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

February 25, 1981

MEMORANDUM FOR: Harold R. Denton, Director
Office of Nuclear Reactor Regulation

FROM: Robert B. Minogue, Director
Office of Nuclear Regulatory Research

SUBJECT: RESEARCH INFORMATION LETTER - #115
INDEPENDENT ASSESSMENT OF TRAC-P1A COMPUTER CODE

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1.0 INTRODUCTION

The Research Information Letter (RIL) No. 92 dated June 1980 described the TRAC-P1A computer code for detailed, best estimate analyses of PWR LOCA. Following the release of this code to the public in mid 1978, RES contracted with three national laboratories to undertake an independent assessment of TRAC-P1A capabilities. Results of their efforts are summarized herein.

The TRAC-P1A code was superseded by the TRAC-PD2 code version when the latter was released to the public in October 1980. Hence, although this information letter describes strengths and weaknesses of the first version of TRAC code, the information here contained will be very valuable in determining whether substantial improvements were made in the subsequent code versions. Independent assessment of the new version (TRAC-PD2) was started in November 1980.

The overall assessment of TRAC will span three to four versions of that code as they are released to the public, starting with TRAC-P1A. Results of hundreds of the integral, separate effects, and basic tests will be utilized over the next 4 to 5 years to quantify the code accuracy. Each new version of TRAC will be subjected to independent assessment utilizing, primarily, new portions of the code assessment matrix, with few repetitions involving those test cases which were poorly predicted with the previous version. RES plans to issue a research information letter describing results of independent assessment of each version of TRAC and RELAP-5 code. The attempt will be made, in each code assessment RIL, to identify the projected code accuracy for LWR application. Reliability of that information will increase with each subsequent RIL as coverage of the assessment matrix increases. The overall code assessment matrix and assessment methodology are described in Reference 1.

2.0 SUMMARY OF RESULTS

The Brookhaven National Laboratory (BNL) provided the bulk of the assessment of TRAC-P1A physical models. As part of this effort, the BNL staff first surveyed the code documentation as well as FORTRAN listings to catalog all physical models, correlations, assumptions and data base. Next, they compared code results against measurements from about 33 "basic tests" selected to illustrate strengths and weaknesses of the adopted models. In some instances, BNL performed sensitivity studies to examine consequences of certain model changes.

In addition, Los Alamos Scientific Laboratory (LASL) staff also performed comparisons of TRAC-P1A results against measurements from several basic tests. Listings of all basic tests utilized in assessment of TRAC-P1A are shown in Table I. Also shown are the laboratory descriptions (where the comparison was made) and overall remarks concerning the code's strong and weak points observed in each comparison.

A listing of about 25 Separate Effects Tests utilized in the assessment of TRAC-P1A is shown in Table II. LASL was responsible for most of the comparisons made in this area.

The nine Integral Systems Tests used in TRAC-P1A assessment are listed in Table III. It can be seen that TRAC-P1A analysis of one of the LOFT tests (L2-3) was performed by both LASL and the Idaho National Engineering Laboratory (INEL). This duplication was undertaken to explore the code user's effect on calculation results. As long as the code user has the liberty to select nodalization (discretization) of the system geometry and several input options, he will impact the code results in some measure; we wished to know how much. One of the major goals in the development of advanced codes was to minimize the user impact.

Finally, INEL was asked to "walk" the code through several challenging PWR LOCA scenarios which the code should be able to handle. They are listed in Table IV.

The detailed description and discussion of all calculations listed in Tables I through IV are given in References 2 through 11.

3.0 OBSERVATIONS

(1) TRAC-P1A can calculate a complete LOCA analysis. Instances of "water packing" have been encountered on various occasions, requiring restarts of calculational segments utilizing smaller time steps.

(2) The code is capable of performing multidimensional analysis of the reactor vessel thermal hydraulics. The results are intuitively correct. Quantification of accuracy of the multidimensional analysis will be made in the future (and with a future version of TRAC) when the required measurements from 2D/3D experiments become available. The code predicted the observed asymmetric refill through the LOFT downcomer. While BNL had difficulties in attempting to calculate the 2D test performed at the Rensselaer Polytechnic Institute (RPI), Sandia staff successfully predicted the jet expansion in the HDR test series.

