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EVALUATION OF COMPLIANT GRID-TYPE
FUEL ROD SPACERS
FOR
FTR FUEL ASSEMBLY
(APPENDIXES)

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(APPENDIXES)

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Prepared Under
Contract AT(30-1)-3684
U.S. AEC New York Operations Office

Issued November, 1968

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C. Roderick
C. Roderick
Project Manager

WESTINGHOUSE ELECTRIC CORPORATION
Advanced Reactors Division
P.O. Box 158
Madison, Pennsylvania 15663

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LIST OF CONTRIBUTORS

A. A. Bishop
E. C. Bishop
S. Dolinar
D. Elliott
H. Garkisch
N. J. Georges
R. P. Harril
S. E. Majka
E. H. Novendstern
W. Pennell
W. E. Ray
J. N. Starr

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APPENDIX A

FATBO2 CODE: ANALYSIS OF THERMAL BOWING IN FUEL ROD

A-2 FATBO2 SPECIFICATION

Geometry

Fuel assembly geometry is shown in Figure A-1.

The temperature distribution of the fuel assembly is specified $T(A,B)$, where A is the sublength of rod between grids A and $(A+1)$. B specifies the flow channel, parallel to the flat.

The number of grids over the length is input as $N1$ as shown in Figure A-2. The length or distance of the J^{th} grid from the bottom grid is given as $X(J)$, where $X(1) = 0$. The maximum number of grids that the program will handle is 15.

Step 1

The modulus of elasticity of the fuel rod is put in as a function of temperature. E is specified at T_{min} and at intervals in temperature of T_{incr} . The modulus of elasticity of a particular section of rod is then determined by interpolation.

Step 2

The number of rods in each region for the honeycomb grid is given by:

Region = I

Number of rods = $XNK(I)$

Number rods across flats = NAF

$$XNK(I) = \begin{cases} NAK + I - 1 & 1 \leq I \leq NAF \\ XNK(I-1) - 1 & NAF + 1 \leq I \leq 2NAF - 1 \end{cases}$$

Step 3

Moments of inertia, area of fuel rods is:

D = Fuel rod diameter

TH = Fuel rod wall thickness

XIR = Moment of inertia of single rod

AR = Area of single rod

XI = Moment of inertia of all rods as a group

$$XIR = \frac{\pi}{64} (D^4 - (D-2TH)^4)$$

$$AR = \frac{\pi}{4} (D^2 - (D-2TH)^2)$$

$$XI = XIR \sum_{I=1}^{2NAF-1} XNK(I) = XIR \times XN$$

(Note: The term ay^2 is omitted because the rods can all slide through the grids. Frictional loads will contribute nothing to the rod bundle bending stiffness provided the ΔT between the Duct/can and the rods is sufficient to cause all rods to slide through the grids. This, in general, is the case.)

Step 4

Gradients:

The individual temperature gradients, Figure A-3, across the rods are taken as the difference in flow channel temperatures divided by the distance between channels.

$$G(I,J) = \frac{2(T(I,J+1) - T(I,J))}{(\text{Pitch} \cdot \sqrt{3})}$$

In a given sublength, the free deflections of each rod will be proportional to its individual gradient. Since the deflections of all the rods in this region must be the same, the rod deflection is governed by the average gradient across the rods.

The average modulus of elasticity of the cross section is $EE(I)$, $1 \leq I \leq N1-1$,

where:

$$EE(I) = \sum_{J=1}^{2NAF-1} \frac{XNK(J) \times (E(I,J) + E(I,J+1))}{2 \times XN}$$

Then the average effective gradient is given by:

$$GAVE(I) = \sum_{J=1}^{2NAF-1} \frac{(E(I,J) + E(I,J+1)) \times G(I,J) \times XNK(J)}{2 \times XN \times EE(I)}$$

Step 5

The lengths of the individual sublengths $XL(J)$, $1 \leq J \leq N1-1$ are calculated in terms of the distances to the grids $X(J)$.

$$XL(J) = X(J+1) - X(J) \quad 1 \leq J \leq N1-1$$

Step 6

The gradient across the can shown in Figure A-4 is approximately equal to the average gradient across the interior rows of rods, so that the can gradient is given as the average of the gradients of rows 7 through 13.

The local (one grid relative to previous grid) deflections (Figure A-5) of the can and rods are calculated as a composite beam:

$$G2(I) = \text{Gradient across can}$$

$$\theta = \text{THA}(I) = \frac{XL(I) \times (AL \times GAVE(I) \times EE(I) \times XI + G2(I) \times EC \times CI \times ALC)}{(EE(I) \times XI + EC \times CI)}$$

$$\delta = \text{DELY}(I) = \text{THA}(I) \times XL(I)/2$$

$$1 \leq I \leq NM1$$

The total can and rod displacements relative to grid 1 as a datum shown in Figure A-6 are given by:

$$\theta(I) = \text{THAT}(I) \quad \delta(I) = \text{DELT}(I)$$

$$\text{THAT}(1) = \text{DELT}(1) = 0$$

$$\text{THAT}(I) = \text{THAT}(I) + \text{THA}(I-1)$$

$$\text{DELT}(I) = \text{DELT}(I-1) + \text{THAT}(I-1) \times \text{XL}(I-1) + \text{DELT}(I-1)$$

$$2 \leq I \leq N1$$

Step 7

Form the stiffness matrix of the individual sublengths of the can or fuel rod.

For the can, $EI = EC \times IC$, and for the rod, $EI = EE(I) \times XIR$. The basic element is shown in Figure A-7.

The stiffness matrix is:

$$\text{XKI}(I, J, K) = \begin{bmatrix} \frac{4EI}{\ell} & \frac{2EI}{\ell} & \frac{-6EI}{\ell^2} & \frac{6EI}{\ell^2} \\ & \frac{4EI}{\ell} & \frac{-6EI}{\ell^2} & \frac{6EI}{\ell^2} \\ & & \frac{12EI}{\ell^3} & \frac{-12EI}{\ell^3} \\ \text{SYM} & & & \frac{12EI}{\ell^3} \end{bmatrix}$$

$$\ell = \text{XL}(K)$$

Step 8

The code system^[26] is used to construct the overall stiffness matrix. Stations for the overall stiffness are shown in Figure A-8.

The code matrix, a matrix which has rows that are the codes of the respective sublength, is:

For the rods;

$$\text{NCODE}(I,J,1) = \begin{bmatrix} 1 & 2 & N1+1 & N1+2 \\ 2 & 3 & N1+2 & N1+3 \\ 3 & 4 & N1+3 & . \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ N1-1 & N1 & 2N1-1 & 2N1 \end{bmatrix}$$

For the can;

$$\text{NCODE}(I,J,2) = \begin{bmatrix} 3 & 4 & 1 & N1+3 \\ 4 & 5 & N1+3 & N1+4 \\ 5 & 6 & N1+4 & . \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ N1 & N1+1 & 2N1-1 & 2N1 \\ N1+1 & N1+2 & 2N1 & 2 \end{bmatrix}$$

Using the code matrices, build the overall stiffness by taking each element matrix individually (over all $\text{XKI}(I,J,K)$).

$$\begin{aligned} & \text{XK}(\text{NCODE}(K,I,L), \text{NCODE}(K,J,L)) = \text{XKI}(I,J,K) \\ & + \text{initial value of } \text{XK}(\text{NCODE}(K,I,L), \text{NCODE}(K,J,L)) \end{aligned}$$

Step 9

Find the can shape. If the code IDEFL=1, this section is skipped, and the rods are assumed to have the same displacements as the duct at all grid locations. If IDEFL=0, the can is only forced to fit the duct at grids 1 and N1.

DELTA(I) = Matrix of thermal displacements of can and rods
corresponding to the sign convention of the overall
stiffness of the rods.

DIS(I) = Input initial deflection of duct.

$$[DIF] = [DIS] - [DELTA]$$

[DIF] is then a matrix which gives the mechanical displacement required to fit the duct. The forces [F] required for this are given by:

$$[F] = [XK][DIF] \quad [XK] = \text{Stiffness}$$

Let

$$XK = \begin{bmatrix} A & C' \\ C & B \end{bmatrix} \begin{matrix} [A]_{2 \times 2} \\ [B]_{2N1-2 \times 2N1-2} \end{matrix}$$

We insist only that the can fit the duct at the ends of the can (stations 1 and 2). The can, therefore, has no mechanical forces on it, since it is considered as a pinned beam with no intermediate forces. The overall displacement can be found using the above stiffness. We force-fit at stations corresponding to [A] and insist on zero force at other stations. Thus:

$$[F] = \begin{bmatrix} F_1 \\ 0 \end{bmatrix} = \begin{bmatrix} A & C' \\ C & B \end{bmatrix} \begin{bmatrix} DIF_1 \\ DIF_2 \end{bmatrix}$$

$$[F_1] = [A][DIF_1] + [C'][DIF_2]$$

$$[0] = [C][DIF_1] + [B][DIF_2]$$

and

$$[DIF_2] = -[B^{-1}][C][DIF_1]$$

and

$$[F] = \{[A] - [C'] [B^{-1}] [C]\} [DIF_1]$$

$[DIF_2]$ = Displacements at stations other than
those forced to fit

and the resulting total mechanical displacements are

$$[DIF] = \begin{bmatrix} DIF_1 \\ DIF_2 \end{bmatrix}$$

These are rearranged to fit the displacement arrangement of the rods. The total displacements are then given as the mechanical and thermal.

$$\begin{array}{lcl} [DIS] = & [DIF] & + [DELTA] \\ \text{Total} & \text{Mechanical} & \text{Thermal} \end{array}$$

Step 9.5

If IDEFL=1, the section is also skipped. Once the final can grid deflection pattern is found, it is scanned to see if any of the grid deflections is beyond that of the input duct deflections plus the allowable GAP. If none of the grid deflections differ from the duct deflection by more than the input GAP, this section is skipped.

The matrix of grid deflections is then scanned for the maximum difference in can deflection and duct deflection. The can and duct are assumed to meet at this grid and the new deflection pattern of the can is found using the code system. Here we force-fit at three stations; grid 1, grid N1, and grid IMAX, which will be stations 1, 2, and 3. The method used in Step 9 is then used to find forces and the additional grid displacements.

Step 10

For each region of rods, calculate the free local thermal displacements (see Figure A-9);

$$DR = \delta_{rod}$$

$$THR = \theta_{rod}$$

$$\left. \begin{array}{l} THR(I,J) = G(I,J) \times AL \times XL(I) \\ DR(I,J) = THR(I,J) \times XL(I)/2 \end{array} \right\} \begin{array}{l} J=1 \text{ to } N4 \\ I=1 \text{ to } NMI \end{array}$$

Step 11

Form the free total thermal displacement of the rods in each region, as in Step 6.

$$THRT(I,J) = 0 \quad J=1 \text{ to } N4$$

$$DRT(I,J) = 0$$

$$\left. \begin{array}{l} THRT(I,J) = THRT(I-1,J) + THR(I,J) \\ DRT(I,J) = DRT(I-1,J) + THRT(I-1,J) \times XL(I-1) + DR(I-1,J) \end{array} \right\} \begin{array}{l} I=2 \text{ to } N1 \\ J=1 \text{ to } N4 \end{array}$$

Step 12

Put total rod displacements into correct sign convention (same as stiffness matrix) into [DELT3].

$$DELT3(I) = - THRT(I,J) \quad I = 1 \text{ to } N1$$

$$DELT3(I+N1) = DRT(I,J)$$

Also, transfer the stiffness of rods into the old position for the stiffness of the can, and invert to obtain the rod flexibility.

Now:

$$XK(I,J,1) = \text{Rod Stiffness}$$

$$XK(I,J,2) = \text{Rod Flexibility}$$

Step 13 (Rods pin-joined to grids)

[DIS] is the matrix of deflections and rotations of the grids. We must have the rod deflections, (not rotations) of each rod region, and match the deflections at each grid. This means we must match the last N1 members of [DIS].

