FRAP-T5 MODEL IMPROVEMENTS AND UNCERTAINTY ANALYSIS CAPABILITIES

Presented at

The Seventh Water Reactor Safety Research Information Meeting

November 5-9, 1979

Gaithersburg, Maryland

Dr. Michael P. Bohn

EG&G. Idaho, Inc.
Idaho National Engineering Laboratory
Idaho Falls, Idaho 83401

FRAP-T5 MODEL IMPROVEMENTS AND UNCERTAINTY ANALYSIS CAPABILITY

Dr. Michael P. Bohn
EG&G Idaho, Inc.

To accurately predict the performance of light-water reactors (LWRs) under hypothesized accident conditions, the NRC has sponsored an extensive program of analytical computer code development as well as both in-pile and out-of-pile experiments against which to demonstrate and assess the analytical code development. The computer code being developed for the transient response of a single fuel rod is the Fuel Rod Analysis Program-Transient (FRAP-T). This summary briefly describes FRAP-T5, which is the fifth in a series of code versions released at approximately one year intervals.(1)

FRAP-T5 predicts the transient behavior of LWR fuel rods during any hypothesized accident ranging from mild operational transients to design basis accidents such as the loss-of-coolant accident and the reactivity initiated accident. A major improvement over previous versions of the code is the incorporation of an automated uncertainty analysis option. When specified by user input, FRAP-T5 calculates the uncertainties in the predicted fuel rod variables due to uncertainties in material properties, power, and cooling. The uncertainty calculations are based on the Response Surface Method. No additional analysis is required on the part of the code user to use this option, and only minimal additional input is required.

FRAP-T5 has a number of major model improvements over the previous version, FRAP-T4. In particular, a set of coupled fuel creep, hot pressing, and relocation models has been included to accurately calculate the response of fuel rods during cyclic operation. A model for the calculation of rod-to-shroud heat transfer has been incorporated in order to more accurately calculate the experimental results obtained in the NRC sponsored Power Burst Facility. A model for a plenum at the bottom of a fuel rod has also been incorporated so that comparisons with German experimental data

1605 192

can be made. The heat transfer package has been completed by incorporation of a reflood cooling model based on the FLECHT data so that, if necessary, fuel rod calculations can be performed for an entire transient sequence, including rewetting. Finally, the calculational scheme has been optimized by use of a new simultaneous strain and strain-rate solution scheme.

The material property and failure models have been updated and improved in FRAP-T5. In particular, an improved fission gas release model has been provided which more accurately accounts for high temperature fission gas release and, in addition, includes the NRC recommended enhanced fission gas release at high burnup. The calculation of cladding material properties has been significantly improved by the modeling of oxygen diffusion into the cladding. In addition, time-dependent annealing of cladding mechanical properties has also been incorporated. Finally, a model for the effect of circumferential temperature gradients on failure strains (based on German data) has been incorporated to more accurately predict failure strain at the occurrence of ballooning.

The utility of the FRAP code has been significantly enhanced by completion of a fully interactive link between FRAP-T5 and the RELAP4/MOD7 code. In this interactive scheme, all conduction calculations are performed by RELAP, while FRAP computes cladding deformation, gas gap, internal pressure, and rod failure. By use of different time steps for the conduction calculations and for the fuel rod response calculations, a high degree of efficiency is obtained.

Together, these models provide a significant improvement in the calculational capability of FRAP-T5 over FRAP-T4. These improvements have been demonstrated by comparison with a number of sets of experimental data.

1605 193

REFERENCES

1. L. J. Siefken et al, FRAP-T5, A Computer Code for the Transient Analysis of Oxide Fuel Rods, NUREG/CR-0840 TREE-1281 (June 1979).

FRAP-T5
Model Improvements and Uncertainty Analysis Capabilities

Presented by
Dr. Michael P. Bohn

EG&G Idaho, Inc.

1605 195

The FRAP Codes

- Modular in construction
- Use common material property subcode MATPRO
- Are subject to extensive independent verification prior to release
- Each released version fully documented

With {
Model description and users manual
MATPRO document
Verification document

INEL-S-21 823

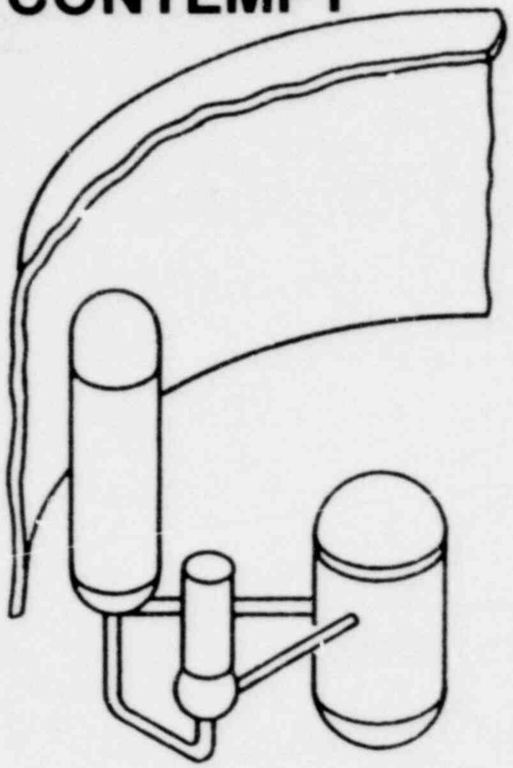
Safety Analysis Codes

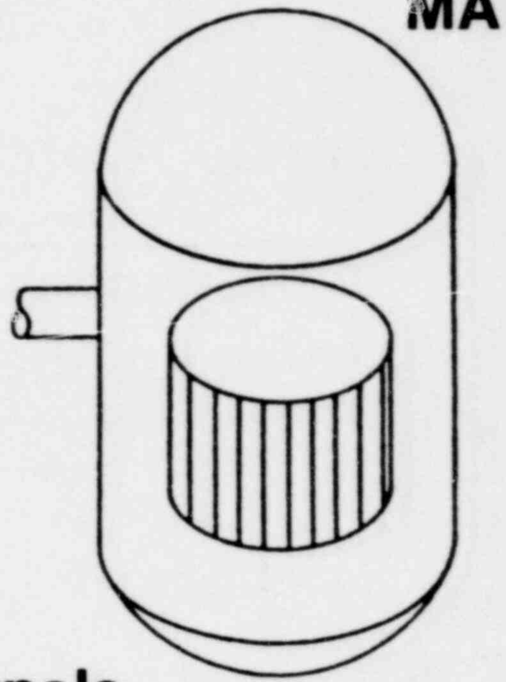
Containment

BEACON
CONTEMPT

Fuel rods

FRAPCON
FRAP-T
MATPRO

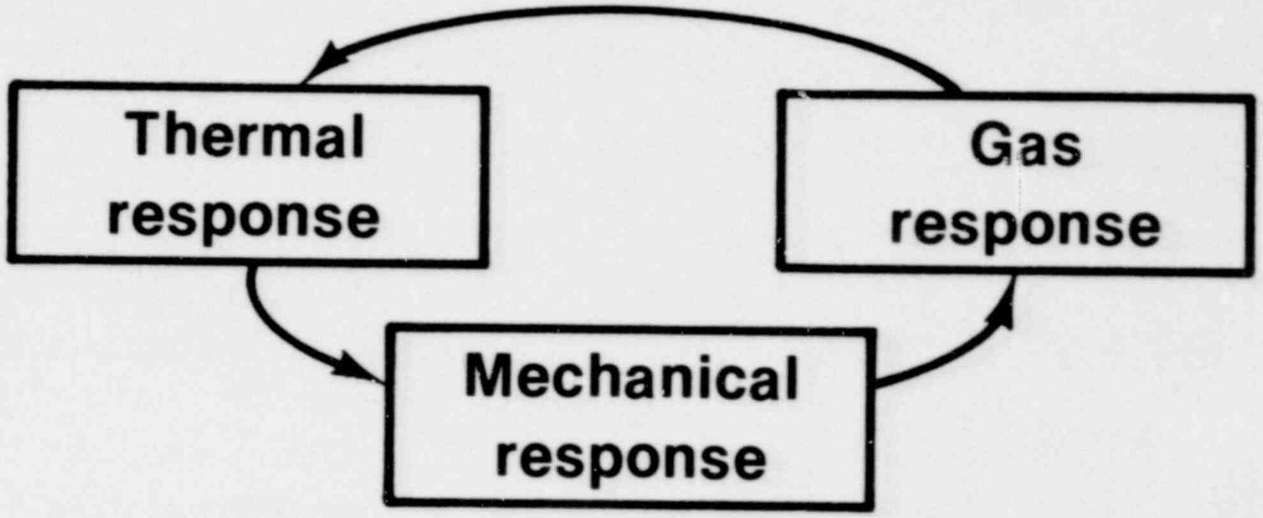




Loop, Vessel and Internals

RELAP4
RELAP5

The FRAP Codes



Both codes use two iteration loops to converge simultaneously on

- Temperature distribution in fuel and clad
- Fuel and clad deformation
- Gas inventory inside fuel rod

Major Model Improvements in FRAP-T5

- Interactive creep, hot pressing and relocation models
- New simulataneous strain and strain-rate scheme
- FLECHT–based reflood cooling model
- Fully-interactive link with RELAP4/MOD7
- Rod to shroud radiation model
- Bottom plenum model
- Automated uncertainty analysis capability

INEL-S-21 816

Major Material Property and Failure Improvements in FRAP-T5

- Improved fission gas release model
- Modeling of oxygen diffusion into cladding
- Time-dependent annealing of cladding mechanical properties
- Model for effect of circumferential temperature gradients on failure strains

Fuel Hot Pressing Model

$$\dot{V}^c = -A\sigma_m^{4.5}\,(V^c + V\mathrm{reloc})\,\mathrm{Exp}\,(-15800/T)$$

V^c = Rate of volumetric strain (1/s)

A = 3.64×10^{-18}

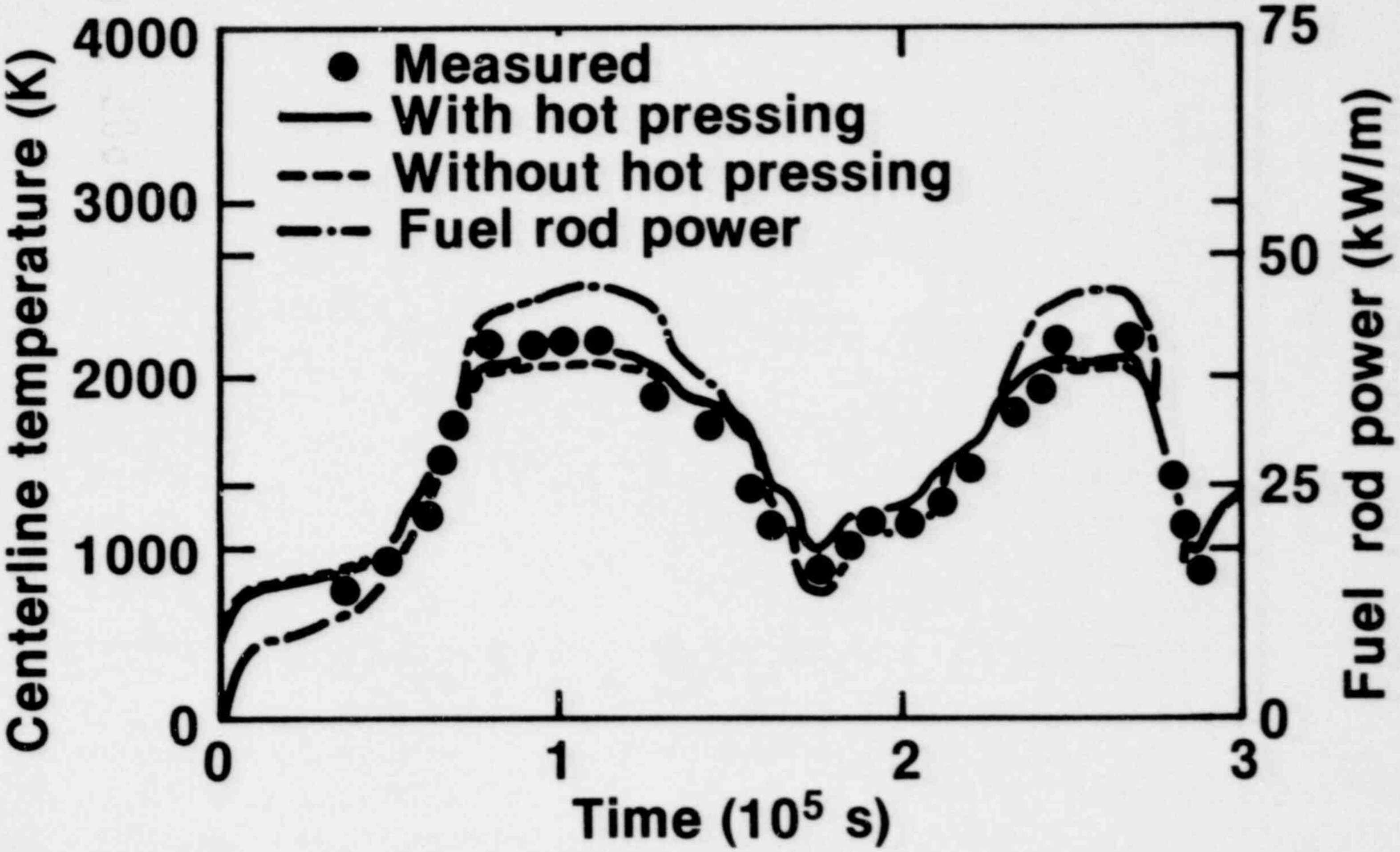
σ_m = Mean stress (N/m^2)

