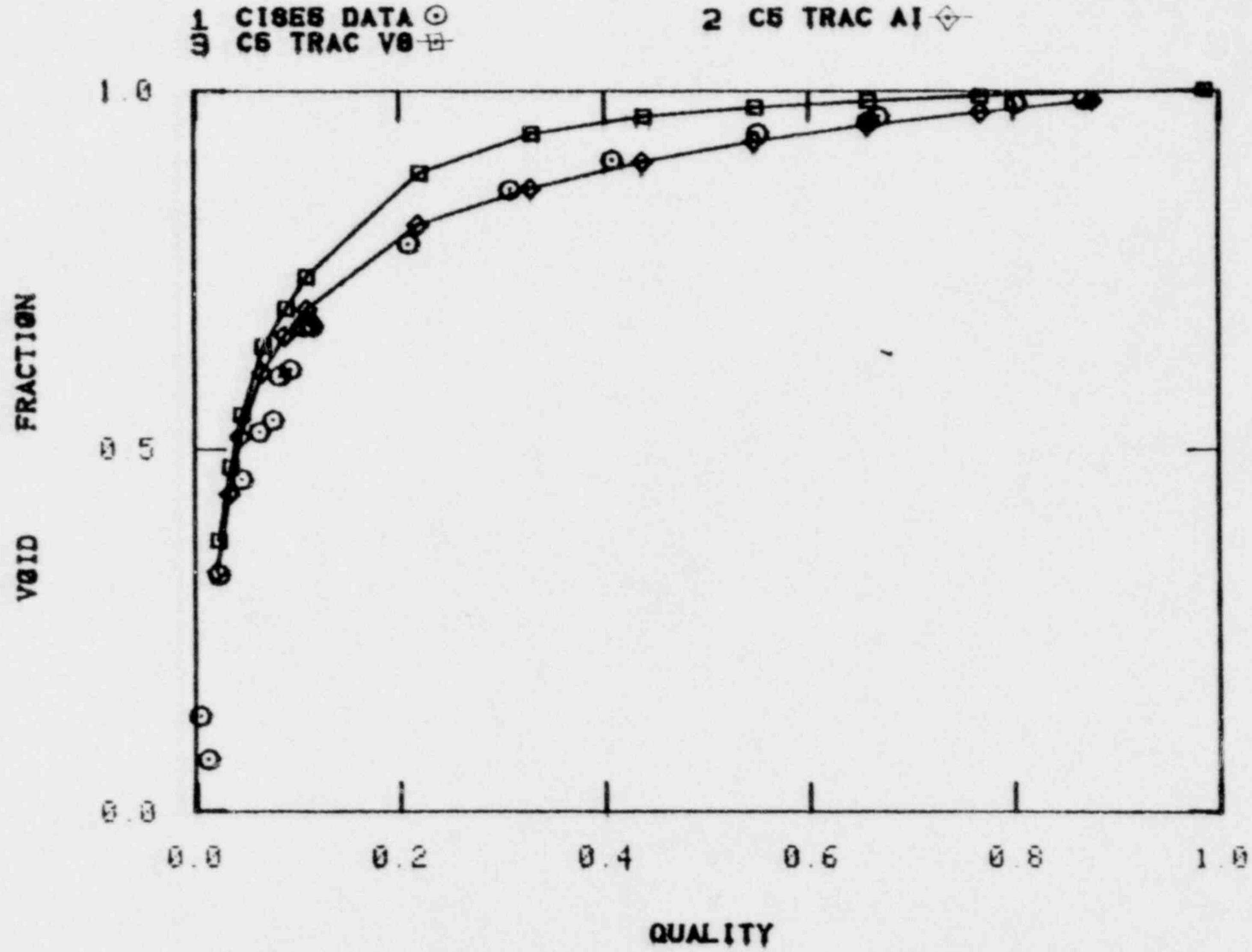

Figure 2. TRAC comparison with CISE Adiabatic tube test (Table 5).