The mechanical displacement we must force is [DIF];

$$[DIF] = [DIS] - [DELT3]$$

As in Step 9

$$[F] = [XK][DIF]$$

$$[F] = \begin{bmatrix} 0 \\ F_1 \end{bmatrix}_{2N1 \times 1} = \begin{bmatrix} A1 & C1 \\ C1' & B1 \end{bmatrix} \begin{bmatrix} DIF_1 \\ DIF_2 \end{bmatrix}_{2N1 \times 1} \quad [A1]_{N1 \times N1}$$

$$[0] = [A1][DIF_1] + [C1][DIF_2]$$

$$[F_1] = [C1'][DIF_1] + [B1][DIF_2]$$

Thus:

$$[F_1] = \{[B1] - [C1'][A1^{-1}][C1]\} [DIF_2]$$

$$[DIF_1] = -[A1^{-1}][C1][DIF_2]$$

The total displacement of a rod region is then given by

$$[DI4] = \begin{bmatrix} DIF_1 \\ DIF_2 \end{bmatrix} = \text{Mechanical Displacement}$$

$$[DI4] + [DELT3] = [DI8]$$

$$\text{Mechanical} + \text{Thermal} = \text{Total}$$

Step 14 (Rods pin joined to grids)

Calculate the internal moment in each rod. The rods only experience shears at the grids, but no moments. The moment at a particular section is given by (See Figure A-10):

$$M(I,J) = 0 \quad I=2 \text{ to } N1$$

$$M(I,J) = M(I-1,J) + \left(\sum_{K=1}^{I-1} F_K \right) XL(I-1) \quad J=1 \text{ to } N4$$

Step 13A (Rods fixed in grids)

[DIS] is the matrix of deflections and rotations of the grids. Since the rods are fixed, they must have the same slope and deflection as the grid and we must force-fit at all grids.

To find these forces, we use the stiffness matrix.

$$[DIF] = [DIS] - [DELT3]$$

$$[F] = [XK][DIF]$$

[F] = Matrix of forces to hold rod

[DIF] = Matrix of mechanical (forced) displacements

[DELT3] = Matrix of free thermal displacements

Step 14A (Rods fixed in grids)

Calculate the internal moment (moment diagram) for each rod. The rods experience both shears and moments at each grid. The moment at a particular section is given by (Figure A-11):

$$M_1(1,J) = M_1(J)$$

$$M_1(I,J) = M_1(I-1,J) + \left(\sum_{K=1}^{I-1} F_K \right) XL(I-1) + M_I(J) \quad \begin{array}{l} J=1 \text{ to } N4 \\ I=2 \text{ to } NMI \end{array}$$

$$M_2(I,J) = M_1(I+1,J) - M_{I+1}(J)$$

Step 14.5

Once the displacements of the rod regions are found, the displacement method is employed to find the center span deflections of each rod region. If the rods are either fixed or pinned in the grid, the slopes and deflections of each rod at the grid locations are known at this time. Using matrix partitions, we now can find the center-span deflections by placing stations at these points and building a new over-all stiffness, and using the method described in Step 9. This yields the total displacement, so that we must subtract the grid deflections to get the "local" center-span deflection.

Step 15

Find the axial loading in each bar. If ICOP=1, the rods are not free to slide through the top grid and the load builds up to the top.

$$P1(N1-I) = I \times PS \times XMU \times XNP \quad I=1 \text{ to } NMI$$

For ICOP=2, the rods are free to slide through, and there is a build-up of load toward the center.

$$\begin{array}{ll} P1(I) = I \times PS \times XMU \times XNP & I=1 \text{ to } N1/2 \quad N1 \text{ even} \\ & \text{or} \\ P1(N1-I) = P1(I) & I=1 \text{ to } \frac{N1-1}{2} \quad N1 \text{ odd} \end{array}$$

Due to relaxation, the axial load will decrease by a factor RC.

Thus:

$$P1(I) \text{ is replaced by } RC \times P1(I)$$

for the buckling formula.

Step 17

For a given reference strain, we look at the low strain rate stress-strain curve to find the corresponding cladding circumferential stress, SIG.

Thus with an internal pressure P,

$$SIG = \frac{P \times D}{2 \times TH}$$

The mean radial stress SIG3 is given by

$$SIG3 = - \frac{P}{2} = - SIG \times TH/D$$

The axial stress SIGL is given by

$$SIGL = - \frac{P}{AR} - \frac{ABS(M_1 + M_2) \times D}{4 \times XIR}$$

Where M_1 and M_2 are the end moments of the rod as shown

NOTE: The mean stress through the wall thickness is considered to be the critical stress governing rod buckling. For this reason the self equilibrating stresses due to radial temperature gradients are not included.

The equivalent state of stress is given by:

$$S_{IGE} = \sqrt{[(S_{IG} - S_{IG3})^2 + (S_{IG} - S_{IGL})^2 + (S_{IGL} - S_{IG3})^2]/2}$$

This locates a point on our life isochronous stress-strain curve, and dictates the secant modulus to be used in the buckling formula.

$$P_{crit} = \frac{ET \times XIR \times \pi^2}{XL^2} \times FIX$$

Where:

ET = the secant modulus

FIX = end fixity factor

This value of the critical load is used in the modified Southwell equation (see Section 4.4).

$$\delta' = a + \delta = \frac{a}{1 - \left[\frac{P1 - \left(\frac{\delta' - a}{K \times XL} \right)^2 E \times AR}{P_{crit}} \right]}$$

E = Elastic modulus

a = Initial elastic center deflection (formed in Step 14) plus initial defects.

P1 = Axial load in given sublength = P1(I)

δ' = DEFL (I,J) = Total deflection

K = 0.613 for pinned rods; $0.613/\sqrt{2}$ for fixed rods

Modified margin of safety:

$$(M.S.)_{modified} = \frac{P_{crit}}{P1 - \left(\frac{\delta' - a}{K \times \ell} \right)^2 E \times AR} - 1$$

Actual margin of safety - (the one printed):

$$(M.S.) = XMS(I,J) = \frac{P_{crit}}{P_1(I)} - 1$$

The creep buckling deflection is calculated for three cases:

$$1) \quad a = \delta_o + A_2 \times \delta_o / \text{ABS}(\delta_o) \quad \text{For all regions and sublengths}$$

$$2) \quad a = \delta_o + A_2 \times \delta_o / \text{ABS}(\delta_o) \quad |\delta_o| \geq A_2$$

$$a = \delta_o - A_2 \times \delta_o / \text{ABS}(\delta_o) \quad |\delta_o| \leq A_2$$

$$3) \quad a = \delta_o + A_2 \quad \text{For odd-numbered regions}$$

$$a = \delta_o - A_2 \quad \text{For even-numbered regions}$$

where:

δ_o = the elastic deflection due to temperature gradients

a = the initial deflection used in the modified Southwell equation

A_2 = the initial cold bow (the manufacturing tolerance on a rod of the particular sublength being analyzed)

Case (3) usually tends to give the maximum channel closing.

A-3 FATBO2 INPUT DESCRIPTION

Card 1 (8F10.0)

cc 1-10 Duct-can clearance (GAP)

Card 2 (8F10.0)

cc 1-10 Initial rod center deflections (cold-bow tolerance). (A2)

Card 3 (5I5)

Col. 5 Set equal to 1 if rods fixed at one end (fixed to prevent axial expansion). Set equal to 2 if rods are free to slide through grids at both ends (ICOP)

Col. 10 Set equal to zero if can type assembly (fits duct at ends). Set equal to 1 if rods are to fit duct at all grid locations. (IDEFL)

Col. 15 IRFIX=0, means rods are free to rotate in grids;
IRFIX≠0, means rods are fixed in grids. (IRFIX)

Card 4 (8F10.0)

cc 1-10 Moment of inertia of the can (in.⁴) (CI)

cc 11-20 Modulus of elasticity of the can (psi) (EC)

cc 21-30 Coefficient of thermal expansion of the can (in./in./°F) - ALC

cc 31-40 Reduction factor for relaxation of axial load equal to $(1 - A_t^B)$. - RC

Card 5 (5I5)

cc 4-5 Number of grids - N1

cc 9-10 Number of rods across the flats of the hexagon - NAF

Col. 15 Set equal to 1 - IPR

Card 6 (8F10.0)

cc 1-10 Total number of rods in the assembly - XN

cc 11-20 Fuel rod diameter (in.) - D

cc 21-30 Fuel rod wall thickness (in.) - TH

cc 31-40 Pitch-diameter ratio - PD

cc 41-50 Coefficient/thermal expansion for fuel rods (AL)

cc 51-60 Pre-load in spring (lbs.) - PS

cc 61-70 Number of spring loads per rod per grid - XNP

cc 71-80 Coefficient of friction between spring and rod - XMU

Card 7 (8F10.0)

Distances to grids (0.0 = distance to first grid)

See Figure A2-2 - X(I)

Cards 8 $\rightarrow 8 + \left[\frac{2(NAF)(N1-1)}{8} \right] (8F10.0)$

Temperatures in the flow channels, starting at low end of active core (sublength 1) giving the temperatures across (2 NAF temperatures). Next take sublength 2, give 2 NAF temperatures, etc. (°F) - T(I,J) see Figure A-1.

Card Q (8F10.0)

cc 1-10 Minimum temperature for library of E vs. T graph for modulus of elasticity for rods. - TMIN

cc 11-20 Constant temperature increment used in E vs. T input curve - TINCR

Card Q+1 (5I5)

cc 4-5 Number of moduli read in for the E vs. T graph - IE

Card Q+2 (8F10.0)

Moduli for E vs. T graph $1 \leq I \leq IE$

YME(1) corresponds to TMIN, YME(2) to TMIN + TINCR.,
etc. - YME(I)

Cards R, R+ (8F10.0)

Initial displacements of the duct. (in.)

Rotations DIS(I) $1 \leq I \leq N1$

Transverse displacements $N1+1 \leq I \leq 2N1$

(Take first 2N1 positions on the cards) - DIS(I)

Card S (6I5)

cc 3-5 Number of strains input to low strain rate curve for fuel
rod swelling. Strain (1)=0. - I1

Card S+1 (7F10.0)

cc 1-10 Maximum stress value on curve 1. (psi) - SIG1X

cc 11-20 Reference strain for cladding swelling - ER

Cards S+1+ (7F10.0)

Values of strain at constant stress for curve 1. (in./in.)

