Gapcon-Thermal-3 Verification and Comparison to In-Reactor Data

**D. D. Lanning
F. E. Panisko
C. L. Mohr**

September 1978

**Prepared for the
Fuel Behavior Research Branch
Division of Reactor Safety Research
U.S. Nuclear Regulatory Commission**

**Pacific Northwest Laboratory
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CONTENTS

INTRODUCTION	1
VERIFICATION OF MATHEMATICAL CONSISTENCY	3
TEMPERATURE CALCULATIONS	3
Steady-State Fuel Temperatures	3
Transient Calculations	6
ELASTIC MECHANICAL CALCULATIONS	7
COMPARISON TO ISOLATED OR SEPARATE EFFECTS	15
THERMAL PROPERTIES AND MODELS VERSUS DATA	16
Fuel Thermal Conductivity	16
Cladding Heat Capacity	16
Thermal Conductivity of Fill Gases	18
Out-of-Pile Gap Conductance Data	19
In-Pile Gap Conductance Tests	24
MECHANICAL PROPERTIES AND MODELS	32
The Elastic Modulus for UO_2	33
Poisson's Ratio for UO_2	35
Thermal Expansion of the UO_2	35
Cladding Hardness	37
Cladding Creep Data	38
Cladding Yield Stress	39
COMPARISON AGAINST IN-REACTOR DATA	41
MEASUREMENTS OF CENTERLINE TEMPERATURE	41
HPR-80 (IFA-11, 21) TEST	41
The IFA-131 Test	44
IFA-130 Irradiation	46
IFA-418 Test (EPRI Case C)	47
The AE-318 Tests (IFA-3, 4, and 10)	49
The AE-411 Experiment	51
The IFA-431/432 Experiment	54
TEMPERATURE AND FISSION GAS RELEASE.	62
The CC-7 Experiment (EPRI Case A)	62
The Belgonucleaire Experiment "ELP".	64
The NRX Fission Gas Release Experiments	66

The S 150 Simulation at Studsvik (EPRI Case E)	. . .	68
Maine Yankee Rod (EPRI Case D)	. . .	70
TEMPERATURE AND CLAD DEFORMATION MEASUREMENTS	. . .	71
The IFA-117 Experiment	. . .	71
IFA-431, (Rod 3)	. . .	75
IFA-132 Startup Ramps to Power	. . .	78
The X-260, 264 Tests	. . .	79
SUMMARY AND CONCLUSIONS	. . .	81
REFERENCES	. . .	82
APPENDIX A	. . .	86

FIGURES

1	Fuel Radial Temperature Profiles in Steady State	4
2	Comparison to an Exact Solution for the Case of Fuel Restructuring	5
3	Fuel Transient Radial Temperature Profiles	6
4	Comparison Between Subroutine DDLR and the Finite-Difference Code TRUMP (UCRL-14754, 1972) for a Step Power Decrease	7
5	Clad Response to Pressure Load	8
6	Clad Response to Temperature Gradient	9
7	Model for GAPCON-3 SAP-IV Comparison	11
8	Detail of the Model for the GAPCON-3 SAP-IV Comparison	11
9	Cladding Elongation and Radial Deflection Under Isothermal Heatup	12
10	Average Radial and Hoop Stresses, in the Cladding in the Contact Region	12
11	Cladding Axial Stress as a Function of Axial Position	13
12	Cladding Hoop Stress as Function of Axial Position	13
13	Data as Compiled in Reference 9 for Thermal Conductivity.	17
14	Fuel Enthalpy Data and GAPCON-3 Prediction	18
15	Comparison of GAPCON-3 Calculated Values for Gas Mixture Thermal Conductivity to Data from the Compilation by Gandhi and Saxena	19
16	GAPCON-3 Calculated Values for Gas Conductance versus Data from the Ex-Reactor Experiment by Ross and Stoute	20
17	Figure 17 GAPCON-3 Calculated Values for Solid-Solid Gap Conductance versus Data from Ross and Stoute	21
18a	Comparison of GAPCON-3 Gap Conductance to Dean Data for Total Conductance in Argon	22
18b	The Same Comparison, Using the Reported Values for UO ₂ Wavelength Rather Than Those Internally Calculated by GAPCON-3	22
19	Ex-Reactor Gap Conductance Data from Battelle Compared to the GAPCON-3 Model	23
20	Experimental Results of Helium Pressure Cycle at 560 W/cm	26
21	Individual Thermocouple Behavior from Argon Pressure Cycle at 490 W/cm	27
22	INEL In-Reactor Data versus GAPCON-3 for 4 mil Gap, He Filled, 97% TD Rod	28
23	INEL Data versus GAPCON-3 for a 4 mil Gap, He Filled, 95% TD Fuel Rod	28

24	GAPCON-3 versus INEL In-Reactor Data for a 9 mil He Filled, 95% TD Rod	29
25	GAPCON-3 versus INEL In-Reactor Data for a 14 mil Gap, He Filled, 95% TD Rod	29
26	GAPCON-3 versus INEL In-Reactor Data for a 4 mil Gap, Ar Filled, 97% TD Rod	30
27	Subroutine DENSF Predictions versus Halden In-Reactor Densification Data	31
28	Calculated versus Measured Gap Closure	32
29	Comparison of GAPCON-3 Values for Young's Modulus of UO_2 versus Data Compiled in MATPRO	33
30	Room Temperature Values of Young's Modulus of UO_2 versus the GAPCON-3 Constant Value	34
31	Young's Modulus of Zy-4 from Busby's Data Compared to GAPCON-3 Values	35
32	Comparison of Subroutine GAPCON-3 Values for UO_2 Thermal Expansion versus Data Compiled in MATPRO	36
33	Axial Thermal Expansion of Zy-4 versus GAPCON-3 Values Over Practical Range	37
34	The GAPCON-3 Values for Zy Meyer Hardness Compared to the MATPRO Correlation	38
35	Comparison of MATPRO and GAPCON-3 Zy Creep Models	39
36	Comparison to HPR-80 Thermocouple Data	42
37	Comparison to HPR-80 Thermocouple Data	43
38	Effect of Burnup on Centerline Temperature of a Small (2 mil) Gap, He Filled Halden Rod	43
39	Temperature versus Power for a He Filled 6 mil Gap Halden Rod	44
40	Centerline Temperature versus Power for a 9 mil Gap, He Filled Halden Rod	45
41	Temperature versus Power for a 12 mil Gap, He Filled Halden Rod	45
42	Steady-State and Approach-to-Power Data Trends for a He Filled, 1 mil Gap, Halden Rod	46
43	Centerline Temperature versus Power for a 9 mil Gap, He Filled, Halden Rod	47
44	Power History for EPRI Case C	48
45	GAPCON-3 versus Centerline Temperature Data for EPRI Case C	48
46	Through-Life Centerline Temperature versus Power for a He Filled, 7 mil Gap Halden Rod	50

47	Through-Life Centerline versus Power Data for a 17 mil Gap, He Filled Halden Rod	50
48	Through-Life Centerline Temperature versus Power Data for a 12 mil Gap, He Filled Halden Rod	51
49	Temperature versus Radius Data from AE-411, at 12.86 kW/ft	52
50	Temperature versus Radius Data from AE-411 at 9.86 kW/ft	53
51	Temperature versus Radius Data from AE-411 at 6.95 kW/ft	53
52	Temperature versus Radius Data from AE-411, at 4.83 kW/ft	54
53	Centerline Temperature Data at Fixed Power versus Burnup from Rod 3 (2 mil Gap, He Fill) Halden Test IFA-431	56
54	Centerline Temperature at Fixed Power versus Burnup for Rod 3 (He Fill, 3 mil Gap) Halden Test IFA-432	56
55	Centerline Temperature at Fixed Power as a Function of Burnup for Rod 1 (9 mil Gap, He Fill), Halden Test IFA-431	57
56	Centerline Temperature at Fixed Power versus Burnup for Rod 1 (9 mil Gap, He Fill) from Halden Test IFA-432	58
57	Centerline Temperature at Fixed Power as a Function of Burnup for Rod 2 (He Filled, 15 mil Gap) from Halden Test IFA-431	59
58	Centerline Temperature at Fixed Power versus Burnup for Rod 2 (15 mil Gap, He Fill) from Halden Test IFA-432	59
59	Centerline Temperature at Fixed Power versus Burnup for Rod 5 (9 mil Gap, He Filled 92% TD Fuel) from Halden Tests IFA-431 and IFA-432	60
60	Centerline Temperature at Fixed Power versus Burnup for Rod 6 (9 mil Gap, He Filled 92% Unstable Fuel) from IFA-432	61
61	Power History, Temperature History and Fission Gas Release for CEA Experiment, Rod 4113, Segment AE1	63
62	Power History, Temperature History, and Fission Gas Release for CEA Experiment, Rod 4112, and Segment BE1	63
63	Grain Growth Boundary Temperature Data from Experiment ELP-9	65
64	ELP-9 Power History and Gas Release Data	66
65	Actual and Input Power Histories for EPRI Case E Comparison	69
66	Input Power History and Calculated Temperature History for EPRI Case D	70
67	Comparison to HPR-107 Thermocouple Data	72
68	Comparison to HPR-107 Elongation Data	74
69	Comparison to IFA-431 Thermocouple Data	76

70	Comparison to IFA-431 Elongation Data	76
71	Total Cladding Elongation versus Burnup for Rod 3, IFA-431 . . .	77
72	Total Cladding Elongation from IFA-432 Experiment	78
73	Diametral Strain for a CANDU Type Rod	79

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GAPCON-THERMAL-3 VERIFICATION AND COMPARISON TO IN-REACTOR DATA

1.0 INTRODUCTION

The GAPCON-THERMAL-3 computer code⁽¹⁾ is an outgrowth of the GAPCON series, written in response to a need to predict the interacting path-dependent thermal and mechanical behavior of oxide fuel rods. Previous GAPCON versions did not include a comprehensive path-dependent prediction of cladding stress and strain that was connected to the thermal history. GAPCON-THERMAL-3 includes an incremental, finite element solution for the cladding that includes elastic, plastic and creep contributions. The stress-strain increments for each time step reflect the thermal-mechanical state of the fuel at that time, so that the evolution of fuel and cladding displacements and temperatures through time is truly interconnected and path dependent.

The creation of such an interdependent mathematical model of a fuel rod involves recognizing a delineation between 1) the proper mathematical functioning of the code, and 2) the adequacy of the explicit and implicit assumptions used in the development of the code. "Verification" of the code is thus divided as follows:

1. Mathematical consistency is verified by comparison to hand calculations and analytical solutions. Simplifications in the code, such as the elimination of temperature dependency of material properties, must often be made to accomplish this.
2. Separate-effects models, such as conductivity of a mixed gas or the creep rate as a function of stress, time and temperature, are verified.
3. Comparison is made to irradiation experiments, including those which involve simultaneous measurement of fuel temperature and cladding deflection.

Section 3.0 presents verification of the mathematical models. Section 4.0 gives a comparison of the major separate-effects models to the data.

Although the GAPCON-THERMAL-3 code is modular in structure, to facilitate the substitution of different models, a user making a major change to the code should repeat some of the verification presented in Section 3.0.

Section 5.0 presents a comparison of the code with irradiation data. The number of cases shown is not exhaustive; it is meant to show the range of problems to which the code may be applied.

2.0 VERIFICATION OF MATHEMATICAL CONSISTENCY

The solutions for temperatures, stresses, and strains in the code are all derived from approximate, iterative techniques--for two reasons. First, the governing differential equations and their boundary conditions are so highly nonlinear that exact analytical solutions do not exist. Secondly, a balance is sought between computer time and cost versus the desired accuracy of the output. For example, owing to input and model uncertainties, it is not sensible to expect calculated temperatures to be accurate to more than a few degrees. Nor is it sensible to calculate stresses to more than about 10% relative.

The foregoing does not excuse the convergence techniques from being mathematically consistent. They must converge toward true solutions for idealized cases where true solutions are known. This section demonstrates that kind of consistency for the temperature and elastic stress/strain calculations.

TEMPERATURE CALCULATIONS

The temperature calculations in the code are based on the assumption of radial heat flow only. The method used for solving the non-linear radial heat transfer equation is orthogonal collocation of fourth order in the fuel and second order in the clad. Reference 1 describes the technique. Examples of its adequacy are given below.

Steady-State Fuel Temperatures

The solution for the fuel temperature distribution in a solid cylindrical fuel rod with constant volumetric heat generation rate and temperature independent conductivity, can be expressed in normalized form as ⁽³⁾

$$T_N = 1 - y^2$$

where

$$T_N = (T - T_S)/(T_0 - T_S)$$

$$y = r/r_S$$

and T_0 , T_s are centerline and surface temperatures, respectively, and r_s is the fuel outer radius. This distribution is shown in Figure 1.

FIGURE 1. Fuel Radial Temperature Profiles in Steady State

Also shown in Figure 1 is the solution (normalized to the same quantity $T_0 - T_s$) for an annular pellet with flux depression appropriate to 10% U-235 enrichment, and temperature-dependent thermal conductivity. The Lyons equation⁽²⁾ was used for the conductivity. The solution was obtained by iterative, point-by-point solution of the integrated heat transfer equation:

$$\int_{T_s}^{T_0} K dt = \int_{r_0}^{r_s} dr/r \int_{r_0}^r r^1 Q(r^1) dr^1$$

where K is the conductivity, Q is the volumetric heat generation rate, and the other symbols have been previously defined. GAPCON-3 calculations are shown for both cases and agree with the analytical solution within 1°C .

Figure 2 shows a steady-state temperature distribution in a fuel rod that has restructured to 32% of the radius. The unrestructured density was 96.35% of theoretical and the restructured density was 98%. This results in porosity correction factors (relative to 95% TD) of 1.021 and 1.047, respectively. The temperature distribution in the figure was found from the exact $\int k dT$ method and the GAPCON-3 points are within 15°C of this curve.

FIGURE 2. Comparison to an Exact Solution for the Case of Fuel Restructuring

Transient Calculations

Figure 3 depicts the temperature response of a solid fuel pellet (with constant heat generation and temperature-independent conductivity) to a sudden application of power at the time - 0. The temperature solution as a function of time t and radius can be expressed as;⁽²⁾

$$T_N = 1 - y^2 - 8 \sum_{n=1}^{\infty} \frac{J_0(\alpha_n y) e^{-\alpha_n^2 \tau}}{\alpha_n^3 J_1(\alpha_n)}$$

where $\tau = \mu t / r_s^2$, μ = diffusivity

and α_n are the roots of $J_0(\alpha_n) = 0$.

$$\text{Also } T_N = (T_0 - T_S) / (T_0^f - T_S) = (T_0 - T_S) / (Q r_s^2 / 4K)$$

where Q = volumetric heat generation rate,

K = conductivity.

T_0 , T_S , r_s and y have their previous meanings.

and the superscript "f" refers to final (steady-state) values.

The GAPCON-3 check points indicated in Figure 3 are within 1°C of the analytical solution.

FIGURE 3. Fuel Transient Radial Temperature Profiles

Although we have not found an analytical solution to a transient case with temperature-dependent conductivity, the finite difference code TRUMP⁽⁴⁾ can calculate transient temperatures to within fractions of a degree, given a 50-node radial mesh. Figure 4 presents a cross comparison between TRUMP and GAPCON-3 for the case of sudden loss of power at time = 0. The rod was enriched to 10% U-235 so that flux depression was an added complication. The two codes compared within 5°C at all times.

FIGURE 4. Comparison Between Subroutine DDLR and the Finite-Difference Code TRUMP (UCRL-14754, 1972) for a Step Power Decrease

$$\text{Note } T_N = \frac{T_C - T_{\text{coolant}}}{T_C^{\text{init.}} - T_{\text{coolant}}}$$

ELASTIC MECHANICAL CALCULATIONS

The mechanical calculations in the code are done on an incremental basis, using finite element methods. However, a comprehensive finite element model of the entire fuel pin is not used. Rather, a simple model of the pin that is adequate and comprehensive in the axial direction is formulated, together with a series of radial models representing thin slices of the pin at different

elevations. The radial model is used to evaluate radial interactive forces between the fuel and the cladding, and these forces are passed on to the axial model in the form of radial point loads. Average axial stresses from the axial model are applied along the top of each radial slice to provide the proper boundary conditions. This chained radial-axial-radial solution technique is discussed in reference 1. Figures 5 and 6 demonstrate the basic functioning of the radial model. Figure 5 shows, for the cladding, the hoop stress response to an external pressure load. For constant material properties, this response is known to be:⁽⁵⁾

$$\sigma_{\text{hoop}} = \left(\frac{-P_o}{1-R} \right) (1 - R^2/y^2)$$

where σ_{hoop} = stress, P_o = external pressure (differential), $R = r_{CI}/r_{CS}$, $y = r/r_{CS}$, and r_{CI} , r_{CS} = cladding inner and outer radii. The agreement between GAPCON-3 and this solution is within 1% relative.

FIGURE 5. Clad Response to Pressure Load (Hoop Stress)

FIGURE 6. Clad Response to Temperature Gradient (Hoop Stresses)

Figure 6 shows the hoop stress response to a logarithmic temperature distribution across the cladding. The response is known to be:⁽⁵⁾

$$\sigma_{\text{hoop}} = \frac{E\alpha\Delta T}{2(1-\mu)\ln(1/R)} \left[1 - \ln(1/y) - \frac{R^2}{1-R^2} (1+y^2)\ln(1/R) \right]$$

for the standard temperature form,

$$T = \frac{\Delta T}{\ln(1/R)} \ln(1/y)$$

where E is the elastic modulus, ΔT is the total temperature drop across the cladding, α is the coefficient of thermal expansion, μ is Poisson's ratio, and y and R have the same meaning as before.

Figures 7 through 12 are meant to show the functioning of the chained radial-axial-radial solution. This situation is sketched in Figure 7. A fuel rod has one axial region in contact, and is isothermally heated to 470°F. The "trapped stack" of pellets below the contact region interact with the cladding axially, and the pellets in the contact region interact with cladding radially. The finite element program SAP-IV⁽⁶⁾ was applied to this problem using the comprehensive model sketched in Figure 8. Figure 9 shows resulting solutions for total cladding axial displacement and radial displacement in the contact region as a function of temperature. The cladding hoop and radial stresses are shown as a function of temperature for the contact region (Figure 10). The axial variation of cladding hoop and axial stress are shown for 400°F above reference in Figures 11 and 12, respectively. The accompanying GAPCON-3 check points on these figures generally demonstrate agreement within 1%.

FIGURE 7. Model for GAPCON-3 SAP-IV Comparison

FIGURE 8. Detail of the Model for the GAPCON-3 SAP-IV Comparison. Each Level Contains 4 Elements. The Axial Heights of the Levels are Noted.