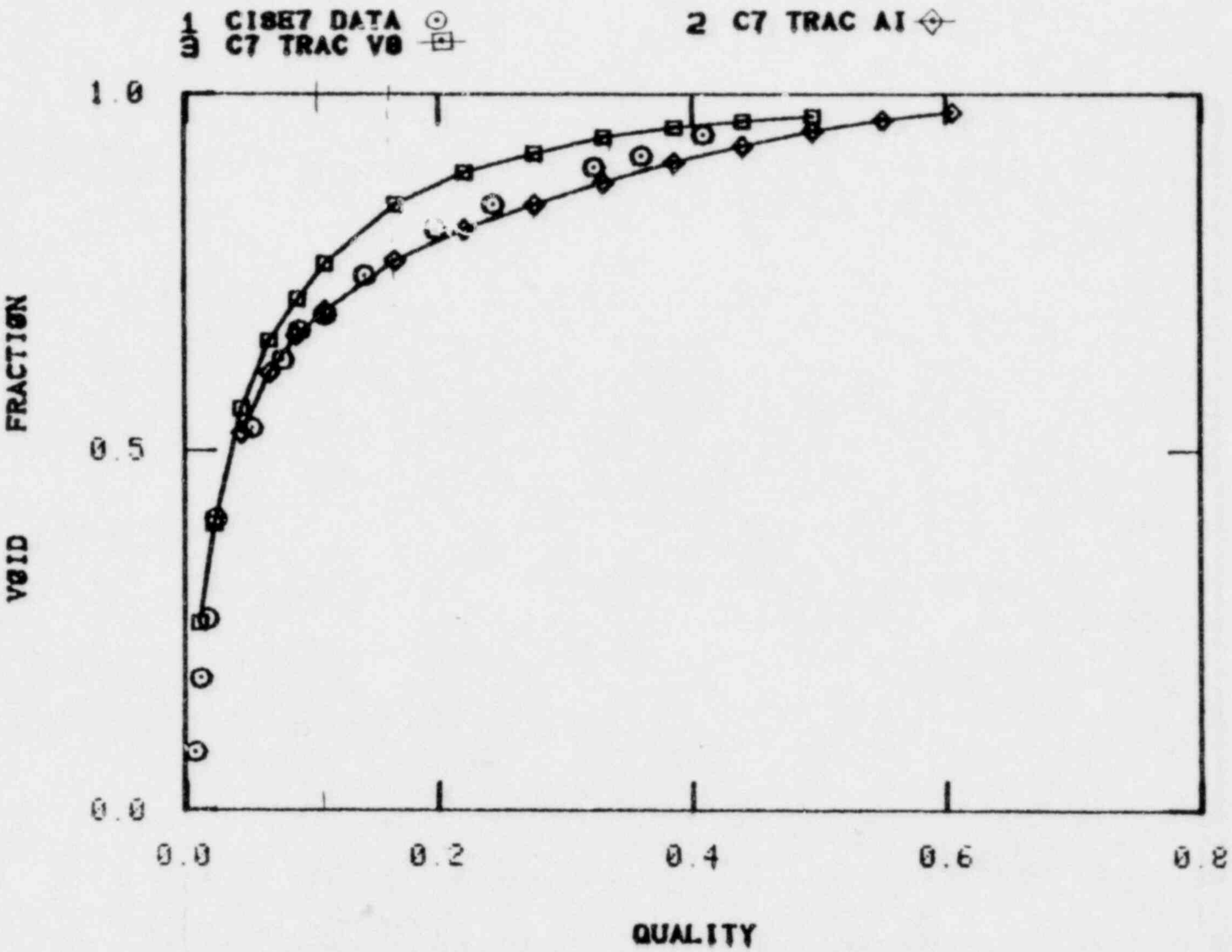

Figure 3. TRAC comparison with CISE Adiabatic test (Table 7).