(3) The six field equation treatment of the vessel hydraulics allows for consideration of the thermal and mechanical non-equillibrium. The physical models dealing with the interfacial transport of mass, momentum, and energy are strongly dependent on the flow regime "map." The latter is based on empirical observations pertinent to steady flows in vertically oriented pipes. While these simplifications appear to be adequate for the bubbly and the dispersed droplets flow regimes, current experience indicates that more sophisticated criteria are needed for the intermediate flow regimes. Such criteria may have to be specialized to different regions of the reactor vessel, to depict global phenomena.

(4) Further improvements are warranted in the models for non-equilibrium vapor generation and condensation, for liquid droplets entrainment and deposition, and for interfacial shear. Modeling of shear between the fluid and the wetted walls and, in particular, between the fluid and the embedded fuel rods, also needs improvement. Better empirical data base is needed to generate an improved model for two-phase flow resistance offered by rod arrays when flows are not purely axial.

(5) Fuel rod quenching treatment in TRAC-P1A is superior to the reflood model in the most recent RELAP code version. Nevertheless, a need for a more mechanistic treatment of the quench front propagation was identified. These improvements were implemented in TRAC-PD2. In addition, treatment of the critical heat flux in TRAC-P1A does not differentiate between the departure from nucleate boiling (DNB) and the burnout or dryout.

(6) Heat conduction within solids, other than the fuel rods, is calculated with a lumped parameter model. Finer radial or lateral discretization is necessary to handle hot wall effects which play an important role in the small-scale test facilities.

(7) A one-dimensional, five-field equation drift flux model, with full thermal non-equillibrium, is used in solving the transient two-phase flow within system components residing outside the reactor vessel. This includes piping, pressurizer, steam generator, ECC accumulator, and valves.

The difference between the vapor and the liquid velocities is prescribed through a constitutive relationship which is a function of the local flow regime.

Inadequate empirical knowledge exists for specification of this so called relative velocity for situations in which the vapor and the liquid flow in opposite directions. Such situations arise in certain small-break scenarios within the U-tube steam generator primary tubing and within the hot leg. The code does not adequately handle the flow regimes in horizontal piping when the fluid velocities are low enough to cause phase separation.

Inability to handle phase separation in horizontal pipes and countercurrent flow in one-dimensional flow paths greatly limits the code ability to handle those small-break LOCA scenarios where these processes play an important role.

(8) Treatment of the steam generator (S.G.) secondary side needs refinement in handling the liquid separation, its downflow and thermal mixing with the upcoming feed flow. More accurate tracking of the S.G. liquid level is also needed, and the ability to model the relief and the isolation valves.

Improvements are also required in the treatment of heat exchange between the primary and the secondary sides in the presence of vapor condensation.

(9) The critical flow through (pipe) breaks and through relief valves is handled in a mechanistic manner. This, however, requires very detailed spatial discretization near the break. Fully implicit numerical solution technique is employed for these regions to avoid the use of very small time steps. While this procedure appears adequate for analyses of large and intermediate break sizes, it still presents a calculational burden which has a detrimental effect on the code running time for very small-break sizes. The code was not able to predict accurately the critical flow of highly subcooled liquid in some of the Marviken experiments. The BNL sensitivity studies indicate that the main cause is the mass exchange model which appears to exaggerate the local vapor production rate. BNL also recommends introduction of the nucleation delay model.

(10) The code also suffers from inadequate mass conservation. While its effect is not important in large-break LOCA analyses, it becomes very detrimental in small-break LOCA analyses.

Some numerical diffusion was also observed, as in every other code that employs the Eulerian fram of reference (e.g., RELAP5, COBRA, etc.).

(11) Improvements are needed in describing the fuel behavior--clad ballooning, gap conductance, thermal conductivity in fuel pellets, etc.