V^c = Volumetric strain

T = Temperature (K)

INEL-S-21 818

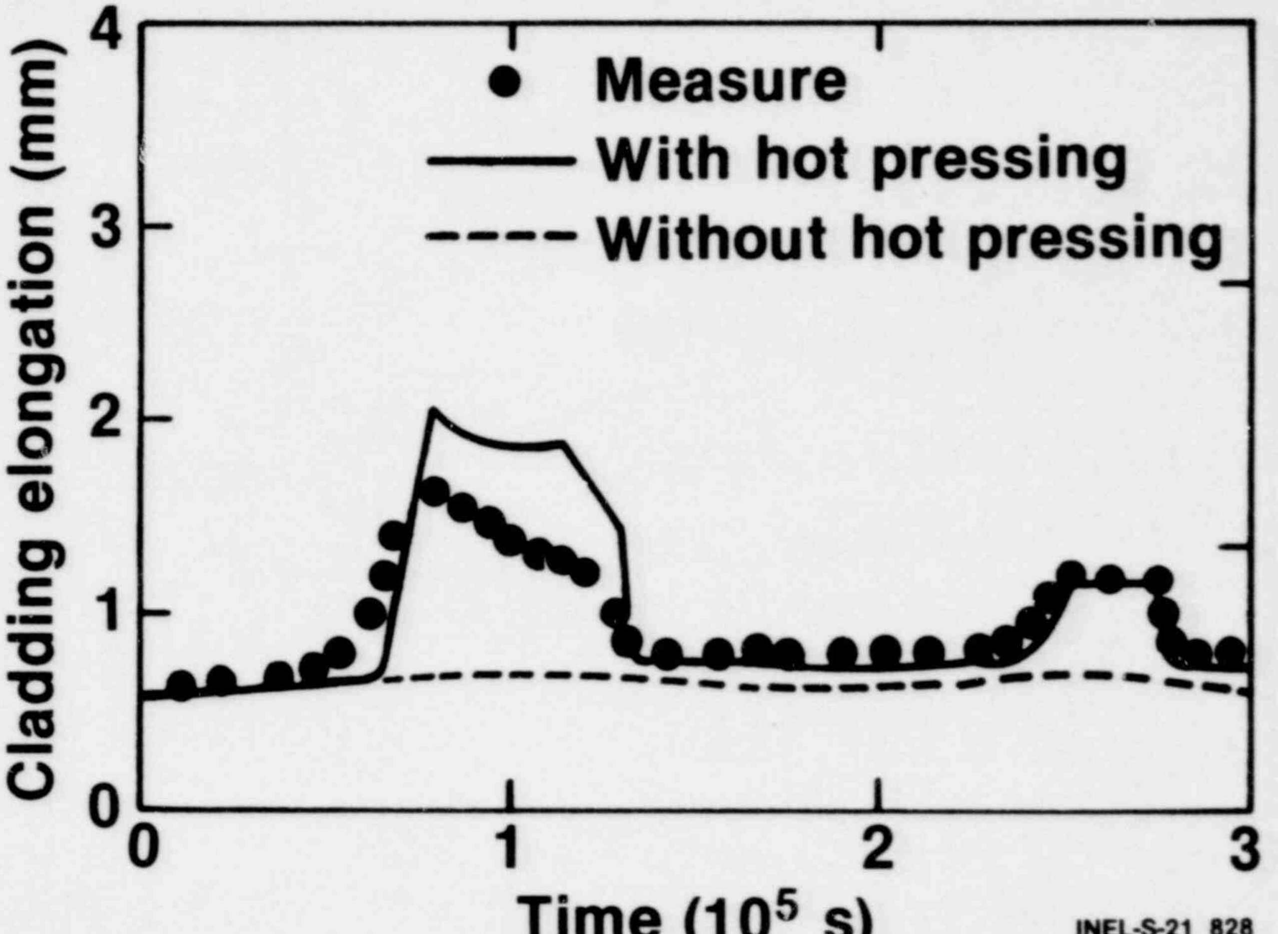
FRAP-T5 Calculation of IFA-226



INEL-S-21 811

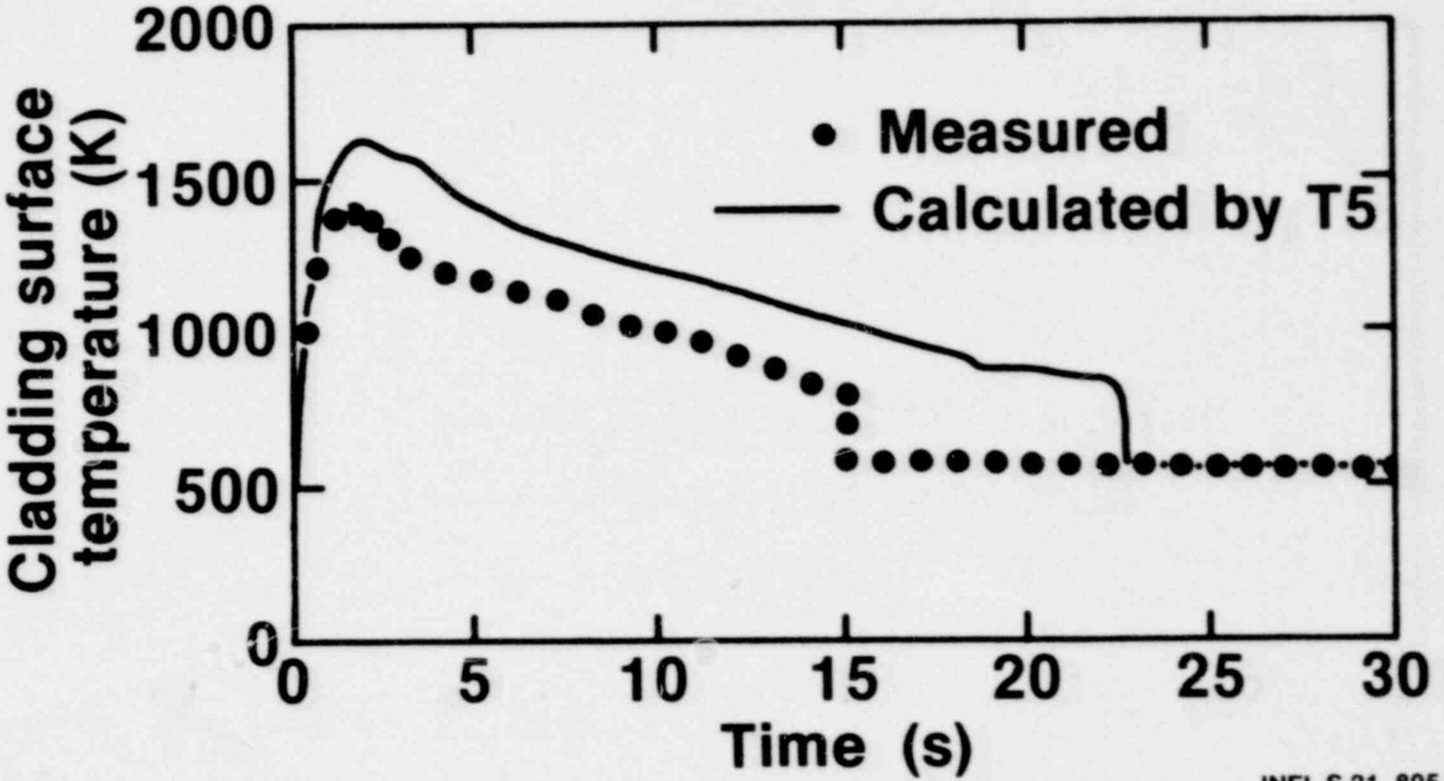
1605 202

FRAP-T5 Calculation of IFA-226



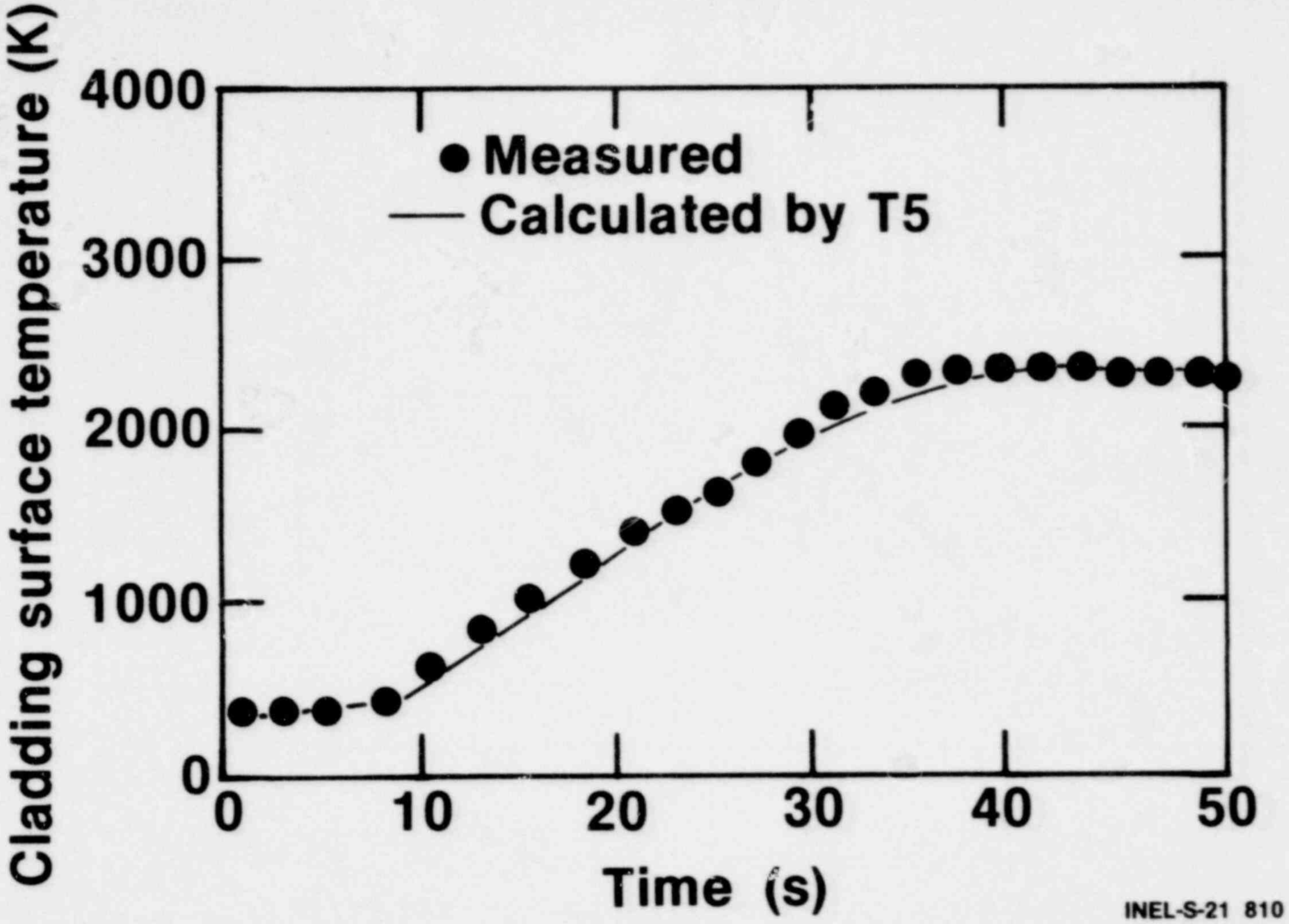
INEL-S-21 828

FRAP-T5 Calculation
PBF RIA 1-1



INEL-S-21 805

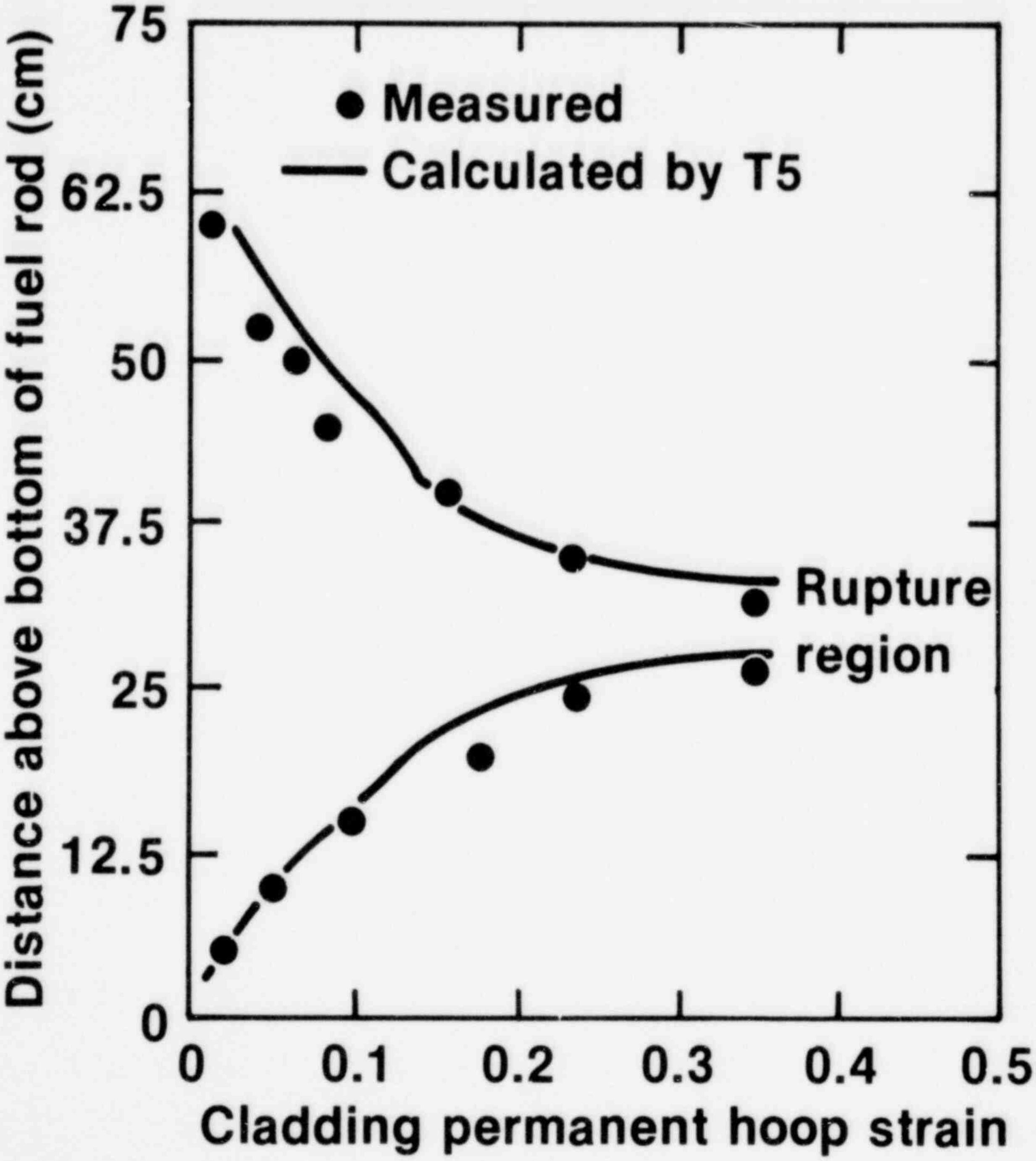
FRAP-T5 Calculation TREAT Test FRF-2