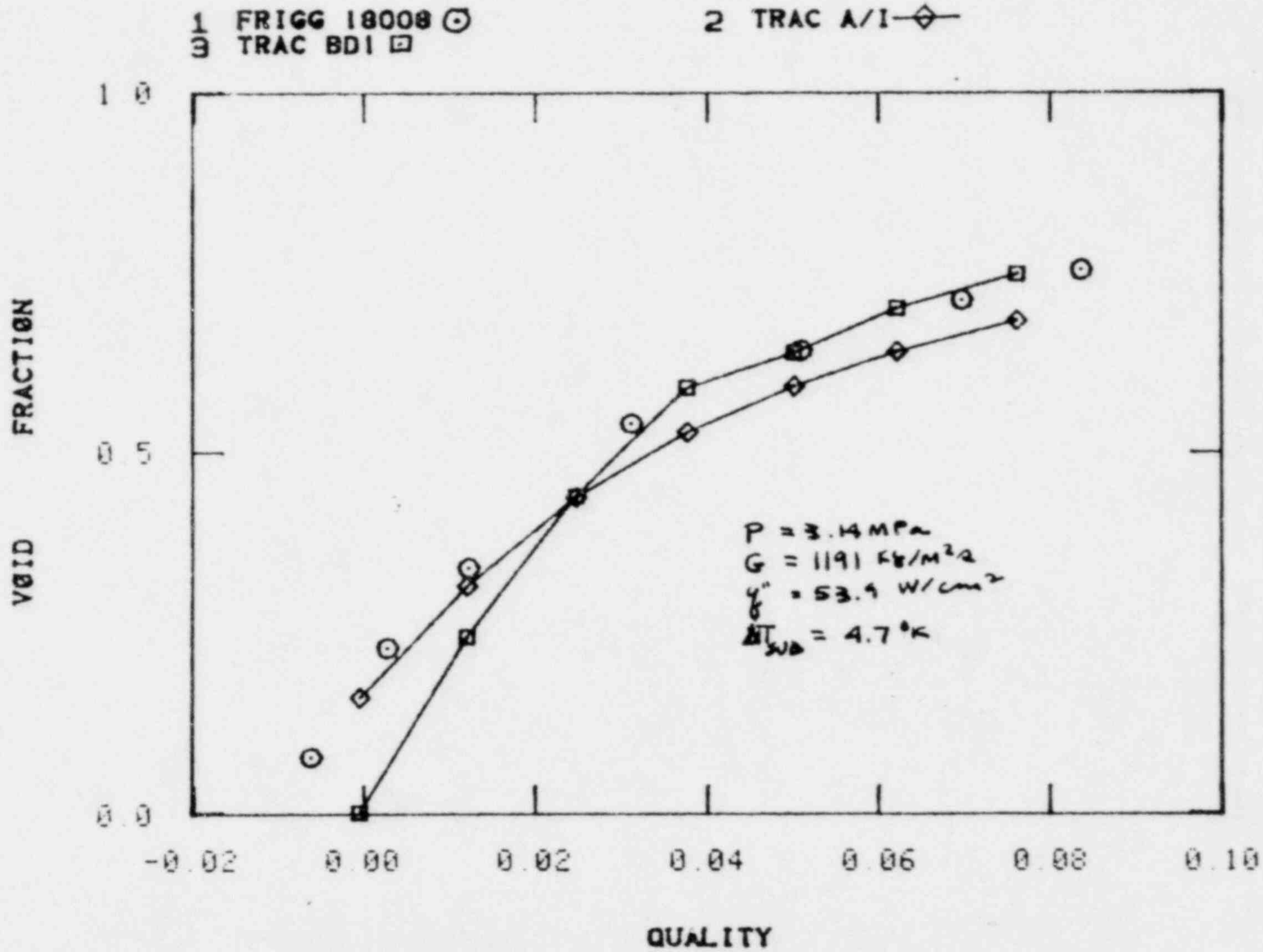

Figure 4. TRAC comparison with FRIGG test 13008.