CONCLUSION:

The TRAC-P1A code has shown a capability to address many and diverse transients involving both single and two-phase fluids. This was the first code capable of multidimensional treatment of the reactor vessel, within the context of the integral system analysis.

In the course of a rather extensive independent assessment of the publicly released version of that code, many weak points were indentified and communicated to the code developers. The development of the new version of TRAC (TRAC-PD2) has greatly benefited from these findings, and attempts were made to remove as many of the identified weaknesses as possible. We are told that TRAC-PD2 is a much more reliable, economical, and accurate code as compared to its predecessor. Validity of these claims will be carefully examined in the course of TRAC-PD2 assessment currently underway.

Information on the predictive capabilities of the TRAC-PIA code reported in this Research Information Letter provides a reference for gauging the progress made with future versions of TRAC. Figure 1 illustrates the uncertainty in the TRAC-P1A prediction of the peak clad temperature (PCT) for the integral systems tests addressed in this assessment, as a function of the test facility scale. Extrapolation to full scale provides a very rough guidance regarding the uncertainty in the prediction of PCT for LOCA in PWR plants. Reliability of this type of information will improve as more cases are addressed in the assessment of future code versions.

TRAC-P1A represents the first version of an advanced systems code. "Teething" problems were, therefore, fully expected and so is their removal, as the maturation process sets in.

Nevertheless, the TRAC code was found to be not only adequate but also essential for the large break LOCA analyses for PWR's, primarily due to strong multidimensional effects observed in some of the cases listed in Table IV. At the same time, and for the reasons given under items (7) through (10) in the preceding section, the TRAC-P1A code is not recommended for application to analysis of the small break LOCA, or for other transients of long duration. For large break PWR LOCA best estimate analysis TRAC-P1A is definitely superior to RELAP-4/MOD 7.

OEBassett

for Robert B. Minogue, Director
Office of Nuclear Regulatory Research

Enclosures:
1. Table I-Basic Tests
2. Table II-Separate Effects Tests
3. Table III-Integral Systems Tests
4. Table IV-PWR LOCA Analyses
5. Figure 1-Diff. Betw. the Pred. and the Meas. Peak Clad Temp. as Func. of Test Facil. Scale
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RECORD NOTE: Walt Jensen (NRR) indicated that he has no objections to issuance of this RIL - February 3, 1981.

*SEE PREVIOUS CONCURRENCES

OFFICE	WRSR:ADB*	WRSR:ADB*	WRSR*	RSR*	RES*	RES*	RES*
SURNAME	SFabic:md	FOdar	CJohnson/ HSullivan	LShao	JLarkins	RBMinogue	OEBassett
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(11) Improvements are needed in describing the fuel behavior; clad ballooning, gap conductance, thermal conductivity in fuel pellets, etc.

CONCLUSION:

The TRAC-PIA code has shown a capability to address many and diverse transients involving both single and two-phase fluids. This was the first code capable of multi-dimensional treatment of the reactor vessel, within the context of the integral system analysis.

In the course of a rather extensive independent assessment of the publicly released version of that code, many weak points were indentified and communicated to the code developers. The development of the new version of TRAC (TRAC-PD2) has greatly benefited from these findings and attempts were made to remove as many of the identified weaknesses as possible. We are told that TRAC-PD2 is a much more reliable, economical, and accurate code as compared to its predecessor. Validity of these claims will be carefully examined in the course of TRAC-PD2 assessment currently underway.

Information on the predictive capabilities of the TRAC-PIA code reported in this Research Information Letter provides a reference for gauging the progress made with future versions of TRAC. Figure 1 illustrates the uncertainty in the TRAC-PIA prediction of the peak clad temperature (PCT) for the integral systems tests addressed in this assessment, as a function of the test facility scale. Extrapolation to full-scale provides a very rough guidance regarding the uncertainty in the prediction of PCT for LOCA in PWR plants. Reliability of this type of information will improve as more cases are addressed in the assessment of future code versions.