INEL-S-21 810

1605 205

FRAP-T5 Calculation TREAT Test FRF2



INEL-S-21 812

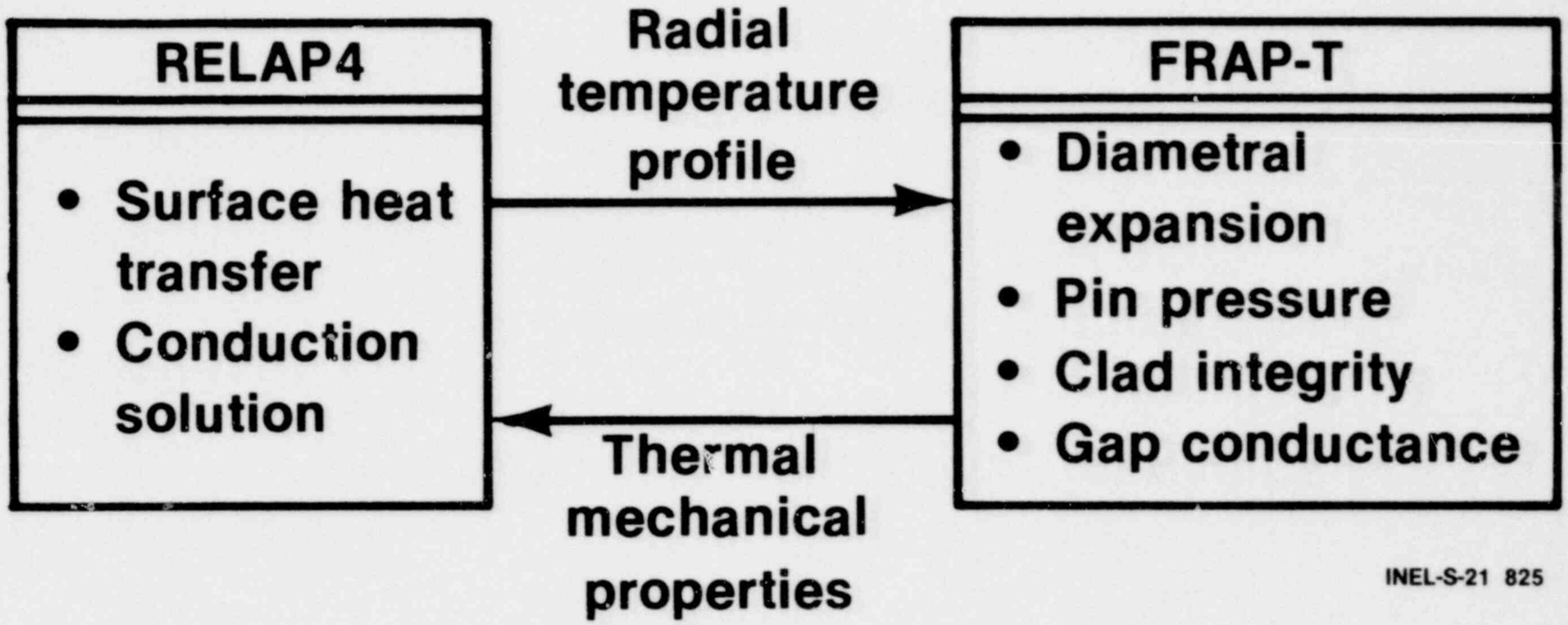
1605 206

RELAP4/FRAP-T Link

- Conduction solution performed by RELAP
- FRAP provides gap conductance and effective conductivity parameter to RELAP
- Thermal-hydraulics, conduction, FRAP-T called at separate timesteps
- Result was essentially same executing time for RELAP4/MOD7 and MOD6