FIGURE 9. Cladding Elongation and Radial Deflection Under Isothermal Heatup

FIGURE 10. Average Radial and Hoop Stresses, in the Cladding in the Contact Region

FIGURE 11. Cladding Axial Stress as a Function of Axial Position (400°F Above Reference Temperature)

FIGURE 12. Cladding Hoop Stress as Function of Axial Position (400°F Above Reference Temperature)

3.0 COMPARISON TO ISOLATED OR SEPARATE EFFECTS

The major models in GAPCON-THERMAL-3 are separately compared against data in this section to assure that they are contributing reasonable results to the code. The discussion of effects involving the interaction and integration of separate models (e.g. fission gas release) has been restricted to Section 5.0. The specific data comparisons made here include the following:

For Thermal Models:

- Fuel (UO_2) thermal conductivity
- Fuel (UO_2) heat capacity
- Fill gas thermal conductivity
- Out-of-pile gap conductance
- In-pile gap conductance (INEL and AECL tests)
- Fuel swelling
- Fuel relocation (gap closure)
- Fuel densification

For Mechanical models:

- Young's Modulus
- Poisson's Ratio
- Thermal expansion
- Cladding Meyer Hardness
- Zircaloy creep
- Zircaloy yield strength

THERMAL PROPERTIES AND MODELS VERSUS DATA

The parts of the code affecting thermal results may be divided into 1) thermal material properties and 2) models which affect the calculation of gap size and gap conductance. The thermal properties assumptions for the fuel are of primary importance; data comparisons will be shown for these. The data base for the clad thermal material properties will be referenced.

Fuel Thermal Conductivity

There are variations in thermal conductivity of unirradiated UO_2 which outweigh those produced by irradiation.⁽⁸⁾ The user may substitute his own expression for fuel thermal conductivity to account for these variations; provision is made for this in the code input. As a default, the code uses the expression developed by Lyons et al.⁽⁴⁾ A comparison of this expression with a compilation^(9, 10) of 485 data points from various authors is given in Figure 13. The agreement with data is reasonable in the range 400-2000°C, where most power reactor fuel is confined. A 1% penalty for every 1% PuO₂ addition is imposed on the fuel conductivity, up to a maximum of 5%. Reference 10 gives the basis for this procedure.

Cladding Thermal Conductivity

The thermal conductivity values for Zircaloy are due to Scott;⁽¹²⁾ those for steel are taken from the Nuclear Materials Systems Handbook⁽¹³⁾ for 304-L stainless steel.

Heat capacity of UO_2 fuel is calculated by a polynomial in temperature as developed by Bates.⁽¹⁴⁾ The expression matches the enthalpy data trend by Kerrisk and Clifton⁽¹⁵⁾ within 1%, as shown in Figure 14.

Cladding Heat Capacity

The values^(a) for cladding heat capacity do not effect stored energy in the fuel, and minimally effect the progress of a transient.

a. The values used are the "typical values" listed in reference 15, p. 67.

FIGURE 13. Data as Compiled in Reference 9 for Thermal Conductivity. The Lyons Conductivity Curve is shown Relative to a Least-Squares Fit Curve, Excluding Lyons Data Above 1600°C.

FIGURE 14. Fuel Enthalpy Data and GAPCON-3 Prediction

Thermal Conductivity of Fill Gases

The familiar equations of Chapman-Encskog theory, as set forth in reference 17, are used to calculate the thermal conductivity of pure monatomic gases. Mixtures of gases are handled by Wilke's simplified equations⁽¹⁸⁾ which are also found in reference 17. Figure 15 gives a comparison of these equations to data for pure and mixed gases. The data comes from the compilation by Gandhi and Saxena.⁽¹⁹⁾ The compilation includes data for pure gases and binary combinations of He, Xe, Ne, Ar and Kr, in the temperature range of 0° to 520°C.

FIGURE 15. Comparison of GAPCON-3 Calculated Values for Gas Mixture Thermal Conductivity to Data from the Compilation by Gandhi and Saxena.⁽¹⁹⁾ (Units of $W/cm-^{\circ}C \times 10^{-3}$)

Out-of-Pile Gap Conductance Data

Ross and Stoute⁽²⁰⁾ and Dean⁽²¹⁾ have made out-of-pile contact conductance measurements on UO_2 -Zircaloy interfaces at representative pressures. The method Ross and Stoute used allowed for an experimental separation of the total contact conductance into that due to solid-solid contact (h_{solid}) and that due to conduction through the gas (h_{gas}). Reference 1 describes the models used for GAPCON-3 for h_{solid} and for h_{gas} . These separate components to the Ross

and Stoute values are compared in Figures 16 and 17. The Ross-Stoute data involved contact pressures from 1500-7000 psi and He, Ar, Kr, and Xe gases at 150° to 300°C. As shown, GAPCON-3 slightly underpredicts this data.

FIGURE 16. GAPCON-3 Calculated Values for Gas Conductance versus Data from the Ex-Reactor Experiment by Ross and Stoute.⁽²⁰⁾ (Units of $W/cm^2-^{\circ}C$)

FIGURE 17. GAPCON-3 Calculated Values for Solid-Solid Gap Conductance versus Data from Ross and Stoute.⁽²⁰⁾ Units of $W/cm^2-^{\circ}C$

The experiment conducted by Dean took place in 1 atm Argon gas. The solid contact and conduction components were not separated experimentally. Accordingly, his values for total conductance are plotted against GAPCON-3 model predictions for total conductance in Figure 18a. Here we see GAPCON-3 significantly underpredicting the data values, possibly because the wavelength (peak-to-peak distance) Dean reported for his UO_2 surface is relatively large compared to his reported UO_2 surface roughness. The wavelength is internally calculated by GAPCON-3 based on input roughness, according to a relationship discussed in reference 21. If the wavelength reported by Dean (rather than the one internally calculated) is used, the GAPCON-3 model agrees much better with Dean's data, as shown in Figure 18b.

FIGURE 18a. Comparison of GAPCON-3 Gap Conductance to Dean Data(21) for Total Conductance in Argon

FIGURE 18b. The Same Comparison, Using the Reported Values for UO_2 Wavelength Rather Than Those Internally Calculated by GAPCON-3 (units of $W/cm^2-^{\circ}C$)

Ex-reactor (open-gap) gap conductance measurements on Zircaloy-UO₂ pairs have recently been made at Battelle-Northwest.⁽²²⁾ These measurements have been made at 1 atm gas pressure by means of the laser-pulse diffusivity measurement described by Garnier and Begej. The data includes pure helium, pure argon, and binary mixtures of helium and argon, and helium and xenon. The gap sizes range from 0.85 to 25 micrometers (i.e. from 30 to 1000 microinches); the temperatures ranged from 20° to 600°C. Figure 19 compares the GAPCON-3 model against this data.

FIGURE 19. Ex-Reactor Gap Conductance Data from Battelle Compared to the GAPCON-3 Model

In-Pile Gap Conductance Tests

Any inference of absolute gap conductance values from in-pile irradiation tests must be based on some indication of fuel temperature at a particular point and time, plus some estimate of the corresponding local power. These inferred conductances are subject to the following sources of uncertainty:

- measured fuel temperature
- corresponding local power
- inferred fuel surface temperature (which involves uncertainty in the fuel thermal conductivity, and the flux depression, to say nothing about bias introduced by cracks and by non-radial components to the heat flow).

The magnitude of these uncertainties is such as to produce uncertainties in gap conductance in excess of 100% for these classes of irradiation tests:

- Tests involving inference of fuel temperatures from post-irradiation fuel microstructure.
- Tests involving thermocouple measurements of fuel centerline temperature only, if the uncertainties on fuel thermal conductivity, flux depression and power (or a combination thereof) exceeds $\sim 10\%$ relative.
- Any test where uncertainty of the cladding inner temperature exceeds $\sim 75^\circ\text{C}$ for some reason.

This leaves tests involving off-center thermocouples in fuel rods with relatively thin cladding and direct heat transfer from cladding to coolant. Use of off-center thermocouples reduces the uncertainty (although it may increase the bias) of inferred gap conductance values. Of course, to actually infer the gap conductance from the measurements requires a two-dimensional heat transfer analysis, to account for azimuthal heat flow in the vicinity of the thermocouple wells.

Two tests involving off-center thermocouples in fuel rods have been performed recently. These are the SEK test in the NRX Reactor⁽²³⁾ at Chalk River, Canada, and the Gap Conductance Test Series at the PBF Reactor,⁽²⁴⁾ Idaho Falls, Idaho. Temperature data of the off-center thermocouples from both tests will be presented, and compared to GAPCON-3 predictions.

The SEK Gap Conductance Test

This test involved one instrumented rod (SEK) and one non-instrumented rod in the X-2 loop of the NRX reactor. The instrumented rod had stainless steel cladding, and was fitted to an external gas composition; pressure could be varied at power. Helium and Argon gas were used interchangeably, at pressures from .001 to 14.0 MPa (.01 to 140 atm). The UO_2 fuel pellets were 1.88 cm in diameter; the three off-center thermocouples were placed 120° apart on the 0.775 cm radius. The thermocouple well diameters were 1.0 mm. The thermocouples were chromel-alamel, incolnel sheathed and grounded. Strain gauges measured cladding radial deflection. The fabricated fuel-cladding gap was 1.4 mm diametral.

The off-center fuel temperature and cladding strain were measured at constant power. The rods hung in-line in the X-2 loop, and the local power associated with the thermocouple readings was deduced from loop calorimetry plus output from four β - current neutron detectors arranged axially and radially just outside the shroud tube. Figure 20 shows temperature data for a pressure ramp at constant power with Helium gas. The actual average peripheral fuel temperatures are plotted. In order to compare these to GAPCON-3, these temperatures should be *increased* $\sim 40^\circ\text{C}$, to compensate for the effect of the thermocouple holes. The pressure dependence of the conductance is being modeled correctly by GAPCON, since the decrease in temperature with increase in pressure is of the right relative magnitude. The reason the code diverges from the data in the regime of fuel-cladding contact is probably due to the input of the (very small) reported roughnesses. As more reasonable values are inserted, GAPCON -3 comes closer to the data. This is indicated in Figure 21--the same presentation as Figure 20 for an Argon pressure cycle.

FIGURE 20. Experimental Results of Helium Pressure Cycle at 560 W/cm

FIGURE 21. Individual Thermocouple Behavior from Argon Pressure Cycle at 490 W/cm

INEL Gap Conductance Tests (23)

An extensive series of tests involving off-center thermocouples in Zircaloy-clad fuel rods is underway at Idaho National Engineering Laboratory (INEL). The test assemblies consist of four instrumented fuel rods in a special flow tube. Local powers are determined from flux wires and β - current neutron detectors distributed axially and radially in the assembly, coupled with loop calorimetry data during calibration runs. The rods nominally contained 1.04 - 1.07 cm diameter pellets with differing densities, gap size and fill gas from rod to rod. Each rod contained a fuel centerline thermocouple. Three off-center thermocouples were generally located in each fuel rod, 120° apart, with centers on the 0.35 cm radius. The thermocouple wells were 1.4 mm in diameter. The off thermocouples were chromel-alumel, incolnel clad. The results of tests with Helium-filled rods were compared to GAPCON-3. To account for the off-center hole, the temperatures plotted in Figures 22-26 should be

raised $\sim 50^{\circ}\text{C}$ at 500 w/cm and proportionately less at lower heat ratings. Figures 22-26 show fair agreement between GAPCON-3 and the data, indicating that the in-pile gap conductance is being estimated correctly.

FIGURE 22. INEL In-Reactor Data versus GAPCON-3 for 4 mil Gap, He Filled, 97% TD Rod

FIGURE 23. INEL Data versus GAPCON-3 for a 4 mil Gap, He Filled, 95% TD Fuel Rod

FIGURE 24. GAPCON-3 versus INEL In-Reactor Data for a 9 mil He Filled, 95% TD Rod

FIGURE 25. GAPCON-3 versus INEL In-Reactor Data for a 14 mil Gap, He Filled, 95% TD Rod

FIGURE 26. GAPCON-3 versus INEL In-Reactor Data for a 4 mil Gap, Ar Filled, 97% TD Rod. Shaded Area Indicates Data Scatter

Fuel Densification

The fuel densification model in the code is that proposed by the USNRC.⁽²⁵⁾ The fuel is assumed to reach its terminal density very rapidly in GAPCON-3. In terms of burnup, terminal density is reached in about 2000 MWd/MTM. The terminal density is user input (FRDEN2). Some fuel stack shortening experiments were performed in the Norwegian Halden Reactor, for which terminal densities were determined. When these were input into the GAPCON model, the comparison shown in Figure 27 was obtained.

Fuel Relocation

The model used in GAPCON-3 for fuel relocation is the same as in GAPCON-THERMAL-2⁽²⁶⁾ and is based on cold diametral gap estimates from micrographs of irradiated fuel.^(27, 28) Figure 28 compares the model to this data. The comparison indicates extremely poor correlation between measured and predicted values. This may simply mean that residual cold gaps measured from micrographs after element disassembly and rod sectioning are a poor indication of in-reactor fuel relocation.

FIGURE 27. Subroutine DENSF Predictions versus Halden In-Reactor Densification Data

FIGURE 28. Calculated versus Measured Gap Closure (% of initial gap)

MECHANICAL PROPERTIES AND MODELS

Although the mechanical properties from the compilation called MATPRO,⁽²⁹⁾ are not used in GAPCON-3, the MATPRO values are easily substituted by use of input options. In this section we will compare the mechanical properties of UO_2 and cladding against the MATPRO data base, and reference the GAPCON-3 data base. We will also show predictions of the Zircaloy creep model relative to data.

The Elastic Modulus for UO_2

The values for the temperature-dependent UO_2 elastic modulus are taken from Marlowe.⁽³⁰⁾ These are shown as a function of temperature and porosity against the MATPRO compilation in Figures 29 and 30, respectively.

FIGURE 29. Comparison of GAPCON-3 Values for Young's Modulus of UO_2 versus Data Compiled in MATPRO

FIGURE 30. Room Temperature Values of Young's Modulus of UO_2 versus the GAPCON-3 Constant Value

The Elastic Modulus for Zircaloy and Stainless Steel

The elastic moduli for Zircaloy-2 and -4 are taken from Scott.⁽¹¹⁾
 Figure 31 shows them relative to MATPRO's preferred set from Busby.⁽³¹⁾

The elastic modulus for stainless steel (304-L) is taken from the Nuclear Materials Handbook.

FIGURE 31. Young's Modulus of Zy-4 from Busby's Data Compared to GAPCON-3 Values

Poisson's Ratio for UO_2

Poisson's ratio for UO_2 is also taken from Marlowe,⁽²⁹⁾ and varies from 0.316 at room temperature down to 0.295 at 2000°C and above. This compares closely with the single value of 0.316 recommended by MATPRO.

Poisson's Ratio for Cladding Materials

The Poisson's ratio for Zircaloy-2 and -4 is taken from Scott.⁽¹¹⁾ Values and references used are the same as recommended by MATPRO. The values for stainless steel come from the Nuclear Materials Handbook.

Thermal Expansion of the UO_2

The equation for linear expansion of UO_2 used in GAPCON-3 is that developed by Conway, Finckel and Hein.⁽³¹⁾ MATPRO uses a regression fit of this, plus other data. Figure 32 compares the two.

FIGURE 32. Comparison of Subroutine GAPCON-3 Values for UO_2 Thermal Expansion versus Data Compiled in MATPRO

Thermal Expansion of Cladding

The values for thermal expansion of Zircaloy are taken from Scott⁽¹¹⁾ for Zircaloy-4. MATPRO uses a regression fit of that data plus data from two other sources. The comparison between MATPRO and GAPCON-3 values is shown in Figure 33. The thermal expansion for stainless steel is taken from the Nuclear Materials Handbook.⁽¹²⁾

FIGURE 33. Axial Thermal Expansion of Zy-4 versus GAPCON-3
Values Over Practical Range (100-500°C)

Cladding Hardness

Zircaloy and stainless steel hardnesses are taken to be promotional to the yield strength of the materials. For the Zircaloy, GAPCON-3 values are compared to a MATPRO regression of several data sources in Figure 34.

FIGURE 34. The CAPGON-3 Values for Zy Meyer Hardness Compared to the MATPRO Correlation

Cladding Creep Data

The Zircaloy equation in GAPCON-3 is a stress-time-temperature and flux correlation developed by P. J. Pankaskie and published in reference 1. Table 1 summarizes a comparison of the in-reactor pressurized tube data.⁽³²⁾ Figure 35 shows a comparison to the MATPRO correlations and is based mainly on Ibrahim's data.⁽³³⁾

The creep rate for stainless steel is taken from the Nuclear Materials Handbook.⁽¹²⁾

FIGURE 35. Comparison of MATPRO and GAPCON-3 Zy Creep Models

Cladding Yield Stress

The time, strain, and temperature dependence of the plastic limit of Zircaloy was expressed by Pankaskie as a single equation. Reference 1 also gives this equation.

No primary term is evident in the MATPRO equation. Even so, the two equations compare fairly closely in strain *rate* for times of interest (10 to 10^4 hrs). The absolute strains in equivalent calculations would also be of the same order.

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4.0 COMPARISON AGAINST IN-REACTOR DATA

This section compares GAPCON-3 against in-reactor data, primarily from instrumented fuel assemblies. The irradiation tests are categorized by their measurement of:

- power and fuel temperature only
- power, fuel temperature, and fission gas release
- power and cladding or fuel strain.

For each test, there will be a synopsis of the test parameters and a brief summary of the irradiation conditions, followed by code-to-data comparisons and discussion. Details of the code input for each case are found in Appendix A.

MEASUREMENTS OF CENTERLINE TEMPERATURE

The following tests involved measurement of the centerline fuel temperature during operation by means of a thermocouple. Reported data points are indicated with boxes drawn to show uncertainty about estimations of temperature and linear heat rating.

HPR-80 (IFA-11, 21) TEST⁽³⁴⁾

This test involved two 5-rod clusters (IFA-11 and 21) irradiated in the Halden Reactor, Norway. Three rods in each assembly had a centerline thermocouple. The power was monitored by cobalt neutron detectors in each assembly. The parameters, which varied from rod to rod, included gap size (2 and 6 mil) and density (98% and 96% TD).

The rods were run to a maximum power of about 15 kW/ft., and the maximum burnup achieved was 4300 MWd/MTM. The Halden Reactor is a boiling heavy water reactor with a coolant inlet temperature of about 230°C and a system pressure at the time of this test of 28 bar.

In the report, thermocouple data as a function of linear heat rating are presented for beginning-of-life and end-of-life (4300 MWd/MTM). Figures 36 and 37 show beginning-of-life data for a 6 and 2 mil rod, respectively. The agreement to GAPCON-3 predictions is excellent. Figure 38 shows the data trend from one of the two surviving thermocouples at 4300 MWd/MTM. Both

surviving thermocouples were in small-gap rods and both showed a definite 60° to 80°C temperature increase over beginning-of-life readings at the same power. A smaller increase is seen over the same burnup for similar rods in the IFA-431, 432 irradiation (q.v.). GAPCON-3 does not predict this increase for such low temperature, low burnup rods.

FIGURE 36. Comparison to HPR-80 Thermocouple Data

FIGURE 37. Comparison to HPR-80 Thermocouple Data

FIGURE 38. Effect of Burnup on Centerline Temperature of a Small (2 mil) Gap, He Filled Halden Rod

The IFA-131 Test⁽³⁵⁾

The instrumented Halden Reactor test IFA-131 represents another case where centerline temperatures were measured as a function of power. The test involved a cluster of 6 rods. Devold presents data for beginning-of-life. The rod-to-rod difference involves difference in gap size only; all rods contained 94% TD fuel. Figures 39-41 show the comparison between the data trends and GAPCON-3 is overpredicting the temperatures; and the extent of overprediction is greatest for the rods with larger gaps. This is consistent with what one would expect from the GAPCON fuel relocation model. That model predicts little relocation until some burnup has been achieved, whereas in fact pellet cracking and some relocation occur on the first rise to power. This same magnitude of overprediction is evident on the first rise to power for IFA-431, (q.v.) whereas the overprediction is much less for ramps later in life.

