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GT2R2: An Updated Version of GAPCON-THERMAL-2

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Operated by
Battelle Memorial Institute

Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

The GAPCON-THERMAL-2 code is used by the U. S. Nuclear Regulatory Commission for audit calculations of nuclear fuel thermal performance computer codes. Since the code was originally written, errors and needed updates have been identified. Revision 2 of GAPCON-THERMAL-2 contains a number of coding corrections and updates, and now conforms with the American National Standards Institute FORTRAN-77 standard. The changes to the code are presented in detail. Benchmarking calculations, concentrating on fuel temperatures and fission gas release, were performed to qualify the effect of model changes on the performance of GAPCON-THERMAL-2, Revision 2. It was concluded that use of the old fuel relocation model combined with the modified ANS 5.4 fission gas release model provides the best overall comparison with the thermal performance and fission gas release data used for the benchmarking exercise. The use of the new fuel relocation model combined with the Beyer-Hann fission gas release model provided the best comparisons of thermal behavior but significantly underpredicted fission gas release.

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1.0 INTRODUCTION

This report has two principal objectives. First, to discuss the changes that make GAPCON-THERMAL-2, Revision 2 (GT2R2) different from the preceeding versions of GAPCON-THERMAL-2. Second, to provide a benchmarking of GT2R2.

GAPCON-THERMAL-2 (GT2)[1] is a computer code designed for the calculation of thermal performance parameters of nuclear fuel rods; i.e., temperature and fission gas release. The code consists of numerous mathematical models that describe physical properties (for example, thermal conductivity) and processes (for example, fuel relocation). The models were developed independently of each other and then combined to form an integrated thermal performance code. As a result, the code as a whole has not been "tuned" or matched to any specific data set and therefore displays an independence not matched by many other fuel codes.

GT2 was originally written by Pacific Northwest Laboratory (PNL)[a] staff under a contract to the U.S. Nuclear Regulatory Commission. GT2, Revision 1 (GT2R1) was also prepared by PNL staff for the NRC. GT2R1 corrected errors that had been found in the original coding of GT2, but no other changes were made.[b] The work on GT2R2 was commissioned with the objective of making the coding more usable for NRC audit calculations. Revisions include reorganization of some of the coding, removal of non-used coding, addition of new coding, modifications to make the coding American National Standards Institute (ANSI) FORTRAN-77 standard, and adding comments to more fully identify variables and clarify the calculational sequence. In addition, the name of the program has been changed to GT2R2 from GAPCON to reflect the numerous coding revisions, and to allow a new subroutine to be named GAPCON.

The development of GT2R2 was performed on a DEC VAX 11/780 machine at PNL. Following, and during, development of the coding, GT2R2 was also placed on CDC computers at Brookhaven National Laboratory (BNL). The FTN5 compiler with the ANSI option was used on the BNL equipment to check for non-ANSI standard coding. This allowed NRC access to the coding for review resulting in comments and suggestions as to additional modifications.

This report presents the coding changes that were made (Section 2), a series of benchmarking/verification runs (Section 3), input instructions for the revised code (Appendix A), and the input used for the benchmarking calculations (Appendix B).

(a) Operated for the U.S. Department of Energy by Battelle Memorial Institute.
(b) No formal documentation was prepared for GT2R1, however the coding was supplied to the National Energy Software Center (NESC) at Argonne National Laboratory. The coding does contain comments discussing some of the changes in GT2R1.

2.0 GT2R2 CODING CHANGES

There are a number of differences between GT2R2 and previous versions of GT2. The differences include:

2.1 REMOVAL OF OLD ROUTINES

Subroutine MOVEKA and Function OMEXP were removed because they were not being used. Function TEPP was removed when Function TERP was modified to handle all calls to the original TERP and TEPP interpolation functions. Subroutine INPT was removed and replaced by Subroutine INPUT.

2.2 MODIFICATION OF OLD ROUTINES

2.2.1 Linear Interpolation

Function TERP was modified to handle all linear interpolation requirements. This necessitated combining some previously singly-dimensioned arrays into one doubly-dimensioned array. For example, the singly-dimensioned arrays TT and TS were combined into the doubly-dimensioned array TT.

2.2.2 Fuel Radial Thermal Expansion

The sum-of-nodes method for fuel radial thermal expansion[2] has been added to Subroutine EXPAND as an option. This method assumes a number of rings of equal width and then sums the thermal expansion of each ring. The increase in thickness of each segment is determined as follows:

$$\Delta t_i = \alpha t(T-T_r)$$

where Δt_i = change in thickness of fuel ring i
α = coefficient of thermal expansion
t = initial thickness of segment i
T = average segment temperature
T_r = reference temperature

The increase in the fuel radius is then the sum of individual increments:

$$\Delta R = \sum_{i=1}^{n} \Delta t_i$$

This option is chosen by setting IEXPND = 1. The default thermal expansion, IEXPND = 0, is the model originally used in GT2.

2.2.3 Fuel Relocation

A recently developed fuel relocation model[3] has been added to subroutine RELOC as an option. The new model is a simple function of linear heat generation rate and burnup as described below:

For LHGR < 20 kW/m:

$$\frac{\Delta G}{G} = 30 + 5*FBU$$

where, $\frac{\Delta G}{G}$ = decrease in hot gap, based on as-fabricated cold gap dimensions (%)

FBU = BURNUP/5, for BURNUP < 5 MWd/kgM
 = 1 , for BURNUP $\geq$ 5 MWd/kgM

BURNUP = segment average fuel burnup (MWd/kgM)

For 20 kW/m < LHGR < 40 kW/m:

$$\frac{\Delta G}{G} = 30 + PFACTOR + (5 + PFACTOR)*FBU$$

where, PFACTOR = (LHR-20) * 5/20
LHGR = linear heat rate (kW/m)

For LHGR > 40 kW/m:

$$\frac{\Delta G}{G} = 35 + 10*FBU$$

This model, therefore, has a minimum relocation of 30% at low linear heat generation ratings and a maximum relocation of 45% at high linear heat generation ratings and burnup > 5 MWd/kgM.

The new fuel relocation model is used when IRELOC = 2. No fuel relocation is the default condition (IRELOC = 0); the standard GT2 fuel relocation model is chosen by setting IRELOC = 1.

2.2.4 Fuel Restructuring

The logic for fuel restructuring has been modified. If the fuel restructuring option is chosen and fuel restructuring is calculated to occur (because of high fuel temperatures), the resulting change in fuel density and increase in central void diameter is carried through the remainder of the time history. Previously fuel restructuring effects on temperature were carried along as a parallel calculation. Fuel restructuring may occur only when FRSIN > FRDEN.

2.3 ADDITION OF NEW ROUTINES

2.3.1 Cladding Creepdown

Subroutine CREEP incorporates the BUCKLE equations[4,5] for calculating cladding creepdown. Cladding creepdown is a function of external coolant pressure, rod internal gas pressure, cladding texture factor (FZ), cladding cold work (CW), incident neutron fluence (local power * FLXFAC), and time. The equations describing the creep behavior are:

Thermally activated creep

$$e = (1 + \alpha * K * \exp(-Kt)) * B * \exp(Q/RT) * \sinh(SC * \sigma)$$

Athermal, irradiation enhanced creep

$$e = (1 + \alpha * K * \exp(-Kt)) * Bi * \phi^n * \exp(Qi/RT) * \sinh(SCi * \sigma)$$

where: e is the tangential strain at the neutral plane
α is the transient creep coefficient
K is the time coefficient
t is time
B is the high temperature creep coefficient
Bi is the low temperature creep coefficient
Q is the high temperature activation energy
Qi is the low temperature activation energy
$= 9500 + 0.0380 * \sigma$
R is the universal gas constant
T is the temperature
SC is the high temperature stress coefficient
SCi is the low temperature stress coefficient
σ is the the tangential stress at the the neutral plane
ϕ is the fast neutron flux

The cladding is allowed to creepdown only until hard fuel-cladding contact (i.e., interfacial pressure greater than zero) is achieved. If hard fuel-cladding contact is achieved the creepdown calculations are then discontinued for the remainder of the time history. If the rod internal gas pressure exceeds the external gas pressure, the cladding is allowed to creep outward.

Subroutine CREEP is used when ICREP = -1. No cladding creepdown is the default condition (ICREP = 0). If desired, a table of creepdown values may still be entered (ICREP > 0).

2.3.2 Peak Fuel Temperature Node

A fuel region that operates at peak power and densifies to the 95/95[6] limit may be carried as a parallel calculation to define peak temperatures. This calculation is performed when the initial density for the peak node (FDEN95) is less than that of the other fuel (FRDEN). A special peak node power history may also be input through the variable POW95. If a specific power history is not entered through POW95, the axial peak power from the standard power history is used for this node. The coolant temperature associated with the standard power history peak node is used for the peak temperature node. This node has no effect on whole-rod calculations such as fission gas release or cladding axial irradiation growth.

2.3.3 Cladding Axial Irradiation Growth

The cladding irradiation axial growth model developed for the MATPRO material properties handbook[7] has been added to GT2R2. This model was added for the purpose of improving the free volume calculation used for the gas pressure calculation. The model is:

$$\frac{\Delta L}{L} = A\,[\exp(240.8/T)]^{1/2}\,(\phi t)^{1/2}\,(1 - 3f_z)\,(1 + 2CW)$$

where, $\frac{\Delta L}{L}$ = fractional change in cladding length due to irradiation growth

A = 1.407E-16 $(n/m^3)^{-1/2}$

T = cladding temperature (K)

ϕ = fast neutron flux, E > 1 MeV $(n/m^2\text{-}s)$

t = time (s)

f_z = texture factor for the tubing axis (typically equal to 0.05)

CW = cold work (fraction of cross-sectional area reduction)

The model is applied by calculating the irradiation growth for each step using the total fluence (ϕt) received from the start of irradiation. The fast neutron flux for each time step is calculated using FLXFAC * PAVG (PAVG is the rod average linear heat rate).

2.3.4 Gas Thermal Conductivity

The gas thermal conductivity coding was removed from the main program and placed into the new subroutine GASCON. In addition to the original GT2 method of calculating gas thermal conductivity,[1] the MATPRO-11[7] formulation has been added as an option. The MATPRO option has been added for comparisons to codes that use this model.

The MATPRO-11 method of calculating gas thermal conductivity consists of correlations for the pure noble gases and a weighting function that combines the thermal conductivity of the pure gases to obtain the thermal conductivity of a gas mixture. The correlations for the pure gases are of the form:

$$k = AT^B$$

where, k = thermal conductivity (W/m-K)
T = gas temperature (K)
A,B = constants for each particular gas

The thermal conductivity of the gas mixture is then calculated by:

$$k_{mix} = \sum_{i=1}^{n} \frac{(k_i x_i)}{x_i + \sum_{\substack{j=1 \\ j \neq i}}^{n} c_{ij} x_j}$$

where,

$$c_{ij} = f_{ij} \left[1 + 2.41 \frac{(M_i - M_j)(M_i - 0.142 M_j)}{(M_i + M_j)^2} \right]$$

$$f_{ij} = \frac{\left[1 + \left(\frac{k_i}{k_j} \right)^{1/2} \left(\frac{M_i}{M_j} \right)^{1/4} \right]^2}{2^{3/2} \left(1 + \frac{M_i}{M_j} \right)^{1/2}}$$

n = number of components in mixture
M_i = molecular weight of component i (kg)
x_i = mole fraction of component i
k_i = thermal conductivity of component i (W/m-K)

The MATPRO gas thermal conductivity is used when KGAS = 1; the default gas thermal conductivity (KGAS = 0) is the original GT2 model.

2.3.5 Temperature Jump Distance

The temperature jump distance coding has been removed from the main program and placed in the new subroutine JUMPD. The method of calculating jump distance (G1PG2) has not been changed.

2.3.6 Gap Conductance

The gap conductance coding has been removed from the main program and placed in the new subroutine GAPCON. The method of calculating gap conductance (HGC) has not been changed.

2.3.7 Fuel Radial Power Profile

A subroutine named RADAR was added to calculate the burnup dependent radial power profile for each axial node. Also added was the function BES to calculate the Bessel functions needed by RADAR. RADAR is a modified version of the RADAR code developed by British Nuclear Fuels Ltd. A description of the RADAR model may be found in Reference 8. The modifications to the original coding of RADAR were performed by PNL staff.

The default values of resonance escape probability (variable ESCAPE) used by RADAR assume no void fraction in the coolant. Since BWR's do have a significant void fraction, an option has been added to calculate the resonance escape probability accounting for this, if desired. Strawbridge[9] has developed an expression for ESCAPE based on coolant density and this correlation is provided in Subroutine VOIDP. This subroutine calculates a value of the resonance escape probability for use in RADAR rather than using the BWR default values.

The default radial power profile model (NFLX = 0) is the original GT2 model in Subroutine DEPRES. The RADAR option is selected by setting NFLX < -1; see Appendix A for further discussion.

2.3.8 Fission Gas Release

GT2 was originally developed using the Beyer-Hann fission gas release model.[10] This model was then modified with the NRC high burnup correction.[11] A major addition to GT2R2 is the ANS-5.4 fission gas release model.[12] The diffusion coefficients used in ANS-5.4 have since been modified[13] to provide better comparisons to data at intermediate burnup levels. The user has the option of using any of these four fission gas release models.

The default fission gas release model (IGAS = 0) is the Beyer-Hann model with the NRC high burnup correction. The other models are selected by setting IGAS ≠ 0; see Appendix A.

2.3.9 Error Checking

Subroutine CHECK has been added to check for several error conditions prior to the execution of the coding. If an error condition is detected, an error message is printed out and the run is stopped. The conditions that are checked are: sorbed gas fractions not adding to 1.; time steps of less than 1/100 day (non-fatal error); selection of a valid fission gas release model; excessive size of problem when using the ANS-5.4 fission gas release model; and equivalent diameter and coolant velocity being provided through input when a cladding-coolant heat transfer coefficient has not been specified.

2.3.10 Variable Initialization

Subroutine INITAL has been added to perform a series of initializations that were previously located in the main program. These initializations include: calculating supplementary dimensions from the input data; calculating number densities; calculating coolant saturation temperature; determining time steps from input burnup; loading fuel and cladding properties into the proper arrays; and zeroing of some variables.

2.4 CHANGE IN INPUT

The changes that were required to make GT2R2 an ANSI-standard code are evident to the user only when providing the data necessary for the code to operate. This is because the previous method of data input, NAMELIST, is non-ANSI. Therefore, NAMELIST input has been replaced by a formatted data input. An effort was made to keep the new input method as simple and flexible as possible; details of the new data input method are provided in Appendix A. The new method maintains a significant amount of the flexibility offered by NAMELIST while also allowing the user the option of including comments with the input data.

To implement the new data input method, Subroutine INPUT was written. This subroutine calls a new routine which initializes all input variables to their default values (Subroutine INIT), reads the input data deck, provides a card image output of the data deck, and lists the values of all input variables. The option to enter multiple jobs (stacked cases) through one input deck is not available.

Separate from the change of format for data input, other changes have also been made relative to earlier versions of the code. These changes involve variables that have been removed, added, or modified:

Removed:
- ISTOR; GT2R2 now automatically calculates and prints out fuel stored energy.
- IRELSE; the option to release fission gas after a time step, rather than during a time step.
- KOOL; the option to set the cladding inner surface temperature equal to the coolant temperature.
- HBC, DBO, KB; the option to have a basket external to the cladding.

Added:
- KPRFIL increases the flexibility in specifying the time dependence of the axial power pofiles. The number of different profiles is entered through NPRFIL and KPRFIL then specifies which profile is used for which time step.
- FZ and CW; parameters used in calculating the cladding irradiation axial growth; FZ is the texture factor and CW specifies the cold work.
- FLXFAC; specifies the conversion factor to determine fast ($E > 1$ MeV) neutron flux from linear heat generation rate; used for both cladding creepdown and irradiation axial growth.
- HRUL; specifies whether time hardening or strain hardening is to be used in calculating cladding creepdown.
- IEXPND; specifies which fuel radial thermal expansion model is to be used.
- FDEN95; specifies starting fuel density (fraction of theoretical) for peak temperature node.
- POW95; specifies axial region linear heat generation rate for peak temperature node.
- PITCH; specifies pitch of square array of fuel rods for calculating coolant void fraction dependent resonance escape probability for use with RADAR.

- RHOH2O; specifies axial change in coolant density for calculating coolant void fraction dependent resonance escape probability for use with RADAR.

- KGAS; specifies gas thermal conductivity model: MATPRO-11 or Bird, Stewart & Lightfoot.

Modified:-IGAS; there are an increased number of fission gas release models which may be selected by this variable.

- NFLX; there are an increased number of radial power profile options which may be selected by this variable.

- ICREP; there are an increased number of cladding creepdown options which may be selected by this variable.

All input variables are further discussed in Appendix A.

2.5 CODING REORGANIZATION

Some reorganization of the coding has been carried out. Principally, a number of calculations have been removed from within the gap conductance convergence loop: cladding temperature, cladding thermal and mechanical properties, cladding creepdown, and cladding thermal expansion.

A reorganization of COMMON blocks has been performed; alphabetization and removal of unneeded variables. In some subroutines/functions a COMMON block has been removed because only one or a few variables were actually used; the required variables are now carried through the call list.

An extensive number of comments have been added to the coding. These comments help clarify the logic of the coding and identify variables (including units).

3.0 BENCHMARKING OF GT2R2

Three topics are presented in this section: a discussion of some of the major model changes; a presentation of cases for the code benchmarking; and the results of the benchmarking exercise. While reviewing the following data and code comparisons, it should be kept in mind that each of the physical models in the code were developed independently of each other; therefore, the code as a whole has not been tuned to any particular data set.

3.1 MAJOR MODEL CHANGES

3.1.1 Fuel Relocation

The new fuel relocation model was developed because of concerns about the behavior of the original model and its impact on calculated fuel temperatures.(3) Major concerns have been significant overpredicting of temperature at beginning-of-life and the underpredicting of temperature later-in-life. The fuel relocation calculated as a function of linear heat generation rate for the two models is presented in Figure 1. Note that the new model provides considerably more relocation at beginning-of-life and will therefore reduce beginning-of-life calculated temperatures. Calculated fuel relocation as a function of burnup for the two models is presented in Figure 2. Note that after 1.0 MWd/kgM the new model provides less relocation than the original model, and therefore will provide higher temperatures later-in-life.

3.1.2 Cladding Creepdown

Prior to GT2R2, cladding creepdown was entered as a table containing time and cladding diametral change due to creepdown. This table was based on either measured creepdown or separate calculations of creepdown. Cladding creepdown in GT2R2 may now be calculated within the code using the equations developed for the BUCKLE code.(4) To check the calculated creepdown, creepdown for Rod PA/29-4 (see Sections 3.2 and 3.3) was compared to the creepdown calculated by BUCKLE using the same pressures and power history. The results of this comparison are presented in Figure 3. Good agreement is evident until fuel-cladding contact is calculated by GT2R2 (point of curve flattening). BUCKLE also calculates a slight reversal in creepdown after the rod internal gas pressure exceeds the external coolant pressure; this is not duplicated in the GT2R2 run because cladding creepdown has been turned off due to the fuel-cladding contact. GT2R2 and BUCKLE creepdown are compared for Rod 386 (a PWR rod, see Sections 3.2 and 3.3) in Figure 4. Again, a good agreement is obtained.

3.1.3 Gas Thermal Conductivity

The subroutine GASCON includes two gas thermal conductivity models: the model originally in GT-2[1] and the model from MATPRO-11.[7] These twc models use slightly different pure gas thermal conductivities and mixing correlations. After a comparison to some published gas thermal conductivity data, it was concluded that there is probably not a major effect upon the integral calculations from using one model over the other. However, as may be seen by comparing Figures 5 and 6, the MATPRO correlation provides a smaller standard error than the GT-2 correlation. For some gas mixtures, the difference in gas thermal conductivity between the two models may approach 10%; however, the agreement is usually better. Both models are provided in the GT2R2 coding for the users option.

3.2 BENCHMARKING CASES

To qualify the changes to GT-2 to produce GT2R2, the code has been compared to a number of well-characterized data sets. This exercise is to help define where the code provides "good" predictions of fuel rod behaviour and where those predictions are not so good. Two areas of fuel rod performance are of principal concern: fuel temperatures and fission gas release.

Data sets have been selected from four reactors for this benchmarking exercise. From the Halden Boiling Water Reactor, rods from assemblies IFA-432,[14,15] IFA-513,[16] IFA-527,[17] IFA-517,[18] and IFA-11[19] have been selected. Additional data sets include two rods that were irradiated at Riso,[20] two rods that were irradiated in the BR-3 reactor,[21] and one rod that was irradiated in the Zorita reactor.[22] A compilation of rod design and instrumentation may be found in Table 1. The reasons for selecting the various data sets are presented in Table 2.

GT2R2 has been run with three basic sets of options for the benchmarking calculations. The first case (Case 1) uses the original fuel relocation model (IRELOC = 1) and the modified ANS-5.4 fission gas release model (IGAS = 3). The second case (Case 2) uses the new fuel relocation model (IRELOC = 2) and the modified ANS-5.4 fission gas release model. The third case (Case 3) uses the new fuel relocation model and the Beyer-Hann fission gas release model without the NRC high burnup correction (IGAS = 1). Radial power profiles as calculated by RADAR were used for all three cases (based on the appropriate reactor type). Also used for all three cases were the original fuel radial thermal expansion model and the original gas thermal conductivity model. Cladding creepdown, as calculated by CREEP, was used for some of the benchmarking cases. A summary of input parameters for the various cases is presented in Appendix B.

TABLE 1. Rod Design and Instrumentation for Benchmarking Data Sets

Reactor	Assembly	Rod	Fuel O.D. (µm)	Diametral Gap (µm)	Fuel Density and Stability[a]	Initial Gas and Pressure	Instrumentation[b]
Halden	IFA-432	1	10.68	230	95% TD, S	100% He, 1 atm	2 TC, EC, PF
Halden	IFA-432	5	10.68	230	92% TD, S	100% He, 1 atm	2 TC, EC, PF
Halden	IFA-432	6	10.68	230	92% TD, U	100% He, 1 atm	2 TC, EC, PF
Halden	IFA-513	1	10.68	230	95% TD, S	100% He, 1 atm	2 TC, EC, PF
Halden	IFA-513	2	10.68	230	95% TD, S	100% He, 3 atm	2 TC, EC, PF
Halden	IFA-513	4	10.68	230	95% TD, S	92% He, 8% Xe, 1 atm	2 TC, EC, PF
Halden	IFA-513	6	10.68	230	95% TD, S	77% He, 22%, 1 atm	2 TC, EC, PF
Halden	IFA-527	1	10.68	230	95% TD, S	100% Xe, 1 atm	2 TC, EC, PF
Halden	IFA-517	R1	10.26	250	95.5% TD, S	100% He, 1 atm	TC, EC
Halden	IFA-11	HBA	12.54	50	98% TD, S	100% He, 1 atm	TC
Halden	IFA-11	HBC	12.42	175	96% TD, S	100% He, 1 atm	TC
Riso	--	PA/29-4	12.60	240	95% TD, S	100% He, 1 atm	--
Riso	--	M2-2C	12.60	240	95% TD, S	100% He, 1 atm	--
BR-3	--	111I5	9.29	185	95% TD, S	100% He, 14.6 atm	--
BR-3	--	36I8	9.29	190	94.5% TD, S	100% He, 14.6 atm	--
Zorita	--	386	9.32	160	95% TD, S	100%, 34 atm	--

(a) S = stable fuel with respect to densification
U = unstable fuel with respect to densification

(b) TC = fuel centerline thermocouple
EC = cladding elongation
PF = rod internal gas pressure.

TABLE 2. Benchmarking Data Set Selection Reasons

Reactor	Assembly	Rod	Reason
Halden	IFA-432	1	Well qualified in-reactor thermal performance data.
Halden	IFA-432	5	Rod 1 is standard design for NRC/PNl test series.
Halden	IFA-432	6	Rod 5 is standard design with lower density fuel. Rod 6 is standard design with densifying fuel.
Halden	IFA-513	1	Well qualified in-reactor thermal performance data.
Halden	IFA-513	2	Rod 1 is standard design for NRC/PNL test series.
Halden	IFA-513	4	Rod 2 has increased initial helium. Rods 4 and 6
Halden	IFA-513	6	have known initial degradation to initial fill gas thermal conductivity: 75 and 50% of pure helium, respectively.
Halden	IFA-527	1	Matches NRC/PNL standard rod, but with minimum fill gas thermal conductivity.
Halden	IFA-517	R1	Well qualified in-reactor thermal data for BWR design slightly different than NRC/PNL test series. EOL fission gas release.
Halden	IFA-11	HBA HBC	Well documented beginning-of-life temperatures
Riso	--	PA/29-4 M2-2C	EOL fission gas release, detailed power history
BR-3	--	111I5 36I8	EOL fission gas release, detailed power history, length increase
Zorita	--	386	EOL fission gas release, detailed power history, diametral creepdown

3.3 BENCHMARKING RESULTS

3.3.1 IFA-432

The irradiation of IFA-432 had peak linear heat generation rates of near 50 kW/m at beginning-of-life with some rods being irradiated to a rod average burnup of over 35 MWd/kgM.[14] By both thermocouple and pressure data it was observed that the rods of IFA-432 experienced thermal feedback by a burnup of approximately 10 MWd/kgM.

Comparison of the as-measured centerline temperatures to the calculated temperatures from the three GT2R2 cases may be found in Figures 7-12. PIE has been performed on Rods 1 and 6[15] and the measured fission gas release is compared to the calculated fission gas release in Table 3. In general, Case 1 (original fuel relocation and modified ANS-5.4 fission gas release) provides the best comparison to the as-measured temperature data.

For the upper thermocouple of Rod 1 (Figure 7), Case 1 predicts temperatures that are initially less than the data. At end-of-life the Case 1 and Case 2 temperatures are in fairly close agreement while the Case 3 predicted temperatures are considerably less. For the lower thermocouple (Figure 8), the Case 1 temperatures are generally closest to the data until a burnup of approximately 25 MWd/kgM at which point the Case 3 temperatures become closest. The Case 2 temperatures are considerably greater than the data for the entire irradiation.

For the upper thermocouple of Rod 5 (Figure 9), Case 3 provides the best comparison to the limited as-measured temperature data. For the lower thermocouple though (Figure 10), Case 2 provides the best temperature comparison until a burnup of approximately 7 MWd/kgM. Beyond this burnup, Case 1 provides the best comparison to the data, though overpredicting the data. The Case 3 temperatures are generally 50 C higher than the Case 1 temperatures.