INEL-S-21 819

RELAP4/FRAP-T Link



RELAP4

- Surface heat transfer
- Conduction solution

Radial temperature profile

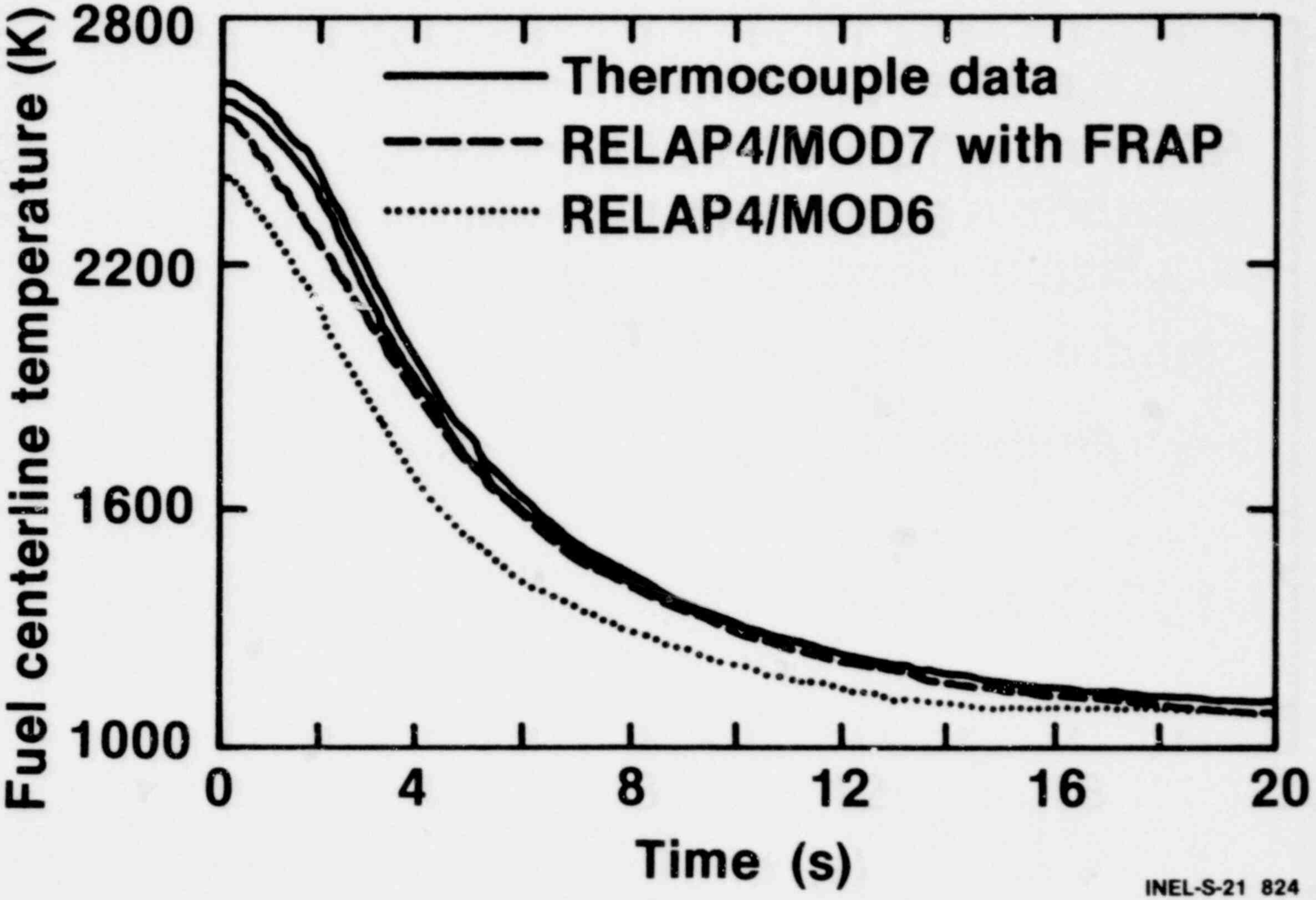
Thermal mechanical properties

FRAP-T

- Diametral expansion
- Pin pressure
- Clad integrity
- Gap conductance

INEL-S-21 825

RELAP/FRAP Interactive Line
LOC-11 Test



INEL-S-21 824

1605 209

Response Surface Methodology

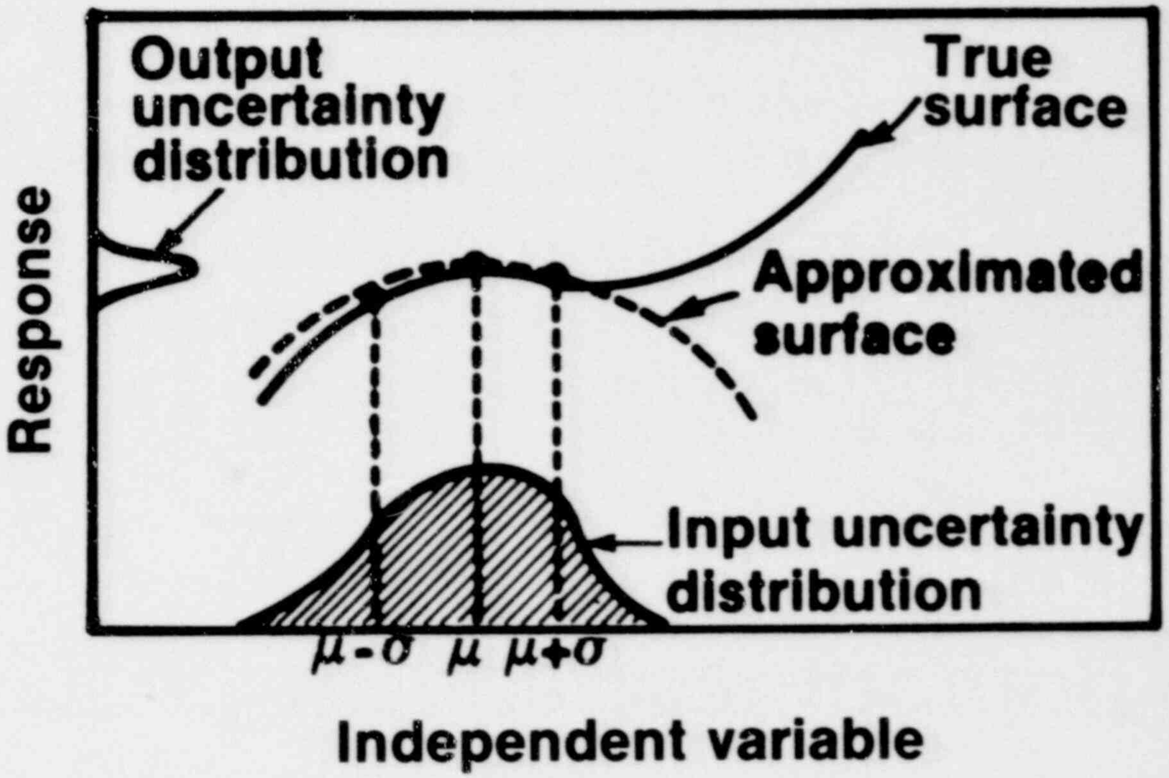
- "Responses" are the code outputs
- Independent variables are code inputs
- The error analysis procedure determines a relationship between each response and the independent variables.

INEL-S-10 674

Response Surface Methodology (cont'd)

- RSM fits a simple polynominal to a portion of the response "surface" about a nominal point via a Taylor series
- Propagation of error and response uncertainty is then inferred from the approximate surface

Response Uncertainty Determination



INEL-S-17 028

Current Capabilities

- Over 50 input variables with uncertainty distributions built into code
- Up to 15 output variables
- User may add variables or change uncertainty distributions on variables

INEL-S-10 665

Automated Error Analysis

- User specifies inputs to vary and responses to analyze
- User specifies degree of polynomial
- Code automatically
  - Determines experimental design and confounding pattern
  - Calls FRAP
  - Fits response polynomial for all responses
  - Estimates means and variances
  - Computes fractional contribution to variance

Response Equation Validation

- Determine whether the response surface equations adequately approximate the unknown functional form of the code response

- Poor approximations will bias estimates of uncertainty

INEL-S-18 762

Analysis of Residuals

- A residual is the difference between the response surface equation and the code calculations at each data point
- Evenly dispersed and well distributed residuals indicate good fit

INEL-S-21 814

Lack of Fit Indications

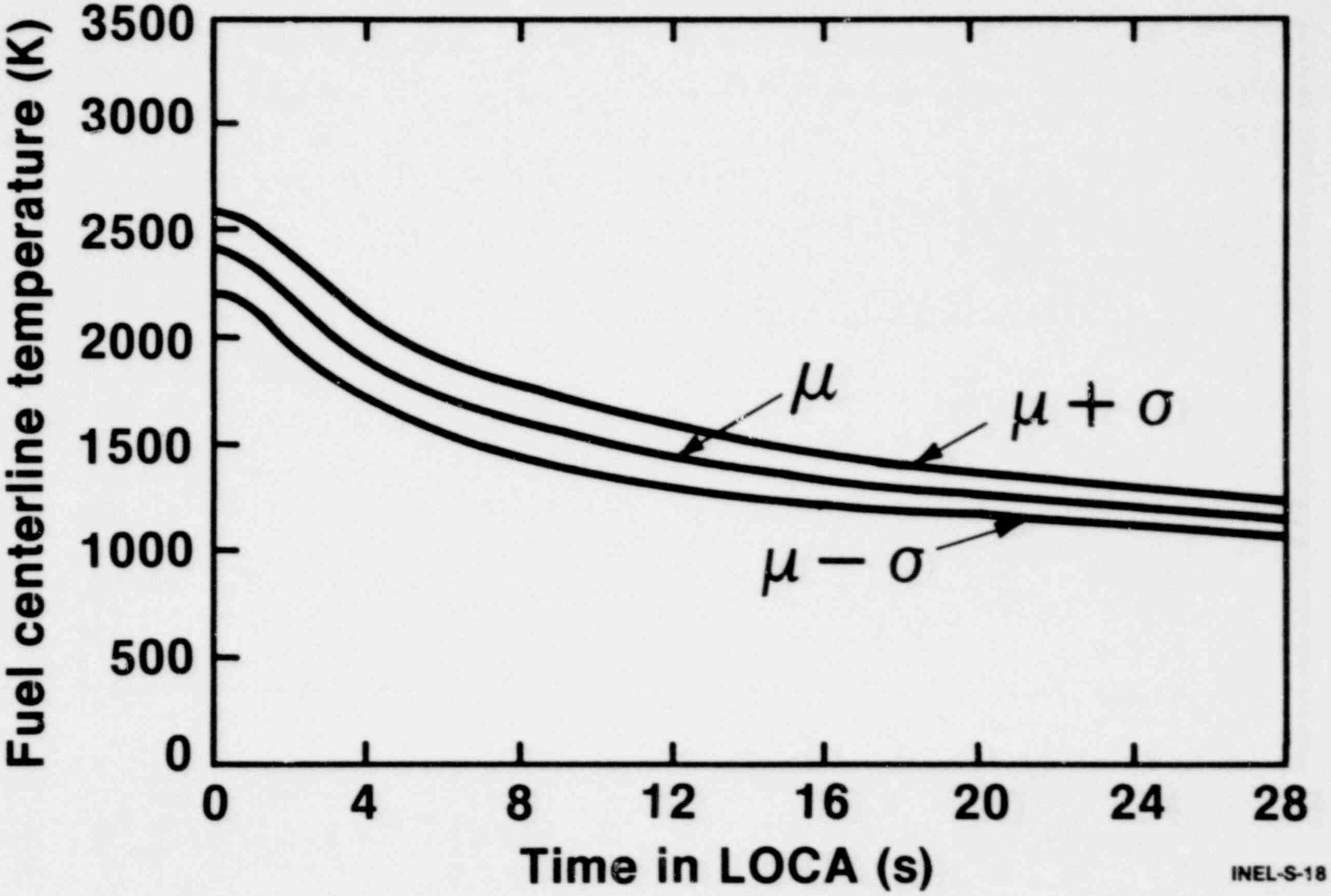
- Very small residuals of like magnitude and alternating sign indicate overfit
- Highly grouped residuals indicate underfit, that is, significant terms omitted
- Well dispersed residuals with one or two outliers indicate a threshold response

INEL-S-21 815

Example Problem

- Fuel rod analysis program-transient (FRAP-T5)
- Uncertainty analysis of a loss of coolant accident (LOCA)
- Linear response equations fit for 10 different responses over a 29 second blowdown history
- 10 input variables considered probabilistic
- 16 FRAP-T5 executions were required

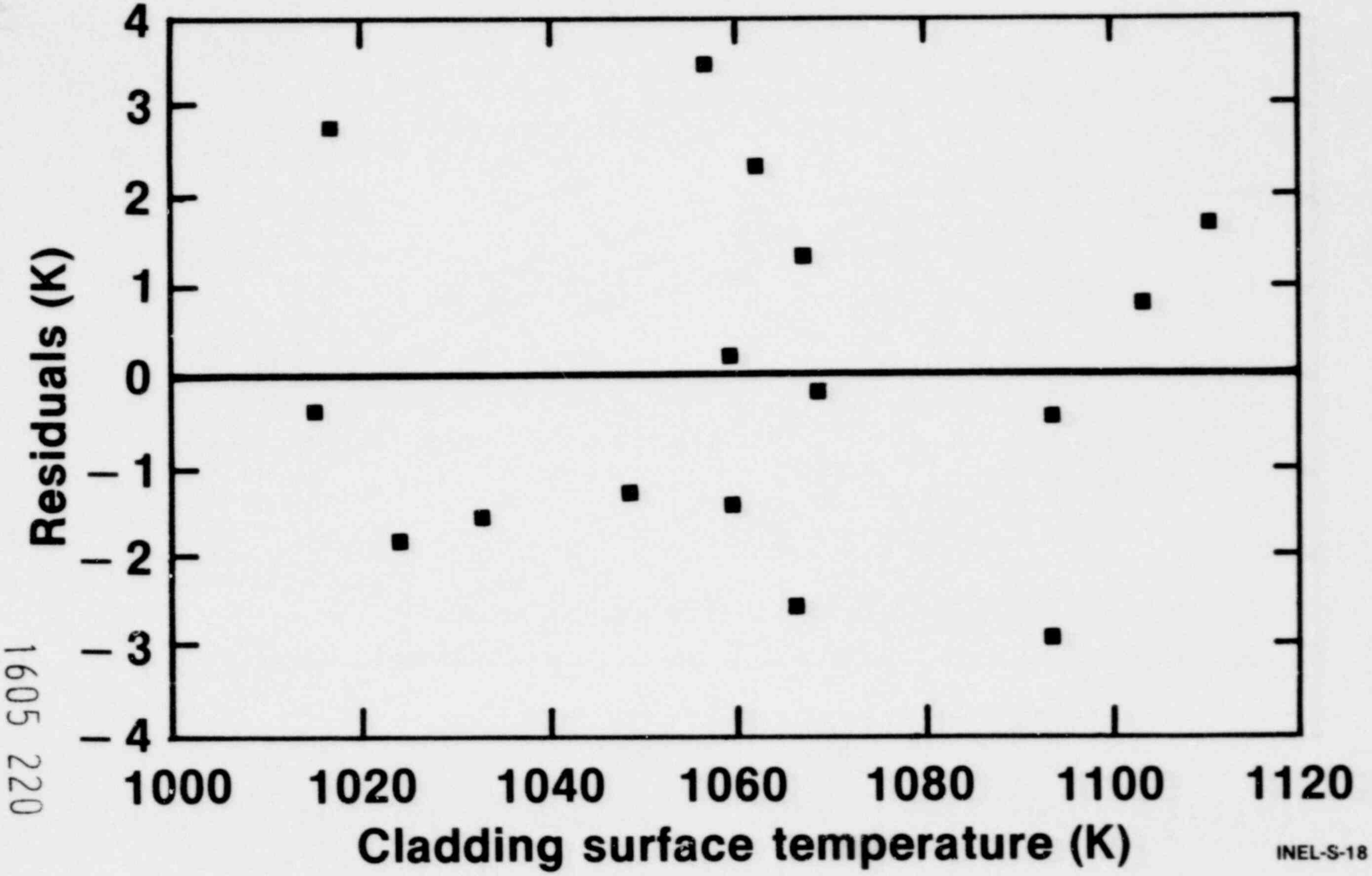
Fuel Centerline Temperature at Core Midplane