FIGURE 39. Temperature versus Power for a He Filled 6 mil Gap Halden Rod

FIGURE 40. Centerline Temperature versus Power for a 9 mil Gap, He Filled Halden Rod

FIGURE 41. Temperature versus Power for a 12 mil Gap, He Filled Halden Rod

IFA-130 Irradiation⁽³⁵⁾

The Halden instrumented test IFA-130 was a companion 6-rod bundle to IFA-131. IFA-130 involved vipac and pelletized fuel, with centerline thermocouples. The fuel pellets were of 94% and 90% TD, the fabricated diametral gaps were 8.7 mils for both.

Figures 42 and 43 present the first approach to power temperature data for the 94% and 90% TD fuel, respectively. GAPCON-3 overpredicts the 94% TD fuel data, by about the same amount as that encountered with the 9 mil diametral rods from IFA-131. The temperature data for the 90% TD fuel is matched quite closely, however. This would appear to indicate that the UO_2 conductivity correction for density may be too weak, since densification would not be expected as a factor in first approach to power.

FIGURE 42. Steady-State and Approach-to-Power Data Trends for a He Filled, 1 mil Gap, Halden Rod

FIGURE 43. Centerline Temperature versus Power for a 9 mil Gap, He Filled, Halden Rod

IFA-418 Test (EPRI Case C)⁽³⁶⁾

IFA-418 represents yet another Halden irradiation in which centerline temperatures were measured. This test is noteworthy in that six vanadium neutron detectors associated with the assembly tended to minimize the uncertainty in linear heat generation rate, and that one thermocouple (rod 6) survived to 13,000 MWd/MTM. Figure 44 presents the power history at the thermocouple location. Figure 45 shows GAPCON-3 prediction relative to thermocouple measurements throughout the life of the pin. Owing to its ability to predict clad creepdown, GAPCON-3 does a much better job on this case than GAPCON-2, which was compared against this data in the EPRI Light Water Reactor Fuel Rod Modeling Code Evaluation.⁽³⁶⁾ Gap closure effects, such as clad creepdown and fuel swelling and densification, are extremely important for this rod in view of its relatively large initial gap (12 mils diametral).

FIGURE 44. Power History for EPRI Case C

FIGURE 45. GAPCON-3 versus Centerline Temperature Data for EPRI Case C

The AE-318 Tests (IFA-3, 4, and 10)⁽³⁷⁾

Three early instrumented irradiation tests from Halden reactor have been compiled in document AE-318. Each of the assemblies consisted of 96% TD UO₂ pellets in Helium-filled fuel rods clad of Zircaloy-2. The assemblies differed in enrichment, pellet diameter, and peak power; these differences are noted below.

Item	IFA-3	IFA-4	IFA-10
Fuel diameter, mm	12.58	12.58	12.47
Fuel-cladding Diametral Gap, mm (mils)	0.18(7)	0.18(7)	0.13(5)
Cladding wall Thickness, mm	0.76	0.76	0.60
Fuel Enrichment % U-235	1.5	6.0	2.5 ^(a)
Peak Power, W/cm (kW/ft)	300(9)	564(17)	400(12)

a. In the region of the thermocouple.

All assemblies contained some rods with fuel centerline thermocouples. Data was taken from these at steady-state periods throughout an entire year. However, it is not clear from the document how much burnup should be associated with each data point. Therefore, the usefulness of the centerline temperature versus power data for code comparison is limited to that from IFA-3. Since IFA-3 maintained temperatures of well below 1200°C, it could be expected to maintain pure Helium as the fill gas. The data for IFA-3 is presented in Figure 46; the agreement with the GAPCON-3 beginning-of-life prediction is excellent. Figures 47 and 48 show data from IFA-4 and -10, respectively. Comparison with the GAPCON-3 beginning-of-life prediction is quite poor; in both cases, the GAPCON prediction lies significantly *below* the data. This indicates significant degradation of the gap conductance due to fission gas release, compounded by fuel relocation. A GAPCON-3 run was made for IFA-10 through one year (200 full-power days). The temperature versus power prediction at the end of this simulated irradiation run (without relocation) overpredicts the temperatures.

FIGURE 46. Through-Life Centerline Temperature versus Power for a He Filled, 7 mil Gap Halden Rod. (GAPCON-3 predictions are for beginning-of-life)

FIGURE 47. Through-Life Centerline versus Power Data for a 17 mil Gap, He Filled Halden Rod, (GAPCON-3 predictions are for beginning-of-life)

FIGURE 48. Through-Life Centerline Temperature versus Power Data for a 12 mil Gap, He Filled Halden Rod (GAPCON-3 predictions are for beginning-of-life)

The AE-411 Experiment⁽³⁸⁾

Document AE-411 describes an experiment conducted at the R2 reactor, Studsvik, Sweden, in which the centerline and 4 off-center thermocouples were inserted in a column of natural UO_2 pellets in an attempt to measure UO_2 thermal conductivity in the pile. The irradiation rig consisted of 17 mm diameter pellets inside a graphite tube cooled by various gas mixtures. Since this design would be difficult to model directly by GAPCON-3, we chose to adjust the gap on a normal Zirconium-clad, water-cooled rod model until the centerline temperature matched the data at a given power. The calculated radial

temperature profile was then plotted and the off-center thermocouple readings (at the 3.0 mm and 4.24 mm radial boundaries) were put on the same graph. The data was thus used to confirm the *shape* of the temperature profile. Figures 49-52 show the results at various power levels. The agreement is quite good; the slight overprediction by GAPCON is due primarily to its inability to model the effect of the off-center holes in the fuel. The open circles in Figure 49 represent the correction for the hole estimated from a two-dimensional heat transfer code. The correction at lower powers would be proportionately less.

FIGURE 49. Temperature versus Radius Data from AE-411, at 12.86 kW/ft

FIGURE 50. Temperature versus Radius Data from AE-411 at 9.86 kW/ft

FIGURE 51. Temperature versus Radius Data from AE-411 at 6.95 kW/ft

FIGURE 52. Temperature versus Radius Data from AE-411, at 4.83 kW/ft

The IFA-431/432 Experiment⁽³⁹⁾

The IFA-431/432 assemblies are recent Halden instrumented 6-rod clusters, sponsored by the USNRC. The assemblies were designed to be identical in geometry and the fuel rod types represented. The difference between the two assemblies was the power level and burnup under which they operated. IFA-431 had peak linear heat ratings of 350 W/cm and a peak burnup of 4300 MWd/MTM; IFA-432 had peak ratings of about 500 W/cm and a peak burnup in excess of 20,000 MWd/MTM. All rods in both assemblies had tungsten-rhenium fuel center-line thermocouples in each end^(a) and contained 10% enriched UO_2 pellets clad in Zircaloy-4 tubing. The differences between the rods included gap size, fuel density, fuel type, and fill gas composition. These differences are summarized below:

(a) Rod 2 in IFA 432 had a gamma thermometer in the upper end.

<u>Rod Number in both IFA-431 and 432</u>	<u>Diametral Gap Size Mils</u>	<u>Fill Gas</u>	<u>Fuel Density % TD</u>	<u>Fuel Type</u>
1	9.	He	95	Stable ^(a)
2	15.	He	95	Stable
3	2.	He	95	Stable
4	9.	Xe	95	Stable
5	9.	He	95	Stable
6	9.	He	95	Unstable ^(a)

a. With respect to in-reactor densification.

These 12 rods constitute 6 different experiments within one irradiation. Many comparisons can be made between assemblies, between rods, and even between ends of the same rod. The temperature data presented here is derived from ramps during the first 5000 MWd/MTM burnup of each assembly, so that they may be directly cross-compared at the same power and burnup. Data from Rod 4 (the Xenon-filled rod) is excluded because this rod is mechanically so complicated that it requires a disproportionate effort to correctly model it with GAPCON-3.

Figures 53 and 54 show data and GAPCON-3 predictions for rod 3, the small gap rod. Consistency between the two assemblies, and between the assemblies and the GAPCON-3 predictions, is quite good, as might be expected.

FIGURE 53. Centerline Temperature Data at Fixed Power versus Burnup from Rod 3 (2 mil Gap, He Fill) Halden test IFA-431

FIGURE 54. Centerline Temperature at Fixed Power versus Burnup for Rod 3 (He Fill, 3 mil Gap) Halden Test IFA-432

Figures 55 and 56 show data and predictions for rod 1, the rod of BWR-6 design with 9 mil gap. It is apparent that the data shows the effect of some relocation, but that the speed and magnitude of relocation are not predicted well by GAPCON-3. GAPCON-3 predicts little relocation on first startup, whereas the data shows evidence of some, leading to a consistent beginning-of-life over prediction of fuel temperature for all rods. On the other hand, the calculated relocation apparently exceeds the actual relocation after about 250 MWd/MTM. The same trends are apparent with rod 2 (Figures 57 and 58) and rod 5 (Figure 59). All of these figures show that relocation is more pronounced at the upper, rather than at the lower, ends of the rods.

FIGURE 55. Centerline Temperature at Fixed Power as a Function of Burnup for Rod 1 (9 mil Gap, He Fill), Halden Test IFA-431

FIGURE 56. Centerline Temperature at Fixed Power versus Burnup for Rod 1 (9 mil Gap, He Fill) from Halden Test IFA-432

FIGURE 57. Centerline Temperature at Fixed Power as a Function of Burnup for Rod 2 (He Filled, 15 mil Gap) from Halden Test IFA-431

FIGURE 58. Centerline Temperature at Fixed Power versus Burnup for Rod 2 (15 mil Gap, He Fill) from Halden Test IFA-432

FIGURE 59. Centerline Temperature at Fixed Power versus Burnup for Rod 5 (9 mil Gap, He Filled 92% TD Fuel) from Halden Tests IFA-431 and IFA-432

The 50° to 75°C leap in temperature common to all IFA-431 rods (except rod 3) between the first and second power ramps is not duplicated by IFA-432 data. Neither is the discontinuity before and after the refueling outage represented by a break in the curves. The 431 data might simply be anomalous on startup ramps; or there may be subtle radial and axial fuel-cladding interactions which are producing these effects in both assemblies, but which are masked by the higher powers and ramp rates experienced by IFA-432.

In any case, it is apparent that for rods where significant gas release is not expected (e.g. rods 1 and 5 from 431), the GAPCON-3 predictions, with and without relocation, bracket the data. However, when significant gas release is predicted, ignoring relocation leads to extremely high predicted temperatures (IFA-431, rod 2, and IFA-432, rods 1 and 5).

The data from rod 6 should be compared with GAPCON-3 runs with densification included since this fuel was expected to densify. Four possible modes of running GAPCON include the following:

- relocation and densification
- no relocation or densification
- densification without relocation
- relocation without densification.

These four possibilities are shown against the IFA-432, rod 6 data for the upper thermocouples in Figure 60. This figure is representative of the entire data set. We see that densification, to any extent that it did occur, must have been overshadowed by relocation, since of the above combinations the only one that leads to reasonable predicted temperatures is the last--relocation without densification.

FIGURE 60. Centerline Temperature at Fixed Power versus Burnup for Rod 6 (9 mil Gap, He Filled 92% Unstable Fuel) from IFA-432. Several Different Assumptions on Relocation and Densification are Shown for GAPCON-3 Predictions

TEMPERATURE AND FISSION GAS RELEASE

There have been numerous experiments in which temperature and gas release measurements have been attempted; the most recent or best known of these are presented here. The estimated maximum fuel temperatures will be presented and compared with GAPCON-3 as well as the fission gas release data since the gas release model in GAPCON-3 is very sensitive to the temperature distribution.

The CC-7 Experiment (EPRI Case A)^(36,40)

A low-burnup, high-temperature irradiation of uninstrumented short fuel capsules in very thick cladding was carried out at the EL3 reactor; Saclay, France. The power output of the capsules was so carefully monitored and the postirradiation microstructure of the rods so thoroughly examined that these rods provide a good case for fission gas release, even in the absence of centerline thermocouples. Data and GAPCON-3 results are presented for two extreme cases of the 16 rods irradiated. These are the same two rods (4113-AE1 and 4112-BE1) used in the EPRI fuel modeling code evaluation.⁽⁴²⁾ Figures 61 and 62 show fission gas release and peak temperature for rods 4113-AE1 and 4112-BE1, respectively. The location and magnitude of the estimated peak temperatures come from the EPRI report, as deduced from equiaxed grain growth boundaries. The error bars represent our own estimate on the uncertainty of the peak fuel temperature based on the input uncertainties for its calculation.

FIGURE 61. Power History, Temperature History and Fission Gas Release for CEA Experiment, Rod 4113, Segment AE1

FIGURE 62. Power History, Temperature History, and Fission Gas Release for CEA Experiment, Rod 4112, and Segment BE1

The agreement with the fission gas release data is quite good. Rod 4112-BE1 ran at a lower power than its counterpart, and also had a smaller diametral fabricated gap (3.5 versus 11.8 mils). These two effects combined to produce lower temperatures and lower gas release for 4112-BE1, as reflected by both the data and the GAPCON-3 predictions.

The peak centerline temperature predicted by GAPCON-3 exceeded the EPRI estimate in both cases. These estimates are based on an assessment of the equiaxial grain boundary location and the assignment of a temperature to that boundary. Both these assessments are subject to error of such proportions as to produce quite a large error band on the "data" value for centerline temperature.

The Belgonucleaire Experiment "ELP"⁽⁴¹⁾

A second set of rods were irradiated at high power and to high burnup at the EL3 reactor.⁽⁴¹⁾ The reference gives average power, burnup, and fission gas release data for 11 rods; unfortunately, explicit power history and power profile is given for only one rod, ELP 9. We therefore ran a comparison for this rod that is representative of the whole set. The "ELP" rods were non-instrumented, which means that only microstructure and fission gas release data can be presented. Figure 63 shows the location of equiaxed and columnar grain boundaries, along with the calculated temperature profile for the corresponding axial position at the time when the peak power occurred.

FIGURE 63. Grain Growth Boundary Temperature Data from Experiment ELP-9

Figure 64 shows the predicted evolution of the gas release through time, along with the end-point data. The agreement is fairly good.

FIGURE 64. ELP-9 Power History and Gas Release Data

The NRX Fission Gas Release Experiments ^(42,43)

Several tests expressly designed to determine fission gas release have been run in reactor NRX at Chalk River, Canada. Data from two of these tests are compared here. The first of these, recorded in document AECL-2230, ⁽⁴³⁾ attempted to correlate fission gas release to fuel density. Eight short 15 cm (1/2 ft) argon-filled rods having UO_2 fuel in the range of 95% to 98% of theoretical density, were all run at approximately 560 W/cm (17 kW/ft) for 84.5 days, achieving a burnup of nearly 2500 MWd/MTM. Table 1 presents the release data from all eight rods, along with the GAPCON-3 predictions for two of the rods. The slight increase in gas release and decrease in fuel density indicated by this data is reproduced by GAPCON-3, but the magnitude of the release is underpredicted.

TABLE 1. Data and Results for NRX "CB" Tests

<u>Rod Number</u>	<u>Fuel Density % TD</u>	<u>Fission Gas Release %</u>	<u>GAPCON-3 % Release</u>	<u>Calculated % Fuel Volume Above 1400°C</u>
CBN	98.	12.	2.7	13.
CBX	95.	19.	3.5	16.
CBP	97.	14.	---	---
CBT	96.	15.	---	---
CBY	95.	17.	---	---
CBO	98.	15.	---	---
CBR	97.	16.	---	---
CBV	96.	16.	---	---

A second test, involving a broader range of rod powers, is documented in AECL-2662.⁽⁴⁴⁾ Four groups of 3 rods, each were irradiated at group-averaged powers ranging from 500 to 750 W/cm (15 to 23 kW/ft) for 108 days. The burnup range was thus from 2200 to 3300 MWd/MTM. The rods were slightly longer than the previous test (24 versus 15 cm) and had fuel densities in the range of 93.5 to 98% ID. Gas release results from all 12 rods, along with GAPCON-3 predictions for 3 of them are recorded in Table 2. We see in Table 2 that a significant fraction of the fuel is above 1200°C, the GAPCON-3 predictions are fairly consistent with the data, they tend to be low when the fraction of fuel above 1400°C is small (cf. as in this test and the previous one).

TABLE 2. Data and Results for NRX "LB" Tests⁽⁴⁴⁾

<u>Rod Designation</u>	<u>Fuel Density % TD</u>	<u>Fission Gas Release, %</u>	<u>GAPCON-3 % Release</u>	<u>% Fuel Volume above 1400°C</u>
LFB	93.5	23.	---	---
LFF	96.	17.	1.6	11.
LFL	98.	6.	---	---
LFD	93.5	46.	---	---
LFH	96	31.	8.6	31.
LFM	98	16.	---	---
LFT	93.5	50.	---	---
LFX	96.	37.	12.7	43.
LFW	98.	25.	---	---
LFE	93.5	> 15.	---	---
LFK	96.	> 28.	---	---
LFS	98.	38.	---	---

The S 150 Simulation at Studsvik (EPRI Case E)^(36,44)

An instrumented test at the R2 reactor of Studsvik, Sweden, included thermocouple measurement of fuel centerline temperature throughout the irradiation and a measurement of fission gas release during post-irradiation examination. The EPRI fuel modeling code evaluation project used this test as one of its standard cases, "Case E". The rod had about 50 cm (1.6 ft) of active fuel, and an 8.2 mil diametral gap. It was Helium filled and contained 94.4% TE UO₂ pellets, 2.04% enriched. The irradiation period was only 75 days, but included several shutdowns and changes in axial flux profile, as indicated in Figure 65. The GAPCON-3 power history did include the major shifts in axial profile; it did not follow the actual power history exactly, but achieved the same rod-averaged final burnup, of approximately 4000 MWd/MTM.

FIGURE 65. Actual and Input Power Histories for EPRI Case E Comparison

The predicted temperatures at various power levels and irradiation times are compared to the data from the thermocouple in Table 3. GAPCON-3 underpredicts the temperatures in general, but the discrepancy is less than 100°C throughout most of the irradiation.

TABLE 3. Thermocouple Data from EPRI Case E⁽³⁶⁾

<u>Irradiation Time, hours</u>	<u>Power at TC Plane, kW/ft</u>	<u>TC Reading °C</u>	<u>GAPCON-3 Prediction, °C</u>
400	8.8	1282	1172
800	10.4	1610	1420
1200	9.9	1510	1477
1800	9.3	1493	1427

The measured fission gas release from this rod was 10%; that predicted by GAPCON-3 is 12%. Since in the peak power regions of the fuel the percent of fuel volume above 1400°C exceeds 40%, this favorable agreement with data is consistent with previous comparisons.