TABLE 3. Measured and Calculated Fission Gas Release for IFA-432

Rod	Measured FGR, %	Calculated FGR, % Case 1	Case 2	Case 3
1	18-22	23.0	31.1	6.4
5	6-10[a]	17.7	30.0	3.5
6	23-29	70.3	84.1	46.1

(a) Estimated from rod internal gas pressure data.

The Rod 6 comparisons (Figures 11 and 12) are considerably different. All three calculated cases greatly overpredicted the temperatures for this rod with densifying fuel. This is also seen in the high calculations of fission gas release. It is believed that even though this rod had high fuel densification, the fuel-cladding gap was still sufficiently closed as to keep fuel temperatures down. This is not reflected in the calculations.

3.3.2 IFA-513

In general, the irradiation of IFA-513 was fairly mild with peak linear heat generation rates of approximately 40 kW/m over the majority of the irradiation.(16) This is reflected in the irradiation data by as-measured fuel centerline temperatures that remained fairly constant, with only very slight increases, during the iradiation. Moderate gas pressure increases were recorded with estimated fission gas release for all rods being 1-2%. This corresponds with the steady temperatures resulting from the absence of thermal feedback, i.e., no significant fission gas release contaminating the helium and raising fuel temperatures.

Calculations were performed for the IFA-513 rods using all three cases. The measured and calculated temperatures are compared in Figures 13-20. In general, there is a difference in the comparison for the upper and lower thermocouples. A comparison of fission gas release estimated from pressure data and the calculated fission gas release is presented in Table 4.

For the upper thermocouples (rod peak LHGR), Case 1 resulted in an initial overprediction of temperatures followed by temperatures quickly dropping to slightly less than the data for burnups less than 7 MWd/kgM. The Case 1 predicted temepratures are considerably less than the data (100-200°C) for burnups greater than 7 MWd/kgM. Case 2 (same gas fission gas release model, different

TABLE 4. Measured and Calculated Fission Gas Release for IFA-513

Rod	FGR Estimated from Pressure Data, % (ΔP, MPa)[a]	FGR Calculated % Case 1	Case 2	Case 3
1	0.0 (0.0)	2.0	7.4	0.9
2	2.2 (0.069)	1.1	2.0	0.6
4	1.4 (0.043)	1.9	8.0	1.0
6	2.0 (0.063)	4.1	12.9	2.4

(a) Measured pressure increases do not greatly exceed assumed repeatability of the measurements therefore leading to a large uncertainty in the estimated fission gas release.

fuel relocation) calculated temperatures greater than the data throughout the burnup range. The difference in temperature exceeds 200C at some time steps. Case 3 (different fission gas release model) illustrates the importance of fission gas release upon these calculations. Temperatures are similar to those of Case 1, while using the fuel relocation of Case 2. Case 3 may be concluded to generally give the best results for this data comparison with Case 1 also providing generally good results.

For the lower thermocouples (approximately 70% of peak LHGR) Case 1 provided better results than was observed for the upper thermocouples. Conversely, the new relocation model (Case 2) generally overcalculated the temperature data by a greater degree than was seen for the upper thermocouple. Case 3 provided temperature calculations between Cases 1 and 2, while generally overpredicting the data. Again the calculated fission gas release affects the temperature calculations.

The difference in calculated temperatures between the two relocation models when using the same fission gas release model is reflected in the calculated fission gas release as shown in Table 4. This table also reflects the difference obtained by using a different fission gas release model with the same fuel relocation model. Case 3 (new relocation model with Beyer-Hann fission gas release model) generally gives the best agreement with the fission gas release deduced from pressure measurements (1-2%). Case 1 also provides a reasonably good prediction of fission gas release with the exception of Rod 6 which is a little high.

3.3.3 IFA-527

Beginning-of-life centerline temperatures as a function of linear heat generation rate are of interest for this case. Because of the xenon fill gas, maximum temperatures are present for the rod design (same design as the IFA-432 fuel rods). Fuel centerline temperatures were obtained for rods operating in both the unfailed and failed (steam as fill gas) condition.[17] Fuel relocation .as been found to have the most impact on calculated temperatures for this rod.

Because calculated fission gas release has no effect on the calculated temperatures for this rod, only GT2R2 Cases 1 and 2 were run for the benchmarking. Case 3 temperatures will be identical to Case 2 temperatures because relocation models are the same. The calculated temperatures are compared to the measured centerline temperatures for Rod 1 of IFA-527 in Figures 21 and 22. Note that using the original relocation fuel model (Case 1) results in temperatures considerably greater than were measured. The new fuel relocation model (Case 2) provides a much better agreement. This indicates that the new fuel relocation model is more appropriate for rods that have been operated at low power as the IFA-527 rods were.

3.3.4 IFA-517, Rod R1

Centerline temperatures for Rod R1 were obtained through a burnup of 7 MWd/kgM.[18] The thermocouple data presented here have been corrected (bad data removed, thermocouple decalibration applied to the data). No significant fission gas release, as deduced from internal gas pressure measurements, was found for this irradiation.

A comparison of the corrected thermocouple data and calculated temperatures using GT2R2 Cases 1 and 2 may be found in Figure 23. Of major importance here is that the calculated temperatures, from either fuel relocation model, are less than the data. The new fuel relocation model (Case 2) does provide the closest agreement to the data, and matches the data by the end of the irradiation. One possible reason for underpredicting the data at beginning-of-life may be fuel densification. The measured resintering densification was low, and this was used in the calculations. If the in-reactor densification was greater, this could help account for the difference between the data and the calculations.

3.3.5 Rods HBA and HBC, IFA-11

Rods HBA and HBC were one of the early fuel centerline temperature measurement experiments performed at Halden.[19] These rods have since been used extensively in code benchmarking exercises. Fuel centerline temperature data obtained at beginning-of-life as a function of linear heat generation rate (no effect of fission gas release) are of importance here.

GT2R2 Cases 1 and 2 were used for the benchmarking exercises. Comparisons of measured and calculated centerline temperature as a function of LHGR are presented in Figures 24 and 25. The data and calculated temperatures for Rod HBA are in very good agreement, with the calculated temperatures slightly higher than the data at linear heat rates in excess of 350 W/cm. The choice of fuel relocation model for the calculated temperatures makes no difference as fuel-cladding contact is calculated immediately and thus removes any differences due to fuel relocation. For Rod HBC, the old fuel relocation model (Case 1) provides the best comparison of calculated temperature to the data. Note though, that the difference between the data and the new fuel relocation model is decreasing for LHGR greater than 400 W/cm.

3.3.6 Riso

Rods M2-2C and PA/29-4 were irradiated at Riso[20] to a peak burnup of 44 MWd/kgM and to fairly high temperatures. Destructive post-irradiation examination on the rods measured fission gas releases of 35.6% and 48.1%, respectively. Columnar grains were observed to 43% and 47% of the fuel radius for M2-2C and PA/29-4, respectively. The corresponding estimating peak centerline temperatures are 1827 and 1927 C.

Benchmarking calculations using all three GT2R2 cases were performed for these rods. The results of the calculations are compared to the measurements in Tables 5 and 6. For both rods , the calculated fission gas release exceeds the measured when using the modified ANS-5.4 fission gas release model, while the Beyer-Hann fission gas release model without the NRC high burnup correction (Case 3) underpredicts the data. The general agreement in centerline temperature for all three calculations indicates that fuel relocation and fission gas release models have little impact on the calculated temperatures for these high burnup rods. Therefore the calculated fission gas release is nearly exclusively dependent upon the selected fission gas release model.

TABLE 5. Measured and Calculated Results for Riso Rod M2-2C

Parameter	Measured	Calculated		
		Case 1	Case 2	Case 3
Fission Gas Release	35.6%	49.8%	49.8%	18.1%
Peak Centerline Temperature	1827°C[a]	2341°C	2341°C	2300°C
Columnar Grain Growth Radius	43%	N/A	N/A	N/A
Cladding Diametral Creepdown	N/A	<------- 0.005 inch ------->		
Cladding Axial Growth	N/A	<------- 0.05 inch -------->		

(a) Estimated from microstructure.

TABLE 6. Measured and Calculated Results for Riso Rod PA/29-4

Parameter	Measured	Calculated		
		Case 1	Case 2	Case 3
Fission Gas Release	48.1%	57.9%	57.9%	22.8%
Peak Centerline Temperature	1927°C[a]	2299°C	2299°C	2266°C
Columnar Grain Growth Radius	47%	N/A	N/A	N/A
Cladding Diametral Creepdown	N/A	<------- 0.004 inch ------>		
Cladding Axial Growth	N/A	<------- 0.05 inch -------->		

(a) Estimated from microstructure.

3.3.7 BR-3

Rods 111I5 and 36I8 were irradiated as part of a Westinghouse-DOE program in the BR-3 reactor.[21] Rod 111I5 had a measured fission gas release of 14.4% and a measured clad elongation of 0.194 inch at an end-of-life peak burnup of 58 MWd/kgM. Rod 36I8 had a measured fission gas release of 33.8% and a measured clad elongation of 0.263 inch at an end-of-life peak burnup of 72 MWd/kgM.

The benchmark calculations were performed using the three different cases. A comparison between the measured data and the calculational results may be found in Tables 7 and 8. As with the Riso rods, it appears that fuel relocation and fission gas release have a low impact on the calculated temperatures. However, the choice of fission gas release model does have a large effect on the calculated fission gas release.

From these comparisons it appears that the MATPRO-11 cladding irradiation axial growth model is doing a reasonable job. Because the model is fast neutron fluence dependent, changing the factor that relates fast neutron flux to power (FFLUX) can affect the comparison in either direction.

3.3.8 Zorita, Rod 386

Fuel rods in four special assemblies were irradiated in the Jose Cabrera (Zorita) reactor in Spain. Interim non-destructive examinations and a detailed destructive post-irradiation examination were performed.[22] Fuel rod 386 was selected for this benchmarking exercise. Measured fission gas release was 22.6% and cladding diametral creepdown of 0.001 inch was measured at a peak burnup of 57 MWd/kgM.

TABLE 7. Measured and Calculated Results for BR-3 Rod 111I5

Parameter	Measured	Calculated Case 1	Calculated Case 2	Calculated Case 3
Fission Gas Release	14.4%	14.1%	14.1%	4.4%
Peak Centerline Temperature	N/A	2249°C(a)	2249°C(a)	2249°C(b)
Cladding Axial Growth	0.194 inch	<--------	0.212 inch	------->
Cladding Diametral Creepdown	N/A	<--------	0.0025 inch	------>

(a) 2249°C was calculated for the first time step, 2065°C was the peak temperature at a burnup of 14 MWd/kgM.

(b) 2249°C was calculated for the first time step, 2014°C was the peak temperature at a burnup of 14 MWd/kgM.

TABLE 8. Measured and Calculated Results for BR-3 Rod 3618

Parameter	Measured	Calculated		
		Case 1	Case 2	Case 3
Fission Gas Release	33.8%	81.5%	81.5%	4.9%
Peak Centerline Temperature	N/A	1912°C	1963°C	1953°C
Cladding Axial Growth	0.236 inch	<----- 0.312 inch ------>		
Cladding Diameteral Creepdown	N/A	<----- 0.0024 inch ----->		

All three calculational cases were made for this rod. The predicted results are compared to the measured values in Table 9. It is quickly noted that the calculated fission gas release is much less than the measured. This is most probably a result of the low calculated fuel temperatures. The low temperatures are a result of high gap conductance values due to small fuel-cladding gaps and calculated fuel-cladding contact during the peak power segment of the power history. As with the previous high burnup fuel rods (Riso and BR-3) there is little difference in calculated temperatures between the three cases. Also, because of the low calculated temperatures, both fission gas release models predicted relatively low fission gas release.

Calculated cladding creepdown is approximately twice that of the measured creepdown.

3.3.9 Conclusions From Benchmarking Exercise

It is concluded that Case 1 (old fuel relocation and modified ANS-5.4 fission gas release) and Case 3 (new fuel relocation and Beyer-Hann fission gas release) options provide the best predictions of the experimental data set. Case 3 is judged to provide better thermal predictions because of better predictions of the IFA-517 and IFA-527 temperatures. However, it should be

TABLE 9. Measured and Calculated Results for Zorita Rod 386

Parameter	Measured	Calculated		
		Case 1	Case 2	Case 3
Fission Gas Release	22.6%	5.1%	5.1%	2.5%
Peak Centerline Temperature	N/A	1369°C	1370°C	1370°C
Cladding Axial Growth	N/A	<-------- 0.68 inch ------------->		
Cladding Diametral Creepdown	0.001 in.	<-------- 0.0022 inch ----------->		

noted that because of their xenon fill gas the IFA-527 fuel rods are atypical of commercial fuel rods. Because Case 1 provided better fission gas release calculations than Case 3 along with reasonably good thermal predictions, it is concluded that Case 1 provides the best overall thermal and fission gas release predictions of the data set.

If the NRC burnup correction factor had been used with the Beyer-Hann fission gas release model in Case 3, the fission gas release predictions for this case would have been substantially higher and thus closer to the high burnup data. For example, based on past predictions using this fission gas release option, it can be estimated that Case 3 fission gas release predictions would have been similar to the Case 1 predictions for IFA-432 Rods 1 and 5 and the two Riso rods. The two BR-3 rods and Zorita Rod 38b would have been significantly overpredicted, however.

From comparisons to the data it is concluded that the cladding irradiation axial growth model is providing reasonable results, however keep in mind that the calculated growth is dependent upon the flux the cladding is exposed to. The calculated cladding diametral creepdown appears to be consistently greater than that measured; but does match that calculated independently by BUCKLE.

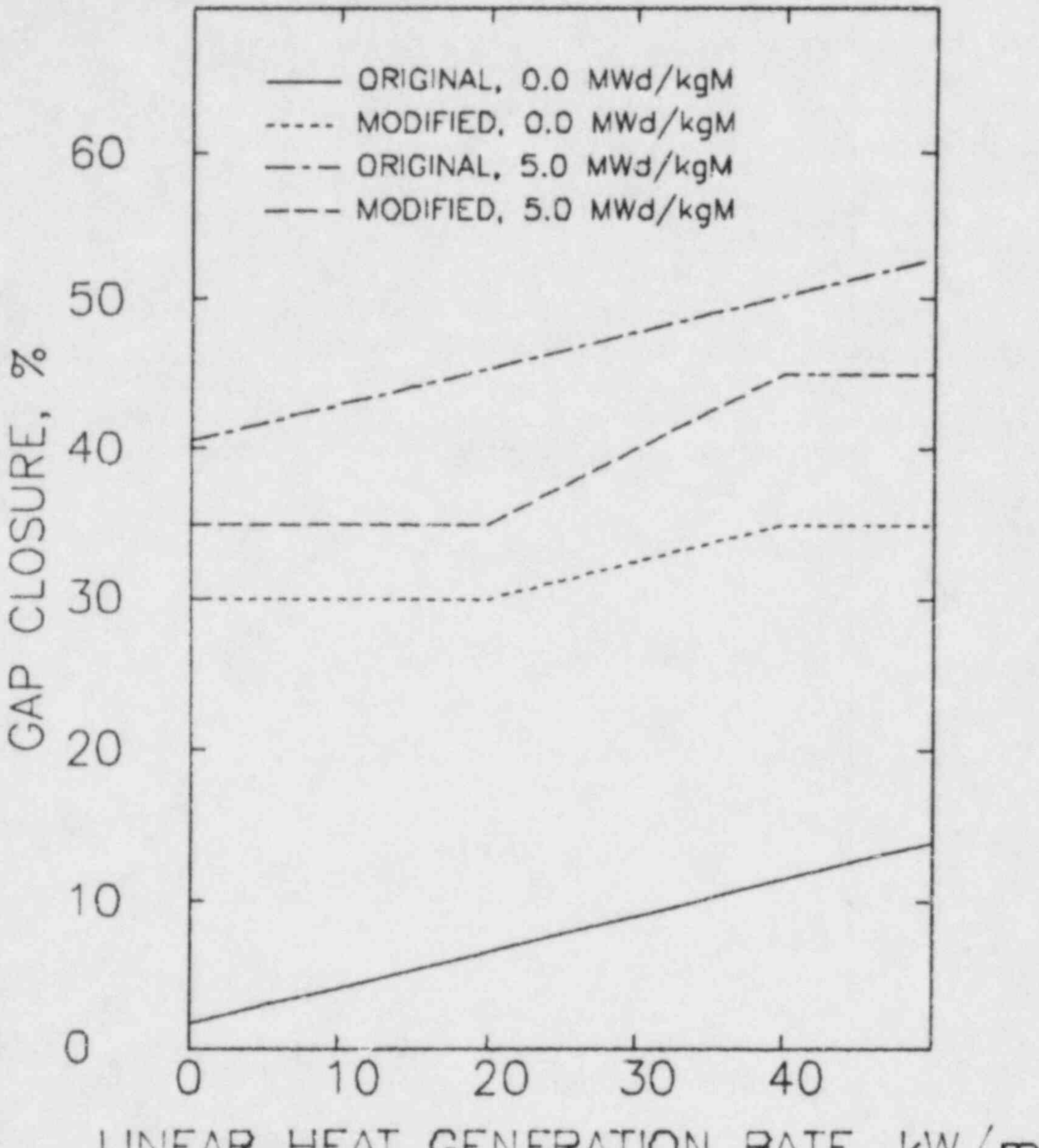

FIGURE 1. Comparison of Original and Modified Relocation Model Predictions of Gap Closure, ΔG/G%, as a Function of Linear Heat Rating at Burnups of 0 and 5 MWd/kgM

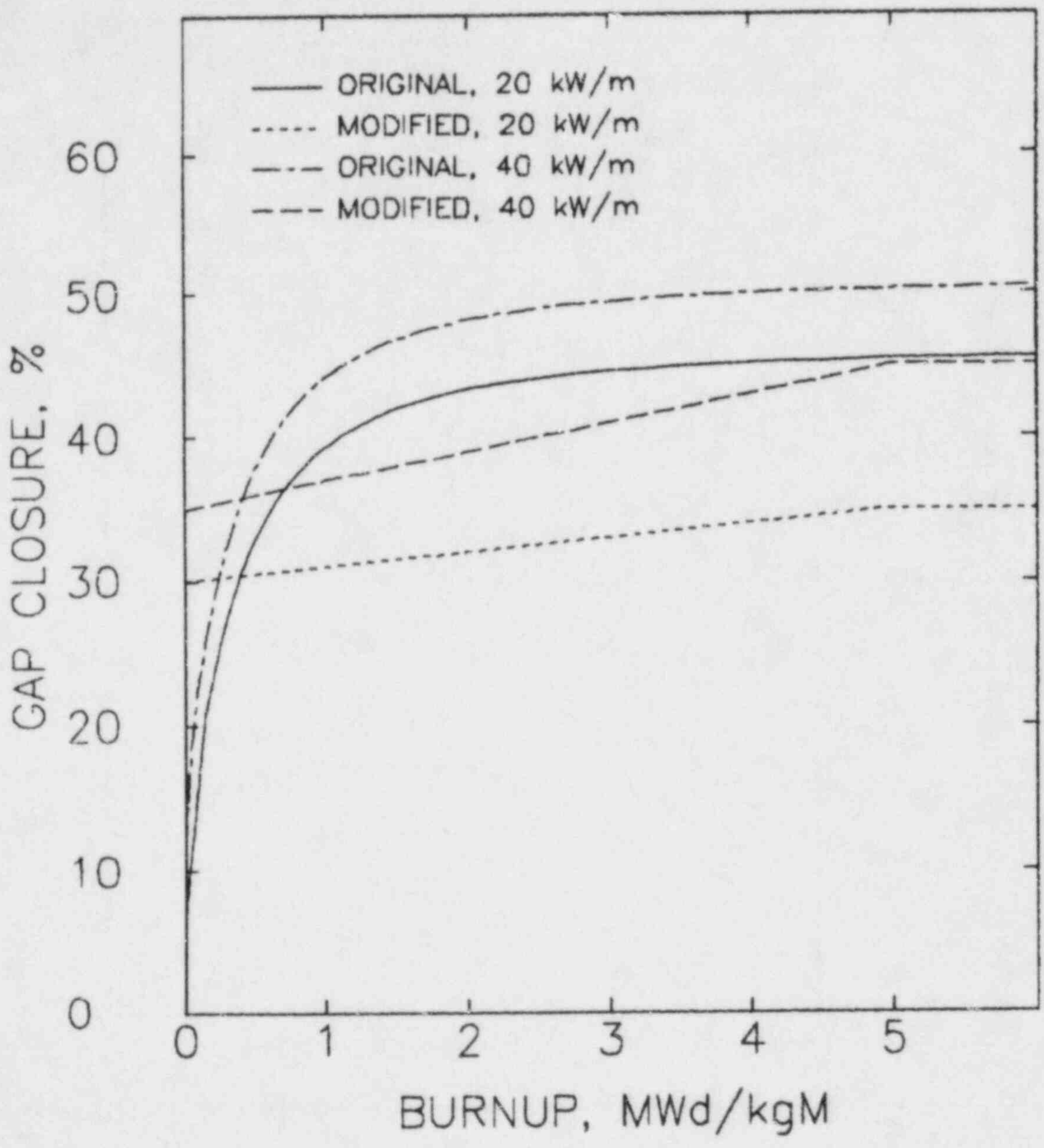

FIGURE 2. Comparison of Original and Modified Relocation Model Predictions of Gap Closure, ΔG/G%,as a Function of Burnup at Heat Ratings of 20 and 40 kW/m