(STRA1(1)=0.0) - STRA1(I)

Card T (7F10.0)

cc 1-10 Modulus of elasticity for fuel rod material - EE

cc 11-20-XK } Constants describing elastic-plastic-primary

cc 21-30-AA } Creep curve

cc 31-40-BB } Strain = $\begin{cases} \text{Stress}/EE & \text{Stress} \leq AA \\ \text{Stress}/EE + XK (\text{Stress}-AA)^{BB} & \text{Stress} \geq AA \end{cases}$

Card T+1 (7F10.0)

cc 1-10 Stress level at which secondary creep comes in (psi) - AAA

cc 11-20-SIG(1) } Coordinates of two points
cc 21-30-SIG(2) } which help to best describe
cc 31-40-EP(1) } isochronous stress strain curve
cc 41-50-EP(2) } above AAA.

$$\text{Strain} = \begin{cases} \text{Stress}/\text{EE} & \text{Stress} \leq \text{AAA} \\ \text{Stress}/\text{EE} + \text{AZ} (\text{Stress}-\text{AAA})^{\text{M}} & \text{AAA} \leq \text{S} \leq \text{AA} \\ \frac{\text{Stress}}{\text{EE}} + \text{AZ} (\text{Stress}-\text{AAA})^{\text{M}} + \text{XK} (\text{Stress}-\text{AA})^{\text{BB}} & \text{AA} \leq \text{S} \end{cases}$$

A-4 TERMS IN PROGRAM FATB02

(STEP) Explanation

A

A	(9)	Part of partitioned stiffness matrix; difference $[A - C'B^{-1}C]$
AC	(13)	Product of $[A1^{-1}][C1]$
ACA	(13)	Product of $[C1'] [A1^{-1}][C1]$; difference $[B1 - C1' A1^{-1}C1]$
AL		Coefficient of thermal expansion of the fuel rod
ALC		Coefficient of thermal expansion of the can
AR		Cross-sectional area of the fuel rod
A1	(13)	Part of the partitioned stiffness matrix
AZ		Initial rod deflections - rod tolerance

B

B	(9)	Part of partitioned stiffness matrix
BC	(9)	Product of $[B^{-1}][C]$
B1	(13)	Part of partitioned stiffness matrix

C

C	(9)	Part of partitioned stiffness matrix
CB	(9)	Product of $[C^1][B^{-1}]$
CBC	(9)	Product of $[C^1][B^{-1}][C]$
CI		Moment of inertia of can cross section
C1	(13)	Part of partitioned stiffness matrix
C1	(17)	In DEL is constant in formula = to 0.613 or $0.613/\sqrt{2}$

D

D		Fuel rod outer diameter
DEFL	(17)	Deflection as calculated by modified Southwell equation
DELTA	(9)	Thermal deflections of can and rods (sign convention 2)
DELTY	(6)	Total thermal deflections of can and rods (sign convention 1)
DELT3	(12)	Thermal deflection of individual fuel rod (sign convention 2)
DELY	(6)	Local thermal deflection of can and rods (sign convention 1)

DET Determinant of inverted matrices
 DIF (9,13) Difference between thermal and mechanical deflections
 DIS (9,13) Input initial deflection of duct; after (9) - deflection
 of cans and rods
 DISX (9.5) Initial deflection of duct
 DI4 (13) Total actual mechanical deflections; N1 slopes, N2 deflections
 DI5 (9) [DIF₂] in write up
 DI7 (13) [DIF₂] in write up
 DI8 (13) Total deflection of a rod region equal to mechanical plus
 thermal deflections
 DI9 (13) [DIF₁] in write up
 DMA (17) Maximum possible δ in $\delta' = \delta + a$
 DR (10) Free local thermal deflection of fuel rods (sign convention 1)

E

E (1) Local elastic modulus of fuel rods
 EC Modulus of elasticity of can
 EE (4) Average modulus across a sublength
 ET (17) Secant modulus used in critical load calculation

F

F (13) Forces acting on each fuel rod in the region
 FOR (9) Forces acting on can from duct

G

G (4) Temperature gradient across a rod sublength in a region
 GAP (9) Duct/can clearance
 GAVE (4) Average effective temperature gradient across a sublength
 (rods)
 G2 (6) Gradient across the can in a given sublength

I

ICOP (input) If equal to one, the fuel rods are fixed axially at top, and friction loads build toward top. If equal to two, the fuel rods are not fixed axially, and friction loads build toward the center.

IDEFL (9) (input) If equal to 1, section 9 is skipped and the can is assumed to fit the duct at all grid locations. If equal to 0, the can is free to deflect and is pin-supported at its end by the duct.

IE (1) Number of points read in for E vs. T curve for the fuel rod material

IE1 (1) IE-1

IMAX

IPR Print code. If equal to zero, only final results printed.

IRFIX If IRFIX=0, rods are free to rotate in grids
If IRFIX≠0, rods are fixed in grids

M

MQ (9.5) $MQ = 2(N1)-3$

N

NAF (input) Number of rods across the flats in the assembly

NCODE (8) Code matrix used to construct stiffness matrix

NMI N1-1

NO N1-2

N1 Number of grids

N2 2 (NAF)

N3 2 (N1)

N4 2 (NAF)-1

N5 NAF-1

P

PCR (17) Critical load matrix
PD (Input) Pitch to diameter ratio
PS (Input) Springfinger preload
P1 (15) Axial load due to springfingers

Q

QA (9.5) Partitioned parts of stiffness matrix
QB
QC

R

RQ (17) Correct root of modified Southwell equation
RC (15) Reduction factor for axial load on rods due to stress relaxation

S

SIG (17) Circumferential stress in fuel rod due to swelling
SIGE (17) Equivalent state of stress
SIG3 (17) Radial stress due to pressure
SIGL (17) Axial stress due to axial load P, and end moments M_1 and M_2
SPX (14) Sum of shears to a particular grid, sum from grid one to I-1 (SPX(1)=0)

T

T (Input) Temperatures of flow channels at each sublength
TH Fuel rod wall thickness
THA (6) Local can-rod slope thermal (sign convention 1)
THAT (6) Total can-rod slope thermal (sign convention 1)
THR (10) Local thermal rod slope (sign convention 1)
THRT (11) Total thermal rod slope (sign convention 1)
TINCR (1) Increment of time at which moduli of elasticity are read in for E-T curve

TMIN (1) Minimum value of T for which curve is read

X

X (Input) Distances to grids

XI (3) Moment of inertia of group of rods

XIR (3) Moment of inertia of a fuel rod

XK (8) Overall stiffness matrix

XKI (7) Element stiffness matrix

XL (5) Length of sublength

XMOME (14) Moments in the fuel rod at grids due to shears

XMS (17) Margin of safety - Buckling

XMS2 (17) Modified margin of safety

XMU (15) Coefficient of friction between springfinger and rod

XN (Input) Number of rods in the assembly

XNK (2) Number of fuel rods in a fuel rod region

XND (15) Number of springs per fuel rod per grid

Y

YME (1) Modulus of elasticity input at constantly incremented values
to temperature for the fuel rod material.

Figure A-1. Geometry

Figure A-2. Grid Locations

Figure A-3. Temperature Gradients

Figure A-4. Temperature versus Grid Row Number

Figure A-5. Grid Deflection

Figure A-6. Total Can and Rod Displacement

Figure A-7.. Stiffness

Figure A-8. Overall Stiffness Matrix

Figure A-9

Figure A-10. Internal Moment (Rods Pin Joined)

Figure A-11. Internal Moment (Rods Fixed)

```

PROGRAM FATH02(INPUT,OUTPUT)                                A0010
REAL M0                                                       A0020
)00003 COMMON/BLOCKA/ AR,D,PCR(14,23),TH,XMS(14,23),XMS2(14,23),COD,C02 A0030
)00003 COMMON/BLOCK/DMA(14,23)                                A0040
)00003 COMMON/BLOCKC/ DEFL(14,23)                             A0050
)00003 COMMON/BLOCK/KC,KU,AL,XIR,OIME(14,23),O1TH(14,23),O1TOT(14,23),O2M A0060
)00003 DE(14,23),O2TOT(14,23),DTH(14,23),DME(14,23),DTOT(14,23) A0070
)00003 DIMENSION X(15),T(14,24),DIS(30),E(14,24),GAVF(14),G(14,23), A0080
)00003 ITHA(14),DFLY(14),THAT(15),DELIY(15),ROUTAV(14,23),TEMPLI(14,23), A0090
)00003 DELTEM(14,23),XKI(4,4,14),NCOUE(14,4,3),XK(30,30,3),S(30),XL(14), A0100
)00003 SPI(15),XMMOF(15,23,2),MO(12),EE(15),XNK(23),SPX(15) A0110
)00003 DIMENSION DELTA(30),DIF(30),S1(30),S2(30),G2(14), A0120
)00003 DDIS1(30),DIS(2),DI6(28),BC(28,2) A0130
)00003 DIMENSIONA(2,2),R(28,28),C(28,2),CB(2,28),CBC(2,2),FOR(30),DSP(30) A0140
)00003 DIMENSION THR(15,23),THKT(15,23),DR(15,23),DRI(15,23),DELT3(30), A0150
)00003 IAI(15,15),BI(15,15),CI(15,15),AC(15,15),ACA(15,15),DI7(15),F(20) A0160
)00003 DIMENSION DIR(30,23) A0170
)00003 DIMENSION DI9(15),DI4(30) A0180
)00003 DIMENSION YME(20) A0190
)00003 DIMENSION TDMAX(20) A0200
)00003 DIMENSION DISX(30) A0210
)00003 DIMENSION QA(3,3),QH(27,27),QC(27,3),QCR(3,27),QCHC(3,3),QD(2), A0220
)00003 QHC(27,3) A0230
)00003 DIMENSION NCOU(28,4),STIF(44,44) A0240
)00003 DIMENSION ZH(14,14),ZC(14,30),ZRC(14,30),ZD(14),ZDT(14) A0250
)00003 EQUIVALENCE (A,QA),(R,QH),(C,QC),(QCR,CH),(CHC,QCHC),(BC,QBC) A0260
)00003 5 CONTINUE A0270
)00003 C02 =0. A0280
)00004 COD =0. A0290
)00005 READ 20,GAP A0300
)00012 READ 20, A2 A0310
)00020 READ 10,ICOP,IDEFL,IRFIX A0320
)00032 READ 20,CI,EC,ALC,RC A0330
)00046 READ 10,N1,NAF,IPR A0340
)00060 10 FORMAT(5I5) A0350
)00060 PRINT 15,N1,NAF A0360
)00070 15 FORMAT(//* NO. OF GRIDS =*I3//* NO.RODS ACROSS FLATS =*I3//) A0370
)00070 READ 20,XN,D,TH,PD,AL,PS,XMP,XMU A0380
)00114 READ 20,(X(I),I=1,N1) A0390
)00127 20 FORMAT(PF10.0) A0400
)00127 PRINT 25,XN,D,TH,PD,AL,PS,XMP,XMU A0410
)00153 25 FORMAT(* TOTAL NO. OF FUEL RODS PER ASSEMBLY =*F6.0//* FUEL ROD DI A0420
)00153 AMETER =*F6.3//* FUEL ROD WALL THICKNESS =*F6.4//* PITCH TO DIAPET A0430
)00153 PER RATIO=*F6.3//* FUEL ROD THERMAL COEF. OF EXPANSION =*F12.4//* P A0440
)00153 3RE-LOAD IN SPRINGFINGER SUPPORT OF ROD =*F4.1,* LRS.*//* NO. SUPPO A0450
)00153 4RTS AT EACH GRID PER FUEL ROD =* F6.0//* COEF. OF FRICTION BETWEEN A0460

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; SPRINGFINGER AND FUEL ROD =*F6.2//)
00153      NM1= N1 -1
00155      N2 = 2*NAF
00160      DO 30 I=1,NM1
00161      READ 20,(T(I,J),J=1,N2)
00175      30 CONTINUE
00200      PRINT 35
00203      35 FORMAT(///* TEMPERATURES BETWEEN REGIONS*/* SURLNGTH */)
00203      DO 50 I=1,NM1
00205      PRINT 40,I,(T(I,J),J=1,N2)
00223      40 FORMAT(15,10F10.0/(5X,10F10.0))
00223      45 FORMAT(15,10F10.1/(5X,10F10.1))
00223      50 CONTINUE
00226      READ 20,TMIN,TINCR
00235      READ 10,IE
00243      IE1 = IE-1
00245      READ 20,(YME(I),I=1,IE)
C          STEP NO. 1
00260      DO 70 I=1,NM1
00262      DO 65 J=1,N2
00263      DO 55 K=1,IE1
00264      QK = K
00265      T1= TMIN + (QK-1.)*TINCR
00271      T2= TMIN + QK *TINCR
00274      IF(T(I,J).GE.T1.AND.T(I,J).LE.T2) GOTO 60
00307      55 CONTINUE
00311      60 E(I,J) = YME(K) + (T(I,J)-T1)*(YME(K+1)-YME(K))/ TINCR
00325      65 CONTINUE
00327      70 CONTINUE
00332      PRINT 75
00335      75 FORMAT(///* MODULUS OF ELASTICITY -BY REGION*/* SURLNGTH*/)
00335      DO 80 I=1,NM1
00337      PRINT 40,I,(E(I,J),J=1,N2)
00355      80 CONTINUE
00360      N3 = 2*N1
00362      READ 20,(DIS(I),I=1,N3)
00375      PRINT 85,(DIS(I),I=1,N3)
00410      85 FORMAT(///* DISPLACEMENT OF CAN */(HE12.4))
C          STEP NO. 2
00410      N4 = 2*NAF -1
00414      DO 90 I=1,NAF
00415      XNK(I) = NAF +I-1
00420      90 CONTINUE
00422      N5 = NAF +1
00423      DO 95 I=N5,N4
00424      XNK(I) = XNK(I-1) -1.
00427      95 CONTINUE