Maine Yankee Rod (EPRI Case D)^(36,45)

Several rods from Maine Yankee Core I underwent detailed PIE as part of a joint CE-EPRI program. Rod JBY097 was selected as a standard case (case D) for the EPRI fuel modeling code evaluation. This rod had an 8 mil diametral gap, and gap-to-diameter ratio of 2.4%. It fell into a group of "high-release" rods, having a measured gas release of 13.4%. It achieved a rod-averaged (burnup of 13,350 MWd/MTM during an irradiation period of 492 days (at power). The rods were filled with a 12% N-He mixture at atmospheric pressure. As Figure 66 shows, the GAPCON-3 temperature predictions fall far below the "data" predictions for peak temperature, deduced from grain growth data. Concomitantly the fission gas release prediction is quite low - 0.6% compared to 13.4%. The uncertainty of the power history of this rod is not clear; since it was not instrumented nor in a controlled loop, but simply in a commercial reactor core, one wonders whether it could have briefly seen powers considerably in excess of those stated. Given the measured gas release, however, the observed microstructure is not inconsistent with the powers there.

FIGURE 66. Input Power History and Calculated Temperature History for EPRI Case D

TEMPERATURE AND CLAD DEFORMATION MEASUREMENTS

The data compared in this section deal with elastic and permanent cladding deformations caused by interaction with the fuel and by creep. Where applicable, the estimated fuel temperatures are also compared to the data, since differential thermal expansion is the cause of fuel-clad mechanical interaction.

The IFA-117 Experiment⁽⁴⁶⁾

The Halden instrumented fuel assemblies IFA-116 and -117 carry fuel centerline thermocouples, but in addition have elongation detectors to measure the real-time total elongation of the rods (relative to zero-power conditions). Figure 67 shows typical beginning-of-life temperature data from rod 5, IFA-117.

The data is compared to two different GAPCON-3 runs. In one run, the nominal, reported fabricated diametral gap of 8.8 mil was input. In the second run, a gap of 5.0 mil was input to account for fabrication tolerances and fuel relocation. The temperatures from the latter run more closely match the data. Furthermore, fuel-clad interaction, which did occur in this rod, is predicted with the 5.0 mil gap input but not with 8.8 mil gap input. This points to probable variation of the actual fabricated gap along the length of the rod.

FIGURE 67. Comparison to HPR-107 Thermocouple Data

Figure 68 presents cladding elongation data from the same run as the temperature data from Figure 67. The GAPCON-3 predicted elongation (5.0 mil gap input) is also shown. A very rough estimate of what the elongation *should* be would be worthwhile. The data indicates fuel cladding contact at roughly 8 kW/ft where the volumetric average fuel temperature is about 600°C. At the peak power of about 14 kW/ft, the volumetric average temperature is about 900°C. Since fuel strain per degree Centigrade is about 0.9×10^{-5} for UO_2 in this temperature range, the expected elongation can be roughly estimated as:

$$\Delta L/L = (900 - 600) \times 0.9 \times 10^{-5} \times 19.2 \text{ inches full length} = .05 \text{ inch}$$

This would be the *maximum*; the axial interaction of fuel cladding would make the actual elongation somewhat lower.

FIGURE 68. Comparison to HPR-107 Elongation Data
(Solid symbols indicate increasing power,
open symbols indicate decreasing power)

Figure 68 shows the elongation data is of the expected order of magnitude. The agreement of the GAPCON-3 prediction is somewhat fortuitous; contact is predicted at 10 kW/ft rather than 8, but the slope of elongation versus power is much steeper than the data would indicate. These two facts combine to make the elongation at peak power comparable to the data. We attribute the steepness of the predicted elongation versus power slope to the lack of any cladding fuel axial slip in the GAPCON-3 mechanical model.

IFA-431, (Rod 3)⁽⁴⁷⁾

Of the IFA-431/432 rods, only rods 3 and 4 recorded significant clad elongation that can be compared to GAPCON-3. The other rods showed some elongation on startup, but this did not persist and must have been due to staggered pellet locations or loose fuel pieces. The design of rod 4 was too complicated to be modeled well by GAPCON-3. That leaves rod 3, the 2 mil gap, Helium-filled rod. Figure 69 shows the first startup temperature data for Rod 3, along with the GAPCON prediction; Figure 70 shows the corresponding elongation data. The situation with the GAPCON comparison is quite similar to the previous case. The occurrence of fuel-cladding contact is predicted at a higher power than the data indicates, but the slope of elongation versus power is steeper than the data, resulting in approximately equal elongations at full power. It is interesting that some slipping of the fuel, relative to the cladding, is apparent even for this small-gap rod.

FIGURE 69. Comparison to IFA-431 Thermocouple Data (Initial Rise to Power)

FIGURE 70. Comparison to IFA-431 Elongation Data (Initial Rise to Power)

Figure 71 shows the Rod 3 cladding elongation at full power (300 W/cm) as a function of burnup. Whereas GAPCON-3 predicts essentially the same behavior at all burnups, the data shows a definite increase in the power at which hard contact occurs, with a consequent lowering of the full-power elongation. This may be due to the formation of axial gaps, wherein sections of the fuel "hang up" upon shutdown. These gaps would have to reclose on startup before the clad could move with the fuel column again.

FIGURE 71. Total Cladding Elongation versus Burnup for Rod 3, IFA-431

IFA-132 Startup Ramps to Power⁽³⁵⁾

G. Testa et al. present cladding elongation data for the first two power ranges in Halden assembly IFA-132. Unfortunately, the corresponding fuel temperatures are not available. Nevertheless, since this is beginning-of-life data, a comparison to GAPCON-3 is justified. The IFA-132 rod had a 11.8 mil diametral gap and a 55 cm fuel length. Figure 72 shows data from the first power ramp. We again see GAPCON-3 overpredicting the elongation, due to the lack of cladding-fuel slip. The occurrence of contact in this case is well predicted.

FIGURE 72. Total Cladding Elongation from IFA-432 Experiment

The X-260, 264 Tests⁽⁴⁸⁾

Diametral expansions were measured with strain gauges in an AECL test of short capsules brought to 20 kW/ft power in the NRX reactor. The data showed definite hysteresis, presumably due to plastic straining of the clad. Figure 73 shows typical results from the X-264 test. The rods contained 1.6% enriched, 16.3% TD UO_2 pellets, with a 0.7303 in. diameter and a 4.3 mil diametral gap.

FIGURE 73. Diametral Strain for a CANDU Type Rod (AECL-4072)

The GAPCON-3 comparison for this first-cycle data also shows some hysteresis related to plastic strain. It is interesting to note that the slope of the clad diameter change is representative of that for the pellet interfaces. It is also interesting that the power at which significant strain begins is smaller for the pellet interfaces than for the pellet mid-plane. This all suggests pellet hourglassing is really affecting the way the fuel interacts with the cladding. The GAPCON-3 model does not account for hourglassing; hence, it predicts significant strain to begin at a point midway between the pellet interface and midplane data. Because of the lack of slipping in the model, the maximum strain prediction is close to that of the pellet interface data. It would appear that the predicted cladding stresses and plastic strains are at least of the right magnitude.

5.0 SUMMARY AND CONCLUSIONS

This report presents evidence of the mathematical consistency of GAPCON-3 subroutines and solution routines. In particular, the temperature calculations are shown to be quite accurate relative to analytical solutions. The chained radial-axial=radial mechanical elastic state solution is also consistent with a fully interconnected, comprehensive, axisymmetric, finite element model, for the case of a "trapped" pellet stack isothermally heated within the cladding.

A detailed comparison of the major models (thermal expansion, creep, elastic moduli, etc.) against generally recognized data sets reveals that all are contributing reasonable results to the overall calculation.

Comparison to integrated tests (fission gas release, rod deformation, centerline temperature, etc.) revealed general agreement. Exceptions included low fission gas release predictions at low temperatures ($< 1400^{\circ}\text{C}$). The onset of pellet-cladding interaction in a power ramp was generally overpredicted, i.e. predicted to occur at higher power than the data would indicate. The irreversibility of the fuel radial relocation in the code causes overprediction of clad strain versus power after contact occurs.

The code tracks the various competing effects of gap size (expansion, pressure, densification, relocation, etc.) out to the point of gap closure as efficiently as GAPCON-2. After gap closure, reasonable estimates of clad stress and strain are obtainable, at the cost of increased run time and limitations on power history modeling. Specifically, because of the irreversible relocation, the code is incapable of modeling power cycling after gap closure. Powerup ramp effects after closure are at least conservatively estimated (high stresses and strains, but reasonable temperatures).

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APPENDIX A

This appendix contains input values for the runs plotted in Figures 36-73, in the order in which they appear in the text.

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. HPR-80, ROD HBA

ATMOS <u> 1. </u>	FRDEN <u> .98 </u>	KSAVE <u> 0 </u>	RADS <u> .0 </u>
CP <u> (1.0) </u>	FRDEN2 <u> .965 </u>	LFUEL <u> 67.2 </u>	RNEWK* <u> </u>
CR <u> (1.0) </u>	FRPU02 <u> .0 </u>	LVOIDZ <u> 67.2 </u>	ROUC <u> .00004 </u>
DCI <u> .4957 </u>	FRSIN <u> .98 </u>	MINI* <u> </u>	ROUF <u> .00016 </u>
DCO <u> .5394 </u>	FR35 <u> .05 </u>	MXPOWR <u> 15.24 </u>	S <u> 0. </u>
DELZA* <u> </u>	FR40 <u> .0 </u>	NC <u> (4) </u>	TIME* <u> </u>
DFS <u> .4937 </u>	FR41 <u> .0 </u>	NCLAD <u> 0 </u>	TINLET <u> 446. </u>
DSINZ <u> .0 </u>	IDENSF <u> 0 </u>	NF <u> (6) </u>	TM <u> (2790°C) </u>
DTEMP <u> 20. </u>	IGAS <u> 0 </u>	NFLX <u> 0 </u>	TPLAS <u> (1200°C) </u>
DVOIDZ <u> .0472 </u>	IOPT <u> 0 </u>	NFUEL <u> 0 </u>	VPLENZ <u> .096 </u>
EXTP <u> 500. </u>	IPEAK <u> 1 </u>	NOH <u> 0 </u>	X <u> 0.14 </u>
FLXRAT <u> (0.01) </u>	IPLT <u> 0 </u>	NPOW <u> 6 </u>	XCO <u> .0 </u>
FRACAR <u> 0. </u>	IRELOC <u> 1 </u>	NSTEPS <u> 0 </u>	XH <u> .0 </u>
FRACH <u> 0 </u>	IRL <u> 0 </u>	NSH <u> 0 </u>	XN <u> .0 </u>
FRACHE <u> 1. </u>	ISTOR <u> 0 </u>	NTIME <u> 7 </u>	Z <u> .125 </u>
FRACKR <u> 0. </u>	ITAPE <u> 0 </u>	PRCDH <u> 0. </u>	ZCLAD <u> .0 </u>
FRACN <u> 0. </u>	ITMCUT <u> 20 </u>	PROFIL* <u> </u>	
FRACXE <u> 0. </u>	JSTART <u> 0 </u>	PSEUDO* <u> </u>	

*DELZA (1) = .5, 11.2, 11.2, 11.2, 11.2, 11.2, 11.2, 11.2, .497

*MINI (1) = 1, 0, 3, 1

*PROFIL (1) =

*PSEUDO (1) = .05, 1.52, 3.05, 6.1, 9.1, 12.2, 15.2

*RNEWK (1) =

*TIME (1) = 0., .017, .035, .069, .099, .139, .174

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. HPR-80 Rod HBC

ATMOS <u> 1 </u>	FRDEN <u> .96 </u>	KSAVE <u> 0 </u>	RADS <u> 0. </u>
CP (1.0) <u> </u>	FRDEN2 <u> </u>	LFUEL <u> 67.48 </u>	RNEWK* <u> </u>
CR (1.0) <u> </u>	FRPU02 <u> .0 </u>	LVOIDZ <u> 67.48 </u>	ROUC <u> .00016 </u>
DCI <u> .4959 </u>	FRSIN <u> .98 </u>	MINI* <u> </u>	ROUF <u> .000049 </u>
DCO <u> .5394 </u>	FR35 <u> .05 </u>	MXPOWR <u> 15.24 </u>	S <u> 0. </u>
DELZA* <u> </u>	FR40 <u> .0 </u>	NC (4) <u> </u>	TIME* <u> </u>
DFS <u> .4894 </u>	FR41 <u> .0 </u>	NCLAD <u> 0 </u>	TINLET <u> 446. </u>
DSINZ <u> .0 </u>	IDENSF <u> 0 </u>	NF (6) <u> </u>	TM (2790°C) <u> </u>
DTEMP <u> 20. </u>	IGAS <u> 0 </u>	NFLX <u> 0 </u>	TPLAS (1200°C) <u> </u>
DVOIDZ <u> .0472 </u>	IOPT <u> 0 </u>	NFUEL <u> 0 </u>	VPLENZ <u> .096 </u>
EXTP <u> 500. </u>	IPEAK <u> 1 </u>	NOH <u> 0 </u>	X <u> .14 </u>
FLXRAT(0.01) <u> </u>	IPL0T <u> 0 </u>	NPOW <u> 6 </u>	XCO <u> .0 </u>
FRACAR <u> .0 </u>	IRELOC <u> 1 </u>	NSTEPS <u> 0 </u>	XH <u> .0 </u>
FRACH <u> .0 </u>	IRL <u> 0 </u>	NSH <u> 0 </u>	XN <u> .0 </u>
FRACHE <u> 1. </u>	ISTOR <u> </u>	NTIME <u> 7 </u>	Z <u> .125 </u>
FRACKR <u> .0 </u>	ITAPE <u> 0 </u>	PRCDH <u> 0. </u>	ZCLAD <u> -1. </u>
FRACN <u> .0 </u>	ITMCUT <u> 20 </u>	PROFIL* <u> </u>	
FRACXE <u> .0 </u>	JSTART <u> 0 </u>	PSEUDO* <u> </u>	

*DELZA (1) = .5, 11.2466666666667, 11.2466666666667, 11.2466667, 11.2466667

*MINI (1) = 1, 0, 3

*PROFIL (1) = .719, .932, 1., .916, .737, .461, .186

*PSEUDO (1) = .005, 1.524, 3.048, 6.096, 9.144, 12.192, 15.24

*RNEWK (1) =

*TIME (1) = 0., .017, .035, .069, .099, .139, .174

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA-131 6 mil Cold Gap App to Power

ATMOS <u>1.</u>	FRDEN <u>.94</u>	KSAVE <u>0</u>	RADS <u>.0</u>
CP <u>(1.0)</u>	FRDEN2 <u>.96</u>	LFUEL <u>18.31</u>	RNEWK*
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>18.31</u>	ROUC <u>.00004</u>
DCI <u>.502</u>	FRSIN <u>.96</u>	MINI* <u>1,2,3,4</u>	ROUF <u>.00008</u>
DCO <u>.557</u>	FR35 <u>.06</u>	MXPOWR <u>13.72</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC <u>(4)</u>	TIME*
DFS <u>.496</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>464</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF <u>(6)</u>	TM <u>(2790°C)</u>
DTEMP <u>10.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.069</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>3.74</u>
EXTP <u>500.</u>	IPEAK <u>1</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT <u>(0.01)</u>	IPL0T <u>0</u>	NPOW <u>3</u>	XCO <u>.0</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>4</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>4</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>.0</u>	ZCLAD <u>.0</u>
FRACN <u>.0</u>	ITMCUT <u>100</u>	PROFIL*	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO*	

*DELZA (1) = .05, 6.1033, 6.1033, 6.1033, 18.896

*MINI (1) =

*PROFIL (1) = 1., 1.2, 1.2, 1.

*PSEUDO (1) = .05, 3., 9., 13.7

*RNEWK (1) = 2., 1.133, 34.07, 26.57, .66E-12

*TIME (1) = .0, .1, .2, .3

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA-131, 9 mil Cold Gap App to Power

ATMOS <u>1.</u>	FRDEN <u>.94</u>	KSAVE <u>0</u>	RADS <u>.0</u>
CP (1.0)	FRDEN2 <u>.96</u>	LFUEL <u>18.31</u>	RNEWK*
CR (1.0)	FRPU02 <u>.0</u>	LVOIDZ <u>18.31</u>	ROUC <u>.00002</u>
DCI <u>.502</u>	FRSIN <u>.96</u>	MINI* <u>1.2.3.4</u>	ROUF <u>.00008</u>
DCO <u>.557</u>	FR35 <u>.06</u>	MXPOWR <u>13.72</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC (4)	TIME*
DFS <u>.493</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>464.</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF (6)	TM (2790°C)
DTEMP <u>10.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS (1200°C)
DVOIDZ <u>.069</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>3.74</u>
EXTP <u>500.</u>	IPEAK <u>1</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT(0.01)	IPLT <u>0</u>	NPOW <u>3</u>	XCO <u>.0</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>4</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>4</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>.0</u>	ZCLAD <u>.0</u>
FRACN <u>.0</u>	ITMCUT <u>100</u>	PROFIL*	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO*	

*DELZA (1) = .5, 6.1033, 6.1033, 6.1033, 18.89619

*MINI (1) =

*PROFIL (1) = 1., 1.2, 1.2, 1.

*PSEUDO (1) = .05, 3., 9., 13.7

*RNEWK (1) = 2., 1.133, 34.07, 26.57, 66E-12

*TIME (1) = .0, .1, .2, .3

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA-131 12 mil Cold Gap App to Power

ATMOS <u>1.</u>	FRDEN <u>.94</u>	KSAVE <u>0</u>	RADS <u>.0</u>
CP (1.0)	FRDEN2 <u>.96</u>	LFUEL <u>18.31</u>	RNEWK*
CR (1.0)	FRPU02 <u>.0</u>	LVOIDZ <u>18.31</u>	ROUC <u>.00002</u>
DCI <u>.502</u>	FRSIN <u>.96</u>	MINI* <u>1,2,3,4</u>	ROUF <u>.00008</u>
DCO <u>.557</u>	FR35 <u>.06</u>	MXPOWR <u>13.72</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC (4)	TIME*
DFS <u>.49</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>464.</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF (6)	TM (2790°C)
DTEMP <u>20.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS (1200°C)
DVOIDZ <u>.069</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>3.74</u>
EXTP <u>500.</u>	IPEAK <u>1</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT(0.01)	IPL0T <u>0</u>	NPOW <u>3</u>	XCO <u>.0</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>4</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>4</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>.0</u>	ZCLAD <u>.0</u>
FRACN <u>.0</u>	ITMCUT <u>100</u>	PROFIL*	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO*	

*DELZA (1) = .5, 6.1033, 6.1033, 6.1033, 18.89619

*MINI (1) =

*PROFIL (1) = 1., 1.2, 1.2, 1.