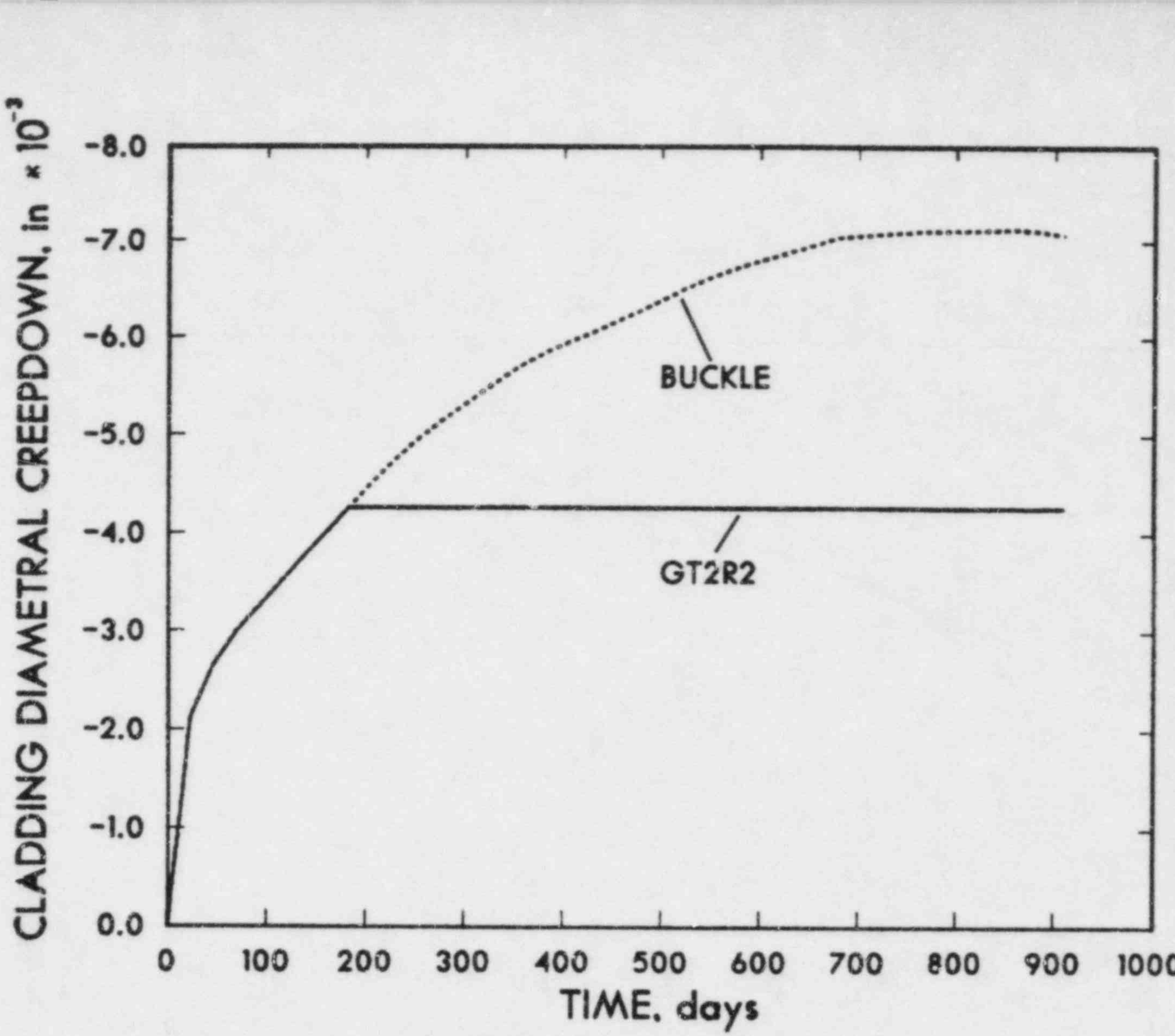

FIGURE 3. Comparison of GT2R2 and BUCKLE Cladding Creepdown for Rod PA/29-4

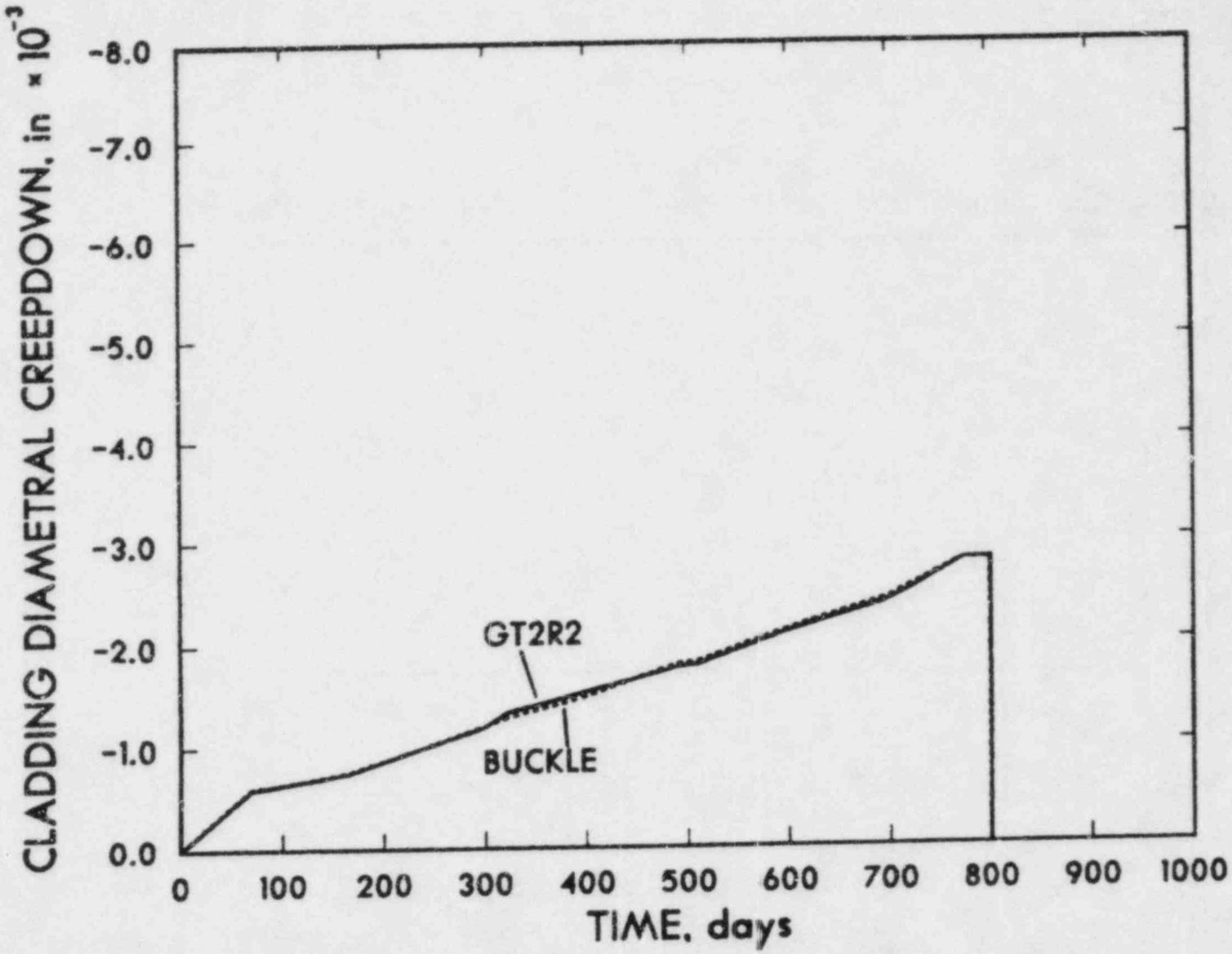

FIGURE 4. Comparison of GT2R2 and BUCKLE Cladding Creepdown for Rod 386

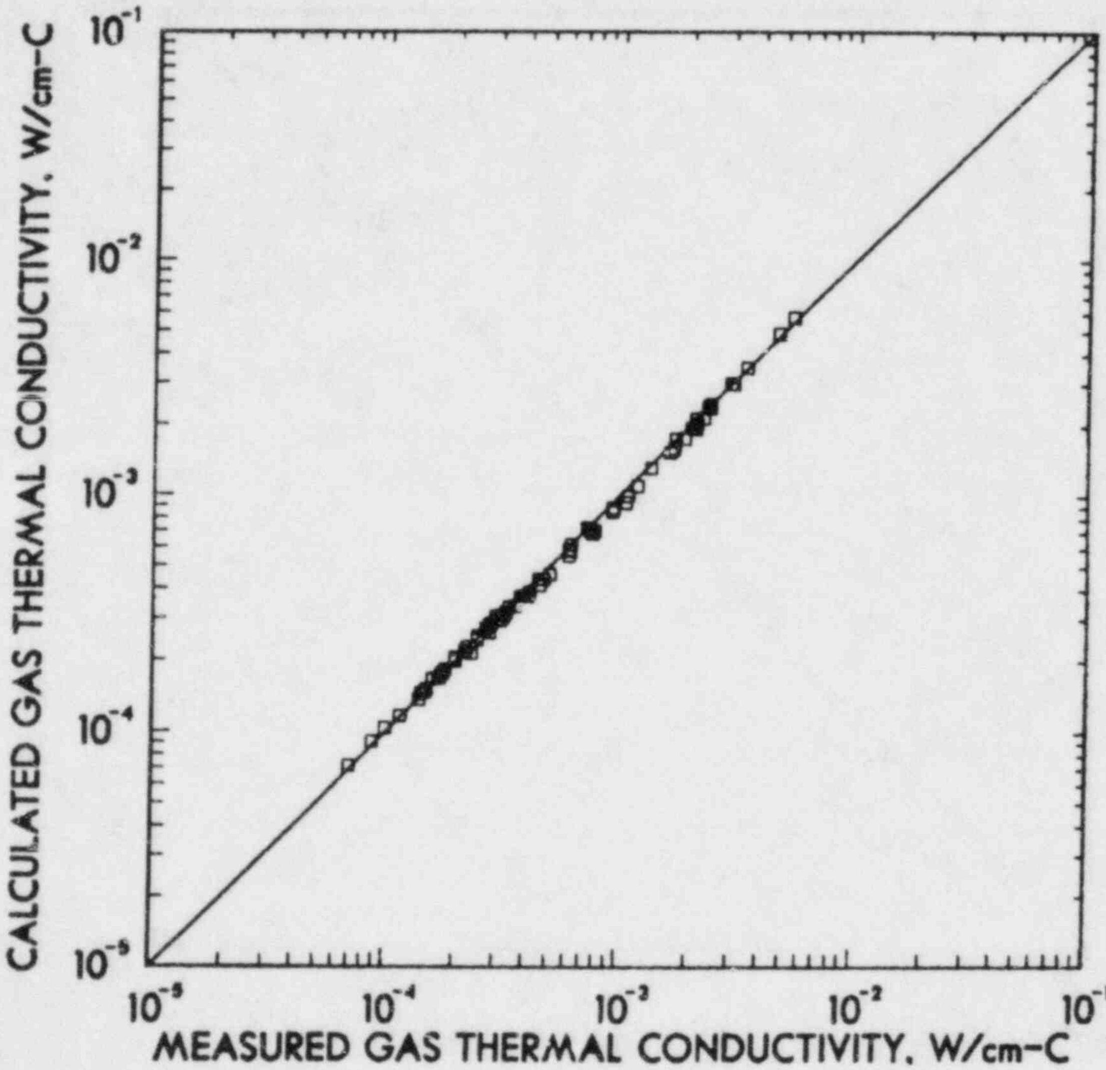

FIGURE 5. MATPRO-11 Gas Thermal Conductivities Compared to Experimental Data

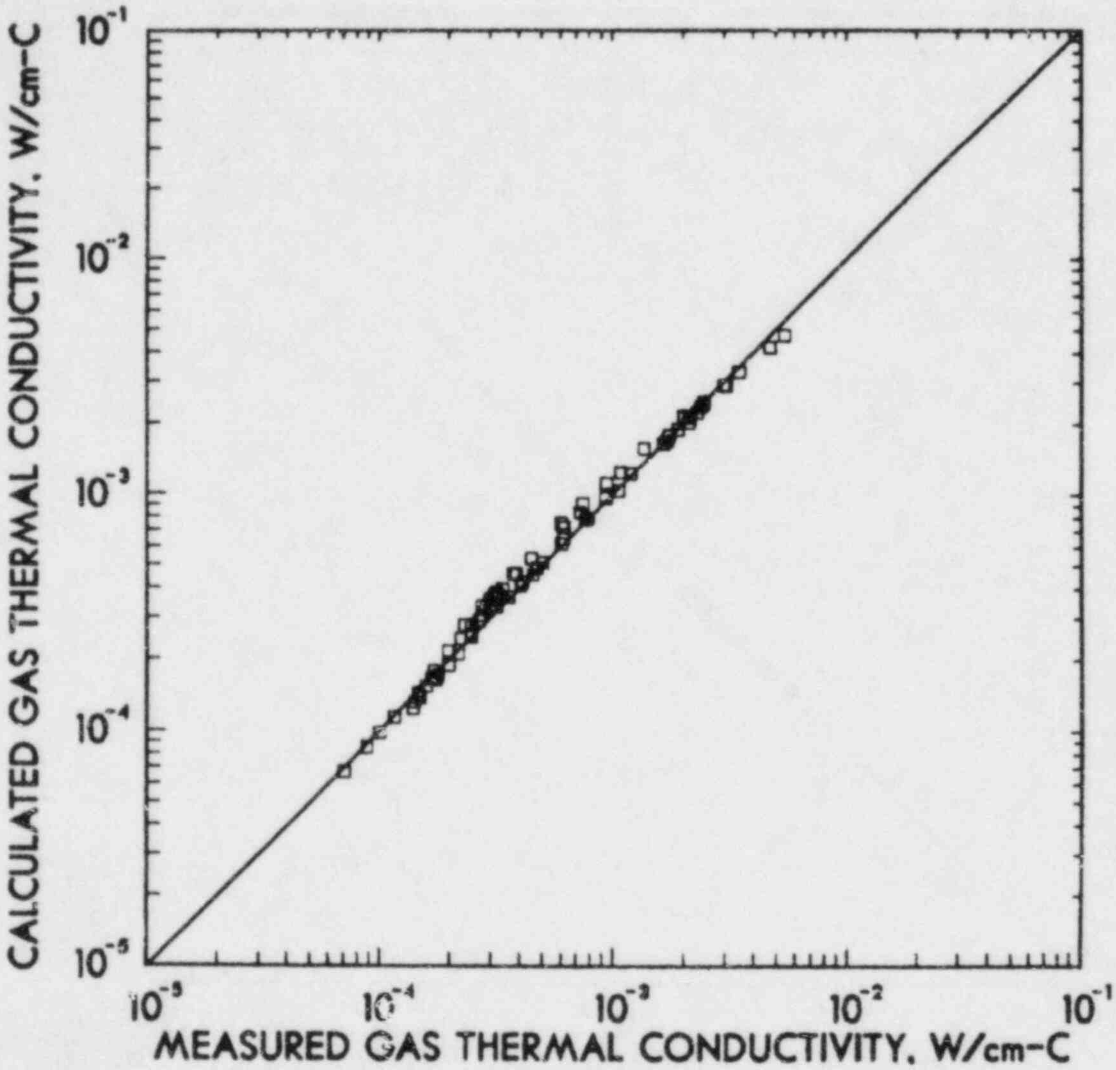

FIGURE 6. Bird, Stewart and Lightfoot Gas Thermal Conductivities Compared to Experimental Data