```

A0470
A0480
A0490
A0500
A0510
A0520
A0530
A0540
A0550
A0560
A0570
A0580
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A0600
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A0690
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A0780
A0790
A0800
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A0820
A0830
A0840
A0850
A0860
A0870
A0880
A0890
A0900
A0910
A0920
A0930

000431	IF(IPR.F0.0) GOTO 115	A0940
000432	PRINT 100	A0950
000435	100 FORMAT(/// * REGION NO. *10X,* NO. RODS IN REGION */)	A0960
000435	DO 110 I=1,N4	A0970
000437	PRINT 105,I,XNK(I)	A0980
000446	105 FORMAT(/I6,23X,F6.0)	A0990
000446	110 CONTINUE	A1000
000451	115 CONTINUE	A1010
	C STEP NO. 3	A1020
000451	XIR = .049087386*(D**4 -(D-2.*TH)**4)	A1030
000457	AR = .785398175*(D**2 -(D-2.*TH)**2)	A1040
000464	XI = XN* XIR	A1050
	C STEP NO. 4	A1060
000466	DO 125 I=1,NM1	A1070
000467	DO 120 J=1,N4	A1080
000470	G(I,J)= 2.*(T(I,J+1)-T(I,J))/(PD*D*SQRT(3.))	A1090
000504	120 CONTINUE	A1100
000506	125 CONTINUE	A1110
000510	IF(IPR.F0.0) GOTO 145	A1120
000511	PRINT 130,XIR,AR,XI	A1130
000523	130 FORMAT(/// * MOMENT OF INERTIA OF INDIVIDUAL FUEL ROD=*E12.4,/* AREA	A1140
	1 OF INDIVIDUAL FUEL ROD=*E12.4,/* MOMENT OF INERTIA OF SECTION OF	A1150
	2 FUEL RODS=*E12.4/)	A1160
000523	PRINT 135	A1170
000527	135 FORMAT(/// * TEMPERATURE GRADIENTS */ * SURLENGTH */)	A1180
000527	DO 140 I=1,NM1	A1190
000531	PRINT 45,I,(G(I,J),J=1,N4)	A1200
000547	140 CONTINUE	A1210
000552	145 CONTINUE	A1220
000552	DO 155 I=1,NM1	A1230
000554	EE(I)=0.0	A1240
000555	DO 150 J=1,N4	A1250
000557	EE(I) = EE(I) + XNK(J)*(E(I,J)+F(I,J+1))/(2.*XN)	A1260
000574	150 CONTINUE	A1270
000577	155 CONTINUE	A1280
000602	DO 165 I=1,NM1	A1290
000603	GAVE(I) =0.0	A1300
000604	DO 160 J=1,N4	A1310
000606	GAVE(I) = GAVE(I) +(E(I,J)+F(I,J+1))*G(I,J)*XNK(J)/(XN*EE(I)*2.)	A1320
000627	160 CONTINUE	A1330
000632	165 CONTINUE	A1340
000635	IF(IPR.F0.0) GOTO 180	A1350
000636	PRINT 170	A1360
000641	170 FORMAT(/// * AVE. TEMPERATURE GRADIENT ACROSS ASSEMBLY */ * SURLENGT	A1370
	1 H*3X,* GRADIENT */)	A1380
000641	DO 175 I=1,NM1	A1390
000643	PRINT 45,I,GAVE(I)	A1400

000652	CONTINUE	A1410
000655	180 CONTINUE	A1420
	C STEP NO. 5	A1430
000655	DO 185 I=1,NM1	A1440
000657	XL(I) = X(I+1)-X(I)	A1450
000662	185 CONTINUE	A1460
000664	IF (IPR.FQ.0) GOTO 200	A1470
000665	PRINT 190	A1480
000670	190 FORMAT(// * LENGTHS OF SUBLNGTHS * /)	A1490
000670	DO 195 I=1,NM1	A1500
000672	PRINT 45,I, XL(I)	A1510
000701	195 CONTINUE	A1520
000704	200 CONTINUE	A1530
	C STEP NO. 6	A1540
000704	DO 205 I=1,NM1	A1550
000706	G2(I)=(G(I,7)+G(I,8)+G(I,9)+G(I,10)+G(I,11)+G(I,12)+G(I,13))/ 7.	A1560
000730	205 CONTINUE	A1570
000733	DO 210 J=1,NM1	A1580
000734	EEE = EE(I)	A1590
000736	THA(I)=XL(I)*(AL*GAVF(I)*EEE*XI+ALC*G2(I)*EC*CI)/(EEE*XI+EC*CI)	A1600
000754	DELY(I)= THA(I)*XL(I)/2.	A1610
000757	210 CONTINUE	A1620
000761	IF (IPR.FQ.0) GOTO 230	A1630
000762	PRINT 215	A1640
000765	215 FORMAT(// * RELATIVE DISPLACEMENTS*/5X,* I*,10X,* THETA(I)*,10X,* D	A1650
	1ELTA(I)* /)	A1660
000765	DO 220 J=1,NM1	A1670
000767	PRINT 225,I,THA(I),DELY(I)	A1680
001000	220 CONTINUE	A1690
001003	225 FORMAT(16,7X,E12.4,7X,E12.4)	A1700
001003	230 CONTINUE	A1710
	C CALCULATE TOTAL DISPLACEMENTS	A1720
001003	THAT(I) = 0.	A1730
001004	DELY(I)= 0.	A1740
001005	DO 235 I=2,N1	A1750
001006	THA(I) = THAT(I-1) +THA(I-1)	A1760
001011	DELY(I) =DELY(I-1) +THA(I-1)*XL(I-1) + DELY(I-1)	A1770
001015	235 CONTINUE	A1780
001017	IF (IPR.FQ.0) GOTO 255	A1790
001020	PRINT 240	A1800
001024	240 FORMAT(//// * TOTAL THERMAL DISPLACEMENTS *// * SUBLNGTH *10X,* DELT	A1810
	1A Y*10X,* THETA X*/)	A1820
001024	DO 250 I=1,N1	A1830
001026	PRINT 245,I,DELY(I),THAT(I)	A1840
001037	245 FORMAT(/16,7X,E12.4,7X,E12.4)	A1850
001037	250 CONTINUE	A1860
001042	255 CONTINUE	A1870

	C	CALCULATE K(I) - STIFFNESS MATRICIES	A1880
	C	STEP NO. 7	A1890
001042		DO 355 I2=1,2	A1900
001044		DO 260 I=1,NM1	A1910
001045		IF(I2.EQ.1) GAMMA = EE(I)*XIR	A1920
001051		IF(I2.EQ.2) GAMMA = EC * CI +EE(I)*XN*XIR	A1930
001060		XKI(1,1,I) = 4.*GAMMA / XL(I)	A1940
001065		XKI(2,2,I) = XKI(1,1,I)	A1950
001071		XKI(1,2,I) = XKI(1,1,I)/2.	A1960
001073		XKI(2,1,I) = XKI(1,2,I)	A1970
001076		XKI(3,1,I) = -1.5*XKI(1,1,I) / XL(I)	A1980
001102		XKI(3,2,I) = XKI(3,1,I)	A1990
001105		XKI(2,3,I) = XKI(3,1,I)	A2000
001107		XKI(1,3,I) = XKI(3,1,I)	A2010
001111		XKI(4,1,I) = -XKI(3,1,I)	A2020
001113		XKI(4,2,I) = XKI(4,1,I)	A2030
001115		XKI(1,4,I) = XKI(4,1,I)	A2040
001117		XKI(2,4,I) = XKI(4,1,I)	A2050
001121		XKI(3,3,I) = 2.*XKI(4,1,I) / XL(I)	A2060
001125		XKI(4,4,I) = XKI(3,3,I)	A2070
001130		XKI(4,3,I) = -XKI(3,3,I)	A2080
001132		XKI(3,4,I) = XKI(4,3,I)	A2090
001134	260	CONTINUE	A2100
001136		IF(IPR.EQ.0) GOTO 285	A2110
001137		DO 280 K=1,NM1	A2120
001141		PRINT 265,K	A2130
001146	265	FORMAT(/* STIFFNESS MATRIX - SURLenght NO.*I3 //)	A2140
001146		DO 275 I=1,4	A2150
001150		PRINT 270,I,(XKI(I,J,K),J=1,4)	A2160
001167	270	FORMAT(15,4E20.4)	A2170
001167	275	CONTINUE	A2180
001171	280	CONTINUE	A2190
001174	285	CONTINUE	A2200
	C	STEP NO. 8	A2210
	C	FORM CODE MATRIX	A2220
001174		DO 290 J=1,NM1	A2230
001176		NCODE(I,1) = I	A2240
001177		NCODE(I,2) = I+1	A2250
001201		NCODE(I,3) = N1+I	A2260
001203		NCODE(I,4) = N1+I+1	A2270
001205	290	CONTINUE	A2280
001207		DO 295 I=1,NM1	A2290
001211		NCODE(I,1,2) = 2+I	A2300
001213		NCODE(I,2,2) = 3+I	A2310
001214		NCODE(I,3,2) = N1+1+I	A2320
001217		NCODE(I,4,2) = N1+2+I	A2330
001221	295	CONTINUE	A2340

001223		NCODE(1,3,2) = 1	A2350
001224		NCODE(NM1,4,2) = 2	A2360
001225		IF(IPR.EQ.0) GOTO 310	A2370
001226		PRINT 300	A2380
001232	300	FORMAT(// * CODE MATRIX * /)	A2390
001232		DO 305 I=1,NM1	A2400
001234		PRINT 10, (NCODE(I,J,12), J=1,4)	A2410
001251	305	CONTINUE	A2420
001254	310	CONTINUE	A2430
	C	BUILD OVER-ALL STIFFNESS MATRIX	A2440
001254		N6= 2*N1	A2450
001257		DO 315 I=1,N6	A2460
001260		DO 315 J=1,N6	A2470
001261		XK(I,J,12) = 0.	A2480
001267	315	CONTINUE	A2490
001273		DO 330 K=1,NM1	A2500
001275		DO 325 I=1,4	A2510
001276		DO 320 J=1,4	A2520
001277		I1= NCODE(K,I,12)	A2530
001305		J1= NCODE(K,J,12)	A2540
001312		XK(I1,J1,12) = XKI(I,J,K) + XK(I1,J1,12)	A2550
001324	320	CONTINUE	A2560
001325	325	CONTINUE	A2570
001327	330	CONTINUE	A2580
001332		IF(IPR.EQ.0) GOTO 350	A2590
001333		PRINT 335	A2600
001336	335	FORMAT(// * TOTAL STIFFNESS * /)	A2610
001336		DO 345 I=1,N3	A2620
001340		PRINT 340, I, (XK(I,J,12), J=1,N3)	A2630
001360	340	FORMAT(/I5,RE12.4/(RE12.4))	A2640
001360	345	CONTINUE	A2650
001363	350	CONTINUE	A2660
001363	355	CONTINUE	A2670
	C	CAL. AVE. ROD TEMPS.	A2680
001365		DO 365 I=1,NM1	A2690
001367		DO 360 J=1,N4	A2700
001370		RODTAV(I,J) = (T(I,J)+T(I,J+1))/2.	A2710
001402	360	CONTINUE	A2720
001404	365	CONTINUE	A2730
	C	CAL. LINEAR TEMP. BETWEEN SUPPORTS	A2740
001406		DO 375 I=1,NM1	A2750
001410		DO 370 J=1,N4	A2760
001411		TEMPLI(I,J) = T(I,1) + J*(T(I,N2)-T(I,1))/N4	A2770
001424		DELTEM(I,J) = RODTAV(I,J) - TEMPLI(I,J)	A2780
001432	370	CONTINUE	A2790
001434	375	CONTINUE	A2800
001436		IF(IPR.EQ.0) GOTO 400	A2810