*PSEUDO (1) = .05, 3., 9., 13.7

*RNEWK (1) = 2, 1.133, 34.07, 26.57, .66E-12

*TIME (1) = 0, 1, 2, 3

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA-130 94%TD App to Power & Steady

ATMOS <u>1.</u>	FRDEN <u>.94</u>	KSAVE <u>0</u>	RADS <u>.0</u>
CP <u>(1.0)</u>	FRDEN2 <u>.96</u>	LFUEL <u>18.31</u>	RNEWK* <u></u>
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>18.31</u>	ROUC <u>.00004</u>
DCI <u>.502</u>	FRSIN <u>.96</u>	MINI* <u></u>	ROUF <u>.00008</u>
DCO <u>.577</u>	FR35 <u>.06</u>	MXPOWR <u>15.2</u>	S <u>.0</u>
DELZA* <u></u>	FR40 <u>.0</u>	NC <u>(4)</u>	TIME* <u></u>
DFS <u>.493</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>464</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF <u>(6)</u>	TM <u>(2790°C)</u>
DTEMP <u>10.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.069</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>3.74</u>
EXTP <u>500.</u>	IPEAK <u>1</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT <u>(0.01)</u>	IPLT <u>0</u>	NPOW <u>3</u>	XCO <u>.0</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>18</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>18</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>.0</u>	ZCLAD <u>.0</u>
FRACN <u>.0</u>	ITMCUT <u>100</u>	PROFIL* <u></u>	
FRACXE <u>.0</u>	JSTART <u></u>	PSEUDO* <u></u>	

*DELZA (1) = .5, 6.10333, 6.10333, 6.10333, 18.89619

*MINI (1) = 1, 2, 3, 4

*PROFIL (1) = 1., 1.2, 1.2, 1.

*PSEUDO (1) = .05, 3., 9., 15.2, 15.2, 15.2, 15.2, 15.2, 15.2, 15.2, 15.2, 9., 3.,
.05, 3., 9., 15.2

*RNEWK (1) =

*TIME (1) = .0, .1, .2, .3, .7, 1, 5, 10, 20, 40, 60, 60.7, 60.9, 61.,
61.1, 61.3, 61.5, 62.

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA-130 90 TD APP To Power

ATMOS <u>1.</u>	FRDEN <u>.9</u>	KSAVE <u>0</u>	RADS <u>.0</u>
CP (1.0)	FRDEN2 <u>.96</u>	LFUEL <u>18.31</u>	RNEWK*
CR (1.0)	FRPU02 <u>.0</u>	LVOIDZ <u>18.31</u>	ROUC <u>.00002</u>
DCI <u>.502</u>	FRSIN <u>.96</u>	MINI* <u>1,2,3,4</u>	ROUF <u>.00008</u>
DCO <u>.577</u>	FR35 <u>.06</u>	MXPOWR <u>15.2</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC (4)	TIME*
DFS <u>.493</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>464.</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF (6)	TM (2790°C)
DTEMP <u>10.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS (1200°C)
DVOIDZ <u>.069</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>3.74</u>
EXTP <u>500.</u>	IPEAK <u>1</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT(0.01)	IPLT <u>0</u>	NPOW <u>3</u>	XCO <u>.0</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>4</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>4</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>0.</u>	ZCLAD <u>.0</u>
FRACN <u>.0</u>	ITMCUT <u>100</u>	PROFIL*	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO*	

*DELZA (1) = .5, 6.1033, 6.1033, 6.1033, 18.89619

*MINI (1) =

*PROFIL (1) = 1., 1.2, 1.2, 1.

*PSEUDO (1) = .05, 3., 9., 15.2

*RNEWK (1) = 2., 1.133, 34.07, 26.57, .66E-12

*TIME (1) = .0, .1, .2, .3

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. EPRI Case C IFA 418 Rod 6

ATMOS	<u>22.</u>	FRDEN	<u>.96</u>	KSAVE	<u>1</u>	RADS	<u>.144</u>
CP (1.0)		FRDEN2		LFUEL	<u>29.4</u>	RNEWK*	
CR (1.0)		FRPU02	<u>.0</u>	LVOIDZ	<u>4.9</u>	ROUC	<u>.00004</u>
DCI	<u>.366</u>	FRSIN	<u>.98</u>	MINI*	<u>1</u>	ROUF	<u>.0001</u>
DCO	<u>.406</u>	FR35	<u>.06</u>	MXPOWR	<u>15.24</u>	S	<u>.0</u>
DELZA*		FR40	<u>.0</u>	NC (4)		TIME*	
DFS	<u>.354</u>	FR41	<u>.0</u>	NCLAD	<u>0</u>	TINLET	<u>465.</u>
DSINZ	<u>.0</u>	IDENSF	<u>0</u>	NF (6)		TM (2790°C)	
DTEMP	<u>20.</u>	IGAS	<u>0</u>	NFLX	<u>0</u>	TPLAS (1200°C)	
DVOIDZ	<u>.071</u>	IOPT	<u>1</u>	NFUEL	<u>0</u>	VPLENZ	<u>.186</u>
EXTP	<u>490.</u>	IPEAK	<u>1</u>	NOH	<u>0</u>	X	<u>.14</u>
FLXRAT(0.01)		IPLLOT	<u>0</u>	NPOW	<u>6</u>	XCO	<u>.0</u>
FRACAR	<u>.0</u>	IRELOC	<u>1</u>	NSTEPS	<u>0</u>	XH	<u>.0</u>
FRACH	<u>.0</u>	IRL	<u>0</u>	NSH	<u>0</u>	XN	<u>.0</u>
FRACHE	<u>1.</u>	ISTOR		NTIME	<u>33</u>	Z	<u>.125</u>
FRACKR	<u>.0</u>	ITAPE	<u>0,1</u>	PRCDH	<u>5.4</u>	ZCLAD	<u>1.</u>
FRACN	<u>.0</u>	ITMCUT	<u>20</u>	PROFIL*			
FRACXE	<u>.0</u>	JSTART	<u>0,13,16</u>	PSEUDO*			

*DELZA (1) = .5, 4.9, 4.9, 4.9, 4.9, 4.9, 4.9, 1.7679

*MINI (1) =

*PROFIL (1) = .99, .99, 1.02, 1.04, 1., .97, .97

*PSEUDO (1) = .05, 5., 9.7, 9.7, 9.7, 9.7, 9.7, 9.7, 9.7, 9.7, 6., .05, 7., 10.8, 10.8, 9.3, 10.4, 9.3, 7., 8.5, 9.2, 7.9, 9.8, 6., .05, 5., 8.8, 8.8, 8.8, 9., 8.4, 8.7, 9.

*RNEWK (1) =

*TIME (1) = .0, .1, .2, .4, .9, 2., 7., 20., 40., 72., 72.03, 72.06, 72.2, 72.25, 72.8, 76., 79.5, 90., 97.5, 110., 140., 152., 156., 156.03, 156.06, 156.2, 156.4, 157., 183., 190., 208., 243., 258.,

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. AE-318 IFA-3

ATMOS <u>1.</u>	FRDEN <u>.96</u>	KSAVE <u>0</u>	RADS <u>0</u>
CP <u>(1.0)</u>	FRDEN2 <u>.98</u>	LFUEL <u>65.35</u>	RNEWK*
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>65.35</u>	ROUC <u>.00002</u>
DCI <u>.502</u>	FRSIN <u>.98</u>	MINI* <u>0,0,0,1</u>	ROUF <u>.00008</u>
DCO <u>562</u>	FR35 <u>.015</u>	MXPOWR <u>9.116</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC (4) <u>3</u>	TIME*
DFS <u>.495</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>446.</u>
DSINZ <u>0</u>	IDENSF <u>1</u>	NF (6) <u>3</u>	TM <u>(2790°C)</u>
DTEMP <u>10.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.043</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.5</u>
EXTP <u>29.61</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT <u>(0.01)</u>	IPLOT <u>0</u>	NPOW <u>3</u>	XCO <u>0</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>0</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>5</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>.0</u>	ZCLAD <u>.0</u>
FRACN <u>.0</u>	ITMCUT <u>100</u>	PROFIL*	
FRACXE <u>0</u>	JSTART <u>0</u>	PSEUDO*	

*DELZA (1) = .5, 21.78, 21.783, 21.783, 2.526

*MINI (1) =

*PROFIL (1) = .9, 1.28, 1.28, .35

*PSEUDO (1) = .05, 1., 3., 5., 9.116

*RNEWK (1) = 2., 1.133, 34.07, 26.57, 66 E-12

*TIME (1) = .0, .2, .4, .6, .8

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA-4, AE-318

ATMOS 1.0	FRDEN 0.96	KSAVE 0.00	RADS 0.00
CP (1.0)	FRDEN2 0.98	LFUEL 62.99	RNEWK* ---
CR (1.0)	FRPU02 0.00	LVOIDZ 62.99	ROUC 2.E-5
DCI 0.502	FRSIN 0.98	MINI*	ROUF 8.E-5
DCO 0.662	FR35 0.06	MXPOWR 17.2	S 0.00
DELZA* ---	FR40 ---	NC (4) 3.00	TIME* ---
DFS 0.495	FR41 ---	NCLAD 0.00	TINLET 446.00
DSINZ 0.00	IDENSF 1.0	NF (6) 3.00	TM (2790°C)
DTEMP 10.0	IGAS 0.00	NFLX 0.00	TPLAS (1200°C)
DVOIDZ 0.043	IOPT 0.00	NFUEL 0.00	VPLENZ 0.5
EXTP 296.0	IPEAK 0.00	NOH 0.00	X 0.14
FLXRAT(0.01)	IPLOT 0.00	NPOW 3.00	XCO ---
FRACAR ---	IRELOC 1.00	NSTEPS 0.00	XH ---
FRACH ---	IRL 0.00	NSH 0.00	XN ---
FRACHE 1.0	ISTOR 0.00	NTIME 0.00	Z 0.125
FRACKR ---	ITAPE 0.00	PRCDH 0.00	ZCLAD 0.00
FRACN ---	ITMCUT 100.	PROFIL* ---	
FRACXE ---	JSTART 0.00	PSEUDO* ---	

*DELZA (1) =

*MINI (1) = 0,0,0,1

*PROFIL (1) = .9, 1.28, 1.28, .35

*PSEUDO (1) = .05, 1., 3., 5., 15., 17.2

*RNEWK (1) = ---

*TIME (1) = 0., 0.2, 0.4, 0.6, 0.8

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. AE-318, IFA-10, 200 days of burnup

ATMOS 1.00	FRDEN .96	KSAVE 0.00	RADS 0.00
CP (1.0)	FRDEN2 .98	LFUEL 67.48	RNEWK*
CR (1.0)	FRPU02 0.00	LVOIDZ 67.48	ROUC .00004
DCI .496	FRSIN .98	MINI* 0,0,0,1	ROUF .00008
DCO .543	FR35 .025	MXPOWR 12.22	S 0.00
DELZA*	FR40 0.00	NC (4) 3.00	TIME*
DFS .491	FR41 0.00	NCLAD 0.00	TINLET 446.00
DSINZ 0.00	IDENSF 1.00	NF (6) 3.00	TM (2790°C)
DTEMP 10.00	IGAS 0.00	NFLX 0.00	TPLAS (1200°C)
DVOIDZ .043	IOPT 0.00	NFUEL 0.00	VPLENZ .5
EXTP 29.61	IPEAK 0.00	NOH 0.00	X .14
FLXRAT(0.01)	IPLOT 0.00	NPOW 3.00	XCO 0.00
FRACAR 0.00	IRELOC 1.00	NSTEPS 0.00	XH 0.00
FRACH 0.00	IRL 0.00	NSH 0.00	XN 0.00
FRACHE 1.00	ISTOR 0.00	NTIME 10.00	Z .125
FRACKR 0.00	ITAPE 0.00	PRCDH 10.00	ZCLAD 0.00
FRACN 0.00	ITMCUT 100.00	PROFIL*	
FRACXE 0.00	JSTART 0.00	PSEUDO*	

*DELZA (1) = .5, 22.4933, 22.4933, 22.5933, 2.5877

*MINI (1) =

*PROFIL (1) = .9, 1.28, 1.28, .35

*PSEUDO (1) = .05, 3., 8., 12., 12., 12., 12., 12., 12., 12., 12., 12., 12.

*RNEWK (1) = 2., 1.133, 34.07, 26.57, 66E-12

*TIME (1) = 0., 2., 3., 4., 5., 10., 50., 10., 150., 200.

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. AE-411 Comparison Run

ATMOS <u>1.00</u>	FRDEN <u>.96</u>	KSAVE <u>0.00</u>	RADS <u>0.00</u>
CP <u>(1.0)</u>	FRDEN2 <u>.98</u>	LFUEL <u>.91</u>	RNEWK*
CR <u>(1.0)</u>	FRPU02 <u>0.00</u>	LVOIDZ <u>.91</u>	ROUC <u>.00002</u>
DCI <u>.689</u>	FRSIN <u>.98</u>	MINI*	ROUF <u>.00008</u>
DCO <u>.721</u>	FR35 <u>.0071</u>	MXPOWR <u>5.944</u>	S <u>0.00</u>
DELZA*	FR40 <u>0.00</u>	NC <u>(4)</u>	TIME*
DFS <u>.669</u>	FR41 <u>0.00</u>	NCLAD <u>0.00</u>	TINLET <u>460.</u>
DSINZ <u>0.00</u>	IDENSF <u>1.00</u>	NF <u>(6)</u>	TM <u>(2790°C)</u>
DTEMP <u>10.00</u>	IGAS <u>0.00</u>	NFLX <u>0.00</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>0.43</u>	IOPT <u>0.00</u>	NFUEL <u>0.00</u>	VPLENZ <u>.4</u>
EXTP <u>500.</u>	IPEAK <u>0.00</u>	NOH <u>0.00</u>	X <u>.14</u>
FLXRAT <u>(0.01)</u>	IPLOT <u>0.00</u>	NPOW <u>2.00</u>	XCO <u>0.00</u>
FRACAR <u>0.00</u>	IRELOC <u>1.00</u>	NSTEPS <u>0.00</u>	XH <u>0.00</u>
FRACH <u>0.00</u>	IRL <u>0.00</u>	NSH <u>0.00</u>	XN <u>0.00</u>
FRACHE <u>1.00</u>	ISTOR <u>0.00</u>	NTIME <u>11.00</u>	Z <u>.125</u>
FRACKR <u>0.00</u>	ITAPE <u>0.00</u>	PRCDH <u>0.00</u>	ZCLAD <u>0.00</u>
FRACN <u>0.00</u>	ITMCUT <u>100.</u>	PROFIL*	
FRACXE <u>0.00</u>	JSTART <u>0.00</u>	PSEUDO*	

*DELZA (1) = .5, .455, .455, 1.072832

*MINI (1) = 0, 0, 0, 1

*PROFIL (1) = 1., 1., 1.

*PSEUDO (1) = .05, 4.834, 9.861, 12.47, 12.66, 10.992, 12.86, 6.714, 6.945,
12.216, 13.492

*RNEWK (1) =

*TIME (1) = 0., .125, .236, .49, 1.531, 2.118, 3.031, 5.031, 6.365, 20.878,
28.248

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA-431, 432, Rod #3

ATMOS 1.0	FRDEN .95	KSAVE 0.00	RADS 0.00
CP (1.0)	FRDEN2	LFUEL 23.146	RNEWK*
CR (1.0)	FRPU02 0.00	LVOIDZ 23.146	ROUC .000021
DCI .4293	FRSIN .98	MINI*	ROUF .000087
DCO .5032	FR35 .1	MXPOWR 12.6	S 0.00
DELZA*	FR40 0.00	NC (4)	TIME*
DFS .4275 (0.4265 for IFA-432)	FR41 0.00	NCLAD 0.00	TINLET 464.
DSINZ 0.00	IDENSF 0.00	NF (6)	TM (2790°C)
DTEMP 20.00	IGAS 0.00	NFLX 0.00	TPLAS (1200°C)
DVOIDZ .069	IOPT 1.00	NFUEL 0.00	VPLENZ 0.15
EXTP 485.00	IPEAK 0.00	NOH 0.00	X .14
FLXRAT(0.01)	IPLT 0.00	NPOW 6.00	XCO 0.00
FRACAR 0.00	IRELOC 1.00	NSTEPS 20.	XH 0.00
FRACH 0.00	IRL 0.00	NSH 6.00	XN 0.00
FRACHE 1.00	ISTOR 0.00	NTIME 20.00	Z .125
FRACKR 0.00	ITAPE 0.00	PRCDH 0.00	ZCLAD 0.00
FRACN 0.00	ITMCUT 20.00	PROFIL*	
FRACXE 0.00	JSTART 12.00	PSEUDO*	

*DELZA (1) = 1., 4.646, 3.7, 3.7, 3.7, 3.7, 3.7, 1.

*MINI (1) = 2, 0, 0, 4, 0, 0, 7, 8

*PROFIL (1) = .643, .77, .85, .905, .955, .983, 1.

*PSEUDO (1) = .01, 3.6, 9.14 (14. for IFA-432), 9.14, 9.14, 9.14, 9.14, 9.14, 9.14, 9.14, 9.14, 9.14

*RNEWK (1) =

*TIME (1) = 0, 0.2, 0.4, 0.6, 1., 5., 10., 20., 30., 50., 70., 90., 100., 110.