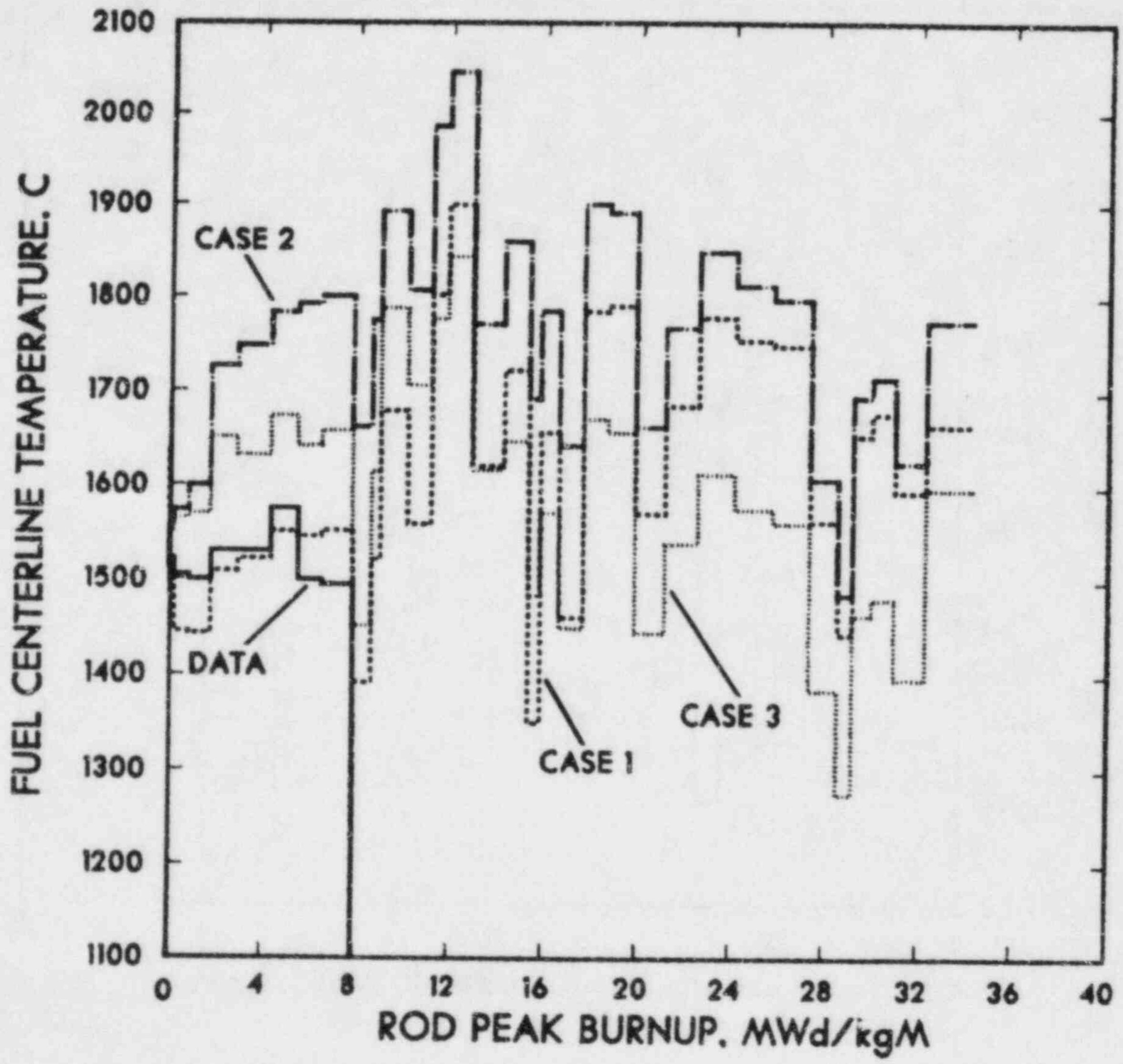

FIGURE 7. GT2R2 Calculations Compared to Rod 1, IFA-432 Upper Thermocouple Data

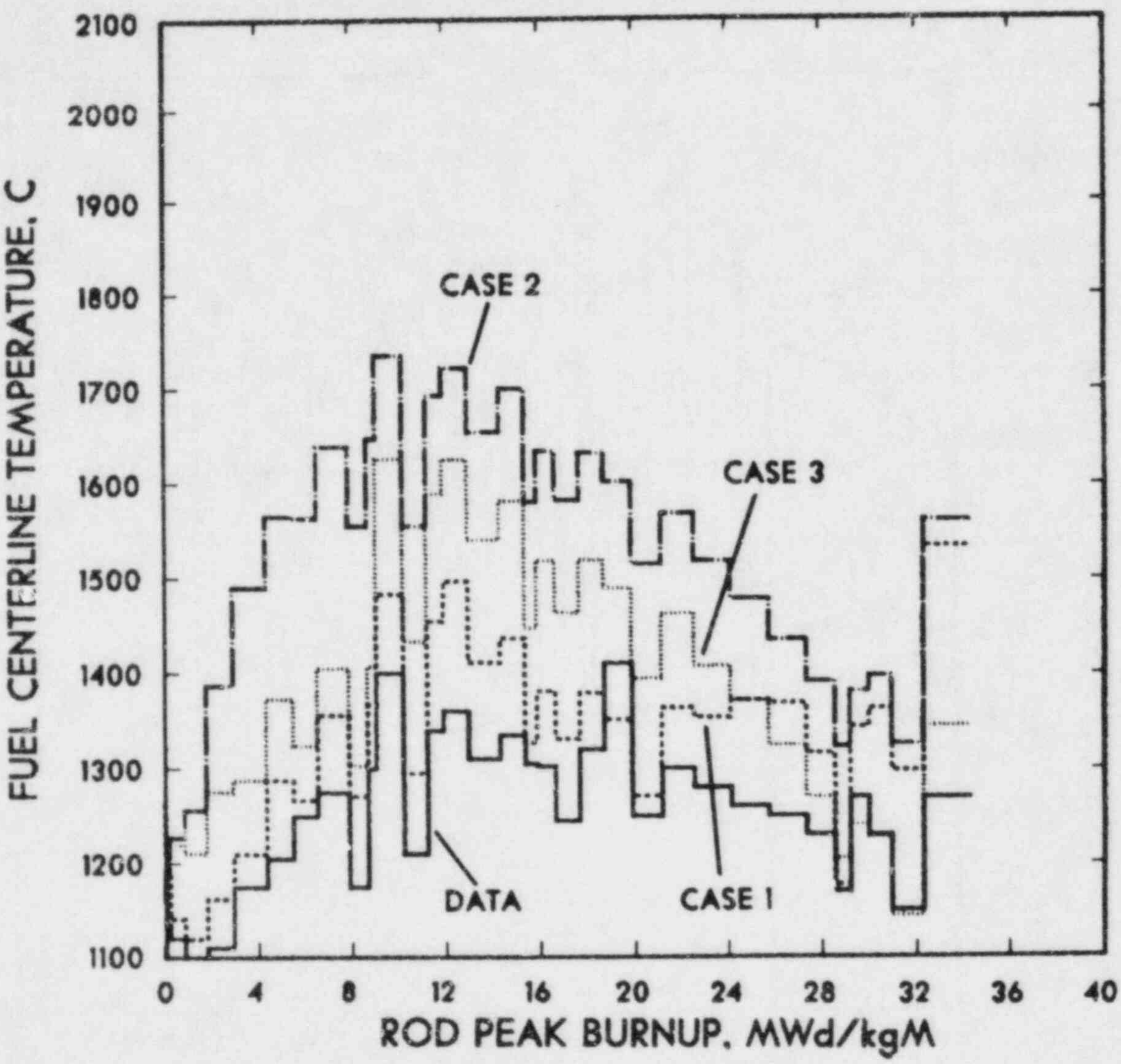

FIGURE 8. GT2R2 Calculations Compared to Rod 1, IFA-432 Lower Thermocouple Data

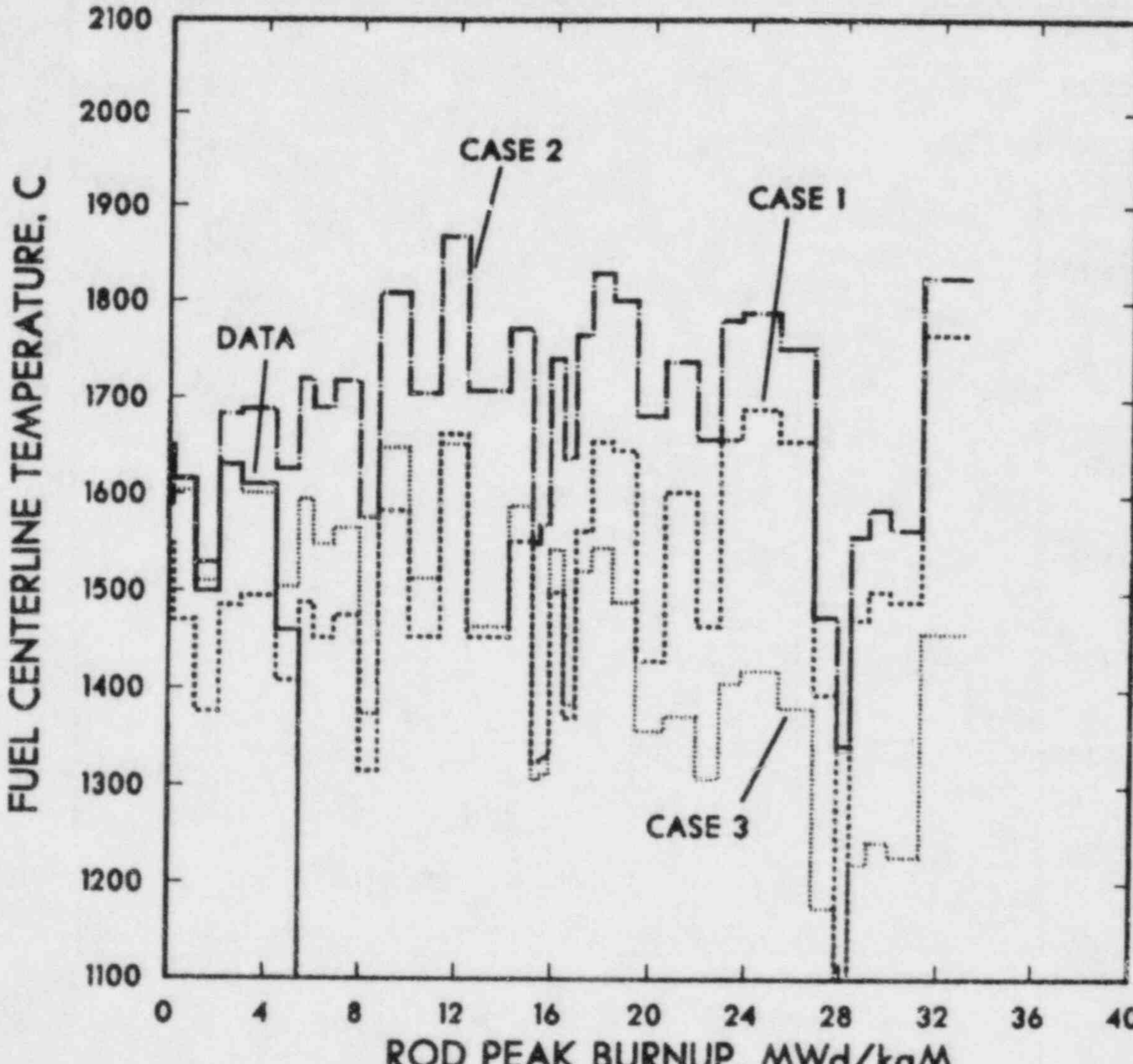

FIGURE 9. GT2R2 Calculations Compared to Rod 5, IFA-432 Upper Thermocouple Data

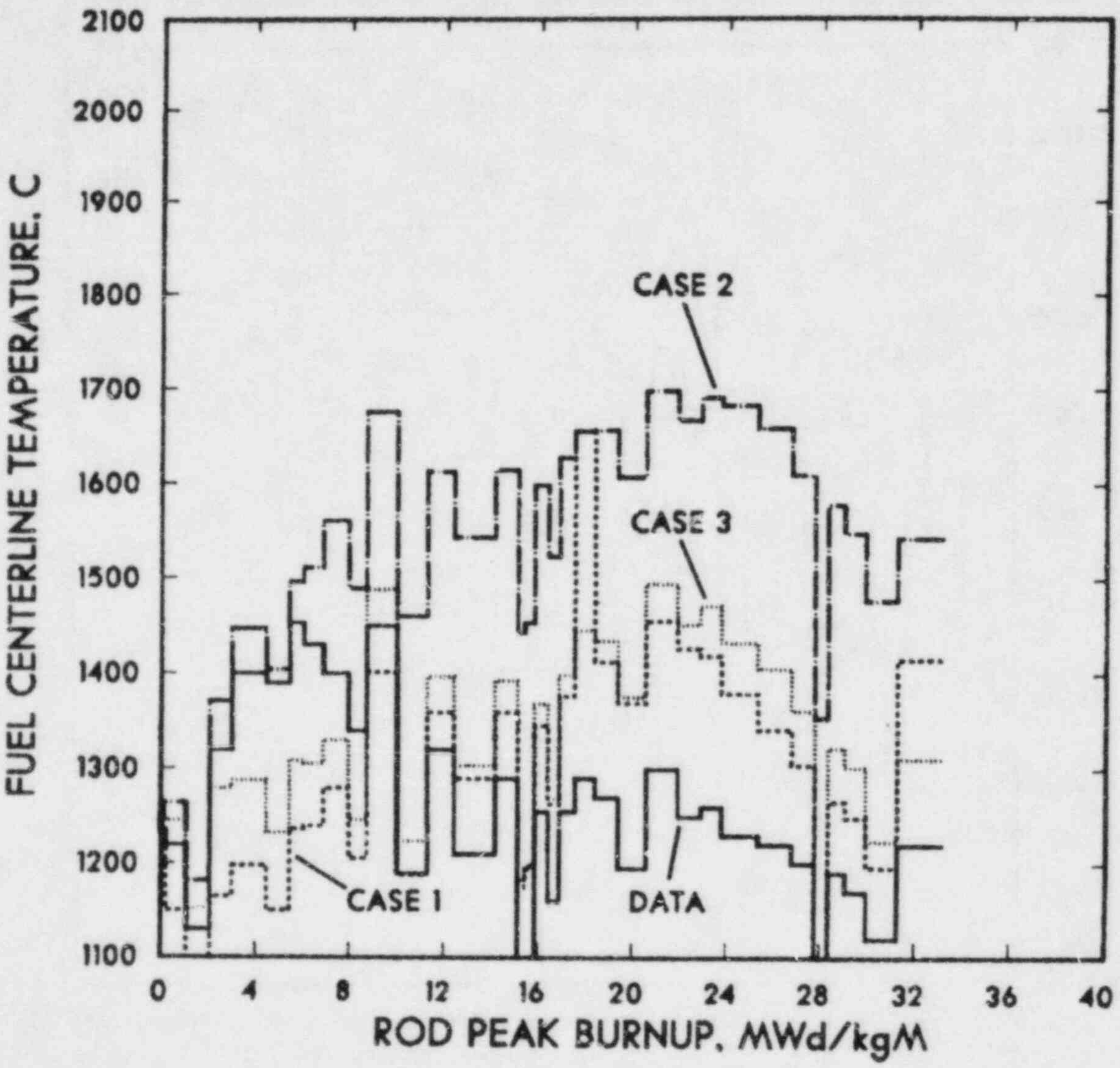

FIGURE 10. GT2R2 Calculations Compared to Rod 5, IFA-432 Lower Thermocouple Data

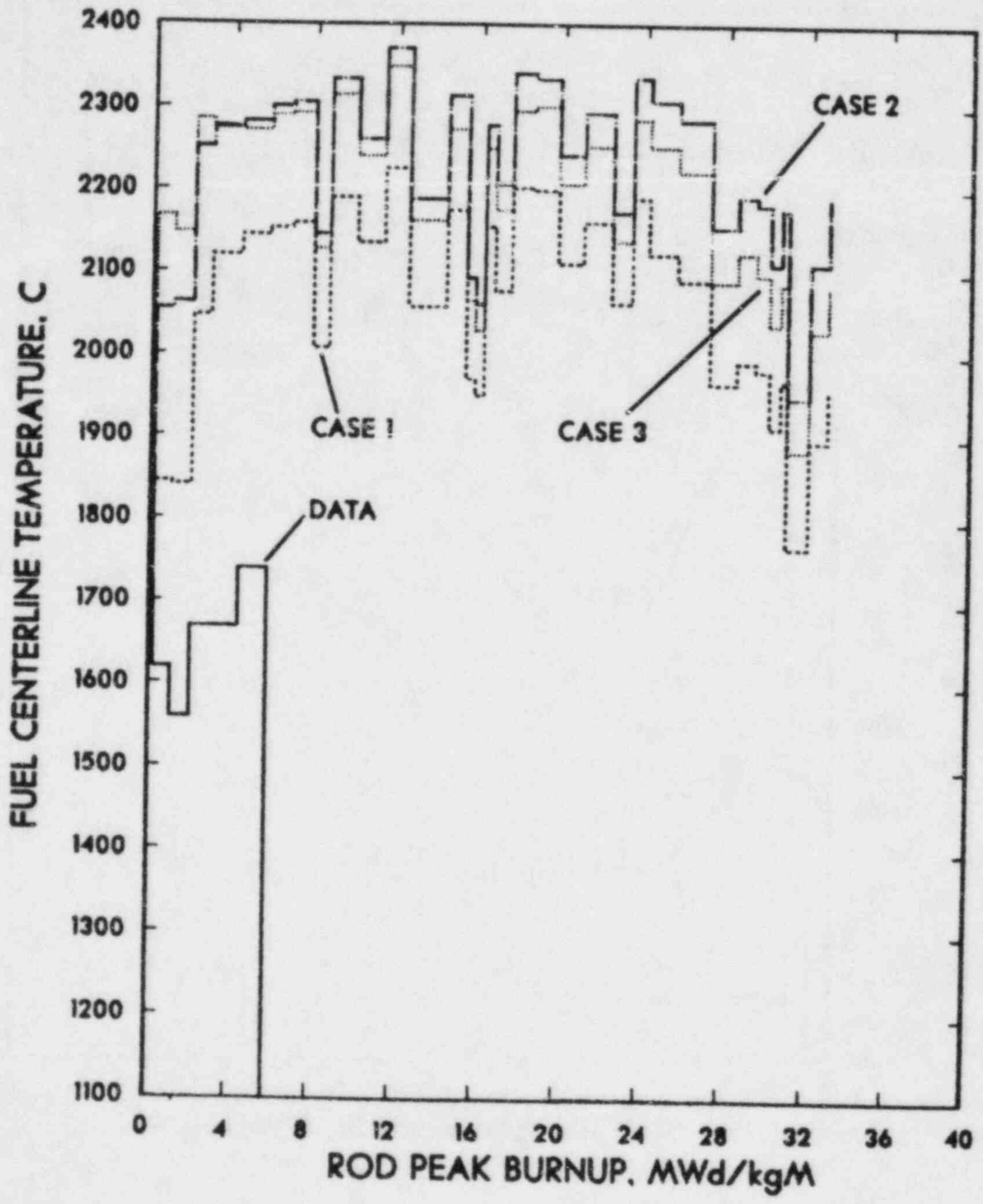

FIGURE 11. GT2R2 Calculations Compared to Rod 6, IFA-432 Upper Thermocouple Data

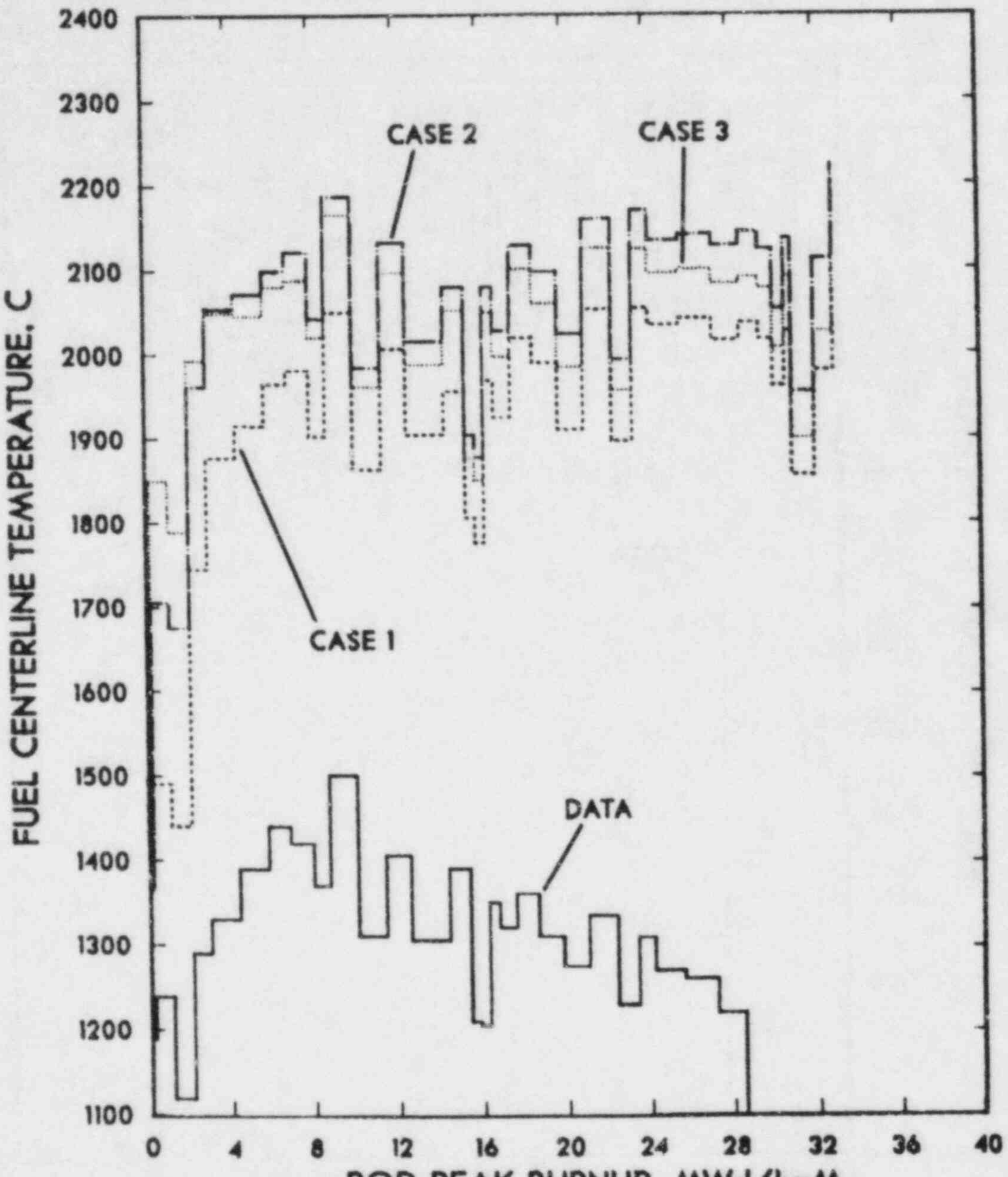

FIGURE 12. GT2R2 Calculations Compared to Rod 6, IFA-432 Lower Thermocouple Data

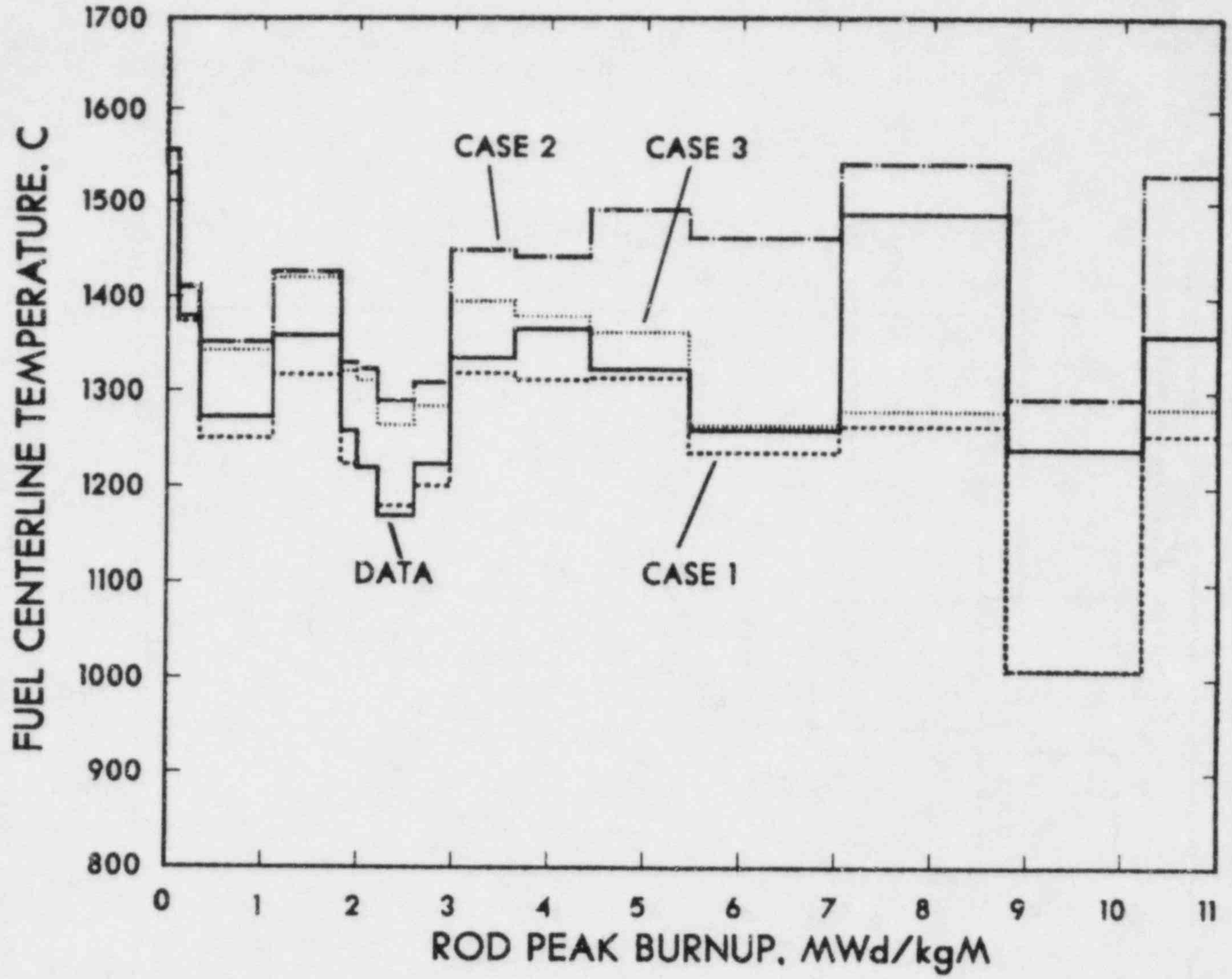

FIGURE 13. GT2R2 Calculations Compared to Rod 1, IFA-513 Upper Thermocouple Data

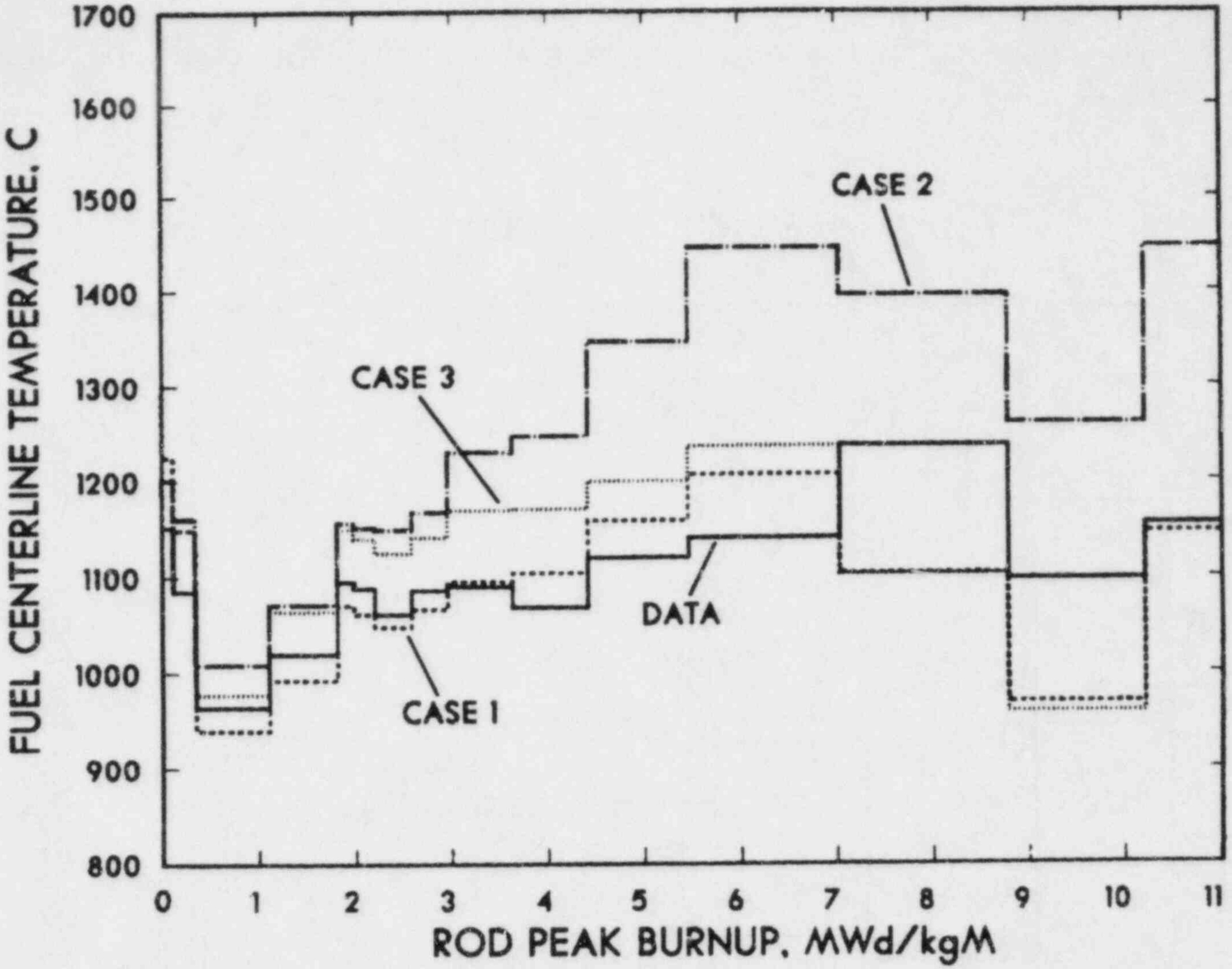

FIGURE 14. GT2R2 Calculations Compared to Rod 1, IFA-513 Lower Thermocouple Data

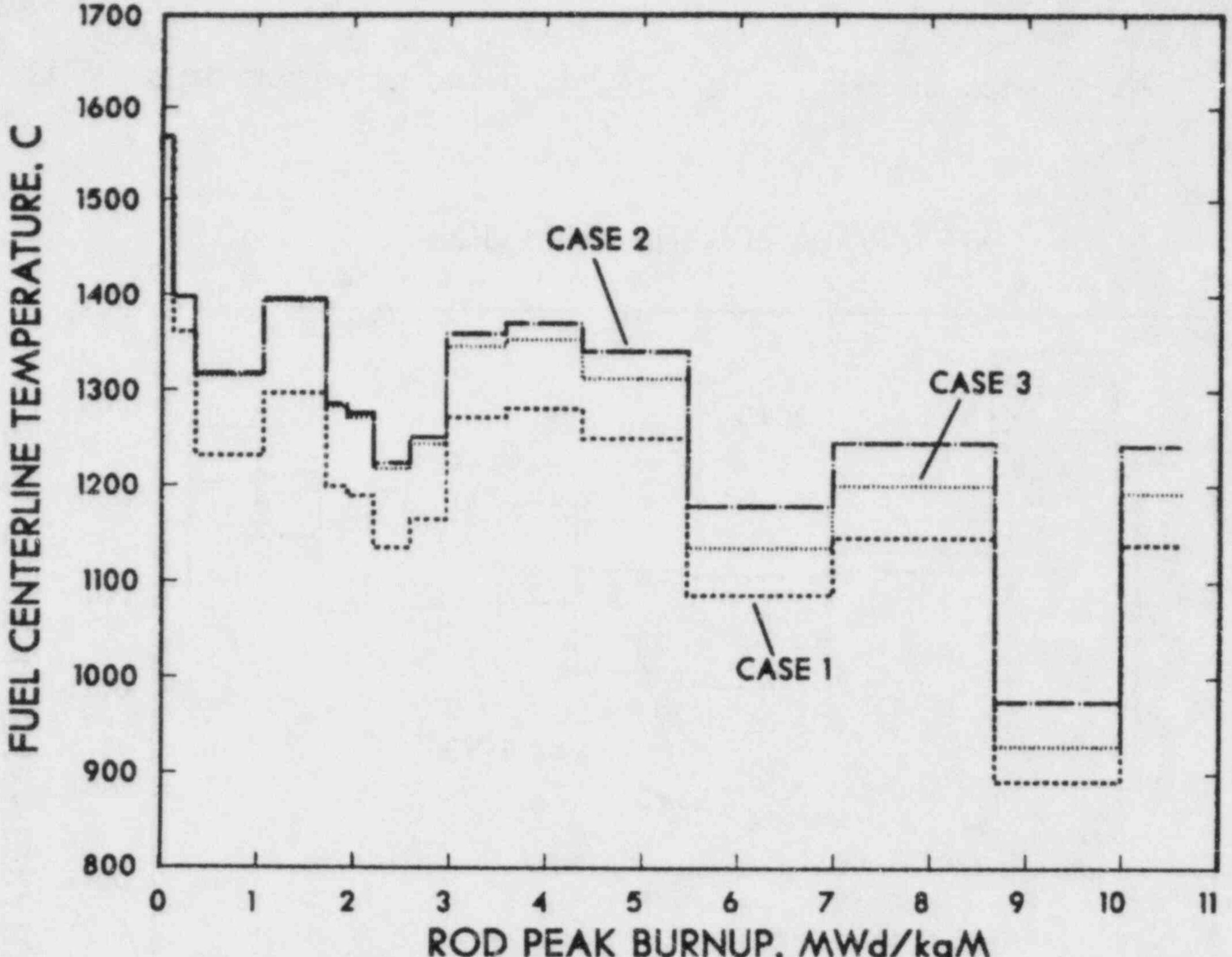

FIGURE 15. GT2R2 Calculations for Rod 2, IFA-513 Upper Thermocouple

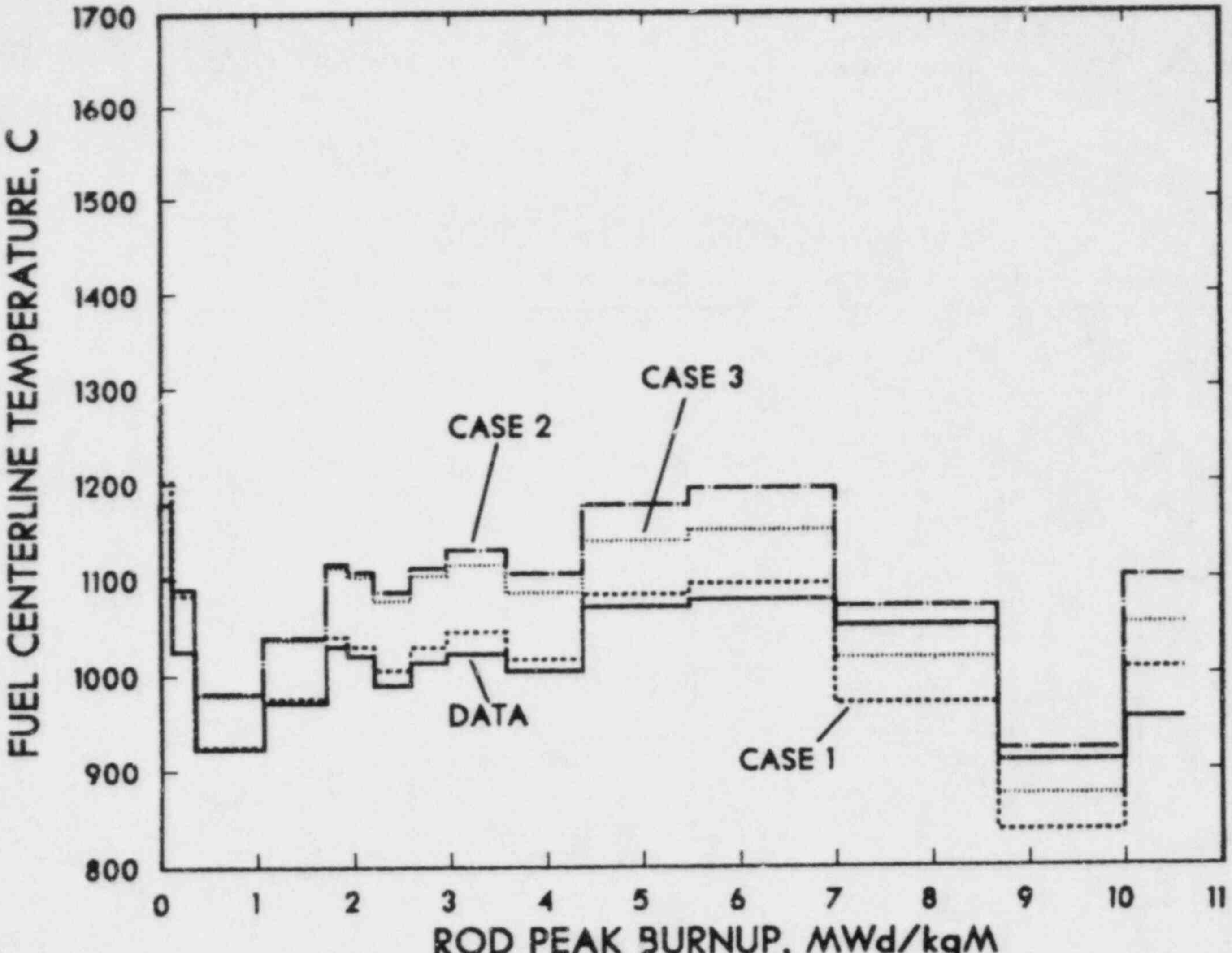

FIGURE 16. GT2R2 Calculations Compared to Rod 2, IFA-513 Lower Thermocouple Data

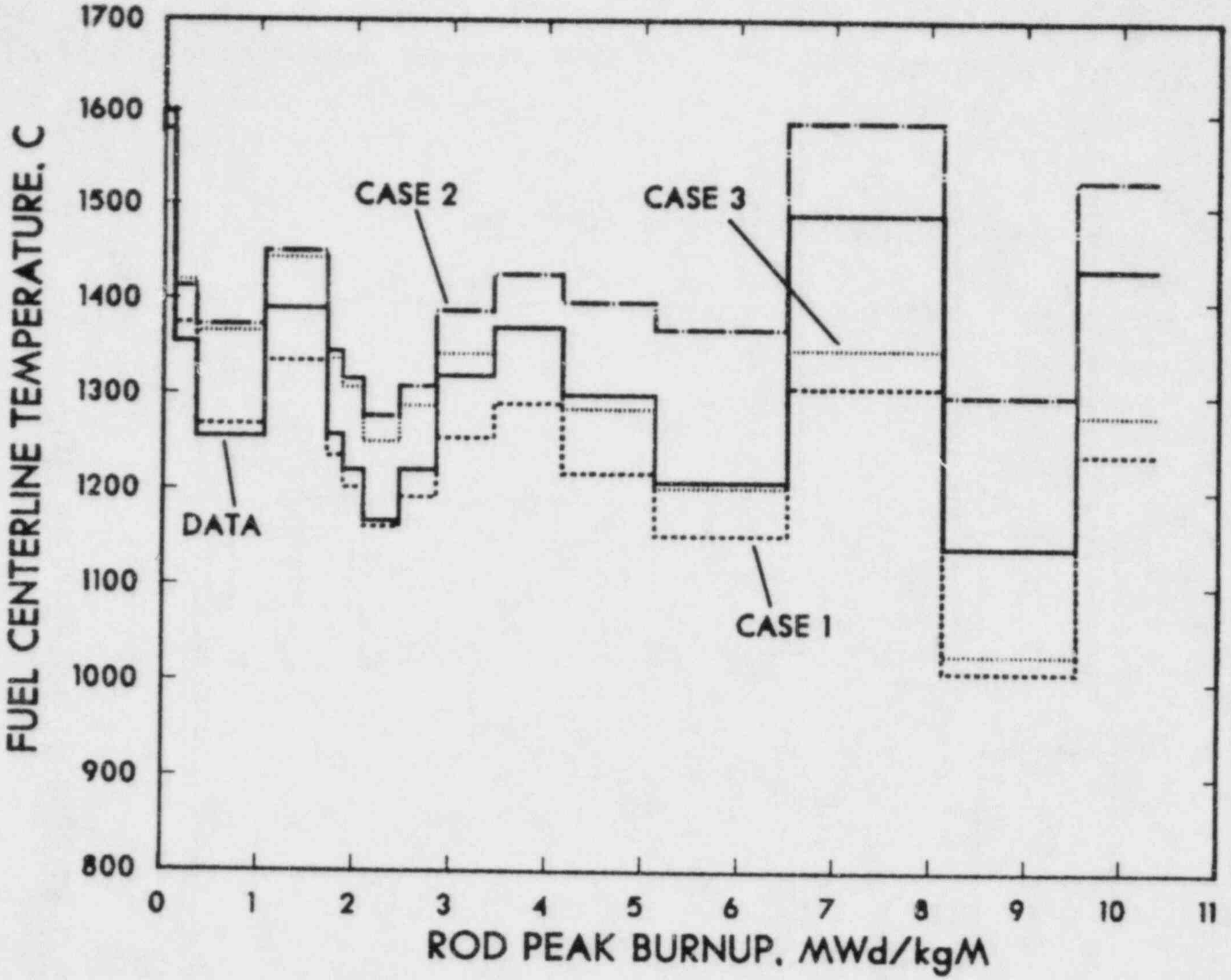

FIGURE 17. GT2R2 Calculations Compared to Rod 4, IFA-513 Upper Thermocouple Data

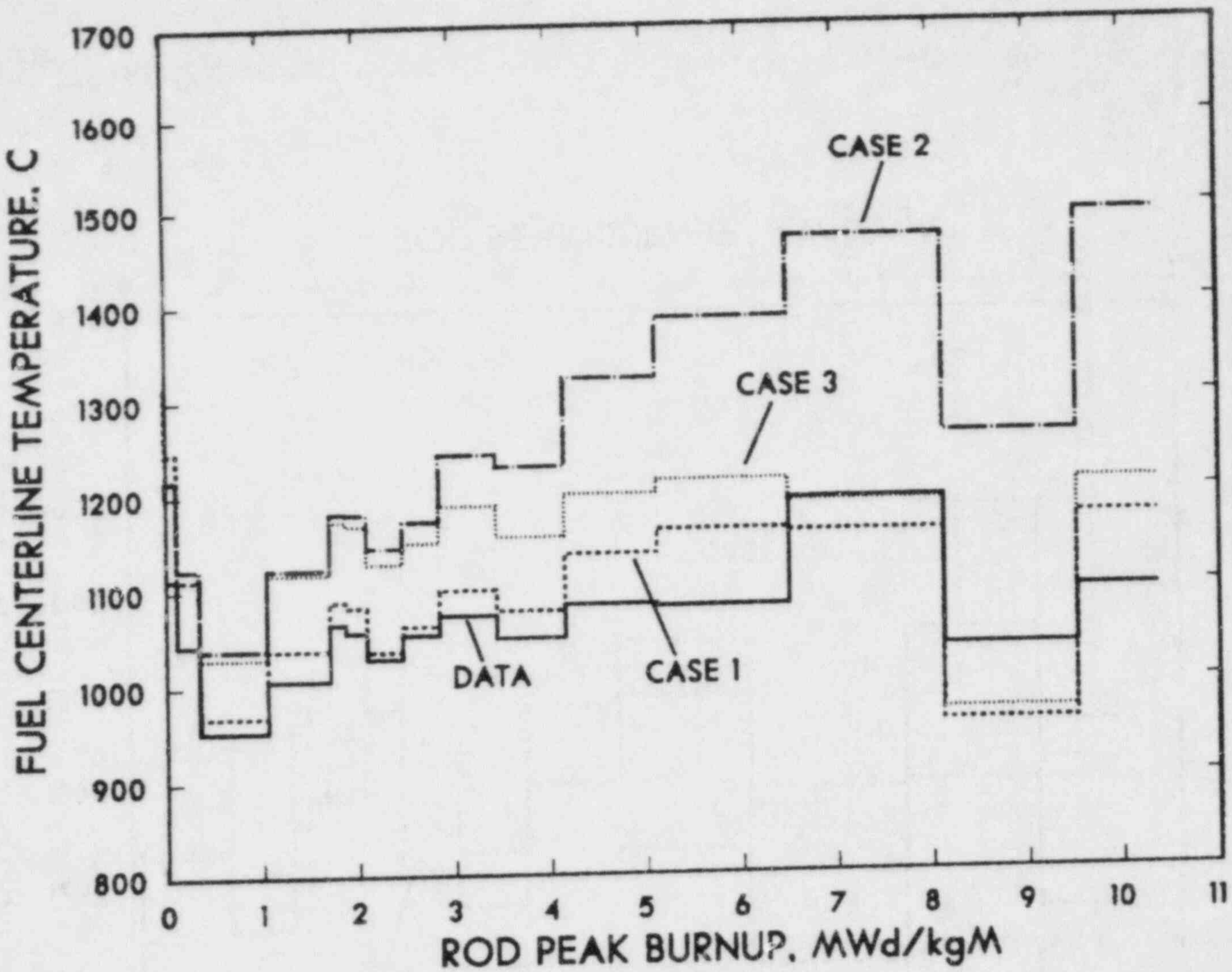

FIGURE 18. GT2R2 Calculations Compared to Rod 4, IFA-513 Lower Thermocouple Data

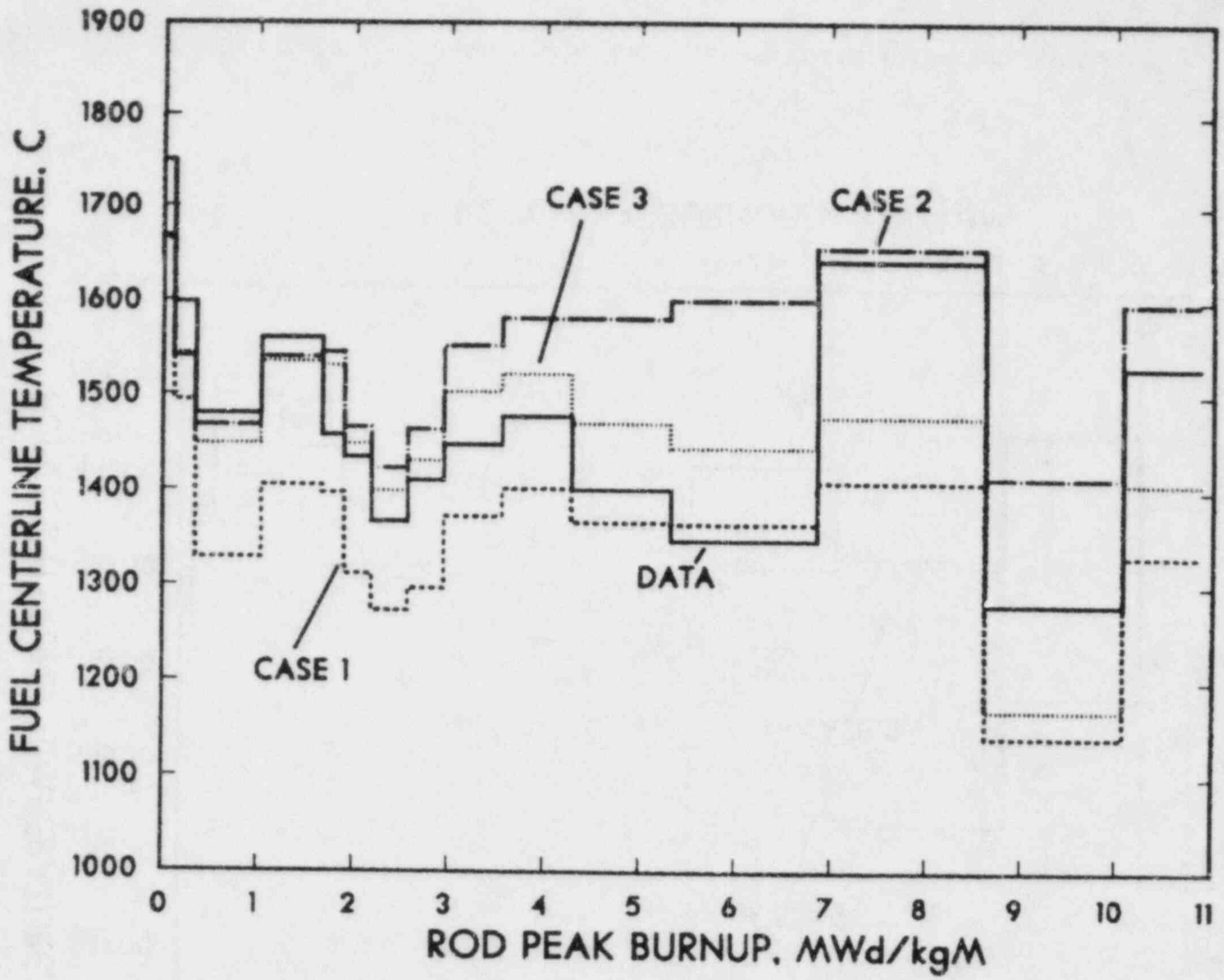

FIGURE 19. GT2R2 Calculations Compared to Rod 6, IFA-513 Upper Thermocouple Data

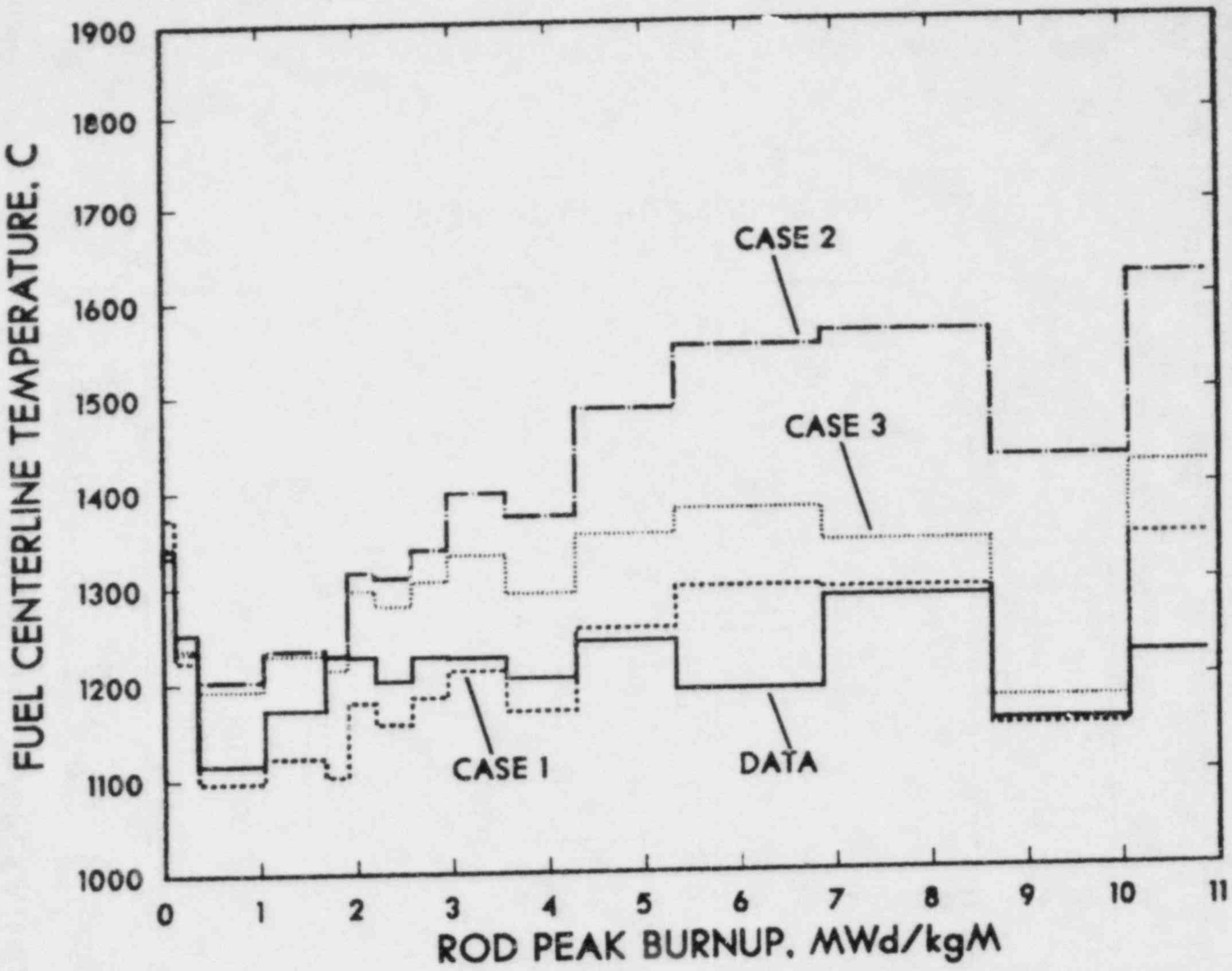

FIGURE 20. GT2R2 Calculations Compared to Rod 6, IFA-513 Lower Thermocouple Data

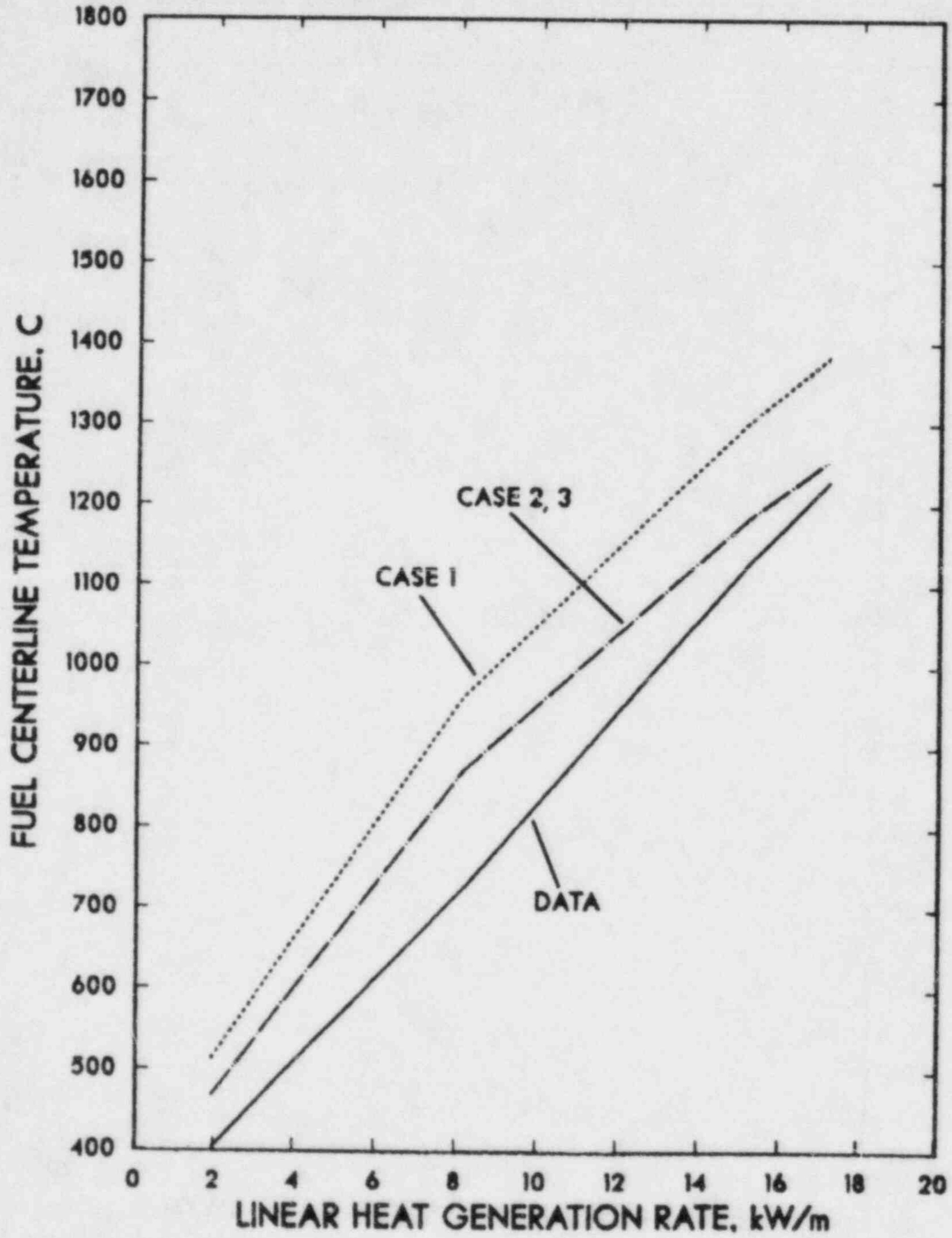

FIGURE 21. GT2R2 Calculations Compared to Rod 1, IFA-527 Upper Thermocouple Data

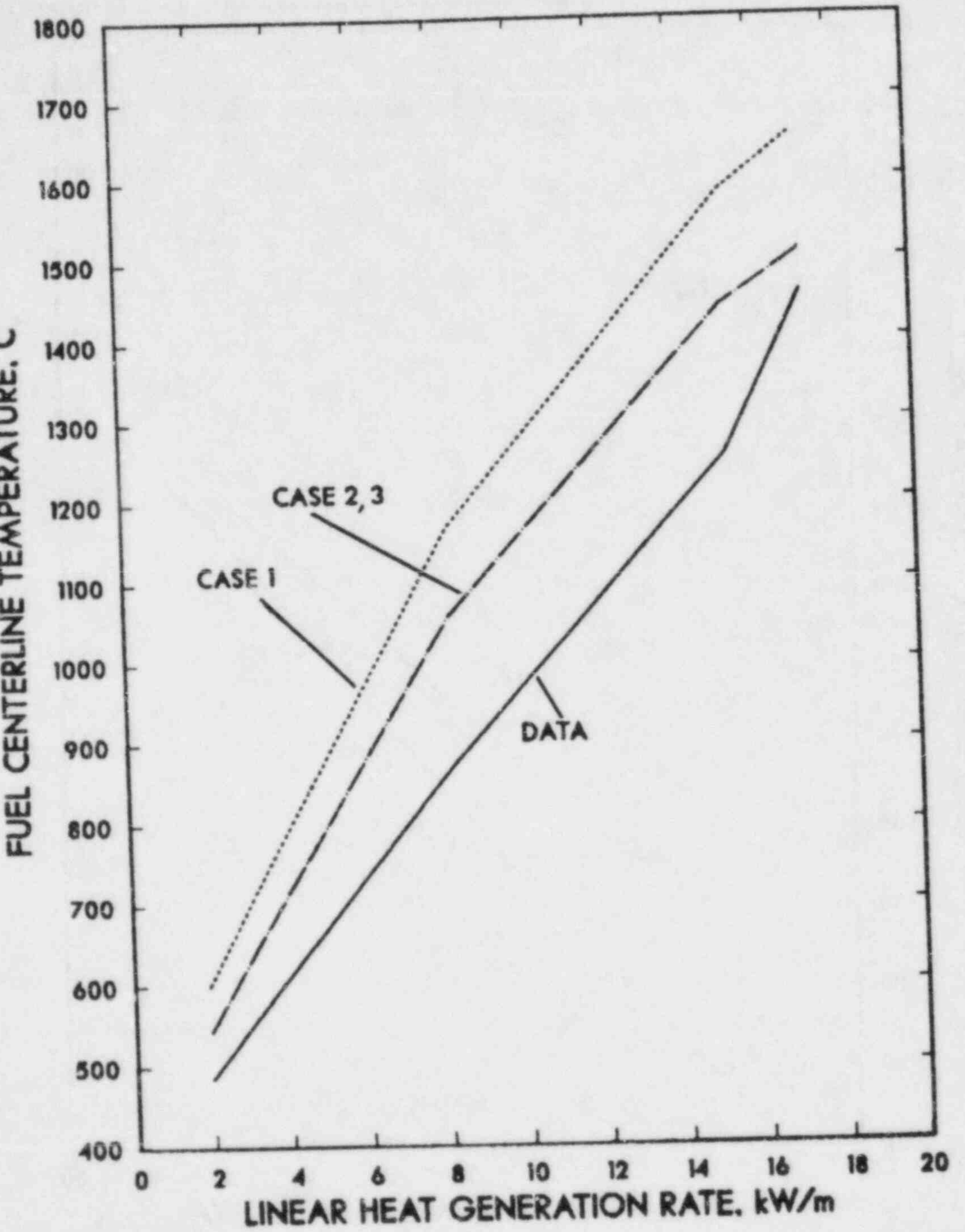

FIGURE 22. GT2R2 Calculations Compared to Rod 1, IFA-527 Lower Thermocouple Data

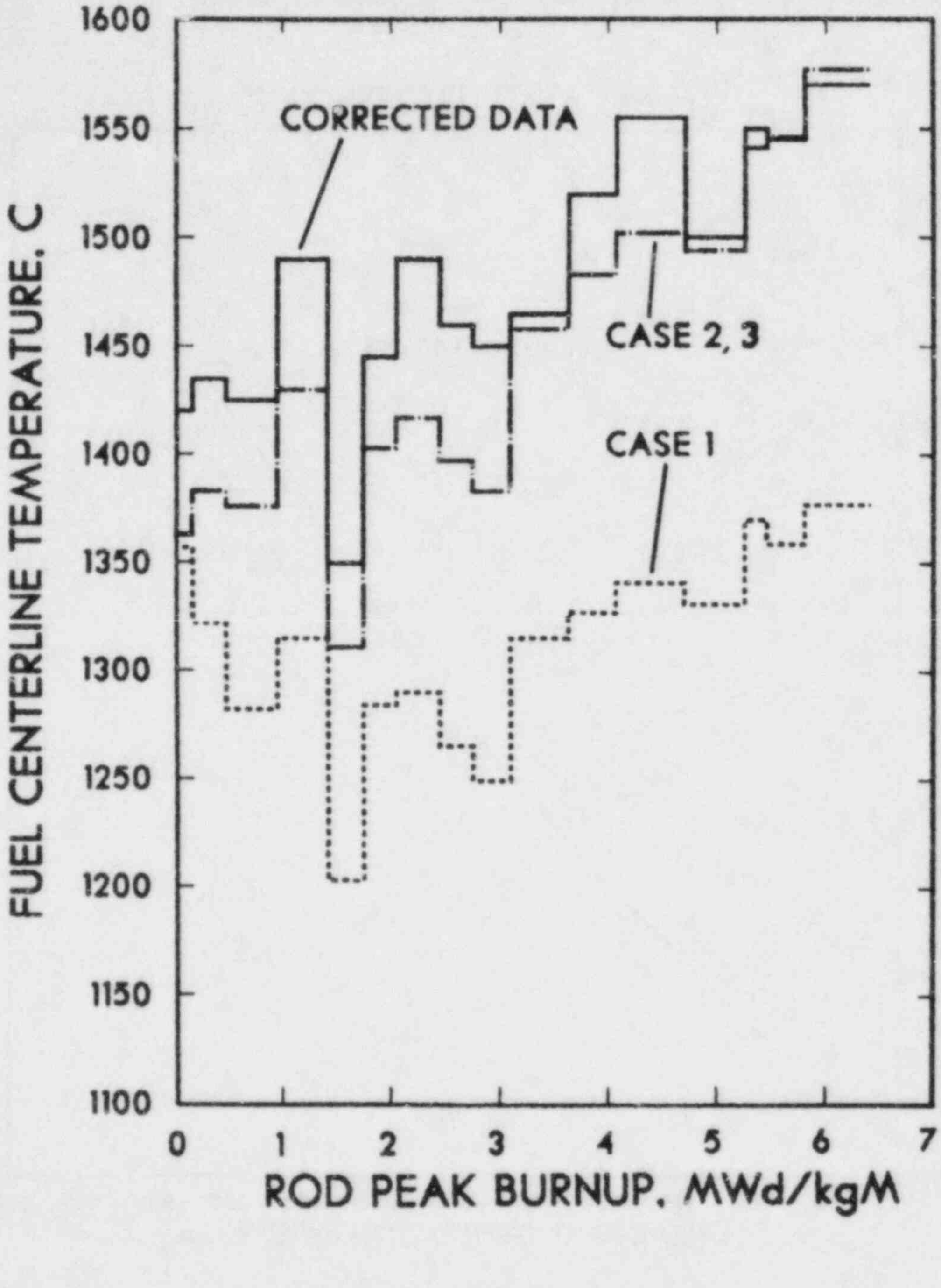

FIGURE 23. GT2R2 Calculations Compared to Rod R1, IFA-517 Thermocouple Data

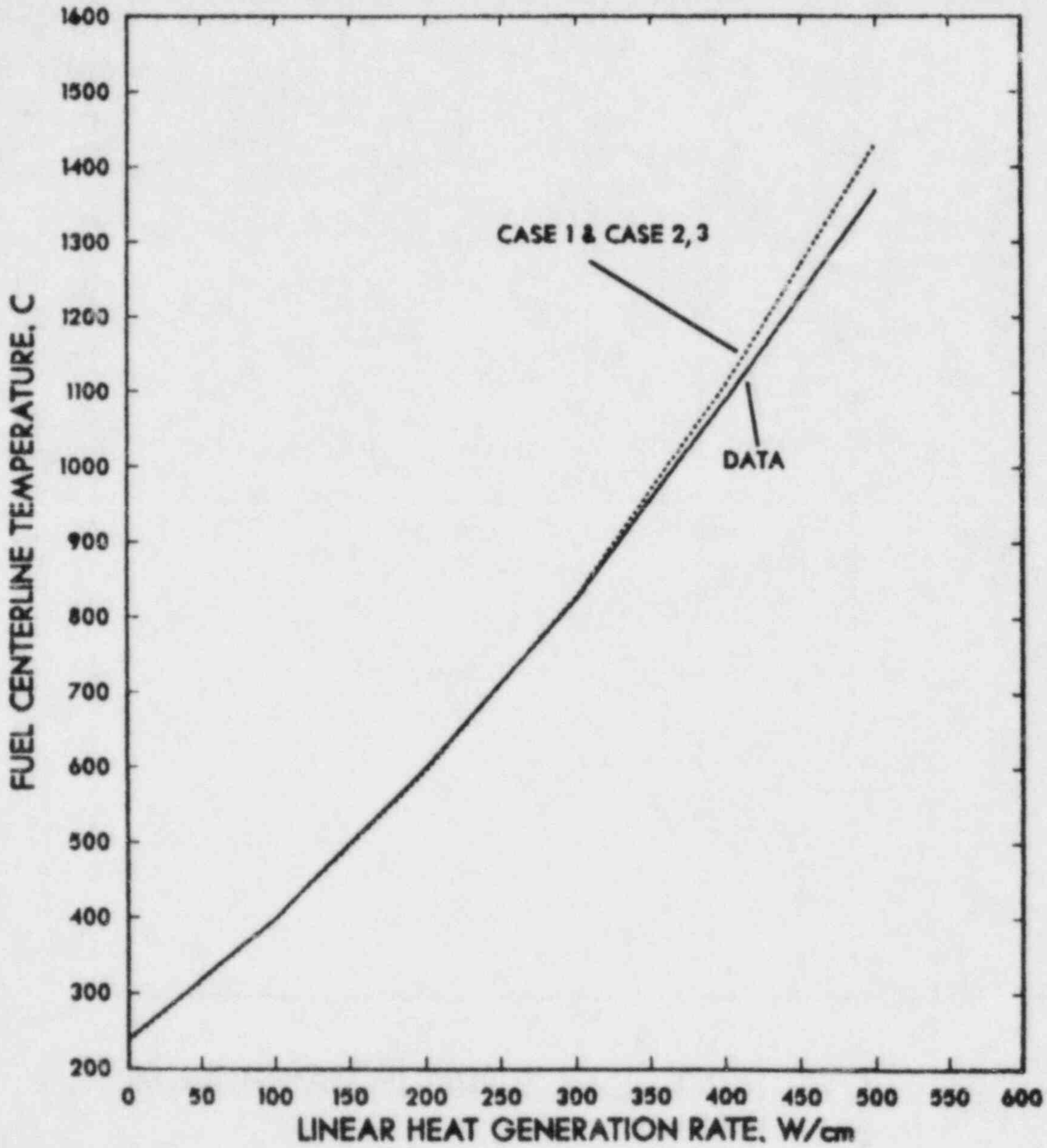

FIGURE 24. GT2R2 Calculations Compared to Rod HBA, IFA-11 Thermocouple Data

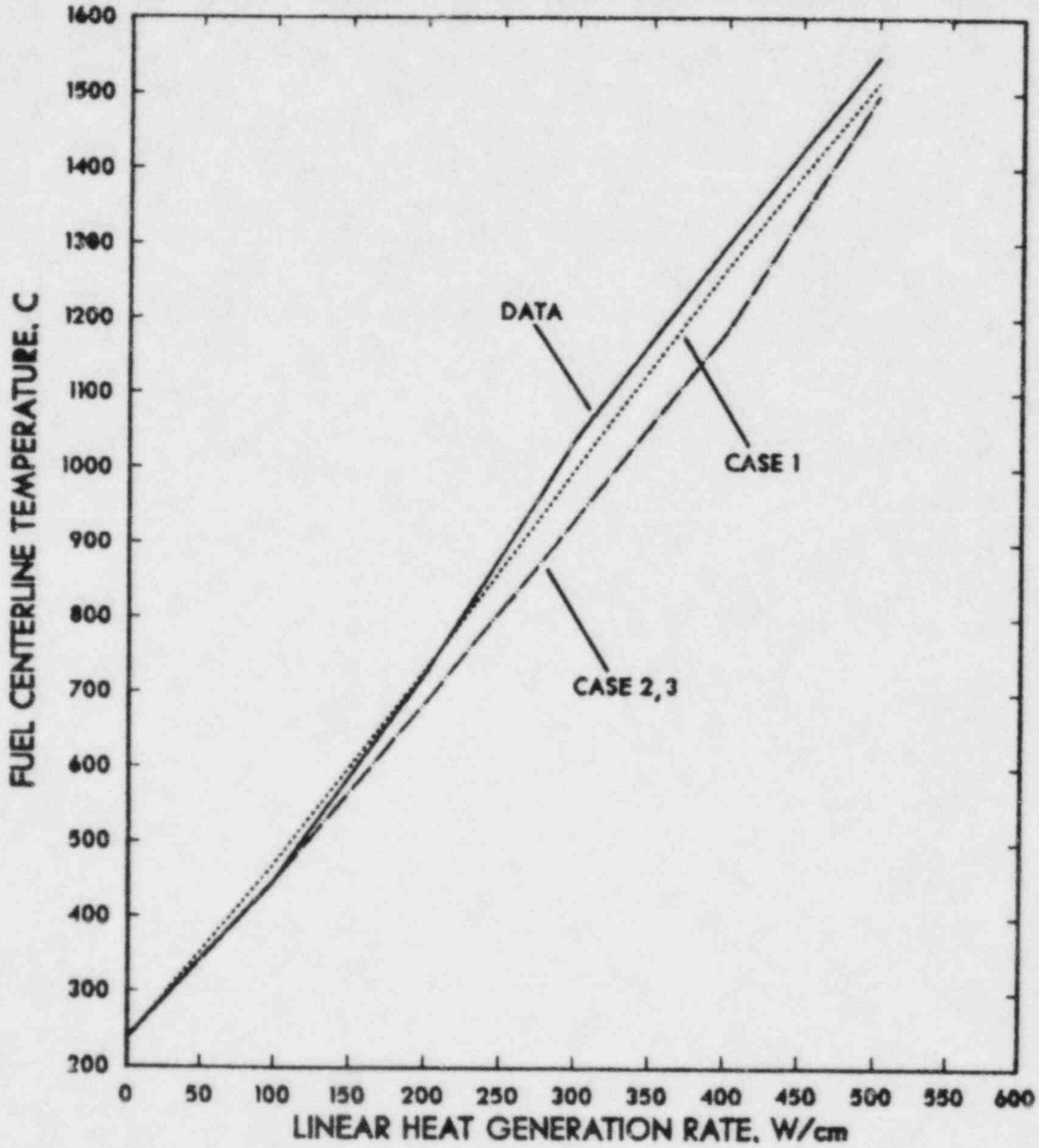

FIGURE 25. GT2R2 Calculations Compared to Rod HBC, IFA-11 Thermocouple Data

4.0 REFERENCES

1. Beyer, C. E., et al. November 1975. GAPCON-THERMAL-2: A Computer Program for Calculating the Thermal Behavior of an Oxide Fuel Rod. BNWL-1898, Pacific Northwest Laboratory, Richland, Washington.

2. Wilson, C. L., and E. L. Courtright. 1977. An Evaluation of Thermal Expansion Models for Calculating Pellet Expansion in the GAPCON-THERMAL Fuel Behavior Codes. FDD-77-1, Pacific Northwest Laboratory, Richland, Washington.

3. Letter, C. E. Beyer (PNL) to J. C. Voglewede (NRC). June 1, 1983.

4. Pankaskie, P. J. May 1974. BUCKLE: An Analytical Computer Code for Calculating Creep Buckling of an Initially Oval Tube. BNWL-1784, Pacific Northwest Laboratory, Richland, Washington.

5. Letter, C. E. Beyer (PNL) to J. C. Voglewede (NRC). August 16, 1982. "Chronology of the Development of the Creep Model Used in BUCKLE and GAPCON."

6. Meyer, R. O. June 1976. The Analysis of Fuel Densification. NUREG-0085, U.S. Nuclear Regulatory Commission, Washington, D.C.

7. Hagrman, D. L., G. A. Reymann, and R. E. Mason. August 1981. MATPRO-Version 11 (Revision 2): A Handbook of Materials Properties for Use in the Analysis of Light Water Reactor Fuel Rod Behavior. NUREG/CR-0479, EG&G Idaho, Inc., Idaho Falls, Idaho.

8. Palmer, I. D., K. W. Hesketh, and P. A. Jackson. 1982. "A Model for Predicting the Radial Power Profile in a Fuel Pin." Presented at the IAEA Specialists Meeting on Water Reactor Fuel Element Performance Computer Modelling. 1982. Preston, UK.

9. Strawbridge, L. E. September. 1963. Calculations of Lattice Parameters and Criticality for Uniform Water Moderator Lattices. WCAP-3269-69.

10. Beyer, C. E., and C. R. Hann. 1974. Prediction of Fission Gas Release From UO2 Fuel. BNWL-1875, Pacific Northwest Laboratory, Richland, Washington.

11. Meyer, R. O., C. E. Beyer, and J. C. Voglewede. March 1978. Fission Gas Release From Fuel at High Burnup. NUREG-0418, U.S. Nuclear Regulatory Commission, Washington, D.C.

12. Rausch, W. N., and F. E. Panisko. August 1979. ANS54: A Computer Subroutine for Predicting Fission Gas Release. NUREG/CR-1213, PNL-3577, Pacific Northwest Laboratory, Richland, Washington.

13. Beyer, C. E., and R. O. Meyer. 1976. "Semiempirical Model for Radioactive Fission Gas Release From UO2." Trans. Am. Nuc. Soc. 23:172.

14. Bradley, E. R., M. E. Cunningham, and D. D. Lanning. May 1982. Final Data Report for the Instrumented Fuel Assembly (IFA)-432. NUREG/CR-2567, PNL-4240, Pacific Northwest Laboratory, Richland, Washington.

15. Lanning, D. D., and E. R. Bradley. October 1983. Irradiation History and Interim Postirradiation Data for IFA-432. NUREG/CR-3071, PNL-4543, Pacific Northwest Laboratory, Richland, Washington.

16. Bradley, E. R., M. E. Cunningham, D. D. Lanning, and R. E. Williford. January 1981. Data Report for the Instrumented Fuel Assembly IFA-513. NUREG/CR-1838, PNL-3637, Pacific Northwest Laboratory, Richland, Washington.

17. Cunningham, M. E., and D. D. Lanning. April 1982. End-of-Irradiation Data Report for the Instrumented Fuel Assembly (IFA)-527. NUREG/CR-2600, PNL-4201, Pacific Northwest Laboratory, Richland, Washington.

18. Cunningham, M. E., K. H. Rising, and J. O. Barner. March 1982. Fuel Performance Analysis of the HBWR IFA-517.1 Test Assembly. DOE/ET/34215-22, PNL-4130, Pacific Northwest Laboratory, Richland, Washington.

19. Kjaerheim, G., and E. Rolstad. December 1967. In-Pile Determination of UO2 Thermal Conductivity, Density Effects and Gap Conductance. HPR-80, Halden Reactor Project, Halden, Norway.

20. Bagger, C., H. Carlson, and P. Knudsen. December 1978. Details of Design, Irradiation and Fission Gas Release for the Danish UO2-Zr Irradiation Test 022. RISO-M-2152, Riso National Laboratory, Denmark.

21. Balfour, M. G., W. C. Chubb, and R. F. Boyle. November 1982. BR-3 High Burnup Fuel Rod Hot Cell Program, Volume 1: Final Report. DOE/ET/34073-1, WCAP-10283, Volume 1, Westinghouse Electric Corp., Pittsburgh, Pennsylvania.

22. Balfour, M. G., E. Roberts, E. DeQuidt, and P. Blanc. September 1982. Zorita Research and Development Program: Volume 1, Final Report. WCAP-10180, Volume 1, Westinghouse Electric Corp., Pittsburgh, Pennsylvania.

APPENDIX A

GT2R2 INPUT INSTRUCTIONS

APPENDIX A

GT2R2 INPUT INSTRUCTIONS

The input for GT2R2 has been changed from that used in GAPCON-THERMAL-2 and GAPCON-THERMAL-2, Rev. 1. The earlier versions used the NAMELIST option; however, NAMELIST is a non-ANSI FORTRAN-77 option. Because of a requirement that GT2R2 be ANSI standard, data input has been changed to be ANSI standard using a FORTRAN-77 compiler.

The first card in the input deck is the title card; the title is entered in columns 1-80. Leave this card blank if no title is desired.