001437	DO 395 J=1,NM1	A2820
001441	PRINT 380,I,(HONTAV(I,J),J=1,N4)	A2830
001457	PRINT 385,(TEPLI(I,J),J=1,N4)	A2840
001474	PRINT 390,(DEFLFM(I,J),J=1,N4)	A2850
001511	380 FORMAT(//15,* MOD TEMPS.* RE12.4/(8E12.4))	A2860
001511	385 FORMAT(// * LINEAR TEMPS.*8F12.4/(8E12.4))	A2870
001511	390 FORMAT(// * TEMP. DIFF.*8E12.4/(8E12.4))	A2880
001511	395 CONTINUE	A2890
001514	400 CONTINUE	A2900
	C FORM PLASTIC MOMENTS (PLASTIC PART HERE)	A2910
001514	N10 = NAF-1	A2920
001516	P3=PS*XMU*XNP*PD*D*SQRT(3.)	A2930
001526	MO(NAF) =0.	A2940
001530	DO 405 J=1,N10	A2950
001531	MO(NAF-J)= P3*XNK(J)*(NAF-J) +MO(NAF-J+1)	A2960
001540	405 CONTINUE	A2970
001542	IF(IDEFL.NE.0) GOTO 595	A2990
	C FORM PLASTIC MOMENTS (ELASTIC PART HERE)	A2980
001543	DO 415 J=2,N10	A3000
001545	XJ= J	A3010
001546	FACTOR =(1./XJ)*P3	A3020
001551	JM1 = J-1	A3030
001552	DO 410 K=1,JM1	A3040
001554	MO(J)= MO(J)+ FACTOR*XNK(NAF-K)*K*K	A3050
001562	410 CONTINUE	A3060
001565	415 CONTINUE	A3070
001567	IF(IPR.EQ.0) GOTO 430	A3080
001570	PRINT 420	A3090
001574	420 FORMAT(// * PLASTIC MOMENTS*/5X,* MO(1)*/)	A3100
001574	DO 425 I=1,N10	A3110
001576	PRINT 20,MO(I)	A3120
001603	425 CONTINUE	A3130
001606	430 CONTINUE	A3140
	C STEP NO. 9	A3150
001606	DO 435 J=1,N1	A3160
001610	DELTA(I) = -THAT(I)	A3170
001612	DELTA(I+N1)= DELTY(I)	A3180
001615	435 CONTINUE	A3190
001617	CALL MATRIX(1,N3,1,0,DIS,30,DISX,30)	A3200
001626	CALL MATRIX(22,N3,1,0,DIS,30,DELTA,30,DIF,30)	A3210
001640	CALL SNATCH(A,2,2,XK(1,1,2),30,30,1,1)	A3220
001650	M9 = N1+N1-2	A3230
001652	CALL SNATCH(B,28,28,XK(1,1,2),30,30,3,3)	A3240
001662	CALL SNATCH(C,28,2,XK(1,1,2),30,30,3,1)	A3250
001672	CALL MATRIX(10,M9,M9,0,H,28,DE1)	A3260
001701	IF(IPR.EQ.0) GOTO 440	A3270
001702	PRINT 800,DET	A3280

01710	4	CONTINUE	A3291
01710		CALL MATRIX(23,M9,2,M9,C,28,R,28,CB,2)	A3300
01722		CALL MATRIX(20,2,M9,2,CH,2,C,28,CBC,2)	A3310
01734		CALL MATRIX(22,2,2,0,A,2,CBC,2,A,2)	A3320
01746		DIS(1) = DIF(1+N1)	A3330
01751		DIS(2) = DIF(N1*2)	A3340
01754		CALL MATRIX(20,2,2,1,A,2,DIS, 2,FOR,30)	A3350
01766		CALL MATRIX(20,M9,M9,2,H,28,C,28,HC,28)	A3360
02000		CALL MATRIX(20,M9,2,1,BC,28,DIS,2,DI6,28)	A3370
02012		DIF(N1+1) =DIS(1)	A3380
02014		DIF(N1*2) =DIS(2)	A3390
02020		NO= N1-2	A3400
02021		DO 445 I=1,N1	A3410
02022		DIF(I) = -DI6(I)	A3420
02024	445	CONTINUE	A3430
02026		DO 450 I=1,NO	A3440
02027		DIF(N1+1+I) = -DI6(N1+I)	A3450
02033	450	CONTINUE	A3460
02035		CALL MATRIX(21,N3,1,0,DIF,30,DELTA,30,DIS,30)	A3470
02046		IQQ = 0	A3480
02047		IF(IPR.EQ.0) GOTO 490	A3490
02050	455	CONTINUE	A3500
02050		PRINT 460	A3510
02054	460	FORMAT(1H1,* GRID*10X,* AMOUNT RODS MOVED BACK TO FIT DUCT*10X,* D 1ISPL. FROM DUCT .ZERO LINE.*/20X,* DELTA*10X,* THETA*20X,* DELTA*1 20X,* THETA*//)	A3520 A3530 A3540
02054		DO 470 I=1,N1	A3550
02056		PRINT 465,I,DIF(I+N1),DIF(I),DIS(I+N1),DIS(I)	A3560
02075	465	FORMAT(/I3,13X,F10.7,6X,F10.7,17X,F10.6,6X,F10.6/(6X,F10.7)/)	A3570
02075	470	CONTINUE	A3580
02100		PRINT 475	A3590
02103	475	FORMAT(//* STATION*15X,* FORCE*15X,* DISPLACEMENT*//)	A3600
02103		DO 485 I=1,4	A3610
02105		PRINT 480,I,FOR(I),DIS(I)	A3620
02116	480	FORMAT(I5,10X,E12.4,10X,E12.4//)	A3630
02116	485	CONTINUE	A3640
02120	490	CONTINUE	A3650
02120		DO 495 I=1,28	A3660
02122		DI6(I) = -DI6(I)	A3670
02124	495	CONTINUE	A3680
02125		IF(IQQ.EQ.1) GO TO 500	A3690
02127		CALL BUTLD(DIS,2,1,DSP,30,1,1,1)	A3700
02137		CALL BUTLD(DI6,28,1,DSP,30,1,3,1)	A3710
02147		CALL MATRIX(20,N3,N3,1,XK(1,1,2),30,DSP,30,FOR,30)	A3720
02161	500	CONTINUE	A3730
02161		IF(IQQ.EQ.0) GO TO 505	A3740
02162		CALL BUTLD(QD,3,1,DSP,30,1,1,1)	A3750

002172	CALL BUILD(DI6,28,1,DSP,30,1,4,1,0,1,2,1)	A3760
002207	CALL MATRIX(20,N3,N3,1,XK(1,1,3),30,DSP,30,FOR,30)	A3770
002221	505 CONTINUE	A3780
002221	IF(IPR.EQ.0) GOTO 515	A3790
002222	PRINT 475	A3800
002226	DO 510 I=1,N3	A3810
002230	PRINT 480,I,FOR(I),DSP(I)	A3820
002241	510 CONTINUE	A3830
002244	515 CONTINUE	A3840
002244	IF(IQQ.NE.0) GO TO 590	A3850
	C STFP NO. 9.5	A3860
002245	DO 520 II=2,NM1	A3870
002247	IF(ABS(DIS(N1+II)-DISX(II+N1))-GAP) 520, 525, 525	A3880
002255	520 CONTINUE	A3890
002260	GOTO 590	A3900
002260	525 IMAX = 2	A3910
002261	DO 530 IK=2,NM1	A3920
002263	IF(ABS(DIS(IK+N1)-DISX(IK+N1)).LT.ABS(DIS(IK+1+N1)-DISX(IK+1+N1)))	A3930
	1 IMAX = IK+1	A3940
002300	530 CONTINUE	A3950
	C BUILD CODE MATRIX	A3960
002303	DO 535 I=1,NM1	A3970
002304	NCODE(I,1,3) = I+3	A3980
002306	NCODE(I,2,3) = I+4	A3990
002310	NCODE(I,3,3) = I+2+N1	A4000
002313	NCODE(I,4,3) = I+3+N1	A4010
002316	535 CONTINUE	A4020
002320	NCODE(1,3,3)=1	A4030
002321	NCODE(NM1,4,3)=2	A4040
002323	NCODE(IMAX-1,4,3)=3	A4050
002325	NCODE(IMAX,3,3) = 3	A4060
002326	NO = NM1-1	A4070
002330	DO 540 I=IMAX,NO	A4080
002331	NCODE(I,4,3) = N1+I+2	A4090
002334	NCODE(I+1,3,3) = N1+I+2	A4100
002336	540 CONTINUE	A4110
002340	PRINT 300	A4120
002343	DO 545 I=1,NM1	A4130
002345	PRINT 10,(NCODE(I,J,3),J=1,4)	A4140
002360	545 CONTINUE	A4150
	C FORM LARGE STIFFNESS	A4160
002363	DO 550 I=1,N3	A4170
002364	DO 550 J=1,N3	A4180
002365	XK(I,J,3) = 0.	A4190
002371	550 CONTINUE	A4200
002375	DO 565 K=1,NM1	A4210
002377	DO 560 I=1,4	A4220

02400	DO 555 J=1,4	A4230
02401	I1= NCONE(K,I,3)	A4240
02405	J1= NCONE(K,J,3)	A4250
02410	XK(I,J1,3) = XKI(I,J,K) + XK(I1,J1,3)	A4260
02420	555 CONTINUE	A4270
02422	560 CONTINUE	A4280
02424	565 CONTINUE	A4290
02426	PRINT 335	A4300
02432	DO 570 I=1,N3	A4310
02434	PRINT 340,I,(XK(I,J,3),J=1,N3)	A4320
02452	570 CONTINUE	A4330
	C FORM PARTITIONED MATRIX	A4340
02455	CALL SNATCH(QA,3,3,XK(1,1,3),30,30,1,1)	A4350
02464	MQ = N1+N1 -3	A4360
02466	CALL SNATCH(QB,27,27,XK(1,1,3),30,30,4,4)	A4370
02476	CALL SNATCH(QC,27,3,XK(1,1,3),30,30,4,1)	A4380
02506	CALL MATRIX(10,MQ,MQ,0,QB,27,DEL)	A4390
02515	CALL MATRIX(23,MQ,3,MQ,QC,27,QB,27,QCB,3)	A4400
02527	CALL MATRIX(20,3,MQ,3,QCB,3,QC,27,QCBC,3)	A4410
02541	CALL MATRIX(22,3,3,0,QA,3,QCBC,3,QA,3)	A4420
02553	CENT = (DIS(N1+IMAX) -DISX(N1+IMAX))	A4430
02557	DIS(N1+IMAX) = DISX(N1+IMAX) +GAP*CENT/ABS(CENT)	A4440
02566	CALL MATRIX(22,N3,1,0,DIS,30,DEL(A,30,0)IF,30)	A4450
02600	QD(1) = DIF(1+N1)	A4460
02603	QD(2) = DIF(2*N1)	A4470
02606	QD(3) = DIF(IMAX +N1)	A4480
02610	CALL MATRIX(20,3,3,1,QA,3,QD,3,FOR,30)	A4490
02622	CALL MATRIX(20,MQ,MQ,3,QB,27,QC,27,QBC,27)	A4500
02634	CALL MATRIX(20,MQ,3,1,QBC,27,QD,3,DI6,28)	A4510
02646	DIF(N1+1) = QD(1)	A4520
02650	DIF(N1+2) = QD(2)	A4530
02654	DIF(N1+IMAX) =QD(3)	A4540
02657	DO 575 I=1,N1	A4550
02660	DIF(I) = -DI6(I)	A4560
02662	575 CONTINUE	A4570
02664	DO 580 I=3,IMAX	A4580
02665	DIF(N1-I+I) = -DI6(N1-2+I)	A4590
02671	580 CONTINUE	A4600
02673	DO 585 I=IMAX,N0	A4610
02674	DIF(N1+I+1) = -DI6(N1-1+I)	A4620
02700	585 CONTINUE	A4630
02702	CALL MATRIX(21,N3,1,0,DIF,30,DELTA,30,DIS,30)	A4640
02713	IQQ =1	A4650
02714	GO TO 455	A4660
02715	590 CONTINUE	A4670
02715	595 CONTINUE	A4680
	C STOP NO. 10	A4690