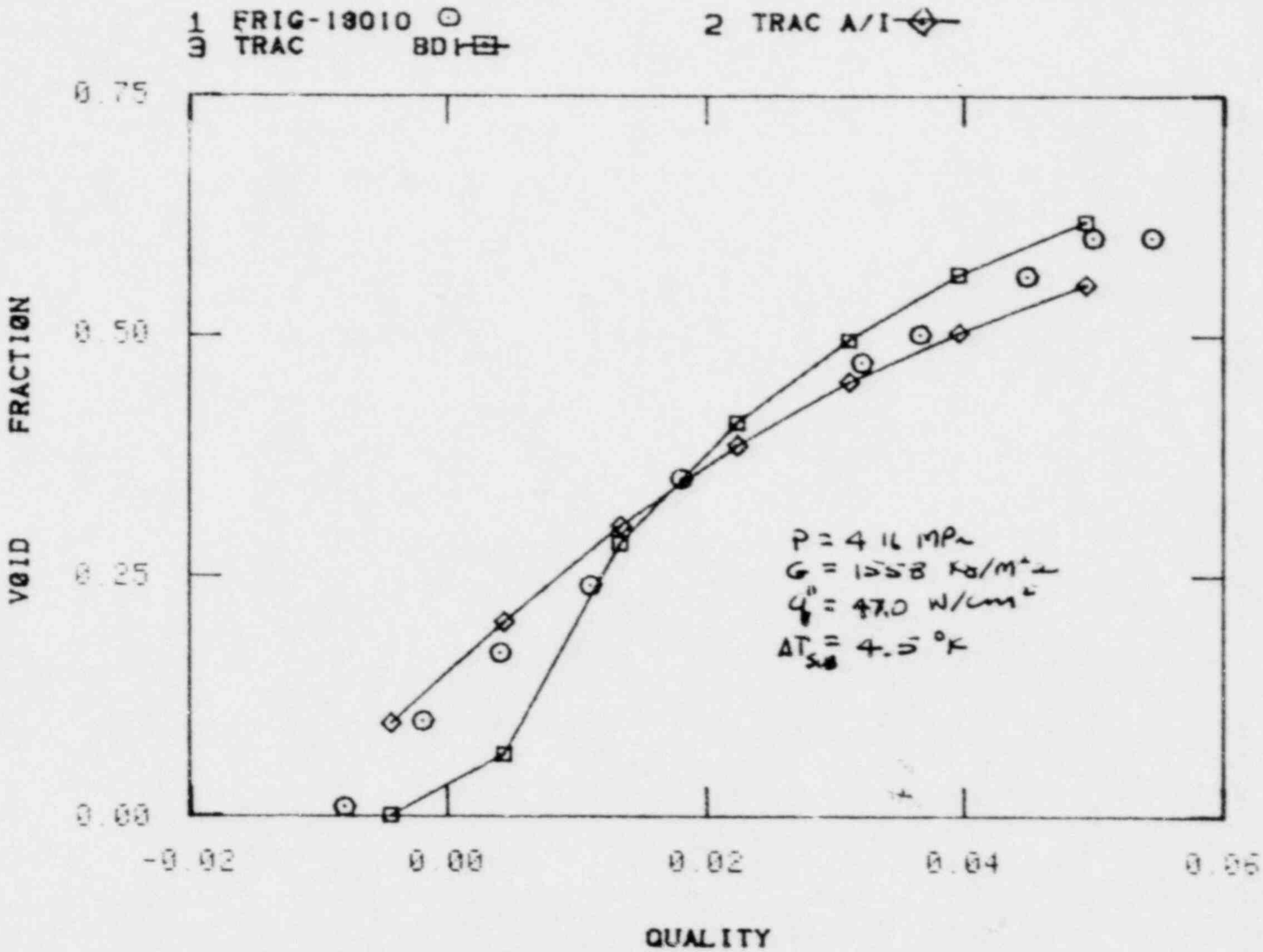

Figure 5. TRAC comparison with FRIGG test 13010.