INEL-S-18 760

1605 219

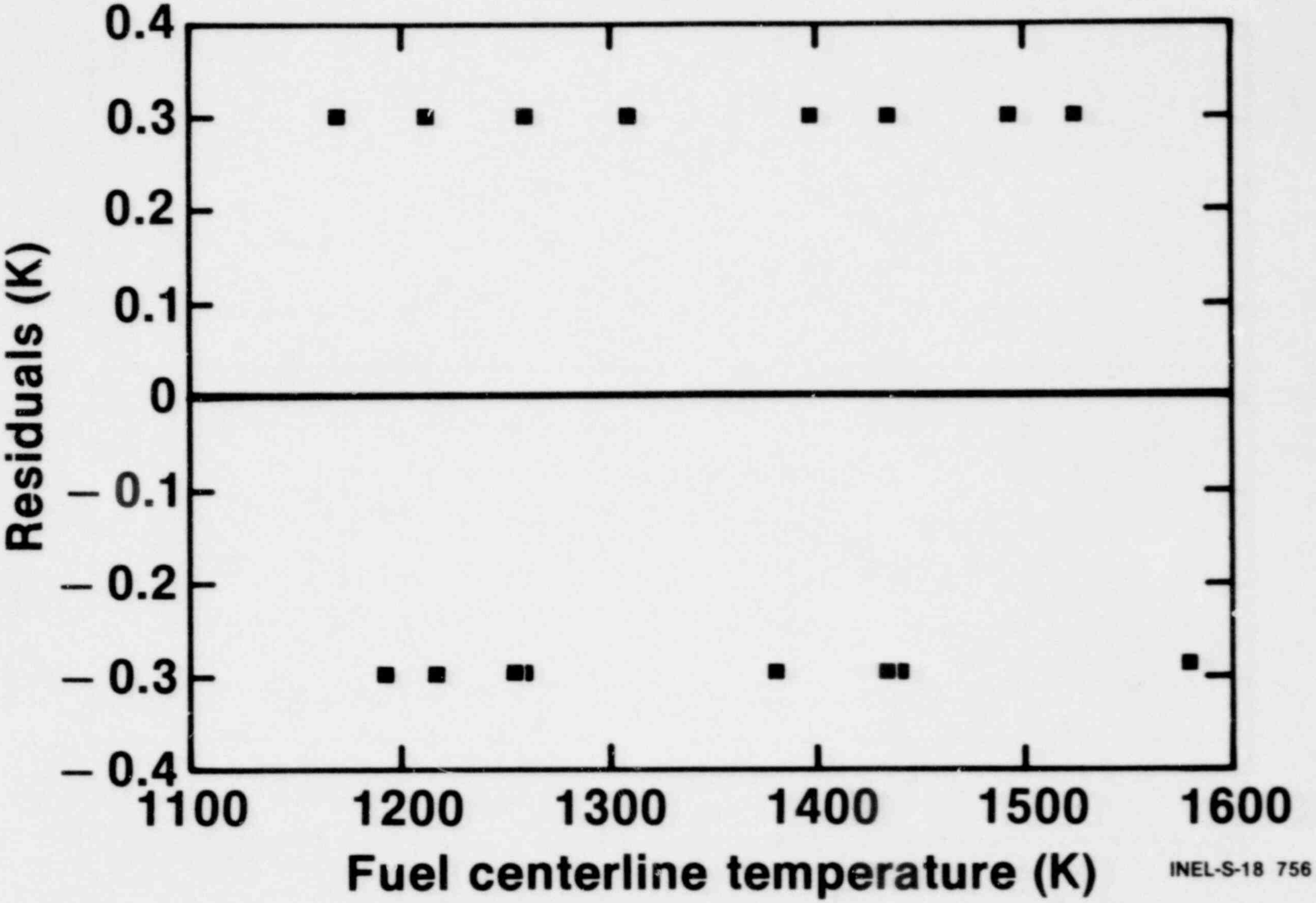
Cladding Surface Temperature Residuals



INEL-S-18 757

1605 220

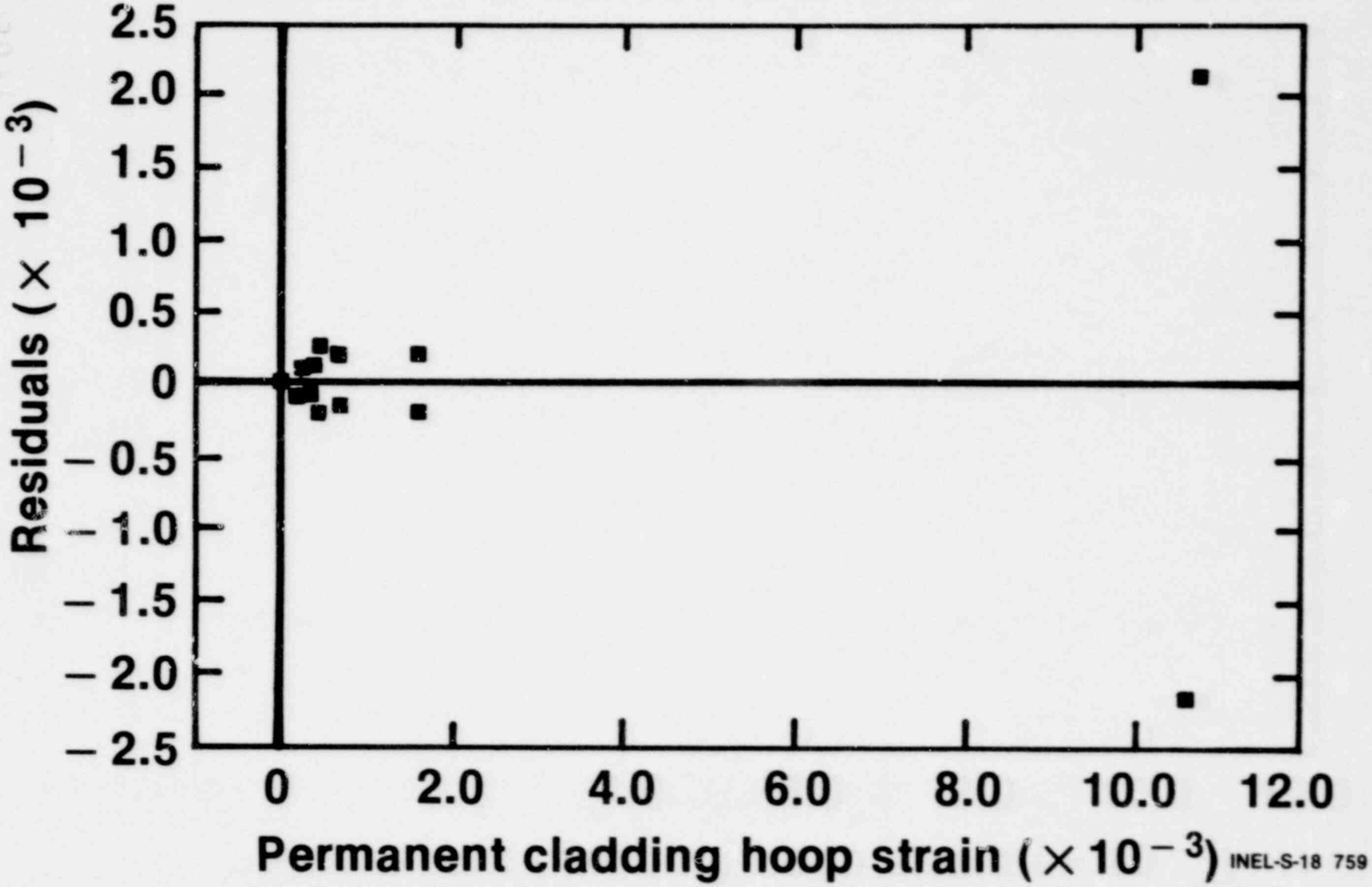
Fuel Centerline Temperature Residuals



INEL-S-18 756

1605 221

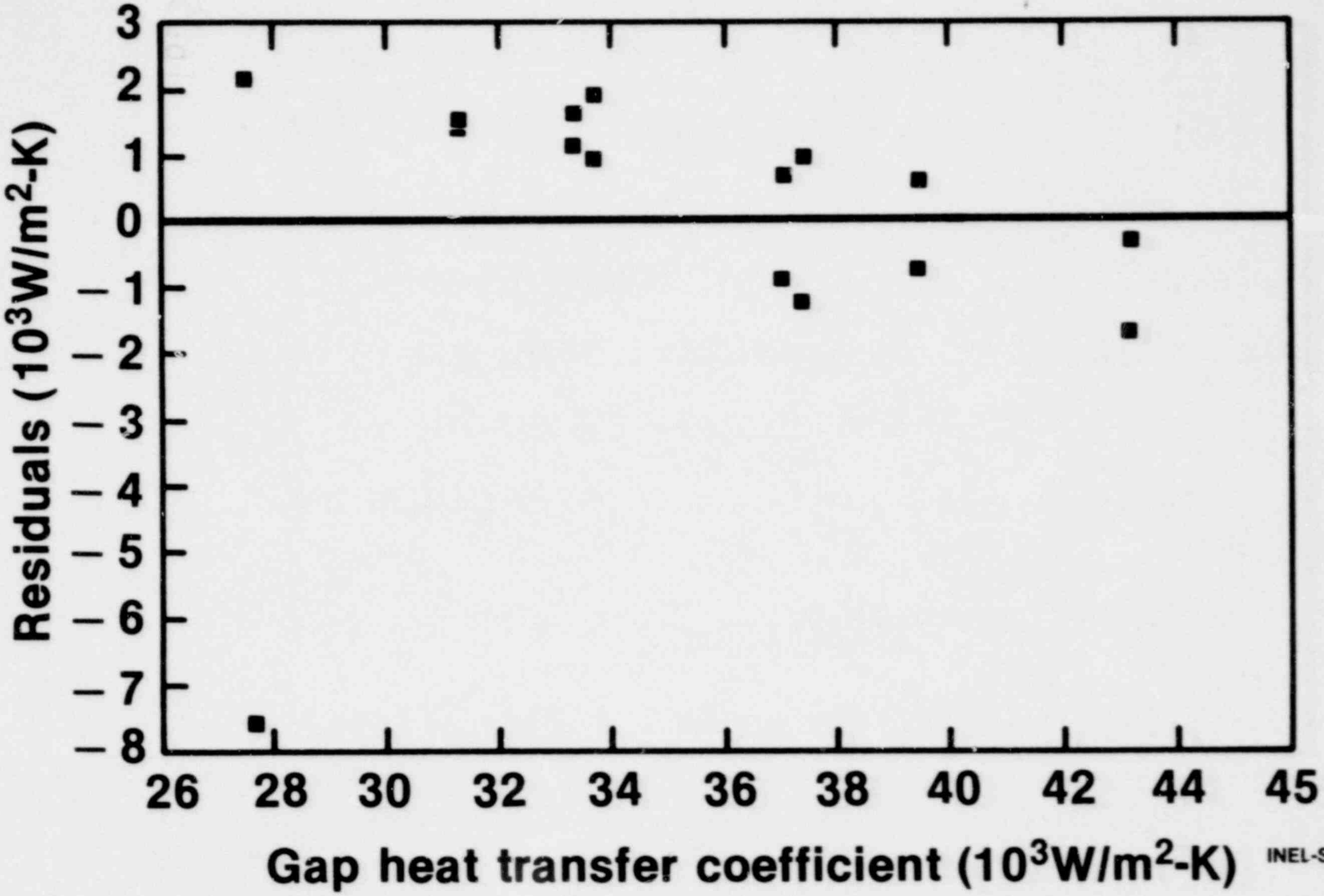
Cladding Hoop Strain Residuals



INEL-S-18 759

1605 222