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TABLE I - BASIC TESTS

TEST CASE	Contractor Performing Analysis	Summary of Findings	
		Code Strengths	Code Weaknesses
I. Critical & Subcritical Flows			
A. Moby-Dick (Steady-State, Air-Water, Critical Flow)	BNL		
1. Zero Quality (subcritical)		Pressure drop	Flow rate is sensitive to friction factor option.
2. Low-intermediate Qualities (5 test conditions)		Pressure drop - Void fraction	Not a smooth steady-state and flow.
3. High Quality			No convergence to a steady-state.
B. Moby-Dick (Steady-State, Steam-Water, critical flow)	BNL		No convergence to a steady-rate.
C. KFK - IRE (Steady-State, critical flow)	BNL		
1. Cold Water (subcritical)		Accurate pressure drop and flow rate with homogeneous friction option.	
2. Air-Water			Agreement of pressure flow rate and vapor fraction, with test data is below expectation.
3. Steam-Water		Vapor fraction calculation is good.	Prediction of pressure and flow rate below expectation.

Table I - Page 2

TEST CASE	Contractor Performing Analysis	Summary of Findings	
		Code Strengths	Code Weaknesses
D. BNL Nozzle Tests (Steady-State) 1 run subcritical 3 runs critical	BNL	Good agreement of pressure, void friction and flow rates with that measured at high flow rates.	Under-prediction of mass flow rate for subcooled inlet conditions. Poor agreement with pressure at low flow rates.
E. Canon Test (transient, blowdown) (4 test conditions)	BNL	Good prediction of pressure until 20 ms.	Overprediction of vapor fraction. Poor predictions of pressures after 20 ms.
F. Super Canon Test (transient, blowdown) (4 test conditions)	BNL	Reasonable prediction of vapor fraction.	Poor prediction of pressure during the entire transient.
G. Edwards Test (transient, blowdown)	LASL	Reasonable predictions of pressure and temperature.	Required additive friction factor.
H. CISE TEST (transient, blowdown with area changes, wall heat transfer, and gravitational effects)	LASL		
1. Unheated		Good prediction of pressure, temperature and mass inventory.	
2. Heated			Prediction of pressure and temperatures below expectation.

TEST CASE	Contractor Performing Analysis	Summary of Findings	
		Code Strengths	Code Weaknesses
II. Counter-Current Flow			
A. University of Houston	BNL		Constitutive relationships do not permit calculation of counter-current flow in a pipe component in churn-turbulent and annular flow regimes.
B. Dartmouth	LASL		Same comment as above. Possibly due to inappropriate nodalization of the upper plenum.
III. Multi-dimensional Steady-State Tests			
A. RPI, 2-D Phase Separation Tests (8 test conditions)	BNL		Code either failed to converge or stopped, stating indefinite or overflow conditions.
B. FRIGG Rod Bundle Test	BNL		Code failed to converge.

TABLE II - SEPARATE EFFECTS TESTS

TEST CASE	Contractor Performing Analysis	Summary of Findings: Code Strengths	Summary of Findings: Code Weaknesses
I. Marviken Tests (Full-scale Vessel Blow-down) (16 test conditions)	BNL & LASL	Reasonably successful predictions of critical flow rates for saturated inlet conditions.	Underprediction of critical flow rates for subcooled inlet conditions. This becomes more pronounced for nozzles with small length-to-diameter ratio.
II. Battelle-Frankfurt (Int. Std. Problem-Top Blowdown)	BNL & LASL		Prediction of critical flow rate for steam and two-phase steam-water wer not as good as expected. Possible experimental errors. Numerical diffusion observed.
III. Semiscal 1-1/2 loop Isothermal Blowdown (Test 1011, Std. Prob. 2)	LASL	Hot leg break flow rate, system pressure and temperatures are well predicted.	Prediction of cold leg break flow rate below expectation.
IV. Semiscale Mod-1 Heated Loop Blowdown (Test S-02-8)	LASL	Reasonable predictions of pressure, break flow rates and loop mass flow rates.	Premature CHF.
V. Crease Counter-Current Flow Test (Counter-current flow, ECC bypass and penetration, 4 subcases run)	LASL	Good predictions of ECC bypass and penetration using the vessel module.	
VI. FLECHT Reflood Tests (forced-bottom-flooding, reflood heat transfer, quenching and liquid entrainment) (3 test conditions)	LASL	Good predictions of clad temperatures for high flooding rate.	Poor prediction of turnaround time, quench time and quench temperatures for low flooding rates.