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA 432 Rod 1

ATMOS <u>1.</u>	FRDEN <u>.95</u>	KSAVE <u>0</u>	RADS <u>.0</u>
CP (1.0)	FRDEN2 <u>.98</u>	LFUEL <u>23.03</u>	RNEWK*
CR (1.0)	FRPU02 <u>.0</u>	LVOIDZ <u>.0</u>	ROUC <u>.00002</u>
DCI <u>.4293</u>	FRSIN <u>.98</u>	MINI* <u>1,2,3,4,5</u>	ROUF <u>.00008</u>
DCO <u>.5035</u>	FR35 <u>.1</u>	MXPOWR <u>14.</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC (4)	TIME*
DFS <u>.4205</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>459.</u>
DSINZ <u>.0</u>	IDENSF <u>0</u>	NF (6)	TM (2790°C)
DTEMP <u>10.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS (1200°C)
DVOIDZ <u>.0</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.342</u>
EXTP <u>500.</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT(0.01) <u>.17</u>	IPLOT <u>0</u>	NPOW <u>4</u>	XCO <u>.0</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>12</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>.0</u>	ZCLAD <u>.0</u>
FRACN <u>.0</u>	ITMCUT <u>1000</u>	PROFIL*	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO*	

*DELZA (1) = .5. 2.76. 6.69. 7.16. 6.42. .59

*MINI (1) =

*PROFIL (1) =

*PSEUDO (1) =

*RNEWK (1) =

*TIME (1) =

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA 431 Rod 1

10 w/cm peak
No densification
No relocation

ATMOS	1.	FRDEN	.95	KSAVE	0	RADS	0
CP (1.0)		FRDEN2	.98	LFUEL	23.03	RNEWK*	
CR (1.0)		FRPU02	.0	LVOIDZ	.0	ROUC	.00002
DCI	.4293	FRSIN	.98	MINI*	1,2,3,4,5	ROUF	.00008
DCO	.5035	FR35	.1	MXPOWR	14.	S	.0
DELZA*		FR40	.0	NC (4)		TIME*	
DFS	.4205	FR41	.0	NCLAD	0	TINLET	459.
DSINZ	.0	IDENSF	0	NF (6)		TM (2790°C)	
DTEMP	10.	IGAS	0	NFLX	0	TPLAS (1200°C)	
DVOIDZ	.0	IOPT	0	NFUEL	0	VPLENZ	.342
EXTP	500.	IPEAK	0	NOH	0	X	.14
FLXRAT	.17	IPLLOT	0	NPOW	4	XCO	.0
FRACAR	.0	IRELOC	0	NSTEPS	0	XH	0
FRACH	.0	IRL	0	NSH	0	XN	.0
FRACHE	1.	ISTOR	0	NTIME	13	Z	.125
FRACKR	.0	ITAPE	0	PRCDH	.0	ZCLAD	.0
FRACN	.0	ITMCUT	1000	PROFIL*			
FRACXE	.0	JSTART	0	PSEUDO*			

*DELZA (1) = .5, 2.76, 6.69, 7.16, 6.42, .59

*MINI (1) =

*PROFIL (1) = .84, 1.01, 1.23, 1.33, 1.33

*PSEUDO (1) = .05, 1., 3., 7., 10., 10., 10., 10., 10., 10., 10., 10., 10., 14., 14.,
14., 11., 8., 5., 2., .05, 2., 5., 8., 11., 14., 14., 14., 14., 14., 14.,
14.,

*RNEWK (1) = 2., 1.133, 34.07, 26.57, .66E-12

*TIME (1) = .05, .1, .2, .3, 14., .5, 3., 10., 20., 40., 60., 80., 100., 120., 140.,
150., 150.1, 150.2, 150.3, 150.4, 150.5, 150.6, 150.7, 150.8, 150.0,
151., 161, 180, 200., 220., 240., 260., 280., 300.,

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA 432 Rod 1 14 kw/ft

ATMOS <u>1.</u>	FRDEN <u>.95</u>	KSAVE <u>0</u>	RADS <u>0</u>
CP (1.0)	FRDEN2 <u>.98</u>	LFUEL <u>23.03</u>	RNEWK*
CR (1.0)	FRPU02 <u>.0</u>	LVOIDZ <u>.0</u>	ROUC <u>.00002</u>
DCI <u>.4293</u>	FRSIN <u>.98</u>	MINI* <u>1, 2, 3, 4, 5</u>	ROUF <u>.00008</u>
DCO <u>.5035</u>	FR35 <u>.1</u>	MXPOWR <u>14</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC (4)	TIME*
DFS <u>.4205</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>459.</u>
DSINZ <u>.0</u>	IDENSF <u>0</u>	NF (6) <u>0</u>	TM (2790°C)
DTEMP <u>10.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS (1200°C)
DVOIDZ <u>.0</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>0.342</u>
EXTP <u>500.</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>0.14</u>
FLXRAT <u>.17</u>	IPLOT <u>0</u>	NPOW <u>4</u>	XCO
FRACAR <u>.0</u>	IRELOC <u>0 (1)</u>	NSTEPS <u>0</u>	XH
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>13</u>	Z <u>0.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>.0</u>	ZCLAD
FRACN <u>.0</u>	ITMCUT <u>1000</u>	PROFIL*	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO*	

*DELZA (1) = .5, 2.76, 6.69, 7.16, 6.42, .59

*MINI (1) =

*PROFIL (1) = .84, 1.01, 1.23, 1.23, 1.33

*PSEUDO (1) = .05, 1., 3., 7., 12., 14., 14., 14., 14., 14., 14., 14., 14., 14.,
8., 5., 2., .05, 2., 5., 8., 11., 14., 14., 14., 14., 14., 14.

*RNEWK (1) = 2., 1.133, 34.07, 26.57, 66E-12

*TIME (1) = .05, .1, .2, .3, .4, .5, 3., 10., 20., 40., 60., 80., 100., 120., 140.,
150., 150.1, 150.2, 150.3, 150.4, 150.5, 150.6, 150.7, 150.8, 150.9, 151
161, 180., 200., 220., 240., 260., 280., 300.

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA 431 Rod 2

ATMOS	1.	FRDEN	.05	KSAVE	0	RADS	.0
CP (1.0)		FRDEN2	.98	LFUEL	23.03	RNEWK*	
CR (1.0)		FRPU02	.0	LVOIDZ	.0	ROUC	.00002
DCI	.4293	FRSIN	.98	MINI* 1, 2, 3, 4, 5		ROUF	.00008
DCO	.5035	FR35	.1	MXPOWR	14.	S	.0
DELZA*		FR40	.0	NC (4)		TIME*	
DFS	.4145	FR41	.0	NCLAD	0	TINLET	459.
DSINZ	.0	IDENSF	0	NF (6)		TM (2790°C)	
DTMP	10.	IGAS	0	NFLX	0	TPLAS (1200°C)	
DVOIDZ	.0	IOPT	0	NFUEL	0	VPLENZ	.342
EXTP	500.	IPEAK	0	NOH	0	X	.14
FLXRAT	.17	IPL0T	0	NPOW	4	XCO	.0
FRACAR	.0	IRELOC	0 (1)	NSTEPS	0	XH	.0
FRACH	.0	IRL	0	NSH	0	XN	.0
FRACHE	1.	ISTOR	0	NTIME	12	Z	.125
FRACKR	.0	ITAPE	0	PRCDH	.0	ZCLAD	.0
FRACN	.0	ITMCUT	1000	PROFIL*			
FRACXE	.0	JSTART	0	PSEUDO*			

*DELZA (1) = .5, 2.87, 6.69, 7.16, 6.42, .59

*MINI (1) =

*PROFIL (1) = .84, 1.01, 1.23, 1.33, 1.33

*PSEUDO (1) = .04, 1., 3., 7., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,

*RNEWK (1) = 2., 1.133, 34.07, 26.57, 66E-12

*TIME (1) = .0, .1, .2, .3, .4, 1., 10., 20., 30., 50., 70., 90., 110., 130., 150.

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA 431 Rod 2 14 kw/ft

ATMOS 1.	FRDEN .95	KSAVE 0	RADS .0
CP (1.0)	FRDEN2 .98	LFUEL 23.03	RNEWK*
CR (1.0)	FRPU02 .0	LVOIDZ .0	ROUC .00002
DCI .4293	FRSIN .98	MINI* 1, 2, 3, 4, 5	ROUF .00008
DCO .5035	FR35 .1	MXPOWR 14.	S .0
DELZA*	FR40 .0	NC (4)	TIME*
DFS .4145	FR41 .0	NCLAD 0	TINLET 459
DSINZ .0	IDENSF 0	NF (6)	TM (2790°C)
DTEMP 10.	IGAS 0	NFLX 0	TPLAS (1200°C)
DVOIDZ .0	IOPT 0	NFUEL 0	VPLENZ .342
EXTP 500.	IPEAK 0	NOH 0	X .14
FLXRAT .17	IPL0T 0	NPOW 4	XCO .0
FRACAR .0	IRELOC 0 (1)	NSTEPS 0	XH .0
FRACH 1.	IRL 0	NSH 13	XN .125
FRACHE .0	ISTOR 0	NTIME .0	Z .0
FRACKR .0	ITAPE 1000	PRCDH	ZCLAD
FRACN .0	ITMCUT 0	PROFIL*	
FRACXE	JSTART	PSEUDO*	

*DELZA (1) = .5, 2.76, 6.60, 7.16, 6.42, .59

*MINI (1) =

*PROFIL (1) = .84, 1.01, 1.23, 1.33, 1.33

*PSEUDO (1) = .05, 1., 3., 7., 12., 14., 14., 14., 14., 14., 14., 14., 14., 14.,
14., 11., 8., 5., 2., .04, 2., 5., 8., 11., 14., 14., 14., 14., 14., 14.,

*RNEWK (1) = 2., 1.133, 34.07, 26.57, .66E-12

*TIME (1) = .05, .1, .2, .3, .4, .5, 3., 10., 20., 40., 60., 80., 100., 120., 140.,
150., 150.1, 150.2, 150.3, 150.4, 150.5, 150.6, 150.7, 150.8, 150.9,
151., 161, 180., 200., 220., 240., 280., 300.

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA 431 Rod 5 10 kw/ft

ATMOS	1.	FRDEN	.92	KSAVE	0	RADS	.0
CP	(1.0)	FRDEN2	.98	LFUEL	23.03	RNEWK*	
CR	(1.0)	FRPUO2	.0	LVOIDZ	.0	ROUC	.00002
DCI	.4293	FRSIN	.09	MINI* 1, 2, 3, 4, 5		ROUF	.00008
DCO	.5035	FR35	.1	MXPOWR	14.	S	.0
DELZA*		FR40	.0	NC (4)		TIME*	
DFS	.4205	FR41	.0	NCLAD	0	TINLET	459
DSINZ	.0	IDENSF	0	NF (6)		TM (2790°C)	
DTEMP	10.	IGAS	0	NFLX	0	TPLAS (1200°C)	
DVOIDZ	.0	IOPT	0	NFUEL	0	VPLENZ	.342
EXTP	500.	IPEAK	0	NOH	0	X	.4
FLXRAT	.17	IPLLOT	0	NPOW	4	XCO	.0
FRACAR	.0	IRELOC	0	NSTEPS	0	XH	.0
FRACH	.0	IRL	0 (1)	NSH	0	XN	.0
FRACHE	1.	ISTOR	0	NTIME	13	Z	.125
FRACKR	.0	ITAPE	0	PRCDH	.0	ZCLAD	10
FRACN	.0	ITMCUT	1000	PROFIL*			
FRACXE	.0	JSTART	.0	PSEUDO*			

*DELZA (1) = .5, 2.76, 6.69, 7.16, 6.42, .59

*MINI (1) =

*PROFIL (1) = .84, 1.01, 1.23, 1.33, 1.33

*PSEUDO (1) = .05, 1., 3., 7., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,
10.,

*RNEWK (1) = 2., 1.133, 34.08, 26.57, .66E-12

*TIME (1) = .0, .1, 12, .3, .4, .5, 3., 10, 20., 40., 60., 80., 100., 120., 140.,
150.,

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA-432 Rod 5

ATMOS 1.	FRDEN .92	KSAVE 0	RADS .0
CP (1.0)	FRDEN2 .98	LFUEL 23.03	RNEWK*
CR (1.0)	FRPU02 .0	LVOIDZ .0	ROUC .00002
DCI .4293	FRSIN .98	MINI* 1, 2, 3, 4, 5	ROUF .00008
DCO .5035	FR35 .1	MXPOWR 14.	S .0
DELZA*	FR40 .0	NC (4)	TIME*
DFS .4205	FR41 .0	NCLAD 0	TINLET 459.
DSINZ .0	IDENSF 0	NF (6)	TM (2790°C)
DTEMP 10.	IGAS 0	NFLX 0	TPLAS (1200°C)
DVOIDZ .0	IOPT 0	NFUEL 0	VPLENZ .342
EXTP 500.	IPEAK 0	NOH 0	X .14
FLXRAT .17	IPL0T 0	NPOW 4	XCO .0
FRACAR .0	IRELOC 0	NSTEPS 0	XH .0
FRACH .0	IRL 0 (1)	NSH 0	XN .0
FRACHE 1.	ISTOR 0	NTIME 6	Z .125
FRACKR .0	ITAPE 0	PRCDH .0	ZCLAD .0
FRACN .0	ITMCUT 1000	PROFIL*	
FRACXE .0	JSTART 0	PSEUDO*	

*DELZA (1) = .5, 2.76, 6.69, 7.16, 6.42, .59

*MINI (1) =

*PROFIL (1) = .84, 1.01, 1.23, 1.33, 1.33

*PSEUDO (1) = .05, 1., 3., 7., 12., 14., 14., 14., 14., 14., 14., 14., 14., 14.,
14., 11., 8., 5., 2., .05, 2., 5., 8., 11., 14., 14., 14., 14., 14., 14.,
14.

*RNEWK (1) = 2., 1.133, 34.07, 27.57, 66E-12

*TIME (1) = .05, .1, .2, .3, .4, .5, 3., 10., 20., 40., 60., 80., 100., 120., 140.,
150., 150.1, 150.2, 150.3, 150.4, 150.5, 150.6, 150.7, 150.8, 150.9,
150., 161., 180., 200., 220., 240., 260., 280., 300.

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No.	IFA 431 Rod 6	14 kw/ft	Relocation No densification
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ATMOS	1.	FRDEN	.92	KSAVE	0	RADS	0
CP (1.0)		FRDEN2	.98	LFUEL	23.03	RNEWK*	
CR (1.0)		FRPU02	.0	LVOIDZ	.0	ROUC	00002
DCI	.4293	FRSIN	.98	MINI* 1, 2, 3, 4, 5		ROUF	.00008
DCO	.5035	FR35	.1	MXPOWR	14.	S	.0
DELZA*		FR40	.0	NC (4)		TIME*	
DFS	.4205	FR41	.0	NCLAD	0	TINLET	459.
DSINZ	.0	IDENSF	0	NF (6)		TM (2790°C)	
DTEMP	10.	IGAS	0	NFLX	0	TPLAS (1200°C)	
DVOIDZ	.0	IOPT	0	NFUEL	0	VPLENZ	.342
EXTP	500.	IPEAK	0	NOH	0	X	.14
FLXRAT(0.01)	.17	IPL0T	0	NPOW	4	XCO	.0
FRACAR	.0	IRELOC	0	NSTEPS	0	XH	.0
FRACH	0	IRL	0	NSH	0	XN	0
FRACHE	1.	ISTOR	0	NTIME	13	Z	.125
FRACKR	.0	ITAPE		PRCDH	.0	ZCLAD	.0
FRACN	.0	ITMCUT	1000	PROFIL*			
FRACXE	.0	JSTART	0	PSEUDO*			

*DELZA (1) = .5, 2.76, 6.69, 7.16, 6.42, 59

*MINI (1) = _____

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*PROFIL (1) = .84, 1.01, 1.23, 1.33, 1.33
```

$$\text{*PSEUDO (1)} = \frac{.05, 1., 3., 7., 12., 14., 14., 14., 14., 14., 14., 14., 14., 14., 14.,}{14., 11., 8., 5., 2., .05, 2., 5., 8., 11., 14., 14., 14., 14., 14., 14.}$$

*RNEWK (1) = 2., 1.133, 34.07, 26.57, 66E-12

*TIME (1) = .05, .1, .2, .3, .4, .5, 3., 10., 20., 40., 60., 80., 100., 120., 140.,
150., 150.1, 150.2, 150.3, 150.4, 150.5, 150.6., 150.7, 150.8, 150.9,
151., 161., 180., 200., 220., 240., 260., 280., 300. above by ()

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA-431 Rod 6 14 kw/ft No Densification, No Relocation

ATMOS	1	FRDEN	92	KSAVE	0	RADS	0
CP (1.0)		FRDEN2	98	LFUEL	23.03	RNEWK*	
CR (1.0)		FRPU02	0	LVOIDZ	0	ROUC	.00002
DCI	.4293	FRSIN	.98	MINI*	1,2,3,4,5	ROUF	.00008
DCO	.5035	FR35	.1	MXPOWR	14	S	.0
DELZA*		FR40	.0	NC (4)		TIME*	
DFS	.4205	FR41	.0	NCLAD	0	TINLET	459.
DSINZ	.0	IDENSF	1	NF (6)		TM (2790°C)	
DTEMP	10.	IGAS	0	NFLX	0	TPLAS (1200°C)	
DVOIDZ	.0	IOPT	0	NFUEL	0	VPLENZ	.342
EXTP	500	IPEAK	0	NOH	0	X	.14
FLXRAT(0.01)	.17	IPLOT	0	NPOW	4	XCO	.0
FRACAR	.0	IRELOC	0	NSTEPS	0	XH	.0
FRACH	.0	IRL	0	NSH	0	XN	.0
FRACHE	1.	ISTOR	0	NTIME	13	Z	.125
FRACKR	.0	ITAPE	0	PRCDH	.0	ZCLAD	.0
FRACN	.0	ITMCUT	1000	PROFIL*			
FRACXE	.0	JSTART	0	PSEUDO*			

```
*DELZA (1) = .5, 2.76, 6.69, 7.16, 6.42, .59
```

```
*MINI (1) =
```

```
*PROFIL (1) = .84, 1.01, 1.23, 1.33, 1.33
```

$$*\text{PSEUDO}(1) = \frac{.05, .1, .3, .7, .12, .14, .14, .14, .14, .14, .14, .14, .14, .14}{14., 14., 11., 8., 5., 2., .05., 2., 5., 8., 11., 14., 14., 14.,}$$
$$14., 14., 14., 14., 14., 14.,$$

```
*RNEWK (1) = 2., 1.133, 34.07, 26.57, .66E-12
```

$$\text{*TIME (1)} = \frac{.05, .1, .2, .3, .4, .5, 3., 10., 20., 40., 60., 80., 100., 12.,}{140, 150., 150.1, 150.2, 150.3, 150.4, 150.5, 150.6, 150.7, 150.8, 150.9, 151.0, 161.0, 180., 200., 220., 240., 260., 280., 300.}$$

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA-431 Rod 6 14 kw/ft No Relocation Densification

ATMOS <u>1.</u>	FRDEN <u>.92</u>	KSAVE <u>0</u>	RADS <u>0</u>
CP (1.0)	FRDEN2 <u>.98</u>	LFUEL <u>23.03</u>	RNEWK* <u></u>
CR (1.0)	FRPU02 <u>.0</u>	LVOIDZ <u>.0</u>	ROUC <u>.00002</u>
DCI <u>.4293</u>	FRSIN <u>.98</u>	MINI* <u>1,2,3,4,5</u>	ROUF <u>.00008</u>
DCO <u>.5035</u>	FR35 <u>.1</u>	MXPOWR <u>14</u>	S <u>.0</u>
DELZA* <u></u>	FR40 <u>.0</u>	NC (4)	TIME* <u></u>
DFS <u>.4205</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>459.</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF (6)	TM (2790°C)
DTEMP <u>10.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS (1200°C)
DVOIDZ <u>.0</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.342</u>
EXTP <u>500</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT(0.01) <u>.17</u>	IPL0T <u>0</u>	NPOW <u>4</u>	XCO <u>.0</u>
FRACAR <u>.0</u>	IRELOC <u>0</u>	NSTEPS <u>0</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>13</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>.0</u>	ZCLAD <u>.0</u>
FRACN <u>.0</u>	ITMCUT <u>1000</u>	PROFIL* <u></u>	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO* <u></u>	

```
*DELZA (1) = .5, 2.76, 6.69, 7.16, 6.42, .59
```

*MINI (1) =

```
*PROFIL (1) = .84, 1.01, 1.23, 1.33, 1.33
```

$$\text{*PSEUDO (1)} = \frac{.05., 1., 3., 7., 12., 14., 14., 14., 14., 14., 14., 14., 14., 14., 14.,}{14., 14., 11., 8., 5., 2., .05., 2., 5., 8., 11., 14., 14., 14.,}$$

$$14., 14., 14., 14., 14., 14.$$