Gap Heat Transfer Coefficient Residuals



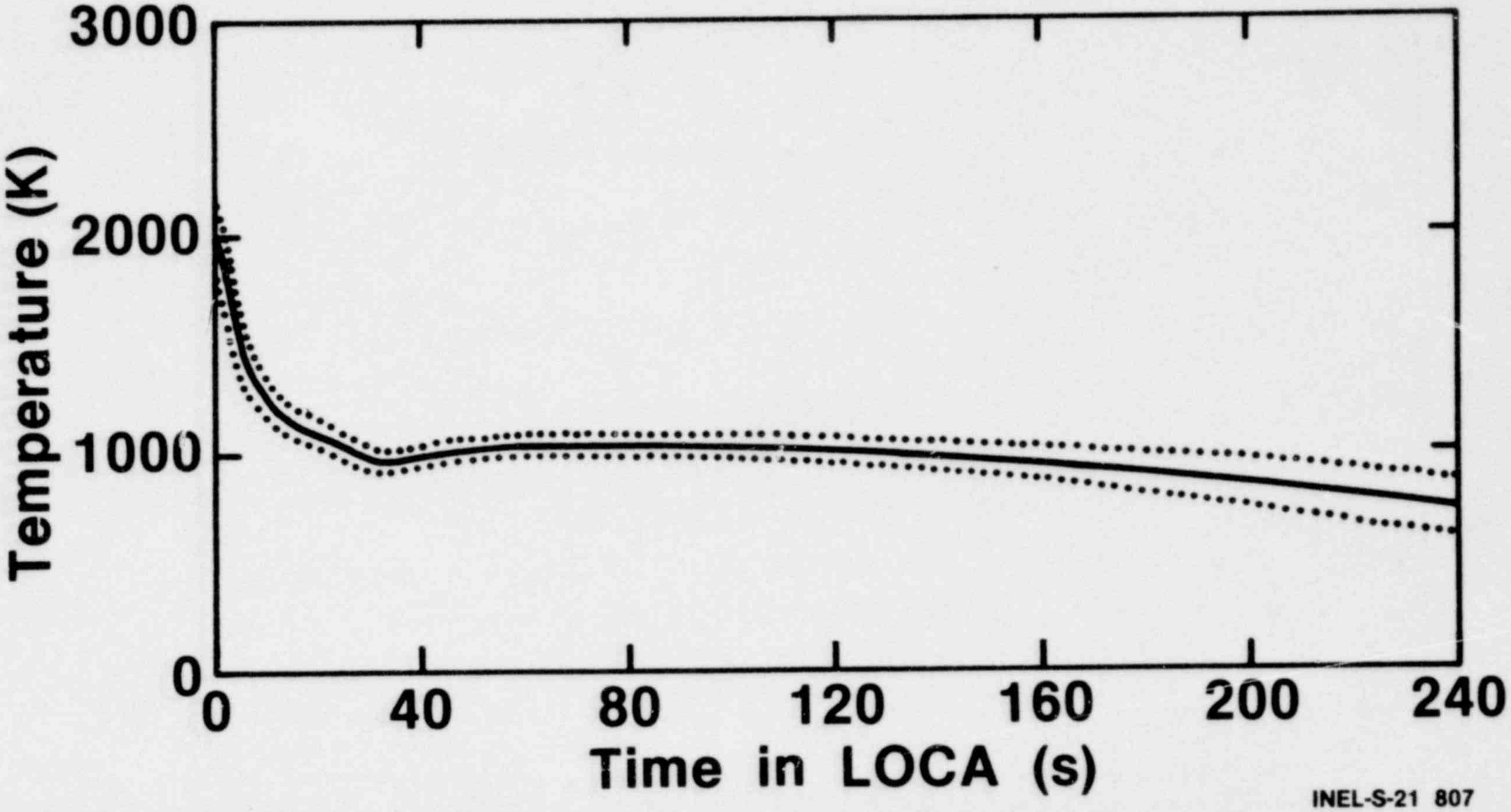
INEL-S-18 758

1605 223

Reflood LOCA Uncertainty Factors

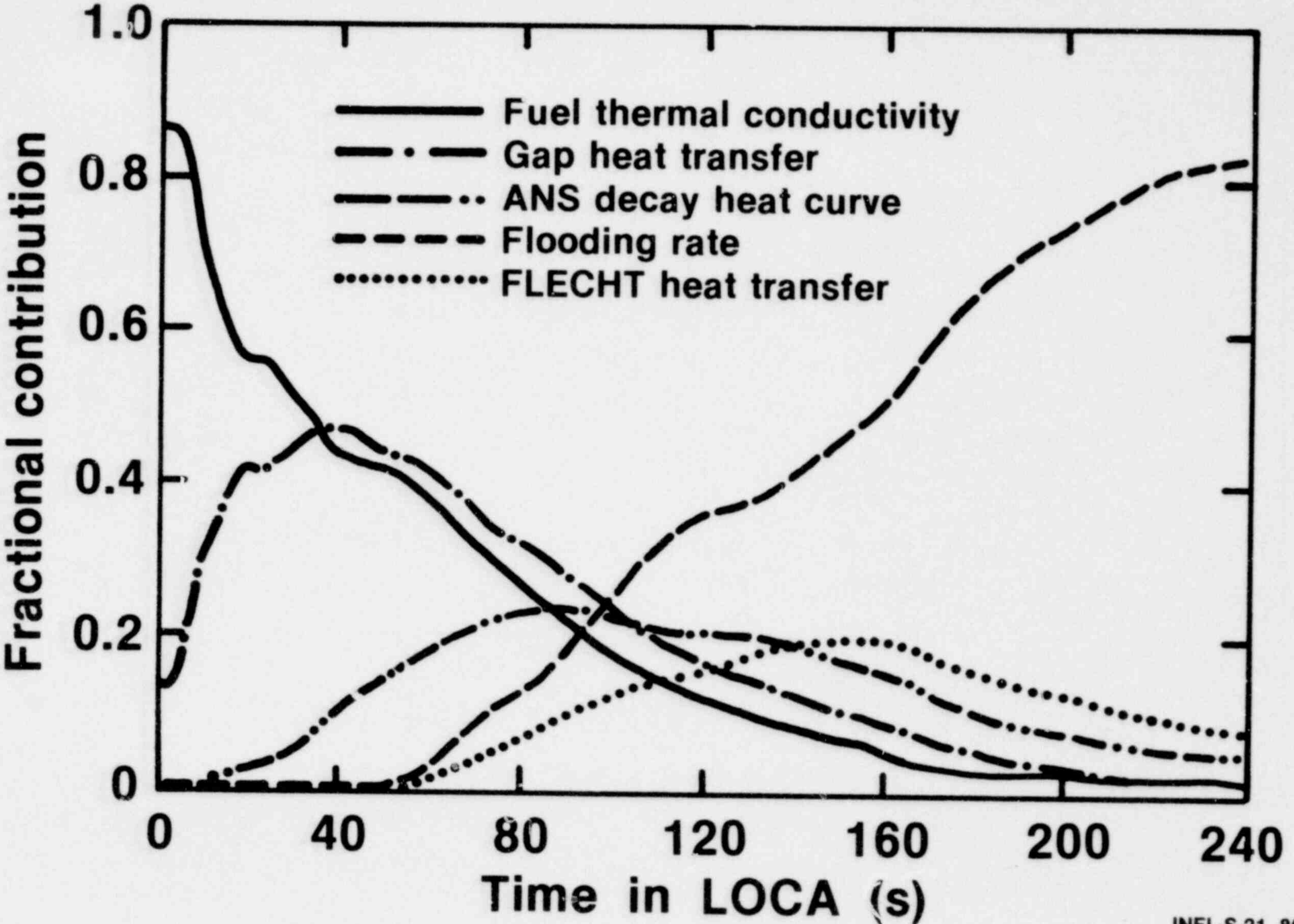
Flooding rate	10%
Flow blockage percentage	5%
FLECHT heat transfer	10%
Carryout fraction	10%
Gap heat transfer	25%
Fuel thermal conductivity	0.4 (w/m-k)
ANS decay heat curve	6.7%