TABLE III - INTEGRAL SYSTEMS TESTS

TEST CASE	Contractor Performing Analysis	Summary of Findings	
		Code Strengths	Code Weaknesses
I. Semiscale Mod-3 (Large Break LOCA Test, Test S-07-6)	LASL	Reasonable agreement with test data during the blowdown.	Poor agreement during refill and and reflood, due to combination of code weakness in calculating downcomer penetration, reflood heat transfer, liquid entrainment and uncertainties in downcomer metal heat transfer.
II. Semiscale Mod-1 (Large Break LOCA Test, Test S-04-6)	INEL	Adequate prediction of clad temperature when CHF was calculated correctly.	Prediction of mass flows including break flow rates, pressures, densities, and fluid temperatures below expectation. Poor prediction of refill.
III. LOBI A1-04 (Blind, pre-test prediction, virgin test facility)	LASL	Accurate prediction of peak clad temperature. Accurate predictions of CHF at different elevations.	Prediction of pressures, fluid temperatures and mass flow rates below expectation.
IV. LOFT L1-4 (Isothermal blowdown with delayed ECC injection)	LASL	Good predictions of mass flow rates, fluid temperatures, densities, pressures and vessel liquid mass. Good representation of integral effects during the blowdown and refill phases.	
LOFT L1-5 (Isothermal blowdown)	LASL	Good predictions of system pressure and densities.	Calculated liquid inventory in the core is lower than that in the test.
LOFT L2-2 (Large break LOCA Test, 50% power)	LASL	Good prediction of system pressure, temperatures, ECC behavior and cladding temperatures at peripheral rods including rewet behavior.	Poor agreement in calculating rewet in high powered region. However, there is uncertainty in measurement of clad temperatures due to fin

Table III - Page 2

TEST CASE	Contractor Performing Analysis	Summary of Findings	
		Code Strengths	Code Weaknesses
LOFT L2-2 (continued)			effects which could also be responsible for overprediction of peak clad temperature in high powered region. Underprediction of critical flow in subcooled inlet conditions.
LOFT L2-3 (Large break LOCA Test, 75% power)	LASL	Reasonable prediction of system pressure, temperatures, ECC behavior and cladding temperatures at peripheral rods including rewet behavior.	Same weaknesses as in L2-2
LOFT L2-3 (Large Break LOCA Test, 75% power)	INEL	Reasonably good agreement with experimental data early in the transient.	Failed to predict positive core inlet flow early during the LOCA and consequently failed to predict rewet. Predictions of break flow rates, pressures, pressure differentials, densities, and clad temperatures below expectation.
LOFT L3-0 (Isothermal blowdown through PORV)	LASL		Inaccurate calculation of mass conservation. Accuracy of predictions of all parameters also suffered from uncertainties in internal vessel leakage (downcomer to upper plenum) and in additive system leakage beyond flow.
LOFT L3-1 (Small Break LOCA Test, 100% power)	LASL		Same weaknesses as in L3-0

TABLE IV - PWR LOCA ANLAYSES

LOCA Scenario	Qualitative Assessment of Code Performance and of Results
1. Large Cold Leg Break (200%)	Satisfactory and reasonable.
2. Intermediate Cold Leg Break (0.25m-diameter)	Satisfactory and reasonable.
3. Small Cold Leg Break (0.10m-diameter)	Results not reasonable.
4. Large Cold Leg Break with rupture of steam generator tube(s) (Two cases, one with small and the other with large number of tubes)	Satisfactory and reasonable. Important 3-D effects observed in results.
5. Large Hot Leg Break (200%)	Satisfactory and reasonable.
6. Large Hot Leg Break with rupture of 16 steam generator tubes	Satisfactory and reasonable.