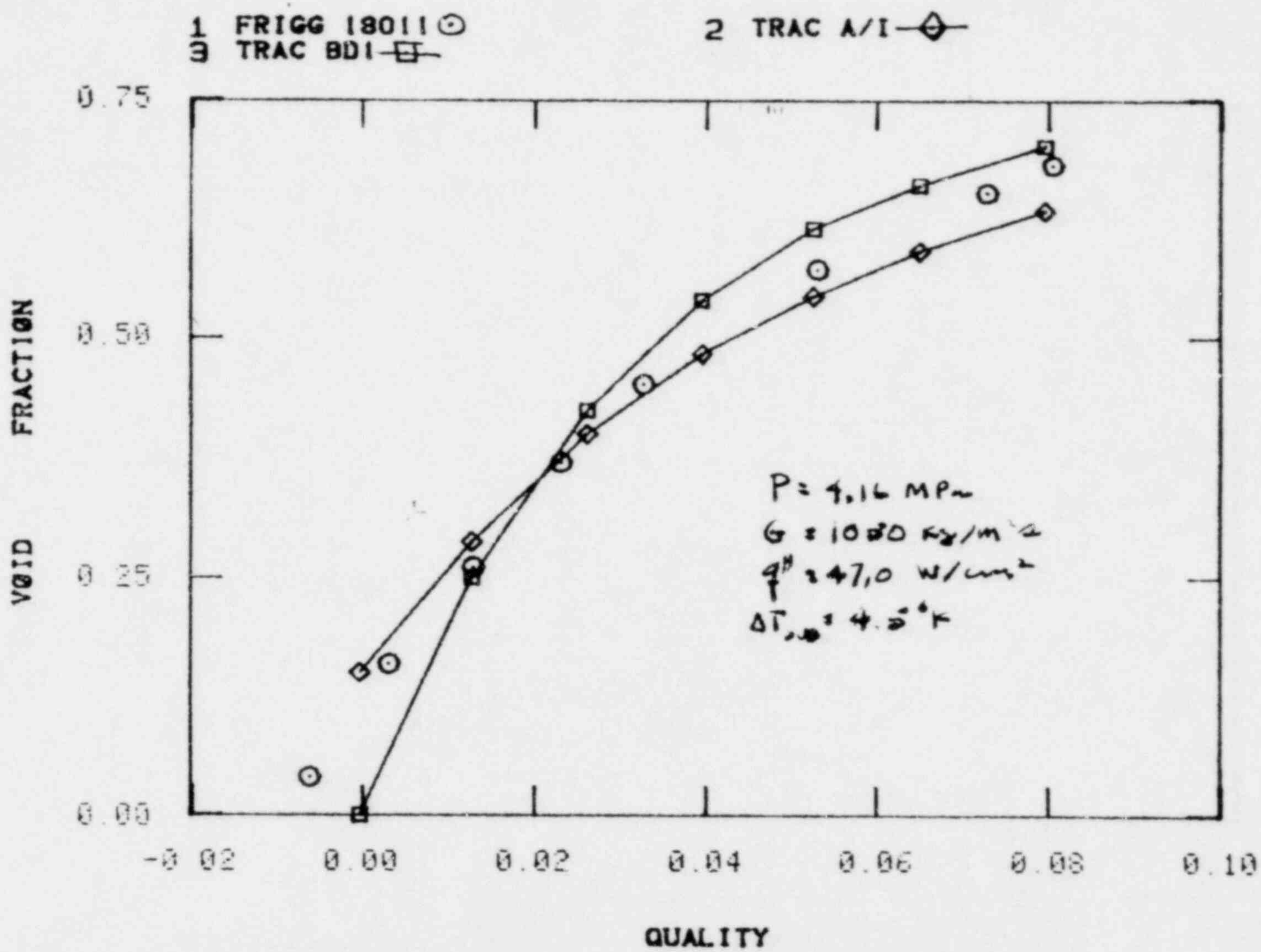

Figure 6. TRAC comparison with FRIGG test 13011.