```
*RNEWK (1) = 2., 1.133, 34.07, 26.57, .66E-12
```

$$\text{*TIME (1)} = \frac{.05, .1, .2, .3, .4, .5, 3., 10., 20., 40., 60., 80., 100., 12, 140, 150., 150.1, 150.2, 150.3, 150.4, 150.5, 150.6, 150.7, 150.8, 150.9, 151.0, 161.0, 180., 200., 220., 240., 260., 280., 300.}{}$$

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA-431 Rod 6 14 kw/ft peak Densification Relocation

ATMOS <u>1.</u>	FRDEN <u>.92</u>	KSAVE <u>0</u>	RADS <u>.0</u>
CP <u>(1.0)</u>	FRDEN2 <u>.98</u>	LFUEL <u>23.03</u>	RNEWK*
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>.0</u>	ROUC <u>.00002</u>
DCI <u>.4293</u>	FRSIN <u>.98</u>	MINI* <u>1,2,3,4,5</u>	ROUF <u>.00008</u>
DCO <u>.5035</u>	FR35 <u>.1</u>	MXPOWR <u>14.</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC <u>(4)</u>	TIME*
DFS <u>.4205</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>459</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF <u>(6)</u>	TM <u>(2790°C)</u>
DTEMP <u>10</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.0</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.342</u>
EXTP <u>500.</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT <u>(0.01) .17</u>	IPLT <u>0</u>	NPOW <u>4</u>	XCO <u>.0</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>13</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>.0</u>	ZCLAD <u>.0</u>
FRACN <u>.0</u>	ITMCUT <u>1000</u>	PROFIL*	
FRACXE <u>.0</u>	JSTART <u>.0</u>	PSEUDO*	

*DELZA (1) = .5, 2.76, 6.69, 7.16, 6.42, .59

*MINI (1) =

*PROFIL (1) = .84, 1.01, 1.23, 1.33, 1.33

*PSEUDO (1) = .05, 1., 3., 7., 12., 14., 14., 14., 14., 14., 14., 14., 14.,
14., 14., 11., 8., 5., 2., .05., 2., 5., 8., 11., 14., 14., 14.,
14., 14., 14., 14., 14., 14.,

*RNEWK (1) = 2., 1.133, 34.07, 26.57, .66E-12

*TIME (1) = .05, .1, .2, .3, .4, .5, 3., 10., 20., 40., 60., 80., 100., 120.,
140., 150., 150.1, 150.2, 150.3, 150.4, 150.5, 150.6, 150.7, 150.8,
150.9, 151., 161., 180., 200, 220., 240., 260., 280., 300.

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. CEA (CC-7) Experiment, PIN 4113-AE1

ATMOS <u>.3</u>	FRDEN <u>.951</u>	KSAVE <u></u>	RADS <u>0</u>
CP <u>(1.0)</u>	FRDEN2 <u></u>	LFUEL <u>4.84</u>	RNEWK* <u></u>
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>.0</u>	ROUC <u>.00001</u>
DCI <u>.5256</u>	FRSIN <u>.965</u>	MINI* <u></u>	ROUF <u>.00004</u>
DCO <u>1.06</u>	FR35 <u>.0289</u>	MXPOWR <u>18.</u>	S <u>0.</u>
DELZA* <u></u>	FR40 <u>.0</u>	NC <u>(4)</u>	TIME* <u></u>
DFS <u>.5138</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>104.</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF <u>(6)</u>	TM <u>(2790°C)</u>
DTEMP <u>18.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.0</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.0534</u>
EXTP <u>.0</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT <u>(0.01)</u>	IPLT <u>0</u>	NPOW <u>2</u>	XCO <u>0.</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>0.</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>16</u>	Z <u>.125</u>
FRACKR <u>0.</u>	ITAPE <u>0</u>	PRCDH <u>0</u>	ZCLAD <u>0.</u>
FRACN <u>0.</u>	ITMCUT <u>100</u>	PROFIL* <u></u>	
FRACXE <u>0.</u>	JSTART <u>0.</u>	PSEUDO* <u></u>	

*DELZA (1) = .5, 2.42, 2.42, .24611651275828

*MINI (1) = 1, 0, 0, 4

*PROFIL (1) = 1., 1., 1., 1., 1.

*PSEUDO (1) = .01, 8., 12., 16., 19.2, 18., 17., 17., 16., .01, .08, 12.
16., 21.6, 19., 17.5,

*RNEWK (1) = 2., 1.133, 34.07, 26.57, .000000000066

*TIME (1) =

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. CC-7 EXP-4112 BE 1

ATMOS <u>.3</u>	FRDEN <u>.951</u>	KSAVE <u>1</u>	RADS <u>0.</u>
CP <u>(1.0)</u>	FRDEN2 <u>.965</u>	LFUEL <u>4.84</u>	RNEWK* <u></u>
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>0.</u>	ROUC <u>.00001</u>
DCI <u>.5145</u>	FRSIN <u>.965</u>	MINI* <u></u>	ROUF <u>.00004</u>
DCO <u>1.06</u>	FR35 <u>.0289</u>	MXPOWR <u>18.</u>	S <u>0.</u>
DELZA* <u></u>	FR40 <u>.0</u>	NC <u>(4)</u>	TIME* <u></u>
DFS <u>.511</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>140.</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF <u>(6)</u>	TM <u>(2790°C)</u>
DTEMP <u>18.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>0.</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.0534</u>
EXTP <u>50.</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT <u>(0.01)</u>	IPLLOT <u>0</u>	NPOW <u>2</u>	XCO <u>0.</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>0.</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>16</u>	Z <u>.125</u>
FRACKR <u>0.</u>	ITAPE <u>0</u>	PRCDH <u>0.</u>	ZCLAD <u>0.</u>
FRACN <u>0.</u>	ITMCUT <u>100</u>	PROFIL* <u></u>	
FRACXE <u>0.</u>	JSTART <u>0</u>	PSEUDO* <u></u>	

*DELZA (1) = .5, 2.42, 2.42, .25685067

*MINI (1) = 1, 0, 0, 4

*PROFIL (1) = 1., 1., 1., 1., 1.

*PSEUDO (1) = .05, 8., 11., 13., 15., 15., 16., 14., 14., .05, 8., 11., 13., 17.7,
15.5, 15.

*RNEWK (1) =

*TIME (1) = 0., .04, .06, .08, .11, 1., 3., 27., 52., 52., 52.5, 52.54, 52.56,
52.58, 52.61, 60., 70.,

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. AECL-2230 Rod CBN

ATMOS <u>1.</u>	FRDEN <u>.981</u>	KSAVE <u>0</u>	RADS <u>.2</u>
CP <u>(1.0)</u>	FRDEN2 <u>.965</u>	LFUEL <u>6.024</u>	RNEWK*
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>.0</u>	ROUC <u>.00002</u>
DCI <u>.644</u>	FRSIN <u>.98</u>	MINI*	ROUF <u>.00008</u>
DCO <u>.7</u>	FR35 <u>.05</u>	MXPOWR <u>17.13</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC <u>(4)</u>	TIME*
DFS <u>.64</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>480</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF <u>(6)</u>	TM <u>(2790°C)</u>
DTEMP <u>3.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.0</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.001</u>
EXTP <u>1180.5</u>	IPEAK <u>1</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT <u>(0.01)</u>	IPLLOT <u>0</u>	NPOW <u>3</u>	XCO <u>.0</u>
FRACAR <u>1.</u>	IRELOC <u>1</u>	NSTEPS <u>13</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>.0</u>	ISTOR <u>0</u>	NTIME <u>14</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>2.058</u>	ZCLAD <u>.0</u>
FRACN <u>.0</u>	ITMCUT <u>100</u>	PROFIL*	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO*	

*DELZA (1) = .5,2.008,2.008,.0030700006983363

*MINI (1) = 1,2,3,4

*PROFIL (1) = 1.,1.019,1.019,1.

*PSEUDO (1) = 0.05,3.,9.,15.,17.1,17.13,17.13,17.13,17.13,17.13,17.13,17.13,17.13,17.13

*RNEWK (1) = 2.,1.133,34.07,26.57,.00000000000066

*TIME (1) = .0.,.1.,.2.,.3.,.4.,.5,1.5,4.5,10.,20.,40.,60.,80.,84.49

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. AECL-2230-CBN

ATMOS <u>1.</u>	FRDEN <u>.981</u>	KSAVE <u>1</u>	RADS <u>.2</u>
CP <u>(1.0)</u>	FRDEN2 <u>.965</u>	LFUEL <u>6.024</u>	RNEWK*
CR <u>(1.0)</u>	FRPU02 <u>0.</u>	LVOIDZ <u>.0</u>	ROUC <u>.00002</u>
DCI <u>.644</u>	FRSIN <u>.98</u>	MINI*	ROUF <u>.00008</u>
DCO <u>.7</u>	FR35 <u>.05</u>	MXPOWR <u>17.13</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC <u>(4)</u>	TIME*
DFS <u>.64</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>480.</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF <u>(6)</u>	TM <u>(2790°C)</u>
DTEMP <u>3.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.0</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.6</u>
EXTP <u>1180.5</u>	IPEAK <u>1</u>	NOH <u>0</u>	X <u>.27</u>
FLXRAT <u>(0.01)</u>	IPL0T <u>0</u>	NPOW <u>3</u>	XCO <u>.0</u>
FRACAR <u>1.</u>	IRELOC <u>1</u>	NSTEPS <u>13</u>	XH <u>.0</u>
FRACH <u>0.</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>0.</u>	ISTOR <u>0</u>	NTIME <u>13</u>	Z <u>.125</u>
FRACKR <u>0.</u>	ITAPE <u>1</u>	PRCDH <u>2.058</u>	ZCLAD <u>.0</u>
FRACN <u>0.</u>	ITMCUT <u>100</u>	PROFIL*	
FRACXE <u>0.</u>	JSTART <u>8</u>	PSEUDO*	

*DELZA (1) = .5,2.008,.2008,2.008,1.8420004190018

*MINI (1) = 1,2,3,4

*PROFIL (1) = 1.,1.019,1.019,1.

*PSEUDO (1) = .05,3.,9.,15.,17.1,17.13,17.13,17.13,17.13,17.13,17.13,17.13,
17.13

*RNEWK (1) = .2,1.133,34.07,26.57,.00000000000066

*TIME (1) = .0,.1,.2,.3,.4,.5,1.5,4.5,10.,20.,40.,60.,80.

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. AECL-2230-CBX

ATMOS <u>1.</u>	FRDEN <u>.9525</u>	KSAVE <u>1</u>	RADS <u>.2</u>
CP <u>(1.0)</u>	FRDEN2 <u>.965</u>	LFUEL <u>6.024</u>	RNEWK* <u></u>
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>0.</u>	ROUC <u>.00002</u>
DCI <u>.644</u>	FRSIN <u>.98</u>	MINI* <u></u>	ROUF <u>.00008</u>
DCO <u>.7</u>	FR35 <u>.05</u>	MXPOWR <u>17.13</u>	S <u>.0</u>
DELZA* <u></u>	FR40 <u>.0</u>	NC <u>(4)</u>	TIME* <u></u>
DFS <u>.64</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>480.</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF <u>(6)</u>	TM <u>(2790°C)</u>
DTEMP <u>3.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.0</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.001</u>
EXTP <u>1180.5</u>	IPEAK <u>1</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT <u>(0.01)</u>	IPLT <u>0</u>	NPOW <u>3</u>	XCO <u>0.</u>
FRACAR <u>1.</u>	IRELOC <u>1</u>	NSTEPS <u>13</u>	XH <u>0.</u>
FRACH <u>0.</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>0.</u>
FRACHE <u>0.</u>	ISTOR <u>0</u>	NTIME <u>14</u>	Z <u>.125</u>
FRACKR <u>0.</u>	ITAPE <u>0</u>	PRCDH <u>2.058</u>	ZCLAD <u>.0</u>
FRACN <u>0.</u>	ITMCUT <u>100</u>	PROFIL* <u></u>	
FRACXE <u>0.</u>	JSTART <u>0</u>	PSEUDO* <u></u>	

*DELZA (1) = .5,2.008,2.008,2.008,.0030700006983363

*MINI (1) = 1.0,3

*PROFIL (1) = 1.,1.019,1.019,1.

*PSEUDO (1) = .05,3.,9.,15.,17.1,17.13,17.13,17.13,17.13,17.13,17.13,17.13,
17.13,17.13

*RNEWK (1) = 2.,1.133,34.07,26.57,.00000000000066

*TIME (1) = .0,.1,.2,.3,.4,.5,1.5,4.5,10.,20.,40.,60.,80.,84.49

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. AECL-2662 LFX

ATMOS <u>1.</u>	FRDEN <u>.958</u>	KSAVE <u>0</u>	RADS <u>.32</u>
CP (1.0)	FRDEN2 <u>.965</u>	LFUEL <u>9.57</u>	RNEWK*
CR (1.0)	FRPU02 <u>.0</u>	LVOIDZ <u>.0</u>	ROUC <u>.00002</u>
DCI <u>.7685</u>	FRSIN <u>.98</u>	MINI*	ROUF <u>.00008</u>
DCO <u>.8039</u>	FR35 <u>.024</u>	MXPOWR <u>15.5</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC (4) <u>3</u>	TIME*
DFS <u>.7638</u>	FR41 <u>.0</u>	NCLAD <u>-1</u>	TINLET <u>410.</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF (8) <u>3</u>	TM (2790°C)
DTEMP <u>10.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS (1200°C)
DVOIDZ <u>.0</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.0018</u>
EXTP <u>1030.</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>.27</u>
FLXRAT(0.01)	IPLT <u>0</u>	NPOW <u>2</u>	XCO <u>.0</u>
FRACAR <u>.024</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>.0</u>
FRACH <u>.6</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>.0</u>	ISTOR <u>0</u>	NTIME <u>9</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>1.</u>	ZCLAD <u>.0</u>
FRACN <u>.0</u>	ITMCUT <u>100</u>	PROFIL*	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO*	

*DELZA (1) = .5, .4, .785, .4, .785, .003805650723072

*MINI (1) = 1, 2, 3, 4

*PROFIL (1) = .88, .9999, 1.12

*PSEUDO (1) = .05, .5, .10, .15, .24, .9, .24, .9, .24, .9, .24, .9, .24, .9

*RNEWK (1) = 2., 1.133, 34.07, 26.57, .000000000000066

*TIME (1) = .0, .1, .2, .3, .4, 10., 30., 70., 110.

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. AECL-2662-LFH

ATMOS <u>1.</u>	FRDEN <u>.958</u>	KSAVE <u>0</u>	RADS <u>.32</u>
CP <u>(1.0)</u>	FRDEN2 <u>.965</u>	LFUEL <u>9.57</u>	RNEWK* <u></u>
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>.0</u>	ROUC <u>.00002</u>
DCI <u>.7685</u>	FRSIN <u>.98</u>	MINI* <u></u>	ROUF <u>.00008</u>
DCO <u>.8039</u>	FR35 <u>.024</u>	MXPOWR <u>15.5</u>	S <u>.0</u>
DELZA* <u></u>	FR40 <u>.0</u>	NC (4) <u>3</u>	TIME* <u></u>
DFS <u>.7638</u>	FR41 <u>.0</u>	NCLAD <u>-1</u>	TINLET <u>410.</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF (6) <u>3</u>	TM <u>(2790°C)</u>
DTEMP <u>10.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.0</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.0018</u>
EXTP <u>1030.</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>.27</u>
FLXRAT <u>(0.01)</u>	IPLOT <u>0</u>	NPOW <u>2</u>	XCO <u>0.</u>
FRACAR <u>1.</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>0.</u>
FRACH <u>0.</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>0.</u>
FRACHE <u>0.</u>	ISTOR <u>0</u>	NTIME <u>9</u>	Z <u>.125</u>
FRACKR <u>0.</u>	ITAPE <u>0</u>	PRCDH <u>1.</u>	ZCLAD <u>0.</u>
FRACN <u>0.</u>	ITMCUT <u>100</u>	PROFIL* <u></u>	
FRACXE <u>0.</u>	JSTART <u>0</u>	PSEUDO* <u></u>	

*DELZA (1) = .5,4.785,4.785,.00388056723072

*MINI (1) = 1,2,3,4

*PROFIL (1) = .93,1.,1.07

*PSEUDO (1) = .05,4.,8.,12.,22.,22.6,22.6,22.6,22.6

*RNEWK (1) = 2.,1,133,34.07,26.57,.000000000000066

*TIME (1) = .0,1,2,3,4,10,30,70,110

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. AECL-2662-LFF NPOW=6

ATMOS <u>1.</u>	FRDEN <u>.958</u>	KSAVE <u>0</u>	RADS <u>.32</u>
CP <u>(1.0)</u>	FRDEN2 <u>.965</u>	LFUEL <u>9.57</u>	RNEWK* <u></u>
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>.0</u>	ROUC <u>.00002</u>
DCI <u>.7685</u>	FRSIN <u>.98</u>	MINI* <u></u>	ROUF <u>.00008</u>
DCO <u>.8039</u>	FR35 <u>.024</u>	MXPOWR <u>15.5</u>	S <u>.0</u>
DELZA* <u></u>	FR40 <u>.0</u>	NC (4) <u>3</u>	TIME* <u></u>
DFS <u>.7638</u>	FR41 <u>.0</u>	NCLAD <u>-1</u>	TINLET <u>410.</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF (6) <u>3</u>	TM <u>(2790°C)</u>
DTEMP <u>10.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.0</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.0018</u>
EXTP <u>1030.</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>.27</u>
FLXRAT <u>(0.01)</u>	IPLT <u>0</u>	NPOW <u>6</u>	XCO <u>0.</u>
FRACAR <u>1.</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>0.</u>
FRACH <u>0.</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>0.</u>
FRACHE <u>0.</u>	ISTOR <u>0</u>	NTIME <u>9.</u>	Z <u>.125</u>
FRACKR <u>0.</u>	ITAPE <u>0</u>	PRCDH <u>1.</u>	ZCLAD <u>0.</u>
FRACN <u>0.</u>	ITMCUT <u>100</u>	PROFIL* <u></u>	
FRACXE <u>0.</u>	JSTART <u>0</u>	PSEUDO* <u></u>	

$$*DELZA(1) = \frac{5.1 \cdot 595.1 \cdot 595.1 \cdot 595.1 \cdot 595.1 \cdot 595.1 \cdot 595.1 \cdot 595.1}{0038805650723072}$$