002715	DO 605 KZ=1,N4	
002717	DO 600 KY=1,NM1	A4720
002720	THR(KY,KZ) = G(KY,KZ)*AL*XL(KY)	A4730
002727	DR(KY,KZ) = THR(KY,KZ)*XL(KY) /2.	A4740
002736	600 CONTINUE	A4750
002740	605 CONTINUE	A4760
	C STEP NO. 11	A4770
002742	DO 615 KZ=1,N4	A4780
002744	THRT(1,KZ)= 0.	A4790
002747	DRT(1,KZ) = 0.	A4800
002751	DO 610 KY=2,N1	A4810
002752	THRT(KY,KZ) = THRT(KY-1,KZ) + THR(KY-1,KZ)	A4820
002760	DRT(KY,KZ) = DRT(KY-1,KZ) +THRT(KY-1,KZ)*XL(KY-1) +DR(KY-1,KZ)	A4830
002767	610 CONTINUE	A4840
002771	615 CONTINUE	A4850
	C ABOVE - FREE THERMAL DEFLECTIONS OF FUEL RODS.	A4860
002774	CALL MATRIX(1,N3,N3,0,XK,30,XK(1,1,2),30)	A4870
003005	CALL MATRIX(10,N3,N3,0,XK(1,1,2),30,DEF)	A4880
	C XK(, 2) = FLEXIBILITY OF A FUEL ROD	A4890
	C XK(, 1) = STIFFNESS OF A FUEL ROD	A4900
	C FORM FUEL ROD STIFFNESS TO GET CENTER SPAN DEFLECTIONS	A4910
003014	DO 620 J=1,NM1	A4920
003016	XKI(1,1,I)= 8.*FE(I)*XIR / XL(I)	A4930
003024	XKI(2,2,I)= XKI(1,1,I)	A4940
003027	XKI(1,2,I)= XKI(1,1,I)/2.	A4950
003031	XKI(2,1,I)= XKI(1,2,I)	A4960
003034	XKI(3,1,I)= -3.*XKI(1,1,I) / XL(I)	A4970
003040	XKI(3,2,I)= XKI(3,1,I)	A4980
003043	XKI(2,3,I)= XKI(3,1,I)	A4990
003045	XKI(1,3,I)= XKI(3,1,I)	A5000
003047	XKJ(4,1,I)=-XKI(3,1,I)	A5010
003051	XKI(4,2,I)= XKI(4,1,I)	A5020
003053	XKI(1,4,I)= XKI(4,1,I)	A5030
003055	XKI(2,4,I)= XKI(4,1,I)	A5040
003057	XKI(3,3,I)= 4. *XKI(4,1,I) /XL(I)	A5050
003063	XKI(4,4,I)= XKI(3,3,I)	A5060
003066	XKJ(4,3,I)=-XKI(3,3,I)	A5070
003070	XKI(3,4,I)= XKI(4,3,I)	A5080
003072	620 CONTINUE	A5090
	C FORM CODE MATRIX	A5100
003074	DO 625 J =1,NM1	A5110
003076	NCOD(2*I-1,1) = I	A5120
003101	NCOD(2*I,1) = 0	A5130
003104	NCOD(2*I-1,2) = 0	A5140
003106	NCOD(2*I,2) = I+1	A5150
003112	NCOD(2*I-1,3) = N1+I	A5160
003115	NCOD(2*I ,3) = N1+N1+I	

103120		NCOD(2*I-1,4) = N1+N1+1	A5170
103123		NCOD(2*I,4) = N1+1+1	A5180
103127	625	CONTINUE	A5190
103131		PRINT 300	A5200
103134		IZQM = 2*NM1	A5210
103137		DO 630 I=1,IZQM	A5220
103140		PRINT 10,(NCOD(I,J),J=1,4)	A5230
103153	630	CONTINUE	A5240
	C	FORM LARGE STIFFNESS MATRIX	A5250
103156		DO 635 I=1,44	A5260
103157		DO 635 J=1,44	A5270
103160		STIF(I,J) = 0.	A5280
103164	635	CONTINUE	A5290
103170		DO 650 K=1,IZQM	A5300
103171		DO 645 I=1,4	A5310
103172		DO 640 J=1,4	A5320
103173		I1 = NCOD(K,I)	A5330
103177		J1 = NCOD(K,J)	A5340
103202		KR0 = (K+1)/2	A5350
103206		IF(I1.EQ.0.OR.J1.EQ.0) GOTO 640	A5360
103214		STIF(I1,J1) = AKI(I,J,KR0) + STIF(I1,J1)	A5370
103224	640	CONTINUE	A5380
103226	645	CONTINUE	A5390
103230	650	CONTINUE	A5400
	C	STEP NO. 12	A5410
103233		DO 735 KZ=1,N4	A5420
103234		DO 655 I=1,N1	A5430
103235		DELT3(I) = -THRT(I,KZ)	A5440
103241		DELT3(I+N1) = DRT(I,KZ)	A5450
103244	655	CONTINUE	A5460
	C	STEP NO. 13	A5470
103246		CALL MATRIX(22,N3,1,0,DIS,30,DELT3,30,DIF,30)	A5480
103257		IF(IRFIX.NE.0) GOTO 675	A5490
103260		CALL SNATCH(A1,15,15,XK,30,30,1,1)	A5500
103270		NP=N1+1	A5510
103272		CALL SNATCH(R1,15,15,XK,30,30,NP,NP)	A5520
103302		CALL SNATCH(C1,15,15,XK,30,30,1,NP)	A5530
103312		CALL MATRIX(10,N1,N1,0,A1,15,DET)	A5540
103321		CALL MATRIX(20,N1,N1,N1,A1,15,C1,15,AC,15)	A5550
103333		CALL MATRIX(23,N1,N1,N1,C1,15,AC,15,ACA,15)	A5560
103345		CALL MATRIX(22,N1,N1,0,R1,15,ACA,15,ACA,15)	A5570
103357		CALL SNATCH(D17,15,1,DIF,30,1,NP,1)	A5580
103367		CALL MATRIX(20,N1,N1,1,AC,15,D17,15,D19,15)	A5590
103401		DO 660 I=1,N1	A5600
103403		D19(I) = -D19(I)	A5610
103405	660	CONTINUE	A5620
103407		CALL BUILD(D19,15,1,D14,30,1,1,1)	A5630

003416	CALL HUTLD(017,15,1,014,30,1,NP,1)	A5640
003426	CALL MATRIX(20,N3,N3,1,XK,30,014,30,F,30)	A5650
003440	CALL MATRIX(21,N3,1,0,014,30,DEL T3,30,DIR(1,KZ),30)	A5660
	STEP NO. 14	A5670
003456	SPX(1) = 0.0	A5680
003457	XMOME(1,KZ) = 0.0	A5690
003462	DO 665 KA=2,N1	A5700
003464	SPX(KA) = SPX(KA-1) + F(KA-1+N1)	A5710
003470	XMOME(KA,KZ) = XMOME(KA-1,KZ) + SPX(KA)*XL(KA-1)	A5720
003477	665 CONTINUE	A5730
003501	DO 670 KA=1,NM1	A5740
003502	XMOME(KA,KZ,2) = XMOME(KA+1,KZ)	A5750
003511	670 CONTINUE	A5760
003513	GOTO 695	A5770
003514	675 CONTINUE	A5780
	STEP NO. 13A	A5790
003514	680 CALL MATRIX(20,N3,N3,1,XK,30,01F,30,F,30)	A5800
003526	CALL MATRIX(1,N3,1,0,01S,30,DIR(1,KZ),30)	A5810
003541	CALL MATRIX(1,N3,1,0,01F,30,014,30)	A5820
	STEP NO. 14A	A5830
003551	SPX(1) = 0.0	A5840
003552	XMOME(1,KZ) = F(1)	A5850
003556	DO 685 KA=2,N1	A5860
003557	SPX(KA) = SPX(KA-1) + F(KA-1+N1)	A5870
003563	XMOME(KA,KZ) = XMOME(KA-1,KZ) + SPX(KA)*XL(KA-1) + F(KA)	A5880
003573	685 CONTINUE	A5890
003575	DO 690 KA=1,NM1	A5900
003577	XMOME(KA,KZ,2) = XMOME(KA+1,KZ) - F(KA+1)	A5910
003607	690 CONTINUE	A5920
003611	695 CONTINUE	A5930
003611	IF(IPR.FQ.0) GOTO 720	A5940
003612	PRINT 700,KZ	A5950
003620	700 FORMAT(1H),* ROD REGION NO.*13,/* GRID*16X,* DELTA*10X,* THETA*15X	A5960
	1,* MOMENT*10X,* SHEAR*/)	A5970
003620	DO 705 I=1,N1	A5980
003622	PRINT 465,I,DIR(I+N1,KZ),DIR(I,KZ),F(I),F(I+N1)	A5990
003645	705 CONTINUE	A6000
003650	PRINT 710	A6010
003653	710 FORMAT(/////* COMPONENTS OF DISPLACEMENTS/* THERMAL*40X,* MECHANIC	A6020
	1AL/* GRID*16X,* DELTA*10X,* THETA*20X,* DELTA*12X,* THETA*/)	A6030
003653	DO 715 I=1,N1	A6040
003655	PRINT 465,I,DEL T3(N1+I),DEL T3(1),014(N1+I),014(I)	A6050
003674	715 CONTINUE	A6060
003677	720 CONTINUE	A6070
003677	NP5 = N1+N1+1	A6080
	STEP NO. 14.5	A6090
003701	CALL SNATCH(ZH,14,14,STIF,44,44,NP5,NP5)	A6100