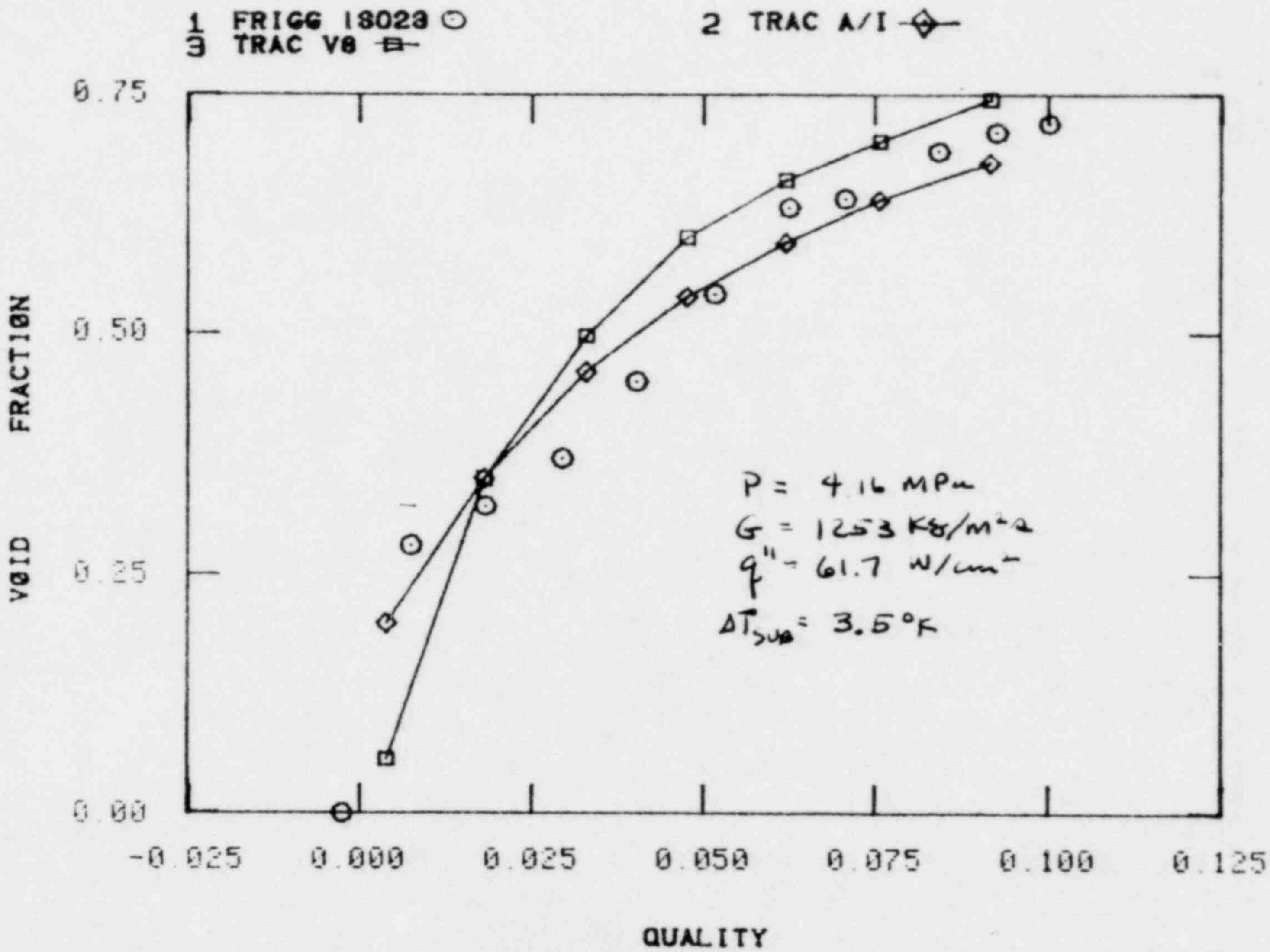

Figure 7. TRAC comparison with FRIGG test 13023.

results due to BD1 are incorrect due to the absence of a subcooled boiling model, which was included in the code version used to test the interfacial package. The tests modeled are 13008, 13010, 13011, and 13023.

The final test case (#5702-16) was run of the GE large vessel level swell tests. The results are shown on Figure 8. No comparison with BD1 results is included since the BD1 calculation showed extreme deviation from the data. This case illustrates a feature noted with this interfacial package in other tests in which it has been used - at high void fractions, the new package tends to overestimate slip (therefore underestimate void fraction). This is not considered a serious deficiency when viewed with the general improvement in behavior.

Microfiche output for three sample runs chosen from the above (one level swell, one FRIGG, one CISE) are included in the Appendix.

The new shear package has also been used in modeling Christenson heated tube void fraction tests and a jet pump sample problem with excellent comparisons to data in both cases.