The cards following the title card contain the input data. The format for these cards is as follows. In columns 1-2, a variable identification number (VNUM) is entered which identifies the variable within the input coding. In columns 3-10, the variable name (VNAME) is entered. This variable name is not used by the input coding, but is included in the input so that the user may label the card for his use. Columns 11-20 contain the value of the variable (VVALUE). The format for reading VVALUE is specified to be F10.0 - entering a decimal point with the value allows that format to be overridden. When entering integer values, either enter the value with a decimal point or right justify the integer value to the 20th column. The input coding will convert the real value to an integer value where needed. Columns 21-80 may be used to add any comments the user desires. All variables which consist of arrays must be entered after the single value variables have been read in. This is because the coding statements to read the arrays are dependent upon previously entered variables. The data for the array variables are also entered somewhat differently than for the single value variables. First, the data are read from cards immediately following the variable identification card, rather than on the variable identification card. Second, free formatting is used to read the data.

To help illustrate the data input, Table A.1 contains a sample input deck. An example of input for the variables AA, CF, CLCRP, and RV is provided in Table A.2. A form which lists all the variables (and their default values) for recording input data is provided in Table A.3.

The input variables, and their variable numbers, are listed below. Unless otherwise specified, all variables default to a value of 0.0. No sample case has been built into the code.

VNUM	Variable

Single value variables:

1 ATMOS - rod initial fill gas pressure at 20C (atmospheres)

2 CRUDTH - initial crud thickness on outer surface of cladding (inch)

3 CW - amount of cold work for cladding (fraction)

4 DCI - cladding outer diameter (inch)

5 DCO - cladding inner diameter (inch)

6 DE - equivalent diameter of the coolant passage (inch); ignored if SIGHF is greater than zero

7 DFS - fuel diameter (inch)

8 DSINZ - initial diameter of restructured fuel (inch);

9 DTEMP - change in coolant temperature from bottom to top of rod (F); not used if nodal coolant temperatures are entered

10 DVOIDZ - diameter of fuel central annulus (inch)

11 EXTP - coolant pressure (psi)

12 FDEN95 - beginning fuel density for peak temperature node; if = 0, or > FRDEN, then the peak temperature node calculation is not performed

13 FLXFAC - factor to convert power in kW/ft to fast neutron flux in n/cm^2-s, E > 1 MeV (default = 1.E13)

14 FRACAR - fraction of initial fill gas that is argon

15 FRACH - fraction of initial fill gas that is hydrogen

16 FRACHE - fraction of initial fill gas that is helium

17 FRACKR - fraction of initial fill gas that is krypton

18 FRACN - fraction of initial fill gas that is nitrogen

19 FRACXE - fraction of initial fill gas that is xenon

20 FRDEN - original fuel density (fraction of theoretical)

21 FRDEN2 - terminal fuel density after densification (fraction of theoretical) (default = 0.965)

22 FRSIN - fuel density after restructuring (fraction of theoretical)

23 FRPUO2 - weight fraction of fuel that is PuO_2

24 FR35 - weight fraction of uranium that is U-235

25 FR40 - weight fraction of plutonium that is Pu-240

26 FR41 - weight fraction of plutonium that is Pu-241

27 FZ - cladding texture factor (default = 0.05)

28 HRUL - flag to specify type of hardening for cladding creepdown calculations; used with ICREP = -1
HRUL = 0; time hardening
HRUL ≠ 0; strain hardening

29 ICDF - flag to specify if cladding elastic deflection due to differential pressure is allowed
ICDF = 0; cladding elastic deflection not used
ICDF ≠ 0; cladding elastic deflection is used

30 ICOR - flag to specify ziracaloy oxidation rate
ICOR = 0; no cladding oxidation
ICOR < 3; PWR oxidation rate
ICOR ≥ 3; BWR oxidation rate

31 ICREP - flag to specify cladding creepdown
ICREP = 0; no cladding creepdown
ICREP = -1; cladding creepdown according to BUCKLE equations
ICREP > 0; cladding creepdown values are entered by user through variable CLCRP; ICREP pairs of time and diametral change are input (maximum of ICREP = 20)

32 IDENSF - flag to specify fuel densification
IDENSF = 0; no fuel densification
IDENSF ≠ 0; fuel densifies to a final density of FRDEN2

33 IEXPND - flag to specify fuel radial thermal expansion
IEXPND ≤ 0; fuel radial thermal expansion calculated according to original GT2 model
IEXPND > 0; fuel radial thermal expansion calculated according to sum-of-nodes model

34 IGAS - flag to specify fission gas release model to be used
IGAS < 0; conservative Beyer-Hann with NRC correction
IGAS = 0; Beyer-Hann with NRC correction
IGAS = 1; Beyer-Hann without NRC correction
IGAS = 2; ANS-5.4 fission gas release model
IGAS = 3; modified ANS-5.4 fission gas release model

35 IPEAK - flag to specify type of linear heat rate being entered
IPEAK = 0; rod peak linear heat rate
IPEAK ≠ 0; rod average linear heat rate

36 IRELOC - flag to specify fuel relocation
IRELOC < 0; conservative fuel relocation
IRELOC = 0; no fuel relocation
IRELOC = 1; original GAPCON fuel relocation
IRELOC > 1; new fuel relocation model

37 IRL - number of boundaries at which to printout radial power profile values, used with NFLX = 0

38 IT - flag to specify type of time being read in
IT = 0; time in days
IT ≠ 0; time in burnup (MWd/MTM)

39 KGAS - flag to specify gas thermal conductivity model
KGAS = 0; model of Bird, Stewart & Lightfoot that was in GT-2 orginally
KGAS ≠ 0; model of MATPRO-11, Revision 2

40 LFUEL - active fuel length (inch)

41 LVOIDZ - length of fuel central annulus (inch)

42 MINI - flag to specify which fuel nodes are to be printed out
MINI < 0; no complete fuel node summary printed out
MINI = 0; complete summary at each time step only for fuel node with highest temperature
MINI > 0; complete summary at each time step for all fuel nodes

43 NCLAD - flag to specify type of cladding
NCLAD < 0; cladding is 304 SS
NCLAD = 0; cladding is Zircaloy
NCLAD > 0; cladding properties are input by user through variable AA; NCLAD sets of temperature and physical properties are input (maximum of NCLAD = 23)

44 NFLX - flag to specify fuel radial power profile
NFLX = -4; RADAR model for D_2O
NFLX = -3; RADAR model for PWR
NFLX = -2; RADAR model for BWR
NFLX = -1; flat radial power profile
NFLX = 0; DEPRES radial power model
NFLX > 0; radial power profile entered by user through variable RV; NFLX pairs of diameter and relative power are input (maximum of NFLX = 20)

45 NFUEL - flag to specify fuel thermal conductivity
NFUEL < 0; $(Pu,U)O_2$ thermal conductivity
NFUEL = 0; UO2 thermal conductivity
NFUEL > 0; fuel thermal conductivity entered by user through variable CF; NFUEL sets of temperature and thermal conductivity are input (maximum of NFUEL = 10)

46 NOH - flag to specify disposition of hydrogen present in the sorbed gas
NOH = 0; hydrogen reacts with cladding
NOH ≠ 0; hydrogen remains as free gas

47 NPOW - number of axial fuel regions, maximum of 20

48 NPRFIL - number of axial relative power profiles to be read
$1 \leq$ NPRFIL $\leq$ NTIME (default = 1)

49 NTIME - number of time steps, maximum of 35

50 PITCH - pitch between fuel rods in a square array (cm), used when RHOH2O ≠ 1.

51 PRCDH - percent of fuel volume that is dish volume

52 RADS - radius of fuel dish (inch)