```
*MINI (1) = 1.2.3.4
```

```
*PROFIL (1) =  .85,.9,.95,1.,1.05,1.15
```

*PSEUDO (1) = .05,4.,8.,12.,17.8,17.8,17.8,17.8,17.8

```
*RNEWK (1) = 2.,1.133,34.07,26.57,.000000000000066
```

```
*TIME (1) = 0.,.1,.2,.3,.4,10.,30.,70.,110.
```

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. AECL-2662-LFF (very poor gas release)

ATMOS <u>1.</u>	FRDEN <u>.958</u>	KSAVE <u>0</u>	RADS <u>.32</u>
CP <u>(1.0)</u>	FRDEN2 <u>.965</u>	LFUEL <u>9.57</u>	RNEWK* <u></u>
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>0.</u>	ROUC <u>.00002</u>
DCI <u>.7685</u>	FRSIN <u>.98</u>	MINI* <u></u>	ROUF <u>.00008</u>
DCO <u>.8039</u>	FR35 <u>.024</u>	MXPOWR <u>15.5</u>	S <u>0.</u>
DELZA* <u></u>	FR40 <u>.0</u>	NC <u>(4) 3</u>	TIME* <u></u>
DFS <u>.7638</u>	FR41 <u>.0</u>	NCLAD <u>-1</u>	TINLET <u>410</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF <u>(6) 3</u>	TM <u>(2790°C)</u>
DTEMP <u>10.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.0</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.0018</u>
EXTP <u>1030.</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>.27</u>
FLXRAT <u>(0.01)</u>	IPLOT <u>0</u>	NPOW <u>2</u>	XCO <u>.0</u>
FRACAR <u>0</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>.0</u>
FRACH <u>0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>.0</u>	ISTOR <u>0</u>	NTIME <u>9</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>1.</u>	ZCLAD <u>.0</u>
FRACN <u>.0</u>	ITMCUT <u>100</u>	PROFIL* <u></u>	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO* <u></u>	

*DELZA (1) = .5,4.785,4.785,.0038805650723072

*MINI (1) = 1,2,3,4

*PROFIL (1) = .85,1.,1.15

*PSEUDO (1) = .05,4.,.8.,.12.,.17,8,17.8,17.8,17.8,17.8

*RNEWK (1) = 2.,1.133,34.07,26.57,.00000000000066

*TIME (1) = .0,.1,.2,.3,.4,10.,30.,70.,110.

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. EPRI CASE E BWR ROD

ATMOS <u>1.</u>	FRDEN <u>.944</u>	KSAVE <u>0</u>	RADS <u>.1364</u>
CP <u>(1.0)</u>	FRDEN2 <u>.95</u>	LFUEL <u>20.06</u>	RNEWK*
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>2.3</u>	ROUC <u>.000031</u>
DCI <u>.4205</u>	FRSIN <u>.967</u>	MINI*	ROUF <u>.000042</u>
DCO <u>.4516</u>	FR35 <u>.0205</u>	MXPOWR <u>20.</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC <u>(4)</u>	TIME*
DFS <u>.4122</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>491.</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF <u>(6)</u>	TM <u>(2790°C)</u>
DTEMP <u>6.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.0842</u>	IOPT <u>1</u>	NFUEL <u>0</u>	VPLENZ <u>.214</u>
EXTP <u>1160.</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT <u>(0.01)</u>	IPL0T <u>0</u>	NPOW <u>6</u>	XCO <u>.0</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>20</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>2.2</u>	ZCLAD <u>1.</u>
FRACN <u>.0</u>	ITMCUT <u>20</u>	PROFIL*	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO*	

*DELZA (1) = .5, 4., 3.8, 2.8, 5., 3.34, 1.12, 1.6

*MINI (1) = 2, 2, 3, 4

*PROFIL (1) = .483, .822, 1., .957, .675, .44, .36

*PSEUDO (1) = .05, 8.1, 12.1, 14.1, 16.55, 16.55, 16.6, 16.6, 17.6, 17.5, 18.,
18.4, 16., 17., 18.4, 16.2, 14.7, 13.2, 10.2, .05

*RNEWK (1) =

*TIME (1) = .0, .15, .25, .35, .42, .5, 1.5, 5., 12., 17.2, 22.7, 33.25, 37.25
50.8, 64., 75.2, 75.3, 75.4, 75.5, 76

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. EPRI CASE D PWR ROD

ATMOS <u>1.</u>	FRDEN <u>.928</u>	KSAVE <u>1</u>	RADS <u>.146</u>
CP (1.0)	FRDEN2 <u>.95</u>	LFUEL <u>136.7</u>	RNEWK*
CR (1.0)	FRPU02 <u>.0</u>	LVOIDZ <u>.0</u>	ROUC <u>.00001</u>
DCI <u>.3885</u>	FRSIN <u>.965</u>	MINI*	ROUF <u>.000098</u>
DCO <u>.4145</u>	FR35 <u>.0201</u>	MXPOWR <u>9.</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC (4)	TIME*
DFS <u>.3795</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>550.</u>
DSINZ <u>.0</u>	IDENSF <u>1</u>	NF (6)	TM (2790°C)
DTEMP <u>54.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS (1200°C)
DVOIDZ <u>0.</u>	IOPT <u>1</u>	NFUEL <u>0</u>	VPLENZ <u>1.126</u>
EXTP <u>1800.</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT(0.01)	IPL0T <u>0</u>	NPOW <u>10</u>	XCO <u>.0</u>
FRACAR <u>.12</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>.88</u>	ISTOR <u>0</u>	NTIME <u>39</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>2.2</u>	ZCLAD <u>1.</u>
FRACN <u>.0</u>	ITMCUT <u>20</u>	PROFIL*	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO*	

*DELZA (1) = .5, 6., 14.5, 15., 16., 16., 20., 21.4, 9.6, 9.5, 8.7, 9.5

*MINI (1) = 1, 0, 3, 0, 5

*PROFIL (1) = .29, .41, .69, .86, .98, 1., .95, .8, .67, .46, .28

*PSEUDO (1) = .05, 4., 6.2, 6.2, 6.2, 6.2, 6.2, 6.56, 6.56, 6.56, 6.56, 6.56
5.09, 12.62, 2.62, 7.22, 7.22, 6.9, 7.13, 7.13, 7.48, 7.1, 7.1, 7.4,
4.79, 7.79, 8.43, 7.09, 7.09, 7.09, 7.09, 7.09, .05

*RNEWK (1) =

*TIME (1) = 0., .2, .3, .5, 1.5, 6.5, 15., 30., 50., 70., 90., 109., 109.1, 109.3,
109.4, 110., 132., 158., 158., 158.1, 195., 195.1, 215., 224., 245.,
277., 295., 315., 335., 335.1, 335.3, 335.5, 340., 352., 358., 360.,
380., 405., 405., 428., 428.1

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA-117 Pin#5 ~~AE-411~~

ATMOS	1.	FRDEN	.913	KSAVE	0	RADS	2333
CP (1.0)		FRDEN2	.95	LFUEL	19.685	RNEWK*	
CR (1.0)		FRPUO2	.0	LVOIDZ	2.5	ROUC	.00002
DCI	.5538	FRSIN	.95	MINI* 1,2,3,4,5		ROUF	.000039
DCO	.614	FR35	.0601	MXPOWR	20.8	S	.0
DELZA*		FR40	.0	NC	3	TIME*	
DFS	.5455	FR41	.0	NCLAD	0	TINLET	464.
DSINZ	.0	IDENSF	0	NF	3	TM (2790°C)	
DTEMP	20.	IGAS	0	NFLX	0	TPLAS (1200°C)	
DVOIDZ	.126	IOPT	1	NFUEL	0	VPLENZ	.293
EXTP	.0	IPEAK	1	NOH	0	X	.14
FLXRAT(0.01)		IPLOT	0	NPOW	4	XCO	.0
FRACAR	.0	IRELOC	1	NSTEPS	0	XH	.0
FRACH	.0	IRL	0	NSH	0	XN	.0
FRACHE	1.	ISTOR	0	NTIME	18	Z	.125
FRACKR	.0	ITAPE	0	PRCDH	2.	ZCLAD	.0
FRACN	.0	ITMCUT	100	PROFIL*			
FRACXE	.0	JSTART	0	PSEUDO*			

*DELZA (1) = .5, 4.921, 4.921, 4.921, 4.021, 1.2163

*MINI (1) =

*PROFIL (1) = .85, .9, .99, 1., .99

*PSEUDO (1) = .005, 3., 9., 12., 19.13, 19.13, 19.13, 18.68, 18.07, 20.35, 20.8,
17.65, 20.51, 19.64, 18.89, 18.2, 20.73, 19.88

*RNEWK (1) = 2., 1.133, 34.07, 26.57, .66E-12

*TIME (1) = .0, .1, .2, .3, .4, .5, 15., 30., 38., 43., 48., 50., 53., 68.,
70., 74., 89., 92.,

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA 117, PIN #5, GAP = 8.8 mils HOLLOW PELLET

ATMOS <u>1.</u>	FRDEN <u>.913</u>	KSAVE <u>0</u>	RADS <u>2333</u>
CP <u>(1.0)</u>	FRDEN2 <u></u>	LFUEL <u>19.2</u>	RNEWK* <u></u>
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>2.5</u>	ROUC <u>.00004</u>
DCI <u>.5543</u>	FRSIN <u>.98</u>	MINI* <u></u>	ROUF <u>.0001</u>
DCO <u>.614</u>	FR35 <u>.06</u>	MXPOWR <u>15.2402</u>	S <u>0.</u>
DELZA* <u></u>	FR40 <u>.0</u>	NC <u>(4)</u>	TIME* <u></u>
DFS <u>.5455</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>464.</u>
DSINZ <u>.0</u>	IDENSF <u>0</u>	NF <u>(6)</u>	TM <u>(2790°C)</u>
DTEMP <u>20.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.126</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.293</u>
EXTP <u>485.</u>	IPEAK <u></u>	NOH <u>0</u>	X <u>.14</u>
FLXRAT <u>(0.01)</u>	IPLOT <u>0</u>	NPOW <u>5</u>	XCO <u>.0</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>12</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>2.</u>	ZCLAD <u>.0</u>
FRACN <u>.0</u>	ITMCUT <u>20</u>	PROFIL* <u></u>	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO* <u></u>	

*DELZA (1) = .5, 4.80125, 4.80125, 4.80125, 2.30125, 2.5, 1.21595,

*MINI (1) = 1, 2, 3, 4, 5, 6,

*PROFIL (1) = .85, .9, .99, 1., 1., .99

*PSEUDO (1) = .005, 1.998, 3.944, 6.191, 8.486, 10.483, 12.879, 13.429, 11.731,
9.584, 7.130, 4.1542

*RNEWK (1) =

*TIME (1) = .0, .042, .094, .125, .167, 208, 25, 292, 333, 375, 417, 458

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA 431, ROD #3, RAMP #A

ATMOS <u>1.</u>	FRDEN <u>.95</u>	KSAVE <u>1</u>	RADS <u>0.</u>
CP <u>(1.0)</u>	FRDEN2 <u></u>	LFUEL <u>23.146</u>	RNEWK* <u></u>
CR <u>(1.0)</u>	FRPU02 <u>0.</u>	LVOIDZ <u>6.5</u>	ROUC <u>.000021</u>
DCI <u>.4293</u>	FRSIN <u>.98</u>	MINI* <u></u>	ROUF <u>.000087</u>
DCO <u>.5032</u>	FR35 <u>.1</u>	MXPOWR <u>12.6</u>	S <u>0.</u>
DELZA* <u></u>	FR40 <u>0.</u>	NC <u>(4)</u>	TIME* <u></u>
DFS <u>.4275</u>	FR41 <u>0.</u>	NCLAD <u>0</u>	TINLET <u>464.</u>
DSINZ <u>.0</u>	IDENSF <u>0</u>	NF <u>(6)</u>	TM <u>(2790°C)</u>
DTEMP <u>41.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200°C)</u>
DVOIDZ <u>.069</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.094</u>
EXTP <u>485.</u>	IPEAK <u>0</u>	NOH <u>0</u>	X <u>.27</u>
FLXRAT <u>(0.01)</u>	IPLOT <u>0</u>	NPOW <u>6</u>	XCO <u>0.</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>0.</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>0.</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>32</u>	Z <u>.125</u>
FRACKR <u>0.</u>	ITAPE <u>1</u>	PRCDH <u>0.</u>	ZCLAD <u>0.</u>
FRACN <u>0.</u>	ITMCUT <u>20</u>	PROFIL* <u></u>	
FRACXE <u>0.</u>	JSTART <u>0</u>	PSEUDO* <u></u>	

*DELZA (1) = 1., 4.646, 3.7, 3.7, 3.7, 3.7, 3.7, 1.

*MINI (1) = 2, 0, 0, 4, 0, 0, 7, 8

*PROFIL (1) = .643, .77, .85, .905, .955, .983, 1.

*PSEUDO (1) = .01, .66, 2., 2.8, 3.87, 4.3, 5., 6.36, 7.1, 8.03

*RNEWK (1) = 0., .4, .5, .55, .6, .65, .7, .75, .8, .85, 1.33

*TIME (1) =

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. IFA-132

ATMOS <u>1.</u>	FRDEN <u>.95</u>	KSAVE <u>1</u>	RADS <u>0</u>
CP (1.0) <u>3.0</u>	FRDEN2 <u>.95</u>	LFUEL <u>21.65</u>	RNEWK*
CR (1.0) <u>1.5</u>	FRPU02 <u>.0</u>	LVOIDZ <u>21.65</u>	ROUC <u>.000021</u>
DCI <u>.5512</u>	FRSIN <u>.98</u>	MINI*	ROUF <u>.00008</u>
DCO <u>.6102</u>	FR35 <u>.1</u>	MXPOWR <u>15.24</u>	S <u>.0</u>
DELZA*	FR40 <u>.0</u>	NC (4)	TIME*
DFS <u>.5413</u>	FR41 <u>.0</u>	NCLAD <u>0</u>	TINLET <u>464</u>
DSINZ <u>.0</u>	IDENSF <u>0</u>	NF (6)	TM (2790°C)
DTMP <u>20.</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS (1200°C)
DVOIDZ <u>.0966</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>1.124</u>
EXTP <u>485.</u>	IPEAK <u>1</u>	NCH <u>0</u>	X <u>.14</u>
FLXRAT(0.01)	IPLLOT <u>0</u>	NPOW <u>5</u>	XCO <u>.0</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>0</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>25</u>	Z <u>.125</u>
FRACKR <u>.0</u>	ITAPE <u>0</u>	PRCDH <u>.0</u>	ZCLAD <u>0</u>
FRACN <u>.0</u>	ITMCUT <u>100</u>	PROFIL*	
FRACXE <u>.0</u>	JSTART <u>0</u>	PSEUDO*	

*DELZA (1) = .5, 4.33, 4.33, 4.33, 4.33, 4.33

*MINI (1) = 1, 0, 0, 1

*PROFIL (1) = .77, .87, 1., .99, .967, .96

*PSEUDO (1) = .05, .05, 10., 15., 16., 17., 18., 19., 20., 21., 22., 23., 24.,
25., 26., 27., 28., 29., 30., 31., 32., 33., 34., 35.

*RNEWK (1) =

*TIME (1) = .0,.02, .04, .072,.0667, .0712, .0735, .079, .0833, .0875, .0917
.0958, 0.1, .1041, .1083, .1125, .1197, .1208, .125, .1292, .1334,
.1376, .142, .1462, .1504

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. AECL - 4072

ATMOS	1.	FRDEN	.9635	KSAVE	0	RADS	.35
CP (1.0)		FRDEN2	.95	LFUEL	15.034	RNEWK*	
CR (1.0)		FRPU02	.0	LVOIDZ	.0	ROUC	.00004
DCI	.7342	FRSIN	.98	MINI*	1,2,3,4	ROUF	.0001
DCO	.77756	FR35	.0159	MXPOWR	20.72	S	.0
DELZA*		FR40	.0	NC (4)		TIME*	413.6
DFS	.73032	FR41	.0	NCLAD	0	TINLET	
DSINZ	.0	IDENSF	0	NF (6)	3	TM (2790°C)	
DTEMP	14.4	IGAS	0	NFLX	0	TPLAS (1200°C)	
DVOIDZ	.0	IOPT	0	NFUEL	0	VPLENZ	.0187
EXTP	1100.	IPEAK	1	NOH	0	X	.14
FLXRAT(0.01)		IPL0T	0	NPOW	3	XCO	.0
FRACAR	.0	IRELOC	1	NSTEPS	0	XH	.0
FRACH	.0	IRL	0	NSH	0	XN	.0
FRACHE	1.	ISTOR	0	NTIME	18	Z	.125
FRACKR	.0	ITAPE	0	PRCDH	3.	ZCLAD	.0
FRACN	.0	ITMCUT	200	PROFIL*			
FRACXE	.0	JSTART	0	PSEUDO*			

*DELZA (1) = .5, 5.0113, 5.0113, 5.0113, .044169

*MINI (1) =

*PROFIL (1) = 1., 1., 1., 1.

*PSEUDO (1) = .005, 2.129, 3.342, 5.509, 7.47, 10.18, 11.883, 13.882, 18.875, 20.72
20.604, 18.682, 17.592, 13.844, 11.637, 8.218, 4.012, .005

*RNEWK (1) = 2., 1.133, 34.08, 27.57, .66E-12

*TIME (1) = .0, .034, .044, .053, .065, .073, .088, .099, .113, .126, .142, .152,
.16, .169, .179, .191, .202, .22

NOTE: All input variables initialized to zero except as shown above by ().

Alphabetical Listing of Input Parameters for GAPCON-THEMAL-3

Sample No. ELP-9

ATMOS <u>1.</u>	FRDEN <u>.934</u>	KSAVE <u>0</u>	RADS <u>.212</u>
CP <u>(1.0)</u>	FRDEN2 <u>.965</u>	LFUEL <u>39.4</u>	RNEWK* <u></u>
CR <u>(1.0)</u>	FRPU02 <u>.0</u>	LVOIDZ <u>0.</u>	ROUC <u>.00002</u>
DCI <u>.3425</u>	FRSIN <u>.02</u>	MINI* <u>18.</u>	ROUF <u>0.</u>
DCO <u></u>	FR35 <u>.0</u>	MXPOWR <u></u>	S <u></u>
DELZA* <u>.292</u>	FR40 <u>.0</u>	NC <u>(4) 0</u>	TIME* <u>212.</u>
DFS <u>.0</u>	FR41 <u>1</u>	NCLAD <u></u>	TINLET <u></u>
DSINZ <u>10.</u>	IDENSF <u>0</u>	NF <u>(6) 0</u>	TM <u>(2790°C)</u>
DTEMP <u>.0</u>	IGAS <u>0</u>	NFLX <u>0</u>	TPLAS <u>(1200²⁷⁵°C)</u>
DVOIDZ <u>50.</u>	IOPT <u>0</u>	NFUEL <u>0</u>	VPLENZ <u>.14</u>
EXTP <u></u>	IPEAK <u>0</u>	NOH <u>3</u>	X <u>.0</u>
FLXRAT <u>(0.01)⁰</u>	IPLT <u>1</u>	NPOW <u>10</u>	XCO <u>.0</u>
FRACAR <u>.0</u>	IRELOC <u>1</u>	NSTEPS <u>10</u>	XH <u>.0</u>
FRACH <u>.0</u>	IRL <u>0</u>	NSH <u>0</u>	XN <u>.0</u>
FRACHE <u>1.</u>	ISTOR <u>0</u>	NTIME <u>10</u>	Z <u>125</u>
FRACKR <u>0.</u>	ITAPE <u>0</u>	PRCDH <u>2.648</u>	ZCLAD <u>.0</u>
FRACN <u>0.</u>	ITMCUT <u>100</u>	PROFIL* <u></u>	
FRACXE <u>0.</u>	JSTART <u>0</u>	PSEUDO* <u></u>	

*DELZA (1) = .5, 13.1313, 13.1313, 13.1313, 3.9322875

*MINI (1) = 1, 2, 3, 4

*PROFIL (1) = 1., 1.12, 1.12, 1.

*PSEUDO (1) = .05, 3., 9., 15., 17.1, 18.3, 18., 16.7, 15.5, 14.6

*RNEWK (1) =

*TIME (1) = 0., .1, .2, .3, .4, 40., 55., 70., 100., 120.

NOTE: All input variables initialized to zero except as shown above by ().

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