103711	CALL SNATCH(ZC,14,30,STIF,44,44,NP5,1)	A6110
103721	CALL MATRIX(10,NM1,NM1,0,ZB,14,DET)	A6120
103730	CALL MATRIX(20,NM1,NM1,N3,ZH,14,ZC,14,ZRC,14)	A6130
103742	CALL MATRIX(20,NM1,N3,1,ZHC,14,DI4,30,ZD,14)	A6140
103754	DO 725 I=1,NM1	A6150
103756	ZD(I) = -ZD(I)	A6160
103760	ZDT(I) = DRT(I,KZ)+THRT(I,KZ)*XL(I)/2. + DP(I,KZ)/4.	A6170
103773	725 CONTINUE	A6180
103775	CALL MATRIX(21,NM1,1,0,ZD,14,ZDT,14,ZDT,14)	A6190
104007	DO 730 I=1,NM1	A6200
104011	D10T(I,KZ) = ZDT(I) -(D18(N)+I,KZ)+D18(N+1+I,KZ))/2.	A6210
104027	730 CONTINUE	A6220
104032	735 CONTINUE	A6230
104035	IF(IPR.EQ.0) GOTO 740	A6240
104036	PRINT 740	A6250
104041	740 FORMAT(1H1,* MOMENTS IN FUEL RODS *//* ROD REGION*//)	A6260
104041	DO 750 KZ=1,N4	A6270
104043	PRINT 755,KZ,(XMOME(KA,KZ,1),KA=1,N1)	A6280
104061	PRINT 745,(XMOME(KA,KZ,2),KA=1,NM1)	A6290
104076	745 FORMAT(/7X,8F12.3)	A6300
104076	750 CONTINUE	A6310
104101	755 FORMAT(/17,8F12.3/(7X,8F12.3))	A6320
104101	760 CONTINUE	A6330
	C FIND (P1)	A6340
	C STEP NO. 15	A6350
104101	Z= PS*XMU*XNP	A6360
104104	IF(ICOP.EQ.1) GOTO 770	A6370
104106	N = N1/2	A6380
104111	DO 765 I=1,N	A6390
104112	P1(I) = I*Z	A6400
104115	P1(N1-I) = P1(I)	A6410
104120	765 CONTINUE	A6420
104122	GOTO 780	A6430
104123	770 DO 775 I=1,NM1	A6440
104125	P1(N)-I) = I*Z	A6450
104131	775 CONTINUE	A6460
104133	780 CONTINUE	A6470
104133	IF(IPR.EQ.0) GOTO 805	A6480
104134	PRINT 785	A6490
104140	785 FORMAT(1H1,* AXIAL LOADS IN RODS*//* SUB-LENGTH*7X,* LOAD*//)	A6500
104140	DO 790 KB=1,NM1	A6510
104142	PRINT 755,KB,P1(KB)	A6520
104151	790 CONTINUE	A6530
104154	795 FORMAT(15,10X,F8.2,16X,F8.2)	A6540
104154	800 FORMAT(F)2.4)	A6550
104154	805 CONTINUE	A6560
104154	DO 810 I=1,NM1	A6570

004156	IF (IPR.EQ.0) GOTO R40	A6590
004160	STEP NO. 16	A6600
004162	IF (IPR.EQ.0) GOTO R40	A6610
004163	PRINT R15	A6620
004167	R15 FORMAT(1H1,* ROD DEFLECTIONS */10X,* AXIAL LOAD = 0.0*//)	A6630
004167	DO R35 K=1,N4	A6640
004171	PRINT R20,KD,(DTOT(KC,KD),KC=1,NM)	A6650
004207	R200 FORMAT (20X,*TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION*	A6660
	Q13, //(R12.7))	A6670
004207	R25 FORMAT (25X,* TOTAL END SLOPE AT SIDE 1* //(R12.7))	A6680
004207	R30 FORMAT (25X,* TOTAL END SLOPE AT SIDE 2* //(R12.7))	A6690
004207	R35 CONTINUE	A6700
004212	R40 CONTINUE	A6710
	C STEP NO. 17	A6720
004212	R45 CONTINUE	A6730
004212	II = IRFIX	A6740
004214	DO R55 J=1,NM1	A6750
004215	DO R50 K=1,N4	A6760
004216	IF (J.EQ.1) XM11 = XMOME(1,K)	A6770
004223	IF (J.NE.1) XM11 = (XMOME(J,K)+XMOME(J-1,K,2))/2.	A6780
004233	IF (J.EQ.NM1) XM22 = XMOME(NM1,K,2)	A6790
004241	IF (J.NE.NM1) XM22 = (XMOME(J,K,2)+XMOME(J+1,K))/2.	A6800
004251	AD = DTOT(J,K)	A6810
004255	CALL DEL (XM11,XM22,XIR,AD) XL(J),P1(J),J,K,II,A2)	A6820
004267	R50 CONTINUE	A6830
004272	R55 CONTINUE	A6840
004274	DO 900 J=1,NM1	A6850
004276	IM = J+1	A6860
004300	PRINT R60,I,I,DIS(I+NM1),P1(I),IM,DIS(IM+NM1)	A6870
004321	R60 FORMAT(1H1, // * LENGTH NO.*I3,41X,* UPPER GRID DEFLECTION (GRID NO.	A6880
	1*I3,*) =*F11.7,* INS.*// * AXIAL LOAD =*F5.1,* LBS*32X,* LOWER	A6890
	2GRID DEFLECTION (GRID NO.*I3,*) =*F11.7,* INS.*//	A6900
004321	PRINT R65	A6910
004325	R65 FORMAT(6X,* ROD / MOMENTS IN RODS /TOTAL LOCAL*,	A6920
	1* / MAXIMUM LOC./CENTER DEFL./ FLOW*3X,	A6930
	2* /CRITICAL/ CREEP /STRUT*)	A6940
004325	PRINT R70	A6950
004331	R70 FORMAT(6X,* ROW */18X,* / CENTER / CREEP /RELATIVE TO*	A6960
	1* / CHANNEL / AXIAL /DEFLECTION/BUCKLING*)	A6970
004331	PRINT R75,I,IM	A6980
004341	R75 FORMAT(6X,* NO. / GRID*I3,* / GRID*I3,* / DEFLECTION */2X,	A6990
	1*DEFLECTION** / EARTH*4X,* / CHANGE / LOAD/COMPON*	A7000
	2*ENT / M.S. */)	A7010
004341	DO R80 J=1,N4	A7020
004343	DUCT = DMA(I,J)	A7030
004347	DUCC = DEFL(I,J) -DTOT(I,J)*(I)+A2/ABS(DTOT(I,J)))	A7040

PROGRAM LENGTH INCLUDING I/O BUFFERS
044746

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

5	-	000003	10	-	004675	15	-	004700	20	-	004707
25	-	004711	35	-	004757	40	-	004766	45	-	004772
60	-	000311	75	-	004777	85	-	005006	100	-	005013
105	-	005021	115	-	000451	130	-	005030	135	-	005050
145	-	000552	170	-	005056	180	-	000655	190	-	005070
200	-	000704	215	-	005076	225	-	005107	230	-	001003
240	-	005113	245	-	005125	255	-	001042	265	-	005133
270	-	005141	285	-	001174	300	-	005144	310	-	001254
335	-	005150	340	-	005154	350	-	001363	355	-	001363
380	-	005160	385	-	005165	390	-	005172	400	-	001514
420	-	005177	430	-	001606	440	-	001710	455	-	002050
460	-	005223	465	-	005243	475	-	005252	480	-	005260
490	-	002120	500	-	002161	505	-	002221	515	-	002244
520	-	002255	525	-	002260	530	-	002300	590	-	002715
595	-	002715	640	-	003224	675	-	003514	680	-	003514
695	-	003611	700	-	005306	710	-	005320	720	-	003677
740	-	005342	745	-	005350	755	-	005353	760	-	004101
770	-	004123	780	-	004133	785	-	005357	795	-	005366
800	-	005372	805	-	004154	815	-	005374	820	-	005403
825	-	005414	830	-	005422	840	-	004212	845	-	004212
860	-	005430	865	-	005453	870	-	005474	875	-	005510
880	-	004506	885	-	005530	890	-	004511	895	-	005542
900	-	004632	905	-	005553						

BLOCK NAMES AND LENGTHS

BLOCKA -	001713	BLOCK	-	000502	BLOCKC -	000502	BLOCK	-	005024
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VARIABLE ASSIGNMENTS

A	-	005645	AC	-	030074	ACA	-	030435	AD	-	040674
AL	-	000002C04	ALC	-	040602	AR	-	000000C01	A1	-	026631
A2	-	040574	R	-	005656	RC	-	007551	R1	-	027172
C	-	007276	CB	-	007417	CHC	-	007540	CENT	-	040657
CI	-	040600	CO0	-	001711C01	CO2	-	001712C01	C1	-	027533
D	-	000001C01	DEFL	-	000000C03	DELTA	-	023431	DEITEM	-	013241
DELTY	-	012016	DEFLT3	-	026573	DFLY	-	011761	DET	-	040650
DIF	-	023467	DIS	-	010445	DISX	-	032462	DIS1	-	023637
DI4	-	032354	DIS	-	023675	DI6	-	023677	DI7	-	030776
DIA	-	031053	DI9	-	032335	DMA	-	000000C02	DME	-	003620C04
DR	-	025311	DRT	-	026042	DSP	-	023771	DTH	-	003116C04

DTOT	-	4322C04	DUCO	-	040677	DUCT	-	0	76	E	-	010503
EARTH	-	040700	FC	-	040601	FF	-	023344		EFE	-	040634
F	-	031015	FACTOR	-	040645	FCC	-	040701		FOR	-	023733
G	-	011241	GAMMA	-	040636	GAP	-	040573		GAVE	-	011223
G2	-	023621	I	-	040614	ICOP	-	040575		IDEFL	-	040576
IE	-	040622	IEI	-	040623	II	-	040653		IK	-	040655
IM	-	040675	IMAX	-	040654	IPR	-	040606		IQQ	-	040652
IRFIX	-	040577	IZQM	-	040662	I1	-	040640		I2	-	040635
J	-	040617	JM1	-	040646	J1	-	040641		K	-	040624
KA	-	040665	KH	-	040671	KC	-	000000C04		KD	-	000001C04
KRO	-	040663	KY	-	040661	KZ	-	040660		MO	-	007672
MQ	-	040656	M9	-	040647	N	-	040670		NAF	-	040605
NCOD	-	032523	NCODE	-	014303	NH1	-	040615		NO	-	040651
NP	-	040664	NP5	-	040666	N1	-	040604		N10	-	040642
N2	-	040616	N3	-	040630	N4	-	040631		N5	-	040632
N6	-	040637	O1ME	-	000004C04	O1TH	-	000506C04		O1TOT	-	001210C04
O2ME	-	001712C04	O2TOT	-	002414C04	PCR	-	000002C01		PD	-	040610
PS	-	040611	P1	-	022043	P3	-	040643		QA	-	005645
QB	-	005656	QBC	-	007551	QC	-	007276		QCR	-	007417
QCHC	-	007540	QD	-	032520	QK	-	040625		RC	-	040603
RODTAV	-	012035	S	-	021767	SPX	-	023412		STIF	-	032703
S1	-	023525	S2	-	023563	T	-	007725		TOMAX	-	032436
TEMPLI	-	012537	TH	-	000504C01	THA	-	011743		THAT	-	011777
THH	-	024027	THRT	-	024560	TINCR	-	040621		TWIN	-	040620
T1	-	040626	T2	-	040627	X	-	007706		XI	-	040633
XIR	-	000003C04	XJ	-	040644	XK	-	014553		XKI	-	013743
XL	-	022025	XMOME	-	022062	XMS	-	000505C01		XMS2	-	001207C01
XMU	-	040613	XM11	-	040672	XM22	-	040673		XN	-	040607
XNK	-	023363	XNP	-	040612	YNE	-	032412		Z	-	040667
ZB	-	036523	ZBC	-	037673	ZC	-	037027		ZD	-	040537
ZDT	-	040555										