53 ROUC - roughness of cladding inner surface (inch)

54 ROUF - roughness of fuel surface (inch)

55 S - fuel sorbed gas content (cm^3/g of fuel)

56 SIGHF - flag to specify the type of coolant
SIGHF $\leq$ 0; coolant is water and heat transfer coefficient between cladding and coolant will be calculated
SIGHF > 0; coolant is unspecified and heat transfer coefficient between cladding and coolant is set equal to SIGHF (BTU/hr-ft2-F)

57 TM - fuel melting temperature (C) (default value = 2790C)

58 TPLAS - fuel plastic temperature (C) (default value = 1200C)

59 V - coolant velocity (ft/sec), not used if SIGHF > 0

60 VPLENZ - free volume in plenum region (in^3); fuel open porosity should be included in the value of VPLENZ

61 XCO - fraction of sorbed gas that is carbon monoxide and carbon dioxide

62 XH - fraction of sorbed gas that is hydrogen and moisture

63 XN - fraction of sorbed gas that is nitrogen

64 ZCLAD - flag to specify type of Zircaloy cladding, used only when NCLAD = 0
ZCLAD $\leq$ 0; Zircaloy-2
ZCLAD $\geq$ 0; Zircaloy-4

Variables consisting of arrays:

65 KPRFIL (35) - specification of which axial profile to use for each time step; NTIME values are input, maximum value for any entry is NPRFIL. For example, if NPRFIL = 3 and NTIME = 9, then a possible entry for KPRFIL would be 1,1,2,2,3,3,3,2,1. (default = 1)

66 POW95 (35) - array of powers to be used with peak temperature node; if POW95 = 0, then axial peak power is used from PSEUDO and PROFIL (kW/ft)

67 PROFIL (21,35) - axial relative power profile, enter NPRFIL sets where each set contains 21 values (NPOW + 1 axial region boundaries per set plus 21 - (NPOW + 1) zeroes) (default = 1.)

68 PSEUDO (35) - power during each time step (kW/ft), NTIME values required

69 RHOH2O (21) - axial array specifying fractional density of water; if ≠ 1., a modified resonance escape probability is calculated for use in RADAR. NPOW values are required.

70 TIME (35) - time at end of each time step, NTIME values, first value must be set equal to 0. Time in days or burnup, as specified by IT. If time is entered in burnup, burnup should be rod average or rod peak, in accordance with linear heat generation rate.

71 TINLET (21) - coolant temperature (F), may enter NPOW values but if only one value is entered, coolant temperature at other nodes is calculated based on DTEMP and axial power profile

72 CF (3,10) - Fuel thermal conductivity values; NFUEL number of entires are required. Each entry consists of three pieces of data: temperature (C), thermal conductivity for as-fabricated fuel (W/cm-C), and thermal conductivity for restructured fuel (W/cm-C). Free formatting is used for reading the data, but the data must be arranged in either ascending or descending temperature order.

73 AA (7,23) - Cladding property values; NCLAD number of entries are required. Each entry consists of seven pieces of data: temperature (F),

thermal conductivity (BTU/hr-ft-F), yield strength (psi), modulus of elasticity (psi), Poisson ratio, linear coefficient of thermal expansion (in/in-F), and Meyer hardness number (kg/cm^2). Free formatting is used for reading the data, but the data must be arranged in either ascending or descending temperature order.

74 RV (2,20) - Radial power profile; NFLX number of entries are required. Each entry consists of two pieces of data: diameter (inch) and relative radial power at that diameter. Free formatting is used for reading the data, but the data must be arranged in either ascending or descending diametral order.

75 CLCRP (2,20) - Cladding creep down; ICREP number of entries are required. required. Each entry consists of two pieces of data: time (days) and cladding diametral change (inch) at that time; a negative diametral change is required for creepdown. Free formatting is used for reading the data, but the data must be arranged in increasing time order.

TABLE A-1. Sample GT2R2 Input Deck

Card Image Columns

```
1234567890123456789012345678901234567890123456789012345678901234567890123456789

TITLE CARD
 1 ATMOS   1.
 4 DCI     0.4295
 5 DCO     0.5035
 7 DFS     0.4205
 9 DTEMP   5.
10 DVOIDZ  0.069
11 EXTP    500.
16 FRACHE  1.
20 FRDEN   0.95
21 FRDEN2  0.955
24 FR35    0.1     10% ENRICHED
29 ICDF    1.      CLAD ELASTIC DEFLECTION
32 IDENSF  1.
34 IGAS    3.      BEYER-HANN WITH NRC CORRECTION
36 IRELOC  1.
40 LFUEL   22.5
41 LVOIDZ  7.5     SHORTER THAN LFUEL SO AS TO GET VOID VOLUME CORRECT
44 NFLX    -4.     RADAR FOR D2O
47 NPOW    4.
48 NPRFIL  3.
49 NTIME   8.
53 ROUC    2.E-5
54 ROUF    8.E-5
56 SIGHF   14000.
60 VPLENZ  0.113   INCLUDES FUEL OPEN VOID VOLUME
64 ZCLAD   -1.     ZRY-2
65 KPRFIL
1,1,1,2,3,3,2,3
67 PROFIL
0.73,0.73,0.87,1.,1.,16*0.
0.71,0.71,0.86,1.,1.,16*0.
0.68,0.68,0.84,1.,1.,16*0.
68 PSEUDO
13.72,13.72,13.57,13.41,14.02,13.72,13.87,13.26
70 TIME
0.,7.,23.,41.,63.,91.,104.,129.
71 TINLET
464.,20*0.
```

TABLE A-2. Example Data Entries for AA, CF, RV, and CLCRP

Card Image Columns

```
1234567890123456789012345678901234567890123456789012345678901234567890123456789

31 ICREP  3.
43 NCLAD  6.
44 NFLX   5.
45 NFUEL  6.
72 CF
70.,3.500,3.500,  500.,3.3423.342,  1000.,2.370,2.370,
2000.,1.568,1.568,  3000.,1.329,1.329,  4000.,1.386,1.386
73 AA
75.,7.3,4.48E4,1.38E7,0.37,3.24E-6,9470.,
212.,7.74,3.48E4,1.30E7,0.400,3.47E-6,7360.,
392.,8.38,2.38E4,1.21E7,0.446,3.70E-6,5030.,
572.,9.02,1.58E4,1.11E7,0.492,3.87E-6,3340.,
752.,9.83,1.21E4,1.01E7,0.492,3.99E-6,2560.,
932.,10.64,1.0E4,9.09E6,0.492,4.08E-6,2110.
74 RV
0.,1.,  0.1,1.001,  0.2,1.005,  0.3,1.01,  0.4205,1.03
75 CLCRP
0.,0.,  100.,-0.0005, 500.,-0.0015
```

TABLE A-3. Input Parameters for GT2R2

(Default values are in parenthesis)

No.	Parameter	Default	No.	Parameter	Default	No.	Parameter	Default
1	ATMOS	(0)	23	FRPUO2	(0)	44	NFLX	(1)
2	CRUDTH	(0)	24	FR35	(0)	45	NFUEL	(0)
3	CW	(0)	25	FR40	(0)	46	NOH	(0)
4	DCI	(0)	26	FR41	(0)	47	NPOW	(0)
5	DCO	(0)	27	FZ	(0.05)	48	NPRFIL	(0)
6	DE	(0)	28	HRUL	(0)	49	NTIME	(0)
7	DFS	(0)	29	ICDF	(0)	50	PITCH	(0)
8	DSINZ	(0)	30	ICOR	(0)	51	PRCDH	(0)
9	DTEMP	(0)	31	ICREP	(0)	52	RADS	(0)
10	DVOIDZ	(0)	32	IDENSF	(0)	53	ROUC	(0)
11	EXTP	(0)	33	IEXPND	(0)	54	ROUF	(0)
12	FDEN95	(0)	34	IGAS	(0)	55	S	(0)
13	FLXFAC	(1.E13)	35	IPEAK	(0)	56	SIGHF	(0)
14	FRACAR	(0)	36	IRELOC	(0)	57	TM	(2805 C)
15	FRACH	(0)	37	IRL	(0)	58	TPLAS	(1200 C)
16	FRACHE	(0)	38	IT	(0)	59	V	(0)
17	FRACKR	(0)	39	KGAS	(0)	60	VPLENZ	(0)
18	FRACN	(0)	40	LFUEL	(0)	61	XCO	(0)
19	FRACXE	(0)	41	LVOIDZ	(0)	62	XH	(0)
20	FRDEN	(0)	42	MINI	(0)	63	XN	(0)
21	FRDEN2	(0.965)	43	NCLAD	(0)	64	ZCLAD	(0)
22	FRSIN	(0)						

65 KPRFIL (35*1) ____________________

66 POW95 (35*0.) ____________________

67 PROFIL (735*1.) ____________________

68 PSEUDO (35*0.) ____________________

69 RHOH2O (20*0.) ____________________

70 TIME (35*0.) ____________________

71 TINLET (21*0.) ____________________

72 CF (3,10*0.) ____________________

73 AA (7,23*0.) ____________________

74 RV (2,20*0.) ____________________

75 CLCRP (2,20*0.) ____________________

APPENDIX B

INPUT PARAMETERS FOR THE BENCHMARKING CASES

APPENDIX B

INPUT PARAMETERS FOR THE BENCHMARKING CASES

This appendix contains tables of the input values used for the benchmarking runs presented in Section 3. One table is presented for each rod; when more than one option is used for a variable, they are all listed in the order of Case 1, Case 2, Case 3.