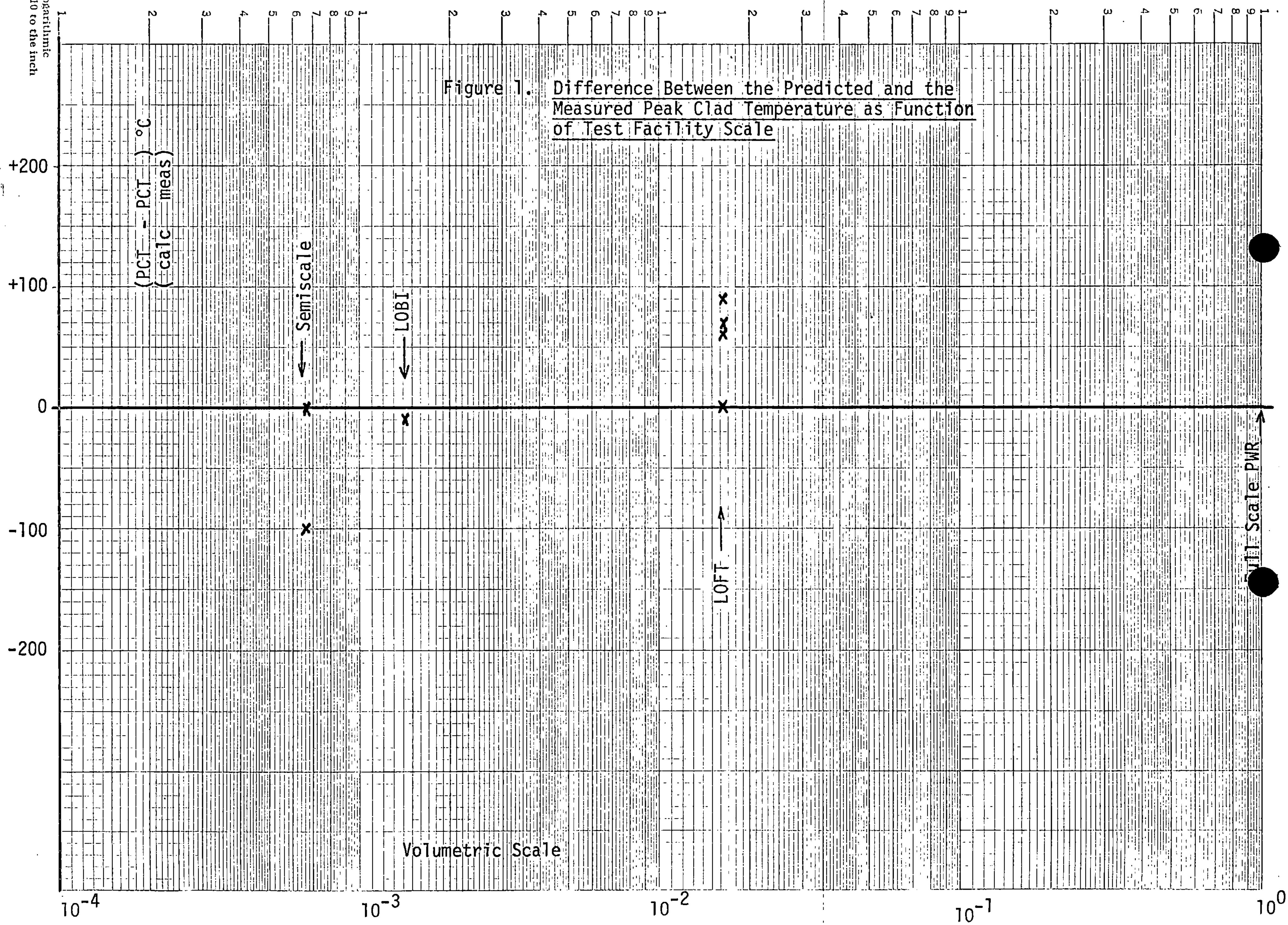

Figure 1. Difference Between the Predicted and the Measured Peak Clad Temperature as Function of Test Facility Scale

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