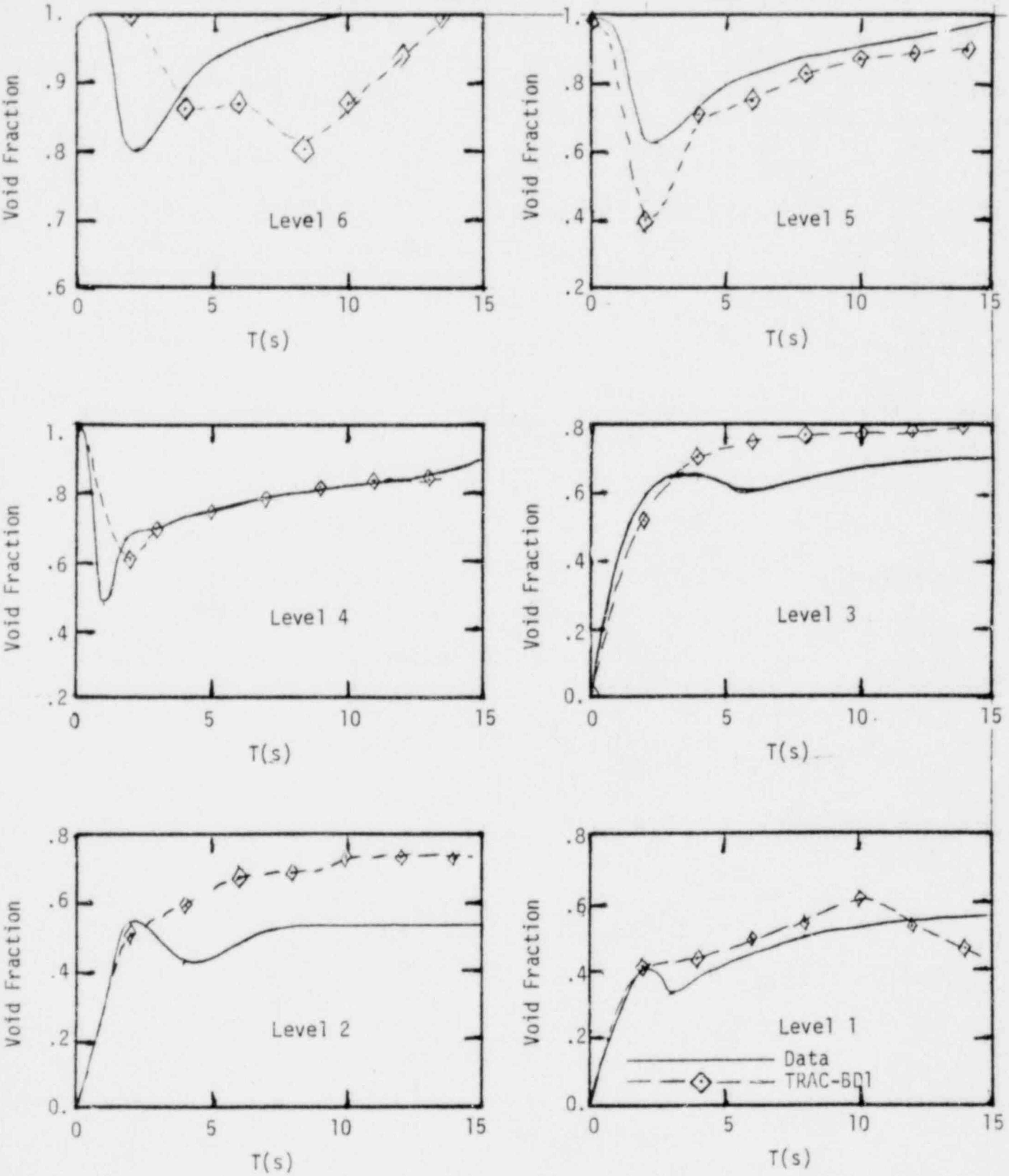

Figure 8. Comparison of TRAC-BD predicted void fraction with GE level swell test 5702-16 at six measurement locations (from bottom).

5. REFERENCES

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APPENDIX

MICROFICHE OUTPUT