Rod: Rod 1, IFA-432

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

Parameter	Value	Default	Parameter	Value	Default	Parameter	Value	Default
ATMOS	1.	(0)	FRSIN		(0)	NFLX	-4	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW		(0)	FR35	0.10	(0)	NOH		(0)
DCI	0.4295	(0)	FR40		(0)	NPOW	4	(0)
DCO	0.5035	(0)	FR41		(0)	NPRFIL	8	(0)
DE		(0)	FZ		(0.05)	NTIME	33	(0)
DFS	0.4205	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR		(0)	PRDCDH		(0)
DTEMP	5.	(0)	ICREP		(0)	RADS		(0)
DVOIDZ	0.069	(0)	IDENSF	1	(0)	ROUC	2.E-5	(0)
EXTP	500.	(0)	IEXPND		(0)	ROUF	8.E-5	(0)
FDEN95		(0)	IGAS	3,3,1	(0)	S		(0)
FLXFAC		(1.E13)	IPEAK		(0)	SIGHF	14000.	(0)
FRACAR		(0)	IRELOC	1,2,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	1.	(0)	IT		(0)	V		(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.113	(0)
FRACN		(0)	LFUEL	22.5	(0)	XCO		(0)
FRACXE		(0)	LVOIDZ	7.5	(0)	XH		(0)
FRDEN	0.95	(0)	MINI		(0)	XN		(0)
FRDEN2	0.955	(0)	NCLAD		(0)	ZCLAD	-1	(0)

KPRFIL (35*1) 1,1,1,2,3,3,2,3,1,4,5,5,6,3,3,2,2,5,2,5,2,2,1,4,5,7,7,8,4,4,4,4

POW95 (35*0.)

PROFIL (735*0.) see next page

PSEUDO (35*0.) see next page

RHOH2O (20*1.)

TIME (35*0.) see next page

TINLET (21*0.) 464.

Rod 1, IFA-432

Input Parameters Contd.

```
PROFIL #1 = 0.73, 0.73, 0.87, 1., 1., 16*0.
       #2 = 0.71, 0.71, 0.86, 1., 1., 16*0.
       #3 = 0.68, 0.68, 0.84, 1., 1., 16*0.
       #4 = 0.81, 0.81, 0.91, 1., 1., 16*0.
       #5 = 0.76, 0.76, 0.88, 1., 1., 16*0.
       #6 = 0.64, 0.64, 0.82, 1., 1., 16*0.
       #7 = 0.78, 0.78, 0.89, 1., 1., 16*0.
       #8 = 0.84, 0.84, 0.92, 1., 1., 16*0.

PSEUDO = 13.72, 13.72, 13.57, 13.41, 14.02, 13.72, 13.87, 13.26, 12.96,
         10.37, 12.20, 13.11, 11.89, 13.41, 13.57, 11.43, 12.04,  9.45,
         11.43, 10.06, 12.04, 11.89, 10.37, 10.98, 11.43, 11.13, 10.98,
          9.76,  8.99, 10.27, 10.37,  9.76, 11.52

TIME =   0., 7., 23., 41., 63., 91., 104., 129., 154., 159., 170., 203.,
         208., 228., 247., 283., 292., 305., 328., 352., 374., 400., 430.,
         465., 498., 535., 569., 590., 601., 629., 646., 697., 715.
```

Rod: Rod 5, IFA-432

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

ATMOS	1.	(0)	FRSIN		(0)	NFLX	-4	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW		(0)	FR35	0.10	(0)	NOH		(0)
DCI	0.4295	(0)	FR40		(0)	NPOW	4	(0)
DCO	0.5035	(0)	FR41		(0)	NPRFIL	9	(0)
DE		(0)	FZ		(0.05)	NTIME	35	(0)
DFS	0.4205	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR		(0)	PRDCDH		(0)
DTEMP	5.	(0)	ICREP		(0)	RADS		(0)
DVOIDZ	0.069	(0)	IDENSF	1	(0)	ROUC	2.E-5	(0)
EXTP	500.	(0)	IEXPND		(0)	ROUF	8.E-5	(0)
FDEN95		(0)	IGAS	3,3,1	(0)	S		(0)
FLXFAC		(1.E13)	IPEAK		(0)	SIGHF	14000.	(0)
FRACAR		(0)	IRELOC	1,2,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	1.	(0)	IT		(0)	V		(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.113	(0)
FRACN		(0)	LFUEL	22.5	(0)	XCO		(0)
FRACXE		(0)	LVOIDZ	7.5	(0)	XH		(0)
FRDEN	0.92	(0)	MINI		(0)	XN		(0)
FRDEN2	0.922	(0)	NCLAD		(0)	ZCLAD	-1	(0)

KPRFIL (35*1) 1,12,3,3,3,2,2,1,1,4,5,6,3,7,1,5,5,1,5,1,1,1,5,4,8,5,7,5,9,1,8,4,5,5

POW95 (35*0.) ____

PROFIL (735*0.) see next page

PSEUDO (35*0.) see next page

RHOH2O (20*1.) ____

TIME (35*0.) see next page

TINLET (21*0.) 464.

Rod 5, IFA-432

Inout Parameters Contd.

```
PROFIL #1 = 0.75, 0.75, 0.88, 1., 1., 16*0.
       #2 = 0.72, 0.72, 0.86, 1., 1., 16*0.
       #3 = 0.70, 0.70, 0.85, 1., 1., 16*0.
       #4 = 0.83, 0.83, 0.92, 1., 1., 16*0.
       #5 = 0.80, 0.80, 0.90, 1., 1., 16*0.
       #6 = 0.67, 0.67, 0.84, 1., 1., 16*0.
       #7 = 0.78, 0.78, 0.89, 1., 1., 16*0.
       #8 = 0.86, 0.86, 0.93, 1., 1., 16*0.
       #9 = 0.92, 0.92, 0.96, 1., 1., 16*0.

PSEUDO = 13.87, 13.87, 13.72, 12.65, 13.87, 13.57, 12.35, 13.26, 12.50,
         12.50, 10.21, 12.50, 10.82, 12.35,  9.76, 11.28,  7.93,  8.08,
         10.76,  8.84, 10.98, 11.43, 11 13,  9.60, 10.52,  9.60, 10.67,
         10.67, 10.37,  8.69,  6.86,  9.15,  9.30,  9.15, 10.67

TIME =   0., 7., 31., 41., 63., 91., 98., 113., 129., 154., 159., 203.,
         208., 247., 283., 292., 298., 315., 328., 338., 359., 374., 400.,
         428., 463., 473., 503., 542., 569., 590., 601., 629., 646., 697.,
         715.
```

Rod: Rod 6, IFA-432

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

Parameter	Value	Default	Parameter	Value	Default	Parameter	Value	Default
ATMOS	1.	(0)	FRSIN		(0)	NFLX	-4	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW		(0)	FR35	0.10	(0)	NOH		(0)
DCI	0.4295	(0)	FR40		(0)	NPOW	4	(0)
DCO	0.5035	(0)	FR41		(0)	NPRFIL	8	(0)
DE		(0)	FZ		(0.05)	NTIME	35	(0)
DFS	0.4205	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR		(0)	PRDCDH		(0)
DTEMP	5.	(0)	ICREP		(0)	RADS		(0)
DVOIDZ	0.069	(0)	IDENSF	1	(0)	ROUC	2.E-5	(0)
EXTP	500.	(0)	IEXPND		(0)	ROUF	8.E-5	(0)
FDEN95		(0)	IGAS	3,3,1	(0)	S		(0)
FLXFAC		(1.E13)	IPEAK		(0)	SIGHF	14000.	(0)
FRACAR		(0)	IRELOC	1,2,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	1.	(0)	IT		(0)	V		(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.124	(0)
FRACN		(0)	LFUEL	22.5	(0)	XCO		(0)
FRACXE		(0)	LVOIDZ	7.5	(0)	XH		(0)
FRDEN	0.92	(0)	MINI		(0)	XN		(0)
FRDEN2	0.945	(0)	NCLAD		(0)	ZCLAD	-1	(0)

KPRFIL (35*1) 1,1,2,3,3,4,4,2,2,5,1,6,3,1,4,1,1,2,1,2,4,2,7,1,1,1,1,8,5,7,7,7,8,7,7

POW95 (35*0.)

PROFIL (735*0.) see next page

PSEUDO (35*0.) see next page

RHOH2O (20*1.)

TIME (35*0.) see next page

TINLET (21*0.) 464.

Rod 6, IFA-432

Input Parameters Contd.

```
PROFIL #1 = 0.77, 0.77, 0.89, 1., 1., 16*0.
       #2 = 0.73, 0.73, 0.87, 1., 1., 16*0.
       #3 = 0.68, 0.68, 0.84, 1., 1., 16*0.
       #4 = 0.70, 0.70, 0.85, 1., 1., 16*0.
       #5 = 0.83, 0.83, 0.92, 1., 1., 16*0.
       #6 = 0.66, 0.66, 0.83, 1., 1., 16*0.
       #7 = 0.81, 0.81, 0.90, 1., 1., 16*0.
       #8 = 0.87, 0.87, 0.94, 1., 1., 16*0.

PSEUDO = 13.51, 13.51, 13.57, 12.80, 13.72, 13.41, 13.11, 12.96, 12.80,
         10.21, 12.80, 11.59, 13.11,  9.91, 11.71,  8.69,  8.38, 11.13,
          9.91, 11.74, 11.59, 10.06, 10.67,  9.15, 11.13, 10.67,  9.15,
          9.76,  9.76,  8.99,  9.82,  7.47,  9.45, 10.82

TIME =    0., 7., 31., 41., 63., 91., 113., 129., 154., 159., 203., 208.,
          247., 283., 292., 305., 315., 328., 352., 374., 400., 428.,
          463., 473., 498., 535., 569., 614., 629., 641., 646., 674.,
          697., 715.
```

Rod: Rod 1, IFA-513

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

ATMOS	1.	(0)	FRSIN		(0)	NFLX	-4	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW		(0)	FR35	0.099	(0)	NOH		(0)
DCI	0.4295	(0)	FR40		(0)	NPOW	4	(0)
DCO	0.5035	(0)	FR41		(0)	NPRFIL	9	(0)
DE		(0)	FZ		(0.05)	NTIME	16	(0)
DFS	0.4205	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR		(0)	PRDCDH		(0)
DTEMP	5.	(0)	ICREP		(0)	RADS		(0)
DVOIDZ	0.069	(0)	IDENSF	1	(0)	ROUC	2.E-5	(0)
EXTP	500.	(0)	IEXPND		(0)	ROUF	8.E-5	(0)
FDEN95		(0)	IGAS	3,3,1	(0)	S		(0)
FLXFAC		(1.E13)	IPEAK	1	(0)	SIGHF	14000.	(0)
FRACAR		(0)	IRELOC		(0)	TM		(2805 C)
FRACH		(0)	IRL	1,2,2	(0)	TPLAS		(1200 C)
FRACHE	1.	(0)	IT	1	(0)	V		(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.319	(0)
FRACN		(0)	LFUEL	30.7	(0)	XCO		(0)
FRACXE		(0)	LVOIDZ	7.5	(0)	XH		(0)
FRDEN	0.95	(0)	MINI		(0)	XN		(0)
FRDEN2	0.953	(0)	NCLAD		(0)	ZCLAD	-1	(0)

KPRFIL (35*1) 1,1,2,3,3,4,4,5,5,6,2,4,7,8,9,4

POW95 (35*0.)

PROFIL (735*0.) see below

PSEUDO (35*0.) 12.1, 12.1, 10.9, 9.8, 10.5, 10.4, 10.3, 10.0, 10.2, 10.9, 10.7, 10.8, 10.3, 9.6, 7.5, 9.9

RHOH2O (20*1.)

TIME (35*0.) 0., 200., 400., 1500., 1600., 1800., 2000., 2500., 2700., 3700., 4100., 5600., 7100., 8900., 9700., 9900.

TINLET (21*0.) 464.

PROFIL #1 = 0.660, 0.740, 0.832, 0.918, 1., 16*0.
#2 = 0.768, 0.756, 0.839, 0.921, 1., 16*0.
#3 = 0.613, 0.710, 0.806, 0.903, 1., 16*0.
#4 = 0.787, 0.841, 0.893, 0.948, 1., 16*0.
#5 = 0.815, 0.862, 0.908, 0.955, 1., 16*0.
#6 = 0.722, 0.790, 0.863, 0.933, 1., 16*0.
#7 = 0.951, 0.962, 0.977, 0.990, 1., 16*0.
#8 = 0.752, 0.813, 0.877, 0.938, 1., 16*0.
#9 = 0.873, 0.905, 0.936, 0.968, 1., 16*0.

Rod: Rod 2, IFA-513

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

ATMOS	3.	(0)	FRSIN		(0)	NFLX	-4	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW		(0)	FR35	0.099	(0)	NOH		(0)
DCI	0.4295	(0)	FR40		(0)	NPOW	4	(0)
DCO	0.5035	(0)	FR41		(0)	NPRFIL	9	(0)
DE		(0)	FZ		(0.05)	NTIME	16	(0)
DFS	0.4205	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR		(0)	PRDCDH		(0)
DTEMP	5.	(0)	ICREP		(0)	RADS		(0)
DVOIDZ	0.069	(0)	IDENSF	1	(0)	ROUC	2.E-5	(0)
EXTP	500.	(0)	IEXPND		(0)	ROUF	8.E-5	(0)
FDEN95		(0)	IGAS	3,3,1	(0)	S		(0)
FLXFAC		(1.E13)	IPEAK	1	(0)	SIGHF	14000.	(0)
FRACAR		(0)	IRELOC	1,2,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	1.	(0)	IT	1	(0)	V		(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.312	(0)
FRACN		(0)	LFUEL	30.7	(0)	XCO		(0)
FRACXE		(0)	LVOIDZ	7.5	(0)	XH		(0)
FRDEN	0.95	(0)	MINI		(0)	XN		(0)
FRDEN2	0.953	(0)	NCLAD		(0)	ZCLAD	-1	(0)

KPRFIL (35*1) 1,1,2,3,3,4,4,5,5,6,2,4,7,8,9,4

POW95 (35*0.)

PROFIL (735*0.) see below

PSEUDO (35*0.) 12.2, 12.2, 10.8, 9.8, 10.5, 10.3, 10.2, 9.8, 10.1, 10.8, 10.7, 10.8, 9.9, 9.5, 7.4, 9.7

RHOH2O (20*1.)

TIME (35*0.) 0., 200., 400., 1400., 1500., 1800., 2000., 2500., 2700., 3600., 4100., 5600., 7000., 8800., 9400., 9700.

TINLET (21*0.) 464.

PROFIL #1 = 0.633, 0.724, 0.816, 0.908, 1., 16*0.
#2 = 0.678, 0.756, 0.839, 0.921, 1., 16*0.
#3 = 0.613, 0.710, 0.806, 0.903, 1., 16*0.
#4 = 0.787, 0.841, 0.893, 0.948, 1., 16*0.
#5 = 0.815, 0.862, 0.908, 0.955, 1., 16*0.
#6 = 0.722, 0.790, 0.863, 0.933, 1., 16*0.
#7 = 5*1., 16*0.
#8 = 0.752, 0.813, 0.877, 0.938, 1., 16*0.
#9 = 0.873, 0.905, 0.936, 0.968, 1., 16*0.

Rod: Rod 4, IFA-513

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

ATMOS	1.	(0)	FRSIN		(0)	NFLX	-4	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW		(0)	FR35	0.099	(0)	NOH		(0)
DCI	0.4295	(0)	FR40		(0)	NPOW	4	(0)
DCO	0.5035	(0)	FR41		(0)	NPRFIL	8	(0)
DE		(0)	FZ		(0.05)	NTIME	16	(0)
DFS	0.4205	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR		(0)	PRDCDH		(0)
DTEMP	5.	(0)	ICREP		(0)	RADS		(0)
DVOIDZ	0.069	(0)	IDENSF	1	(0)	ROUC	2.E-5	(0)
EXTP	500.	(0)	IEXPND		(0)	ROUF	8.E-5	(0)
FDEN95		(0)	IGAS	3,3,1	(0)	S		(0)
FLXFAC		(1.E13)	IPEAK	1	(0)	SIGHF	14000.	(0)
FRACAR		(0)	IRELOC	1,2,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	0.92	(0)	IT	1	(0)	V		(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.300	(0)
FRACN		(0)	LFUEL	30.7	(0)	XCO		(0)
FRACXE	0.08	(0)	LVOIDZ	7.5	(0)	XH		(0)
FRDEN	0.95	(0)	MINI		(0)	XN		(0)
FRDEN2	0.953	(0)	NCLAD		(0)	ZCLAD	-1	(0)

KPRFIL (35*1) 1,1,2,3,1,4,5,5,5,4,6,7,8,4,7,7

POW95 (35*0.)

PROFIL (735*0.) see below

PSEUDO (35*0.) 11.9, 11.9, 10.4, 9.6, 10.4, 10.1, 9.9, 9.4, 9.7, 10.2, 10.2, 9.9, 9.5, 9.8, 7.1, 9.5

RHOH2O (20*1.)

TIME (35*0.) 0., 200., 400., 1400., 1500., 1700., 1900., 2400., 2600., 3500., 3900., 5300., 6600., 8400., 9200., 9300.

TINLET (21*0.) 464.

PROFIL #1 = 0.633, 0.724, 0.816, 0.908, 1., 16*0.
#2 = 0.678, 0.756, 0.839, 0.921, 1., 16*0.
#3 = 0.613, 0.710, 0.806, 0.903, 1., 16*0.
#4 = 0.787, 0.814, 0.893, 0.948, 1., 16*0.
#5 = 0.815, 0.862, 0.908, 0.955, 1., 16*0.
#6 = 0.722, 0.790, 0.863, 0.933, 1., 16*0.
#7 = 0.873, 0.905, 0.936, 0.968, 1., 16*0.
#8 = 5*1., 16*0.

Rod: Rod 6, IFA-513

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

Parameter	Value	Default	Parameter	Value	Default	Parameter	Value	Default
ATMOS	1.	(0)	FRSIN		(0)	NFLX	-4	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW		(0)	FR35	0.099	(0)	NOH		(0)
DCI	0.4295	(0)	FR40		(0)	NPOW	4	(0)
DCO	0.5035	(0)	FR41		(0)	NPRFIL	9	(0)
DE		(0)	FZ		(0.05)	NTIME	16	(0)
DFS	0.4205	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR		(0)	PRDCDH		(0)
DTEMP	5.	(0)	ICREP		(0)	RADS		(0)
DVOIDZ	0.069	(0)	IDENSF	1	(0)	ROUC	2.E-5	(0)
EXTP	500.	(0)	IEXPND		(0)	ROUF	8.E-5	(0)
FDEN95		(0)	IGAS	3,3,1	(0)	S		(0)
FLXFAC		(1.E13)	IPEAK	1	(0)	SIGHF	14000.	(0)
FRACAR		(0)	IRELOC	1,2,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	0.77	(0)	IT	1	(0)	V		(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.325	(0)
FRACN		(0)	LFUEL	30.7	(0)	XCO		(0)
FRACXE	0.23	(0)	LVOIDZ	7.5	(0)	XH		(0)
FRDEN	0.95	(0)	MINI		(0)	XN		(0)
FRDEN2	0.953	(0)	NCLAD		(0)	ZCLAD	-1	(0)

KPRFIL (35*1) 1,1,1,2,3,4,5,6,6,7,2,6,8,5,9,9

POW95 (35*0.)

PROFIL (735*0.) see below

PSEUDO (35*0.) 12.0, 12.0, 10.7, 9.8, 10.43, 10.3, 10.2, 9.8, 10.1, 10.6, 10.5, 10.4, 10.2, 9.9, 7.5, 9.8

RHOH2O (20*1.)

TIME (35*0.) 0., 200., 400., 1400., 1500., 1800., 2000., 2500., 2700., 3600., 4000., 5500., 6900., 8800., 9600., 9700.

TINLET (21*0.) 464.

PROFIL #1 = 0.660, 0.746, 0.832, 0.918, 1., 16*0.
#2 = 0.678, 0.756, 0.839, 0.921, 1., 16*0.
#3 = 0.633, 0.724, 0.816, 0.908, 1., 16*0.
#4 = 0.613, 0.710, 0.806, 0.903, 1., 16*0.
#5 = 0.787, 0.841, 0.893, 0.948, 1., 16*0.
#6 = 0.815, 0.862, 0.908, 0.955, 1., 16*0.
#7 = 0.752, 0.813, 0.877, 0.938, 1., 16*0.
#8 = 0.873, 0.905, 0.936, 0.968, 1., 16*0.
#9 = 0.951, 0.962, 0.977, 0.990, 1., 16*0.

Rod: Rod 1, IFA-527

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

Parameter	Value	Default	Parameter	Value	Default	Parameter	Value	Default
ATMOS	1.	(0)	FRSIN		(0)	NFLX	-4	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW		(0)	FR35	0.10	(0)	NOH		(0)
DCI	0.4295	(0)	FR40		(0)	NPOW	4	(0)
DCO	0.5035	(0)	FR41		(0)	NPRFIL	1	(0)
DE		(0)	FZ		(0.05)	NTIME	9	(0)
DFS	0.4205	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR		(0)	PRDCDH		(0)
DTEMP	5.	(0)	ICREP		(0)	RADS		(0)
DVOIDZ	0.069	(0)	IDENSF	1	(0)	ROUC	2.E-5	(0)
EXTP	500.	(0)	IEXPND		(0)	ROUF	8.E-5	(0)
FDEN95		(0)	IGAS	3,3	(0)	S		(0)
FLXFAC		(1.E13)	IPEAK	1	(0)	SIGHF	14000.	(0)
FRACAR		(0)	IRELOC	1,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE		(0)	IT		(0)	V		(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.15	(0)
FRACN		(0)	LFUEL	30.5	(0)	XCO		(0)
FRACXE	1.	(0)	LVOIDZ		(0)	XH		(0)
FRDEN	0.95	(0)	MINI		(0)	XN		(0)
FRDEN2	0.955	(0)	NCLAD		(0)	ZCLAD	-1	(0)

KPRFIL (35*1) __________

POW95 (35*0.) __________

PROFIL (735*0.) 1., 0.908, 0.805, 0.697, 0.589

PSEUDO (35*0.) 0.5, 0.5, 2.1, 3.9, 4.4, 4.4, 4.4, 4.4, 4.4

RHOH2O (20*1.) __________

TIME (35*0.) 0., 0.1, 0.2, 0.3, 0.4, 1., 20., 40., 60.

TINLET (21*0.) 464.

Rod: Rod R1, IFA-517

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

ATMOS	1.	(0)	FRSIN		(0)	NFLX	-4	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW		(0)	FR35	0.11	(0)	NOH		(0)
DCI	0.4138	(0)	FR40		(0)	NPOW	3	(0)
DCO	0.4854	(0)	FR41		(0)	NPRFIL	1	(0)
DE		(0)	FZ		(0.05)	NTIME	17	(0)
DFS	0.4039	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR		(0)	PRDCDH	1.	(0)
DTEMP	5.	(0)	ICREP		(0)	RADS	0.13	(0)
DVOIDZ	0.0846	(0)	IDENSF	1	(0)	ROUC	2.E-5	(0)
EXTP	500.	(0)	IEXPND		(0)	ROUF	8.E-5	(0)
FDEN95		(0)	IGAS	3,3	(0)	S		(0)
FLXFAC		(1.E13)	IPEAK		(0)	SIGHF	14000.	(0)
FRACAR		(0)	IRELOC	1,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	1.	(0)	IT	1	(0)	V		(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.245	(0)
FRACN		(0)	LFUEL	18.2	(0)	XCO		(0)
FRACXE		(0)	LVOIDZ	3.5	(0)	XH		(0)
FRDEN	0.954	(0)	MINI		(0)	XN		(0)
FRDEN2	0.955	(0)	NCLAD		(0)	ZCLAD	-1	(0)

KPRFIL (35*1)

POW95 (35*0.)

PROFIL (735*0.) 0.9, 0.9, 1., 1.

PSEUDO (35*0.) 11.89, 11.89, 12.12, 12.04, 12.50, 11.22, 12.20, 12.27, 11.98, 11.74, 12.50, 12.65, 12.65, 12.44, 12.96, 12.73, 12.65

RHOH2O (20*1.) 0., 300., 650., 1250., 1600., 1900., 2200., 2700., 2800., 3400., 3850., 4300., 5100., 5400., 5500., 6100., 7000.

TIME (35*0.) 464.

TINLET (21*0.)

Rod: HBA

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

Parameter	Value	Default	Parameter	Value	Default	Parameter	Value	Default
ATMOS	1.	(0)	FRSIN		(0)	NFLX	-4	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW		(0)	FR35	0.05	(0)	NOH		(0)
DCI	0.4956	(0)	FR40		(0)	NPOW	6	(0)
DCO	0.5394	(0)	FR41		(0)	NPRFIL	1	(0)
DE		(0)	FZ		(0.05)	NTIME	6	(0)
DFS	0.4397	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR		(0)	PRDCDH		(0)
DTEMP	20	(0)	ICREP		(0)	RADS		(0)
DVOIDZ	0.0472	(0)	IDENSF	1	(0)	ROUC	5.E-5	(0)
EXTP	500.	(0)	IEXPND		(0)	ROUF	1.6E-4	(0)
FDEN95		(0)	IGAS	3,3	(0)	S		(0)
FLXFAC		(1.E13)	IPEAK		(0)	SIGHF	1400.	(0)
FRACAR		(0)	IRELOC	1,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	1.	(0)	IT		(0)	V		(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.96	(0)
FRACN		(0)	LFUEL	67.48	(0)	XCO		(0)
FRACXE		(0)	LVOIDZ	13.40	(0)	XH		(0)
FRDEN	0.98	(0)	MINI		(0)	XN		(0)
FRDEN2	0.982	(0)	NCLAD		(0)	ZCLAD	-1	(0)

KPRFIL (35*1) ____

POW95 (35*0.) ____

PROFIL (735*0.) 0.744, 0.965, 1.035, 0.948, 0.763, 0.477, 0.193

PSEUDO (35*0.) 0.05, 3.05, 6.10, 9.15, 12.20, 15.24

RHOH2O (20*1.) ____

TIME (35*0.) 0., 0.017, 0.035, 0.099, 0.120, 0.137, 0.150

TINLET (21*0.) 446.