Fuel Centerline Temperature



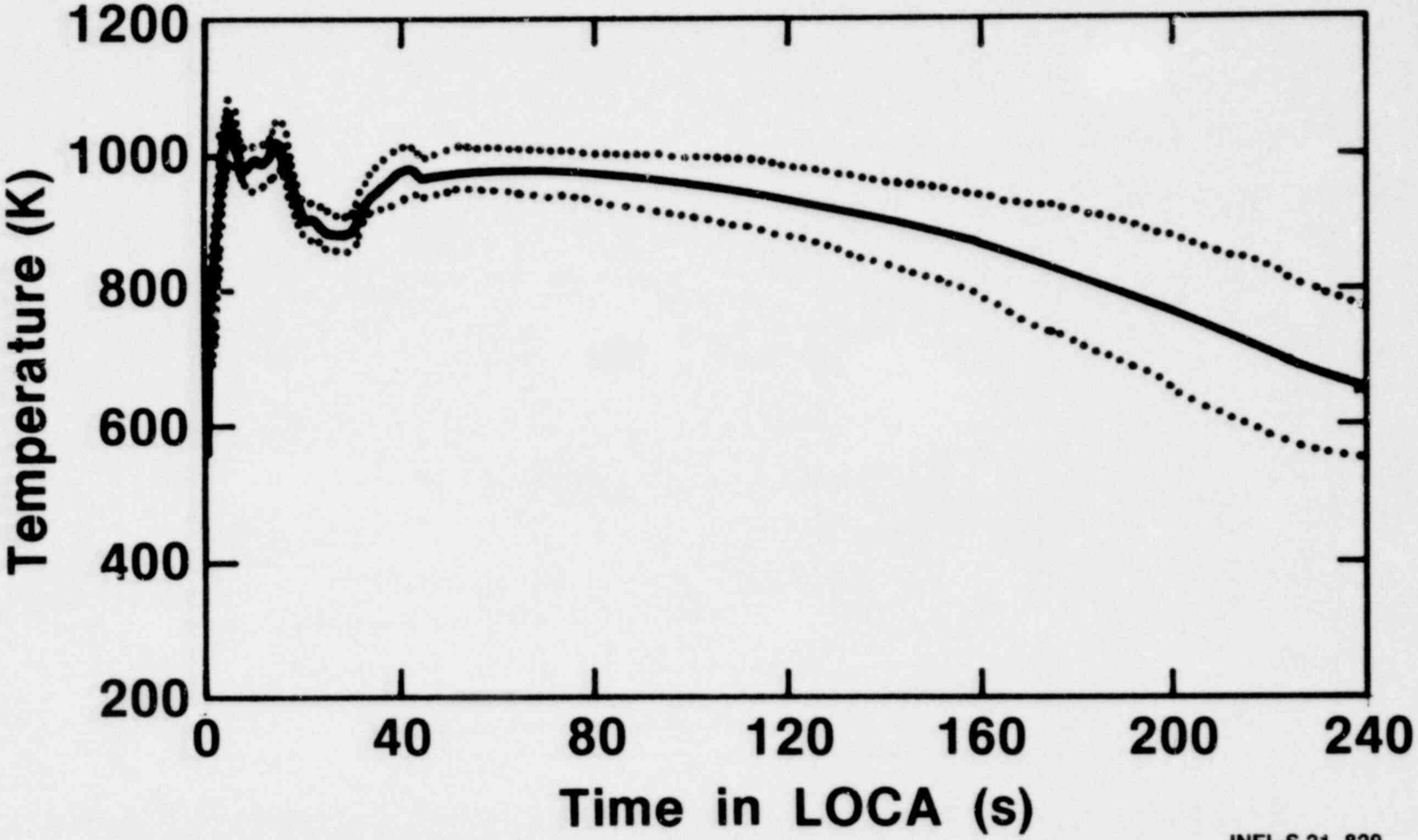
INEL-S-21 807

Fractional Contributions to Variance of Fuel Centerline Temperature



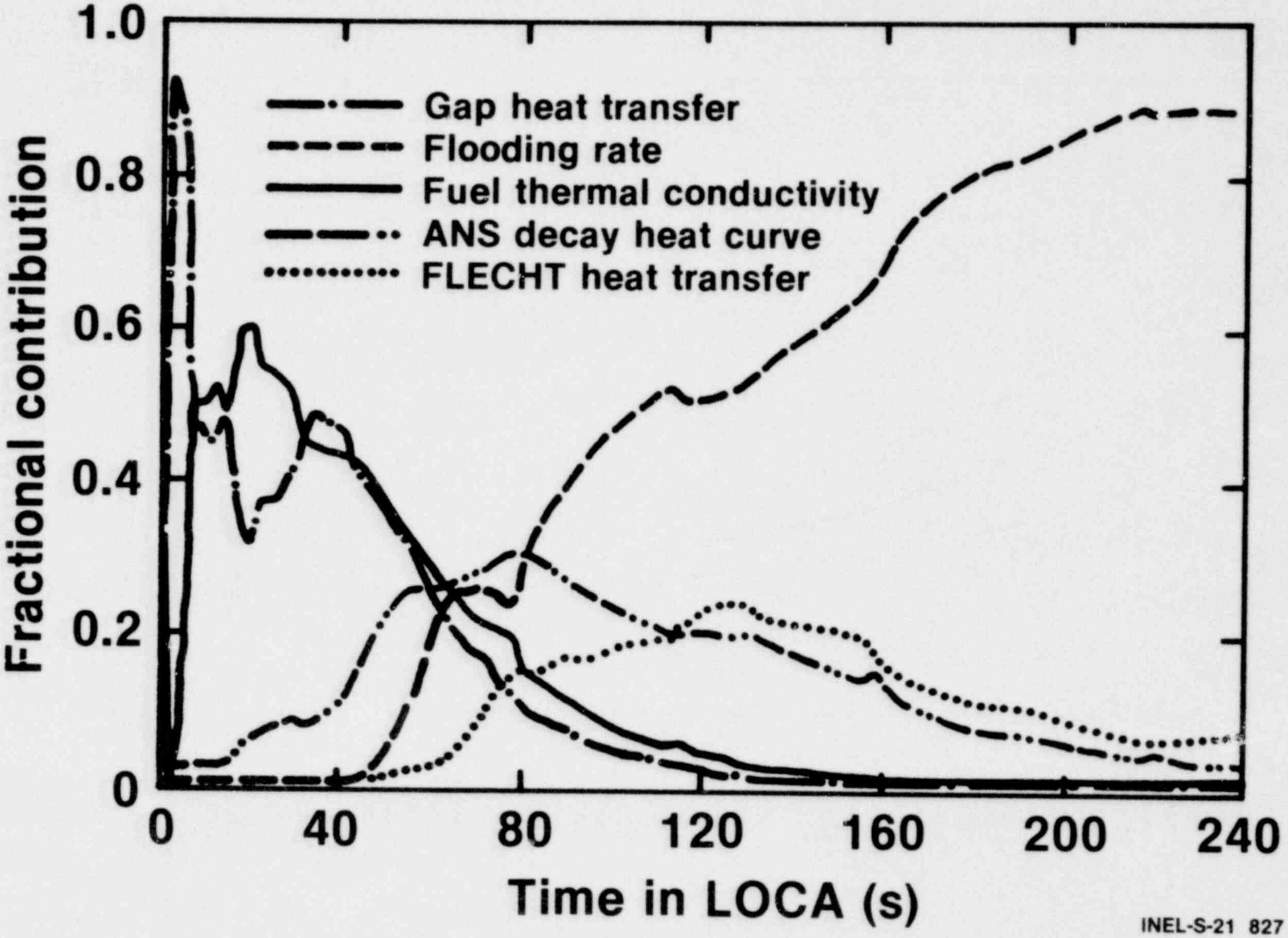
INEL-S-21 808

Cladding Surface Temperature



INEL-S-21 829

Fractional Contribution to Cladding Surface Temperature

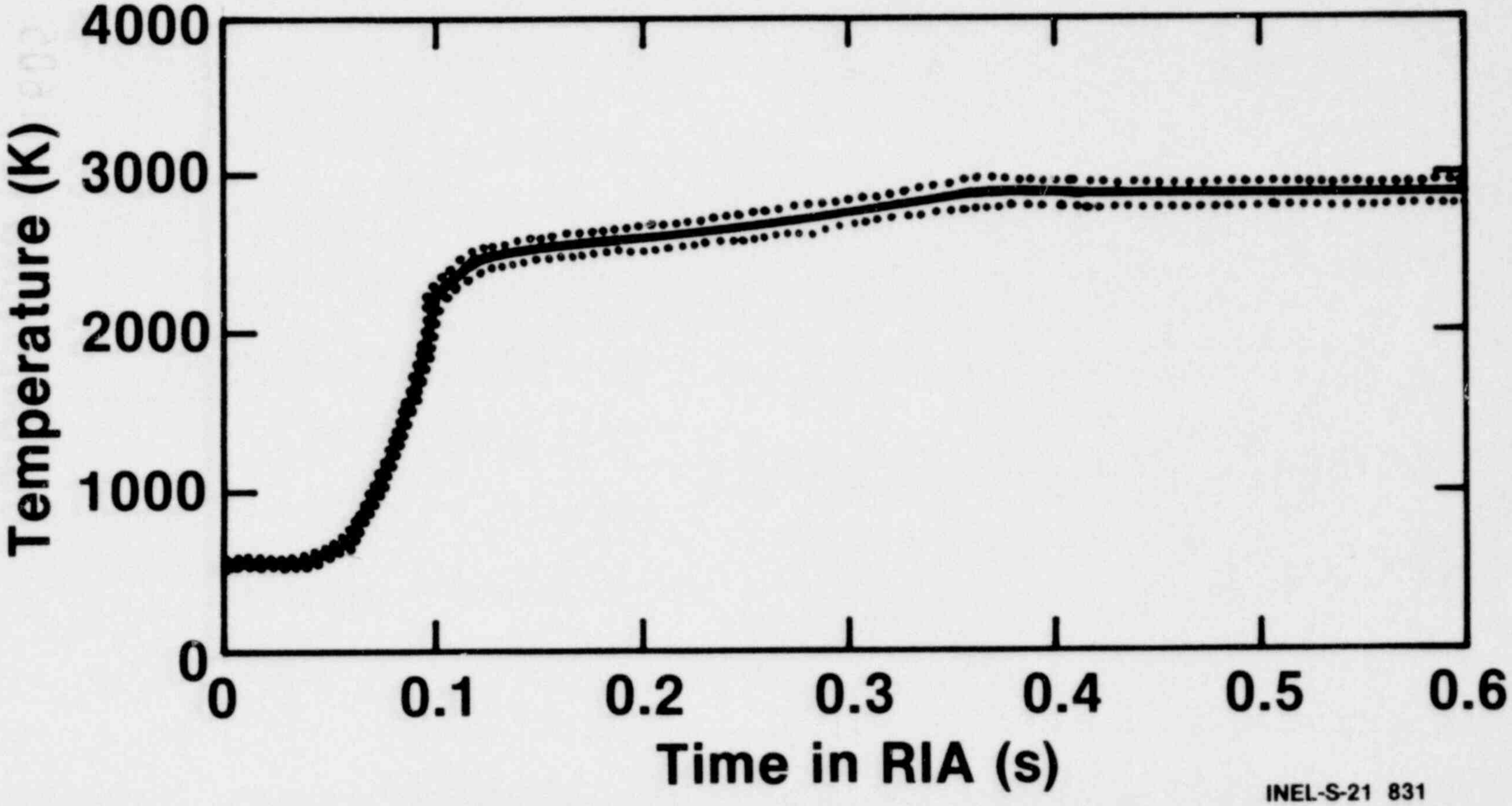


INEL-S-21 827

BWR RIA Uncertainty Factors

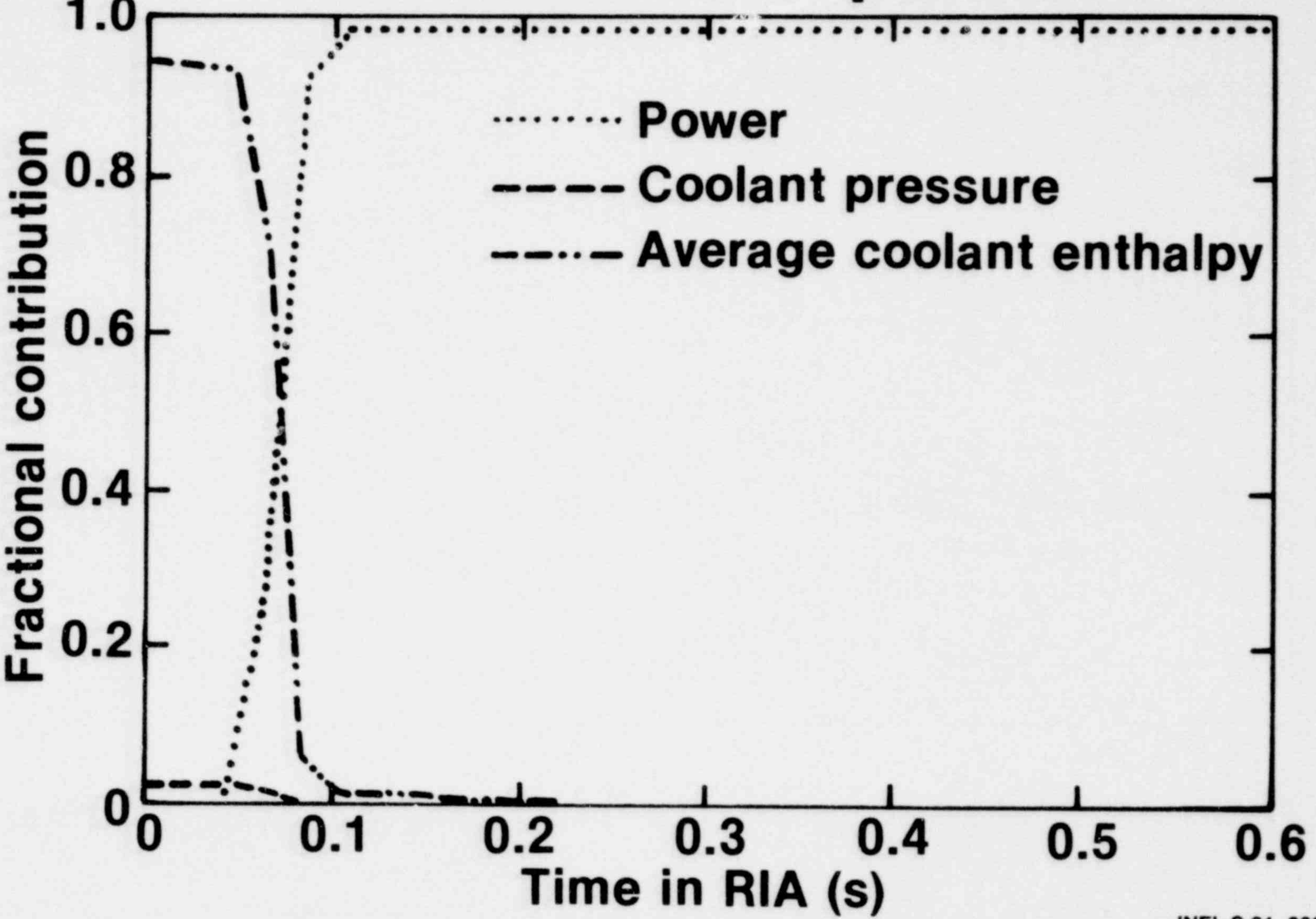
Power	5%
Fuel thermal conductivity	0.4 (w/m-k)
Gap heat transfer	25%
Surface heat transfer	10%
Coolant pressure	5%
Coolant mass flux	5%
Average coolant enthalpy	5%
Flow channel area	5%
Amount of gas in the rod	3.4%
Equivalent heated diameter	1%
Cladding strength coefficient	29×10^6 Pa