Rod: HBC

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

ATMOS	1.	(0)	FRSIN		(0)	NFLX	-4	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW		(0)	FR35	0.05	(0)	NOH		(0)
DCI	0.4959	(0)	FR40		(0)	NPOW	6	(0)
DCO	0.5394	(0)	FR41		(0)	NPRFIL	1	(0)
DE		(0)	FZ		(0.05)	NTIME	6	(0)
DFS	0.4890	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR		(0)	PRDCDH		(0)
DTEMP	20.	(0)	ICREP		(0)	RADS		(0)
DVOIDZ	0.0472	(0)	IDENSF	1	(0)	ROUC	5.E-5	(0)
EXTP	500.	(0)	IEXPND		(0)	ROUF	1.6E-4	(0)
FDEN95		(0)	IGAS	3,3	(0)	S		(0)
FLXFAC		(1.E13)	IPEAK		(0)	SIGHF	14000.	(0)
FRACAR		(0)	IRELOC	1,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	1.	(0)	IT		(0)	V		(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.096	(0)
FRACN		(0)	LFUEL	67.48	(0)	XCO		(0)
FRACXE		(0)	LVOIDZ	31.40	(0)	XH		(0)
FRDEN	0.96	(0)	MINI		(0)	XN		(0)
FRDEN2	0.965	(0)	NCLAD		(0)	ZCLAD	-1	(0)

KPRFIL (35*1)

POW95 (35*0.)

PROFIL (735*0.) 0.744, 0.965, 1.035, 0.948, 0.763, 0.477, 0.193

PSEUDO (35*0.) 0.05, 3.05, 6.10, 9.15, 12.20, 15.24

RHOH2O (20*1.)

TIME (35*0.) 0., 0.017, 0.035, 0.069, 0.099, 0.120, 0.139, 0.174

TINLET (21*0.) 446.

Rod: M2-2C

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

Parameter	Value	Default	Parameter	Value	Default	Parameter	Value	Default
ATMOS	1.	(0)	FRSIN		(0)	NFLX	-2	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW		(0)	FR35	0.028	(0)	NOH		(0)
DCI	0.5055	(0)	FR40		(0)	NPOW	10	(0)
DCO	0.5472	(0)	FR41		(0)	NPRFIL	32	(0)
DE	0.1	(0)	FZ		(0.05)	NTIME	33	(0)
DFS	0.49606	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR	4	(0)	PRDCDH	1.88	(0)
DTEMP	40.	(0)	ICREP	-1	(0)	RADS	0.22	(0)
DVOIDZ		(0)	IDENSF	1	(0)	ROUC	3.5E-5	(0)
EXTP	1029.	(0)	IEXPND		(0)	ROUF	3.5E-5	(0)
FDEN95		(0)	IGAS	3,3,1	(0)	S		(0)
FLXFAC		(1.E13)	IPEAK	1	(0)	SIGHF		(0)
FRACAR		(0)	IRELOC	1,2,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	1.	(0)	IT		(0)	V	67.5	(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.122	(0)
FRACN		(0)	LFUEL	5.04	(0)	XCO		(0)
FRACXE		(0)	LVOIDZ		(0)	XH		(0)
FRDEN	0.949	(0)	MINI		(0)	XN		(0)
FRDEN2	0.96	(0)	NCLAD		(0)	ZCLAD		(0)

KPRFIL (35*1) 1,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22, 23,24,25,26,27,28,29,30,31,32

POW95 (35*0.)

PROFIL (735*0.) see next page

PSEUDO (35*0.) see next page

RHOH2O (20*1.)

TIME (35*0.) see next page

TINLET (21*0.) 537.8

Rod M2-2C

Input Parameters Contd.

PROFIL

#1 = 0.144, 0.994, 1.019, 1.043, 1.068, 1.092, 1.117, 1.141, 1.166, 1.190, 0.195, 10*0.
#2 = 0.247, 0.982, 1.006, 1.030, 1.054, 1.078, 1.103, 1.127, 1.151, 1.175, 0.342, 10*0.
#3 = 0.331, 0.972, 0.996, 1.020, 1.044, 1.068, 1.092, 1.116, 1.140, 1.164, 0.446, 10*0.
#4 = 0.425, 0.962, 0.986, 1.009, 1.033, 1.056, 1.080, 1.103, 1.127, 1.151, 0.562, 10*0.
#5 = 0.501, 0.953, 0.976, 1.000, 1.023, 1.047, 1.070, 1.094, 1.117, 1.141, 0.659, 10*0.
#6 = 0.538, 0.949, 0.972, 0.996, 1.019, 1.042, 1.065, 1.088, 1.111, 1.134, 0.708, 10*0.
#7 = 0.560, 0.947, 0.970, 0.993, 1.016, 1.039, 1.062, 1.085, 1.108, 1.131, 0.734, 10*0.
#8 = 0.582, 0.944, 0.967, 0.990, 1.013, 1.036, 1.059, 1.083, 1.106, 1.129, 0.762, 10*0.
#9 = 0.618, 0.940, 0.963, 0.986, 1.009, 1.032, 1.055, 1.078, 1.101, 1.124, 0.806, 10*0.
#10 = 0.640, 0.938, 0.961, 0.984, 1.006, 1.029, 1.052, 1.075, 1.097, 1.120, 0.835, 10*0.
#11 = 0.658, 0.935, 0.958, 0.981, 1.004, 1.027, 0.050, 1.073, 1.096, 1.119, 0.854, 10*0.
#12 = 0.669, 0.934, 0.957, 0.980, 1.003, 1.026, 1.048, 1.071, 1.094, 1.117, 0.869, 10*0.
#13 = 0.685, 0.933, 0.956, 0.979, 1.001, 1.024, 1.046, 1.069, 1.091, 1.114, 0.889, 10*0.
#14 = 0,710, 0.931, 0.953, 0.976, 0.998, 1.021, 1.043, 1.065, 1.088, 1.110, 0.919, 10*0.
#15 = 0.730, 0.929, 0.951, 0.974, 0.996, 1.018, 1.041, 1.063, 1.085, 1.108, 0.940, 10*0.
#16 = 0.741, 0.927, 0.950, 0.972, 0.994, 1.017, 1.039, 1.061, 1.084, 1.106, 0.956, 10*0.
#17 = 0.763, 0.925, 0.947, 0.970, 0.992, 1.014, 1.036, 1.058, 1.081, 1.103, 0.985, 10*0.
#18 = 0.777, 0.924, 0.946, 0.968, 0.990, 1.012, 1.035, 1.057, 1.079, 1.101, 0.985, 10*0.
#19 = 0.786, 0.922, 0.945, 0.967, 0.989, 1.011, 1.033, 1.056, 1.078, 1.100, 1.000, 10*0.
#20 = 0.795, 0.921, 0.943, 0.965, 0.988, 1.010, 1.032, 1.054, 1.077, 1.099, 1.012, 10*0.
#21 = 0.805, 0.920, 0.942, 0.965, 0.987, 1.009, 1.031, 1.053, 1.076, 1.098, 1.026, 10*0.
#22 = 0.811, 0.921, 0.943, 0.965, 0.986, 1.008, 1.030, 1.052, 1.073, 1.095, 1.033, 10*0.
#23 = 0.818, 0.919, 0.941, 0.963, 0.985, 1.007, 1.028, 1.051, 1.073, 1.095, 1.043, 10*0.
#24 = 0.827, 0.919, 0.941, 0.962, 0.984, 1.006, 1.028, 1.050, 1.072, 1.093, 1.051, 10*0.
#25 = 0.841, 0.917, 0.939, 0.961, 0.983, 1.005, 1.026, 1.048, 1.070, 1.092, 1.063, 10*0.
#26 = 0.845, 0.916, 0.938, 0.960, 0.982, 1.004, 1.026, 1.048, 1.070, 1.092, 1.077, 10*0.
#27 = 0.846, 0.915, 0.937, 0.959, 0.981, 1.003, 1.025, 1.048, 1.070, 1.092, 1.087, 10*0.
#28 = 0.851, 0.915, 0.937, 0.959, 0.981, 1.003, 1.025, 1.048, 1.070, 1.092, 1.094, 10*0.
#29 = 0.859, 0.915, 0.937, 0.959, 0.981, 1.002, 1.025, 1.047, 1.069, 1.091, 1.099, 10*0.
#30 = 0.873, 0.915, 0.937, 0.959, 0.980, 1.002, 1.024, 1.046, 1.068, 1.089, 1.098, 10*0.
#31 = 0.881, 0.913, 0.935, 0.957, 0.979, 1.001, 1.023, 1.045, 1.067, 1.089, 1.098, 10*0.
#32 = 0.908, 0.913, 0.935, 0.957, 0.978, 1.000, 1.021, 1.043, 1.065, 1.086, 1.095, 10*0.

PSEUDO = 15.33, 15.33, 16.49, 16.00, 14.46, 15.18, 14.75, 15.97, 15.15, 14.43, 13.69,
15.15, 13.47, 12.82, 11.62, 13.75, 15.58, 14.63, 13.53, 14.33, 16.82, 13.50,
13.08, 13.93, 12.68, 11.64, 14.23, 14.75, 15.15, 13.46, 13.84, 14.66, 13.84

TIME = 0., 22.92, 46.17, 69.58, 135.58, 182.33, 205.33, 228.67, 251.88, 275.29,
298.67, 345.38, 361.79, 384.96, 431.29, 501.13, 524.54, 555.04, 585.17,
608.46, 654.75, 678.17, 701.38, 724.40, 747.67, 771.29, 817.75, 864.38,
886.13, 909.04, 930.71, 982.92, 1028.92, 1052.00, 1079.79

Rod: PA/29-4

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

ATMOS	1.	(0)	FRSIN		(0)	NFLX	-2	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW		(0)	FR35	0.028	(0)	NOH		(0)
DCI	0.5055	(0)	FR40		(0)	NPOW	10	(0)
DCO	0.55197	(0)	FR41		(0)	NPRFIL	30	(0)
DE	0.1	(0)	FZ		(0.05)	NTIME	35	(0)
DFS	0.49606	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR	4	(0)	PRDCDH	1.88	(0)
DTEMP	4.	(0)	ICREP	-1	(0)	RADS	0.2205	(0)
DVOIDZ		(0)	IDENSF	1	(0)	ROUC	3.54E-5	(0)
EXTP	1029.	(0)	IEXPND		(0)	ROUF	3.54E-5	(0)
FDEN95		(0)	IGAS	3,3,1	(0)	S		(0)
FLXFAC		(1.E13)	IPEAK	1	(0)	SIGHF		(0)
FRACAR		(0)	IRELOC	1,2,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	1.	(0)	IT		(0)	V	67.5	(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.122	(0)
FRACN		(0)	LFUEL	5.04	(0)	XCO		(0)
FRACXE		(0)	LVOIDZ		(0)	XH		(0)
FRDEN	0.949	(0)	MINI		(0)	XN		(0)
FRDEN2	0.959	(0)	NCLAD		(0)	ZCLAD		(0)

KPRFIL (35*1) 1,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23,24,25,26,27,28,29,5*30

POW95 (35*0.)

PROFIL (735*0.) see next page

PSEUDO (35*0.) see next page

RHOH2O (20*1.)

TIME (35*0.) see next page

TINLET (21*0.) 537.8

Rod PA/29-4

Input Parameters Contd.

```
PROFIL #1 = 0.263, 9*1.082, 0.263, 10*0.
       #2 = C.382, 9*1.069, 0.382, 10*0.
       #3 = 0.466, 9*1.059, 0.466, 10*0.
       #4 = 0.639, 9*1.040, 0.639, 10*0.
       #5 = 0.679, 9*1.036, 0.679, 10*0.
       #6 = 0.701, 9*1.033, 0.701, 10*0.
       #7 = 0.723, 9*1.031, 0.723, 10*0.
       #8 = 0.741, 9*1.029, 0.741, 10*0.
       #9 = 0.759, 9*1.027, 0.759, 10*0.
      #10 = 0.783, 9*1.024, 0.783, 10*0.
      #11 = 0.798, 9*1.022, 0.798, 10*0.
      #12 = 0.811, 9*1.021, 0.811, 10*0.
      #13 = 0.828, 9*1.019, 0.828, 10*0.
      #14 = 0.852, 9*1.016, 0.852, 10*0.
      #15 = 0.870, 9*1.014, 0.870, 10*0.
      #16 = 0.883, 9*1.013, 0.883, 10*0.
      #17 = 0.896, 9*1.012, 0.896, 10*0.
      #18 = 0.907, 9*1.010, 0.907, 10*0.
      #19 = 0.919, 9*1.009, 0.919, 10*0.
      #20 = 0.929, 9*1.008, 0.929, 10*0.
      #21 = 0.939, 9*1.007, 0.939, 10*0.
      #22 = 0.946, 9*1.006, 0.946, 10*0.
      #23 = 0.955, 9*1.005, 0.955, 10*0.
      #24 = 0.961, 9*1.004, 0.961, 10*0.
      #25 = 0.971, 9*1.003, 0.971, 10*0.
      #26 = 0.983, 9*1.002, 0.983, 10*0.
      #27 = 0.990, 9*1.001, 0.990, 10*0.
      #28 = 0.990, 9*1.001, 0.995, 10*0.
      #29 = 0.995, 9*1.001, 0.995, 10*0.
      #30 = 11*1., 10*0.

PSEUDO = 16.28, 16.28, 17.50, 16.98, 15.33, 16.09, 15.64, 16.92, 16.06,
         15.51, 15.09, 14.51, 16.06, 14.30, 13.58, 12.32, 15.09, 16.52,
         15.64, 15.36, 14.34, 15.18, 17.87, 14.30, 13.87, 14.75, 13.41,
         12.31, 15.09, 15.64, 16.06, 14.25, 14.66, 15.54, 14.66

TIME = 0., 22.92, 46.17, 69.58, 135.58, 182.33, 205.33, 228.67, 251.88,
       275.29, 298.67, 345.38, 361.79, 384.96, 431.29, 501.13, 524.54,
       555.04, 585.17, 608.46, 654.75, 678.17, 701.38, 724.40, 747.67,
       771.29, 817.75, 864.38, 886.13, 909.04, 930.71, 982.92, 1028.92,
       1052.00
```

Rod: 11115

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

Parameter	Value	Default	Parameter	Value	Default	Parameter	Value	Default
ATMOS	14.59	(0)	FRSIN		(0)	NFLX	-3	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW	0.1	(0)	FR35	0.025	(0)	NOH		(0)
DCI	0.3732	(0)	FR40		(0)	NPOW	10	(0)
DCO	0.4220	(0)	FR41		(0)	NPRFIL	5	(0)
DE	0.5343	(0)	FZ		(0.05)	NTIME	24	(0)
DFS	0.3659	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR	1	(0)	PRDCDH	1.4	(0)
DTEMP	43.	(0)	ICREP	-1	(0)	RADS	0.1327	(0)
DVOIDZ		(0)	IDENSF	1	(0)	ROUC	1.97E-5	(0)
EXTP	2199.	(0)	IEXPND		(0)	ROUF	2.36E-5	(0)
FDEN95		(0)	IGAS	3,3,1	(0)	S		(0)
FLXFAC	7.E12	(1.E13)	IPEAK	1	(0)	SIGHF	14000.	(0)
FRACAR		(0)	IRELOC	1,2,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	1.	(0)	IT		(0)	V		(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.3762	(0)
FRACN		(0)	LFUEL	38,38	(0)	XCO		(0)
FRACXE		(0)	LVOIDZ		(0)	XH		(0)
FRDEN	0.9477	(0)	MINI		(0)	XN		(0)
FRDEN2	0.957	(0)	NCLAD		(0)	ZCLAD	1	(0)

KPRFIL (35*1) 2*1, 5*2, 9*3, 3*4, 5*5

POW95 (35*0.)

PROFIL (735*0.) see below

PSEUDO (35*0.) 13.93, 13.93, 12.70, 4*12.90, 12.70, 12.40, 3*11.70, 11.10, 11.10, 10.50, 10.50, 8.10, 8.20, 8.10, 7.70, 8.10, 8.40, 8.30, 8.30

RHOH2O (20*1.)

TIME (35*0.) 0., 10., 35., 70., 105., 140., 167., 208., 250., 285., 320., 350., 385., 417., 460., 500., 554., 602., 656., 720., 753., 760., 810., 860.

TINLET (21*0.) 491.

PROFIL

#1 = 0.710, 0.870, 1.040, 1.180, 1.240, 1.245, 1.265, 0.598, 0.890, 0.815, 0.700, 10*0.
#2 = 0.450, 0.745, 0.980, 1.125, 1.190, 1.185, 1.210, 1.160, 1.050, 0.840, 0.500, 10*0.
#3 = 0.775, 0.940, 1.070, 1.080, 1.050, 1.010, 1.020, 1.035, 1.060, 0.960, 0.720, 10*0.
#4 = 0.610, 0.730, 0.940, 1.145, 1.245, 1.260, 1.265, 1.185, 1.055, 0.830, 0.200, 10*0.
#5 = 0.740, 0.905, 1.045, 1.100, 1.060, 1.035, 1.045, 1.080, 1.085, 0.945, 0.660, 10*0.

Rod: 3618

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

ATMOS	14.59	(0)	FRSIN		(0)	NFLX	-3	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW	0.1	(0)	FR35	0.085	(0)	NOH		(0)
DCI	0.3732	(0)	FR40		(0)	NPOW	10	(0)
DCO	0.4220	(0)	FR41		(0)	NPRFIL	6	(0)
DE	0.5343	(0)	FZ		(0.05)	NTIME	33	(0)
DFS	0.3657	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR	1	(0)	PRDCDH	1.4	(0)
DTEMP	43.	(0)	ICREP	-1	(0)	RADS	0.1327	(0)
DVOIDZ		(0)	IDENSF	1	(0)	ROUC	1.97E-5	(0)
EXTP	2199.	(0)	IEXPND		(0)	ROUF	2.36E-4	(0)
FDEN95		(0)	IGAS	3,3,1	(0)	S		(0)
FLXFAC	8.E12	(1.E13)	IPEAK	1	(0)	SIGHF	14000.	(0)
FRACAR		(0)	IRELOC	1,2,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	1.	(0)	IT		(0)	V		(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	0.3672	(0)
FRACN		(0)	LFUEL	38.38	(0)	XCO		(0)
FRACXE		(0)	LVOIDZ		(0)	XH		(0)
FRDEN	0.9453	(0)	MINI		(0)	XN		(0)
FRDEN2	0.955	(0)	NCLAD		(0)	ZCLAD	1	(0)

KPRFIL (35*1) 4*1, 3*2, 6*3, 4*4, 7*5, 4*6, 5*5

POW95 (35*0.)

PROFIL (735*0.) see next page

PSEUDO (35*0.) see next page

RHOH2O (20*1.)

TIME (35*0.) see next page

TINLET (21*0.) 491.

Rod 3618

Input Parameters Contd.

PROFIL #1 = 0.34, 0.67, 0.96, 1.18, 1.31, 1.36, 1.31, 1.19, 0.98, 0.70, 0.35, 10*0.
#2 = 0.43, 0.72, 0.97, 1.15, 1.26, 1.31, 1.27, 1.16, 0.93, 0.75, 0.45, 10*0.
#3 = 0.46, 0.70, 0.95, 1.14, 1.22, 1.23, 1.27, 1.21, 1.03, 0.75, 0.45, 10*0.
#4 = 0.45, 0.75, 0.98, 1.13, 1.19, 1.19, 1.21, 1.16, 1.05, 0.84, 0.50, 10*0.
#5 = 0.78, 0.94, 1.07, 1.08, 1.05, 1.01, 1.02, 1.04, 1.06, 0.96, 0.72, 10*0.
#6 = 0.51, 0.68, 0.92, 1.13, 1.24, 1.26, 1.27, 1.18, 1.C4, 0.80, 0.45, 10*0.

PSEUDO = 7.45, 7.45, 7.45, 7.0, 6.6, 4.9, 5.7, 6.0, 6.5, 6.3, 2.7, 11.7, 12.5,
11.8, 5*12.6, 12.2, 12.2, 11.8, 11.8, 11.4, 9.4, 9.4, 9.7, 9.7, 9.3,
9.8, 10.3, 10.2, 10.2

TIME = 0., 25., 52., 88., 96., 136., 148., 180., 224., 254., 274., 280., 286.,
310., 350., 400., 450., 500., 526., 565., 609., 650., 700., 750., 800.,
830., 882., 932., 997., 1029., 1037., 1087., 1137.

Rod: 386

Input Parameters for GT-2, Rev. 2

(Default values are in parenthesis)

ATMOS	34.	(0)	FRSIN		(0)	NFLX	-3	(0)
CRUDTH		(0)	FRPUO2		(0)	NFUEL		(0)
CW	0.1	(0)	FR35	0.06	(0)	NOH		(0)
DCI	0.3732	(0)	FR40		(0)	NPOW	14	(0)
DCO	0.4230	(0)	FR41		(0)	NPRFIL	10	(0)
DE	1.012	(0)	FZ		(0.05)	NTIME	35	(0)
DFS	0.3669	(0)	ICDF	1	(0)	PITCH		(0)
DSINZ		(0)	ICOR	1	(0)	PRDCDH	1.17	(0)
DTEMP	50.	(0)	ICREP	-1	(0)	RADS	0.1328	(0)
DVOIDZ		(0)	IDENSF	1	(0)	ROUC	2.E-5	(0)
EXTP	1990.	(0)	IEXPND		(0)	ROUF	8.E-5	(0)
FDEN95		(0)	IGAS	3,3,1	(0)	S		(0)
FLXFAC	6.E12	(1.E13)	IPEAK	1	(0)	SIGHF		(0)
FRACAR		(0)	IRELOC	1,2,2	(0)	TM		(2805 C)
FRACH		(0)	IRL		(0)	TPLAS		(1200 C)
FRACHE	1.	(0)	IT		(0)	V	12.8	(0)
FRACKR		(0)	KGAS		(0)	VPLENZ	1.44	(0)
FRACN		(0)	LFUEL	85.	(0)	XCO		(0)
FRACXE		(0)	LVOIDZ		(0)	XH		(0)
FRDEN	0.948	(0)	MINI		(0)	XN		(0)
FRDEN2	0.968	(0)	NCLAD		(0)	ZCLAD	1	(0)

KPRFIL (35*1) 2*1, 4*2, 3*3, 6*4, 5, 6, 4*7, 8, 7*9, 6*10

POW95 (35*0.)

PROFIL (735*0.) see next page

PSEUDO (35*0.) see next page

RHOH2O (20*1.)

TIME (35*0.) see next page

TINLET (21*0.) 533.

Rod 386

Input Parameters Contd.

PROFILE
#1 = 0.285, 0.520, 0.718, 0.862, 1.084, 1.203, 1.204, 1.304, 1.340, 1.293, 1.278, 1.205, 1.066, 0.907, 0.729, 6*0.
#2 = 0.432, 0.710, 0.881, 0.949, 1.101, 1.148, 1.096, 1.161, 1.188, 1.159, 1.179, 1.148, 1.063, 0.963, 0.829, 6*0.
#3 = 0.477, 0.761, 0.930, 0.961, 1.069, 1.083, 1.015, 1.070, 1.100, 1.083, 1.133, 1.149, 1.111, 1.072, 0.988, 6*0.
#4 = 0.609, 0.882, 1.005, 0.989, 1.071, 1.061, 0.976, 1.017, 1.040, 1.018, 1.061, 1.087, 1.079, 1.080, 1.030, 6*0.
#5 = 0.700, 0.878, 0.955, 0.973, 1.029, 1.044, 1.034, 1.056, 1.059, 1.051, 1.078, 1.070, 1.049, 1.034, 0.989, 6*0.
#6 = 1.090, 1.145, 1.170, 1.180, 1.170, 1.155, 1.130, 1.090, 1.050, 0.990, 0.930, 0.850, 0.770, 0.700, 0.640, 6*0.
#7 = 0.689, 0.926, 1.010, 1.012, 1.066, 1.066, 1.030, 1.045, 1.046, 1.026, 1.053, 1.048, 1.018, 1.003, 0.961, 6*0.
#8 = 0.753, 0.942, 1.037, 1.002, 1.079, 1.071, 0.985, 1.013, 1.022, 0.990, 1.042, 1.051, 1.014, 1.010, 0.988, 6*0.
#9 = 0.574, 0.774, 0.915, 0.960, 1.089, 1.132, 1.085, 1.138, 1.152, 1.110, 1.131, 1.100, 1.020, 0.951, 0.867, 6*0.
#10 = 0.758, 0.958, 1.035, 1.004, 1.068, 1.065, 0.995, 1.031, 1.047, 1.021, 1.021, 1.026, 1.000, 0.991, 0.971, 6*0.

PSEUDO = 5.78, 5.78, 4.01, 4.28, 7.03, 7.39, 7.95, 5.34, 6.36, 7.77, 6.91, 3.00, 7.77, 6.94, 9.47, 10.59, 10.59, 9.94, 10.15, 9.56, 3.87, 5.38, 7.11, 7.78, 9.07, 8.43, 8.85, 8.41, 8.41, 8.03, 5.30, 7.89, 5.21, 7.89

TIME = 0., 69., 123., 165., 232., 298., 322., 368., 400., 472., 491., 509., 600., 697., 720., 774., 774.33, 805., 820., 900., 981., 994., 1007., 1032., 1041., 1069., 1077., 1138., 1200., 1264., 1295., 1302., 1312., 1320., 1334.

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The GAPCON-THERMAL-2 code is used by the U. S. Nuclear Regulatory Commission for audit calculations of nuclear fuel thermal performance computer codes. Since the code was originally written, errors and needed updates have been identified. Revision 2 of GAPCON-THERMAL-2 contains a number of coding corrections and updates, and now conforms with the American National Standards Institute FORTRAN-77 standard. The changes to the code are presented in detail. Benchmarking calculations, concentrating on fuel temperatures and fission gas release, were performed to qualify the effect of model changes on the performance of GAPCON-THERMAL-2, Revision 2. It was concluded that use of the old fuel relocation model combined with the modified ANS 5.4 fission gas release model provides the best overall comparison with the thermal performance and fission gas release data used for the benchmarking exercise. The use of the new fuel relocation model combined with the Beyer-Hann fission gas release model provided the best comparisons of thermal behavior but significantly underpredicted fission gas release.

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