Fuel Centerline Temperature



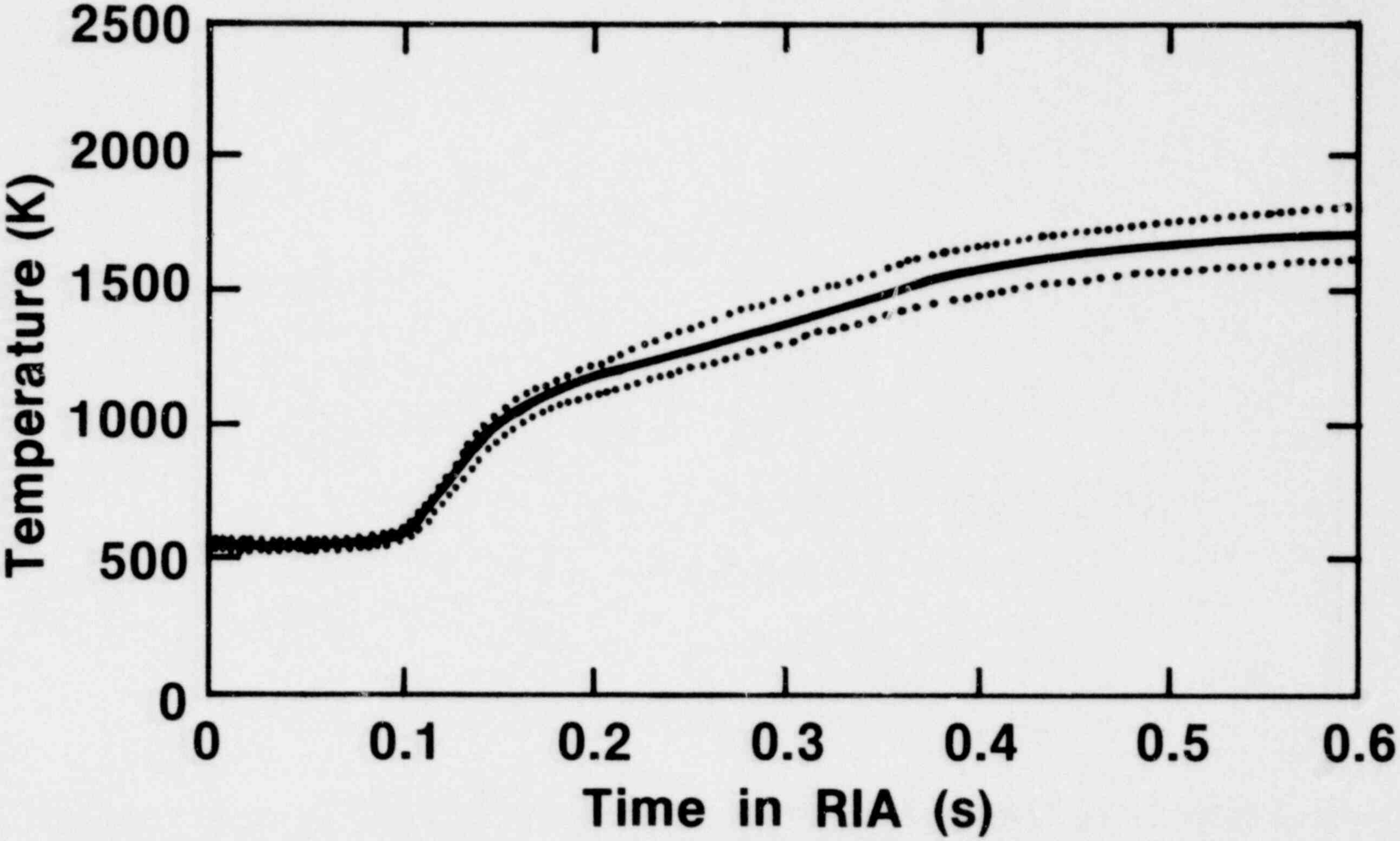
INEL-S-21 831

Fractional Contribution to Fuel Centerline Temperature



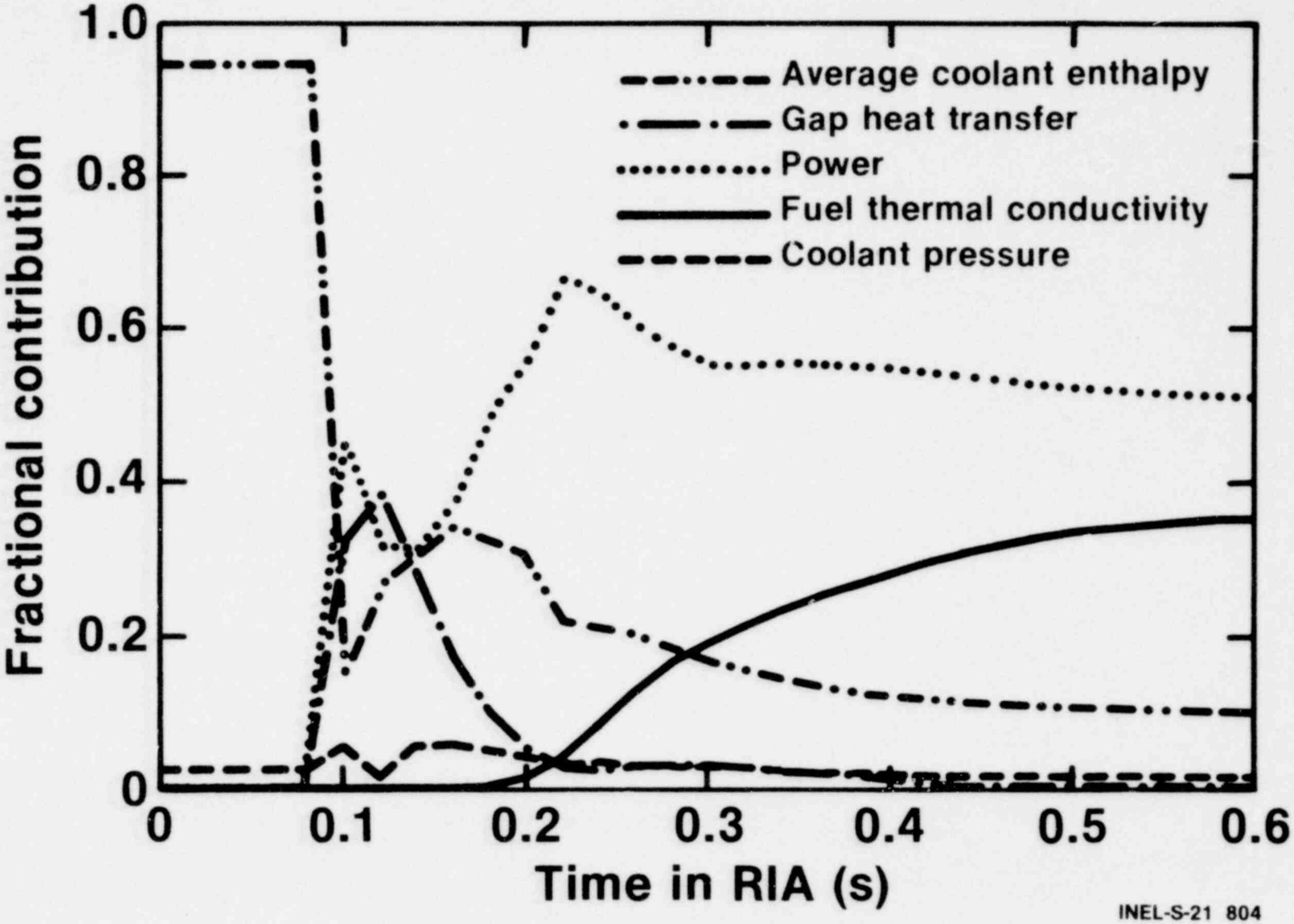
INEL-S-21 809

Cladding Surface Temperature



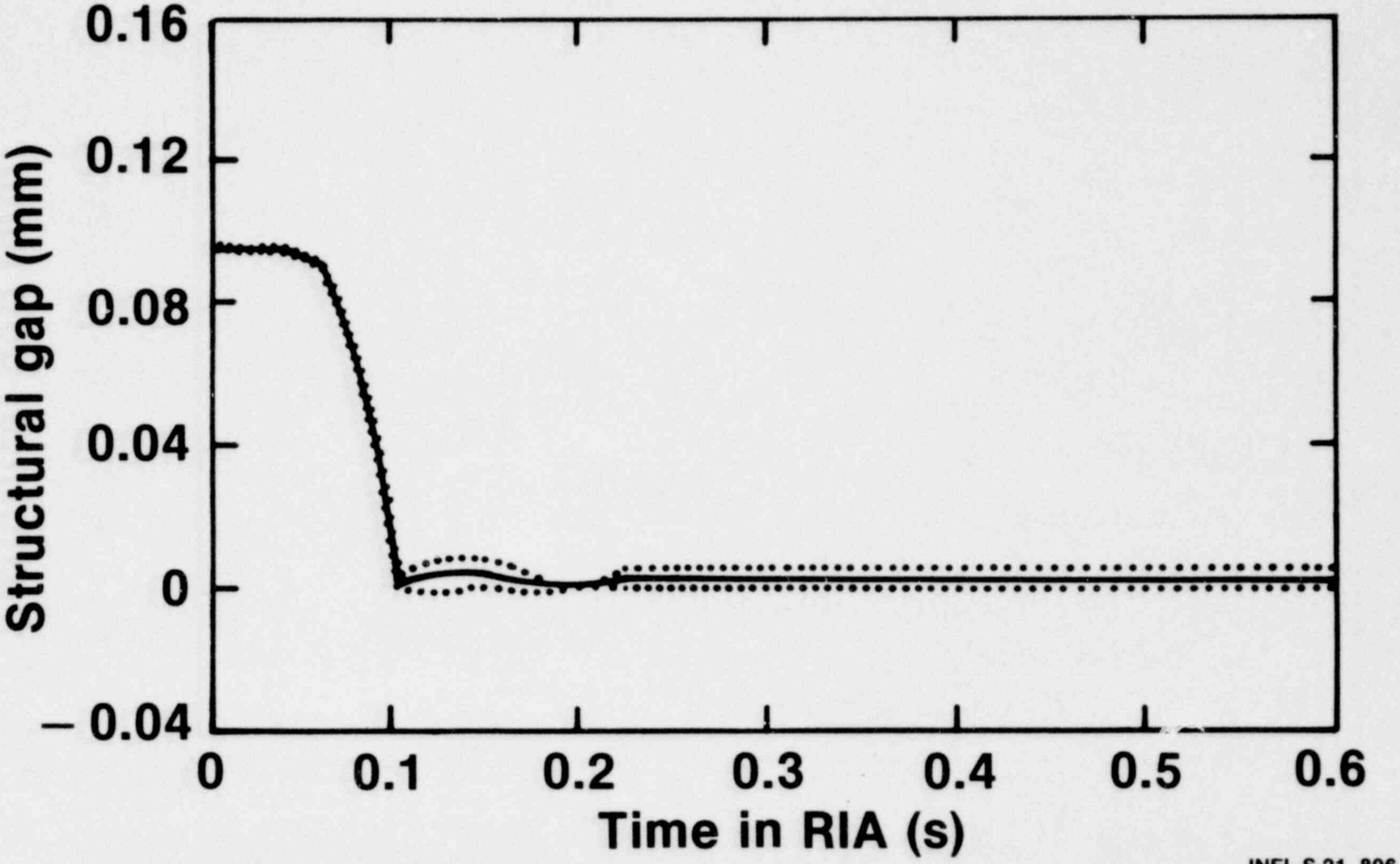
INEL-S-21 830

Fractional Contribution to Variance of Cladding Surface Temperature



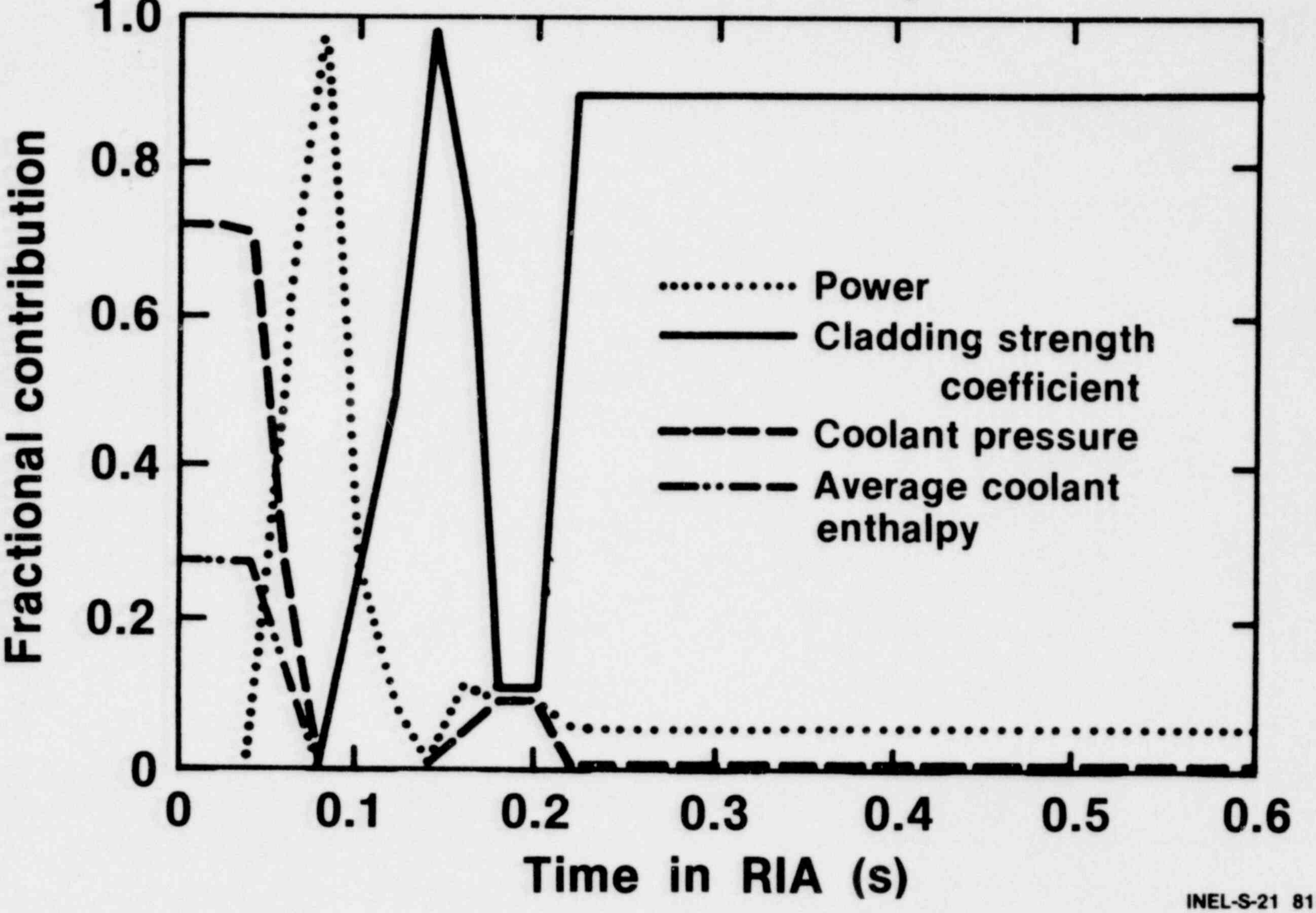
INEL-S-21 804

Structural Gap



INEL-S-21 806

Fractional Contribution to Structural Gap



INEL-S-21 813