START OF CONSTANTS

004666

START OF TEMPORARIES

005563

START OF INDIRECTS

005601

UNUSED COMPILER SPACE

070300


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SUBROUTINE BUILD (B,NH,MB,A,LA,KA,IA,JA,ITRANS,NB1,NB2,MB1,MB2)  MMAP0010
DIMENSION B(NH,MR), A(LA,KA)  MMAP0020
LOGICAL LADY,LUCK  MMAP0030
LUCK = .TRUE.  MMAP0040
GOTO 5  MMAP0050
ENTRY SNATCH  MMAP0060
LUCK = .FALSE.  MMAP0070
5 I = IA - 1  MMAP0080
CALL COUNT (NUMBER)  MMAP0090
LADY = .TRUE.  MMAP0100
IF (NUMBER.NE.13) GO TO 10  MMAP0110
N1 = NB1  MMAP0120
M1 = MB1  MMAP0130
N2 = NB2  MMAP0140
M2 = MB2  MMAP0150
IF (1.GT.N1.OR.N1.GT.N2.OR.N2.GT.NB) GO TO 30  MMAP0160
IF (1.GT.M1.OR.M1.GT.M2.OR.M2.GT.NR) GO TO 30  MMAP0170
GOTO 20  MMAP0180
10 N1 = 1  MMAP0190
M1 = 1  MMAP0200
N2 = NB  MMAP0210
M2 = MB  MMAP0220
IF (NUMBER.EQ.8) GOTO 25  MMAP0230
IF (NUMBER.EQ.9) GOTO 20  MMAP0240
CALL ERROR(40HINCORRECT NUMBER OF CALLING PARAMETERS )  MMAP0250
15 CALL EXIT  MMAP0260
20 IF (ITRANS.NE.0) LADY = .FALSE.  MMAP0270
25 IF (LADY) GOTO 55  MMAP0280
IF ((IA+M2-M1).GT.LA) GOTO 30  MMAP0290
IF ((JA+M2-M1).LE.KA) GOTO 75  MMAP0300
30 CALL ERROR(20H HAD INDICES INPUT )  MMAP0310
PRINT 35,NUMBER  MMAP0320
35 FORMAT(//# NUMBER OF CALLING PARAMETERS =#I3/)  MMAP0330
PRINT 40,NB,MR,LA,KA,IA,JA  MMAP0340
400FORMAT(//# NH=#I4,/# MH=#I4,/# LA=#I4,/# KA=#I4,/# IA=#I4,/# JA=#I4)  MMAP0350
14)  MMAP0360
IF (NUMBER.GE.9) PRINT 45,ITRANS  MMAP0370
45 FORMAT(* ITRANS=#I2)  MMAP0380
IF (NUMBER.EQ.13) PRINT 50,NB1,NB2,MB1,MB2  MMAP0390
50 FORMAT(* NB1=#I4,/# NB2=#I4,/# MB1=#I4,/# MB2=#I4)  MMAP0400
GOTO 15  MMAP0410
C CHECKS FOR REGULAR  MMAP0420
55 IF ((IA+M2-M1).GT.LA) GOTO 30  MMAP0430
IF ((JA+M2-M1).GT.KA) GOTO 30  MMAP0440
IF (LUCK) GOTO 65  MMAP0450
C SNATCH REGULAR  MMAP0460

```

000277	DO 60 N=N1,N2	MMAP0470
000301	I = I + 1	MMAP0480
000303	J = JA - 1	MMAP0490
000304	DO 60 M=M1,M2	MMAP0500
000306	J = J + 1	MMAP0510
000310	60 R(N,M) = A(I,J)	MMAP0520
000326	RETURN	MMAP0530
	C BUILD REGULAR	MMAP0540
000327	65 DO 70 N=N1,N2	MMAP0550
000331	I = I + 1	MMAP0560
000333	J = JA - 1	MMAP0570
000334	DO 70 M=M1,M2	MMAP0580
000336	J = J + 1	MMAP0590
000340	70 A(I,J) = R(N,M)	MMAP0600
000356	RETURN	MMAP0610
000356	75 IF (LUCK) GOTO 85	MMAP0620
	C SNATCH TRANSPOSE	MMAP0630
000360	DO 80 M=M1,M2	MMAP0640
000362	I = I + 1	MMAP0650
000364	J = JA - 1	MMAP0660
000365	DO 80 N=N1,N2	MMAP0670
000367	J = J + 1	MMAP0680
000371	80 R(N,M) = A(I,J)	MMAP0690
000407	RETURN	MMAP0700
	C BUILD TRANSPOSE	MMAP0710
000410	85 DO 90 M=M1,M2	MMAP0720
000412	I = I + 1	MMAP0730
000414	J = JA - 1	MMAP0740
000415	DO 90 N=N1,N2	MMAP0750
000417	J = J + 1	MMAP0760
000421	90 A(I,J) = R(N,M)	MMAP0770
000436	RETURN	MMAP0780
000437	END	MMAP0790

SUBPROGRAM LENGTH

000531

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

5	-	000053	10	-	000125	15	-	000142	20	-	000147
25	-	000152	30	-	000164	35	-	000453	40	-	000461
45	-	000471	50	-	000474	55	-	000265	65	-	000327
75	-	000356	85	-	000410						

BLOCK NAMES AND LENGTHS

VARIABLE ASSIGNMENTS

I	-	000520	IA	-	000000	ITRANS	-	000002	J	-	000527
JA	-	000001	LADY	-	000516	LUCK	-	000517	M	-	000530
MB1	-	000005	MB2	-	000006	M1	-	000523	M2	-	000525
N	-	000526	NR1	-	000003	NR2	-	000004	NUMBER	-	000521
N1	-	000522	N2	-	000524	SNATCH	-	000514			

START OF CONSTANTS

000441

START OF TEMPORARIES

000502

START OF INDIRECTS

000512

UNUSED COMPILER SPACE

107100

```

000000 03172516245555000001
000001 0200000001 R COUNT
000002 5110000001 R
          21136
000003 5221777776
          5212000001
000004 43566
          21136
          5211777776
000005 21122
          15615
          56610
000006 0400000001 R
    
```

ASCENT
ENTRY COUNT

```

VFD D42/COUNT,N18/1
JP * J. KASDORF
SA1 COUNT
AX1 30
SA2 X1-1
SA1 X2+1
MX5 54
AX1 30
SA1 X1-1
AX1 18
BX6 -X5*X1
SA6 R1
EQ R0 R0 COUNT
END
    
```

•THIS PROGRAM DETERMINES THE NUMB
•OF ARGUMENTS USED IN THE CALL TO
•THE PROGRAM WHICH CALLS COUNT.

J. KASDORF

•ADDRESS+1 OF RJ IN CALLING PROGE

•ENTRY OF CALLING PROGRAM

•SET TASK

•ADDRESS+1 OF RJ IN CALLING PROGE

•NO OF ARGUMENTS IN CALLING PROGE

•SET UP FOR RETURN

NUMBER OF LINES WITH DIAGNOSTICS ---

0

```

000307      20 DO 25 I=1,11                                DEL 0470
000311      IF(STRA1(I).GE.FW) GOTO 30                    DEL 0480
000315      25 CONTINUE                                    DEL 0490
000317      30 ZI =(I-2)                                    DEL 0500
000322      SIGD = SIGX /(I1-1)                            DEL 0510
000326      SIG= SIGD*(ZI + (EK-STRA1(I-1))/(STRA1(I )-STRA1(I-1))) DEL 0520
000337      SIG3 =-SIG * T/D                               DEL 0530
000342      SIGL=-P /AR- ARS(XM1+XM2)*D/(4.*XI)            DEL 0540
000352      SIGE = SQRT(((SIG3-SIGL)**2+(SIG3-SIG )**2+(SIGL-SIG )**2)/2.) DEL 0550
000367      IF(SIGE.LE.AAA) ET=EE                          DEL 0560
000374      IF(SIGE.LT.AA.AND.SIGE.GT.AAA) ET =SIGE/(SIGE/EE +AZ*TIME*(SIGE-AADEL 0570
1A)**XM)                                                  DEL 0580
000414      IF(SIGE.GE.AA)                                ET =SIGE/(SIGE/EE +AZ*TIME*(SIGE-AADEL 0590
1A)**XM+ XK*(SIGF-AA)**BB)                                DEL 0600
000437      IF(A2.GE.ABS(A1)) CON = 1. + CON              DEL 0610
000445      Z = A1/ARS(A1)                                  DEL 0620
000447      IF(CO2-1.0) 35, 40, 55                       DEL 0630
000452      35 A1 = A1 +A2*Z                               DEL 0640
000455      GO TO 60                                        DEL 0650
000456      40 IF(A2-ARS(A1)) 45, 45, 50                 DEL 0660
000462      45 A1 = A1 +A2*Z                               DEL 0670
000465      GO TO 60                                        DEL 0680
000466      50 A1 = A1 -A2*Z                               DEL 0690
000471      GO TO 60                                        DEL 0700
000472      55 CONTINUE                                    DEL 0710
000472      IF(CO2.NE.2.0) GO TO 60                      DEL 0720
000474      MA=K/2.                                         DEL 0730
000500      MA2=(K+1)/2                                    DEL 0740
000503      QQ=1.                                           DEL 0750
000505      IF(MA.EQ.MA2)QQ=-1.                             DEL 0760
000510      A1=A1+A2*QQ                                     DEL 0770
000513      60 CONTINUE                                    DEL 0780
000513      FIX=1.                                           DEL 0790
000515      IF(IQ.NF.0) FIX =4.                             DEL 0800
000520      PCRIT =FIX*ET*XI*9.8696 /(XL**2)              DEL 0810
000524      C1 =.613                                         DEL 0820
000526      IF(IQ.NF.0) C1 =.613/SQRT(2.)                DEL 0830
000537      XCOEF(1) = -A1                                    DEL 0840
000540      XCOEF(2) = 1. - P/PCRIT + A1**2*EE *AR/(( C1 *XL)**2*PCRIT) DEL 0850
000552      XCOEF(3) = -2.*A1* EE * AR/ (( C1 *XL)**2 *PCRIT) DEL 0860
000557      XCOEF(4) = EE *AR / (( C1 *XL)**2 *PCRIT)     DEL 0870
000564      CALL POLRT(XCOEF,COEF,3,RR,RI,IER)             DEL 0880
000574      IF(IPRINT.EQ.0) GOTO 75                       DEL 0890
000575      PRINT 65,J,K,IER                                DEL 0900
000612      65 FORMAT(/,* I =*I5,* J =*I5,* IER=*I4)     DEL 0910
000612      PRINT 70,RR                                    DEL 0920
000623      PRINT 70,RI                                    DEL 0930

```

000634	70	FORMAT(10E12.4)	DEL 0940
000634	75	CONTINUE	DEL 0950
000634		XMS(J,K) = PCRIT/P -1.	DEL 0960
000644		DO 80 I=1,3	DEL 0970
000646		IF(RI(I).NE.0.) GOTO 80	DEL 0980
000650		SI = A1 / RR(I)	DEL 0990
000653		IF(SI.GF.0.) RQ = RR(1)	DEL 1000
000657	80	CONTINUE	DEL 1010
000661		DEFL(J,K) = RQ	DEL 1020
000670		XMS2(J,K)=- (P-PCRIT - ((RQ-A1)/(C1 *XL))**2*EE*AR)	DEL 1030
000703		DMA(J,K) = C1 *XL*SQRT(P/(EE*AR))	DEL 1040
000722		PCR(J,K) = PCRIT	DEL 1050
000727		RETURN	DEL 1060
000730		END	DEL 1070

SURPROGRAM LENGTH

001623

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

5	-	000734	10	-	000736	15	-	000261	20	-	000307
30	-	000317	35	-	000452	40	-	000456	45	-	000462
50	-	000466	55	-	000472	60	-	000513	65	-	000754
70	-	000761	75	-	000634	80	-	000657			

BLOCK NAMES AND LENGTHS

BLOK	-	000502	BLOCKA	-	001713	BLOCKC	-	000502
------	---	--------	--------	---	--------	--------	---	--------

VARIABLE ASSIGNMENTS

AA	-	001574	AAA	-	001576	AR	-	000000C02	A7	-	001601
A2	-	000003	BB	-	001575	COD	-	001711C02	COEF	-	001064
C02	-	001712C02	C1	-	001617	D	-	000001C02	DEFL	-	000000C03
DET	-	001600	DMA	-	000000C01	EE	-	001572	EP	-	001555
ER	-	001570	ET	-	001610	FIX	-	001615	I	-	001571
IEP	-	001620	IPRINT	-	001565	IQ	-	000002	II	-	001566
J	-	000000	K	-	000001	MA	-	001612	MA2	-	001613
PCR	-	000002C02	PCRIT	-	001616	QQ	-	001614	RT	-	001073
RQ	-	001622	RR	-	001070	SI	-	001621	SIG	-	001553
SIGD	-	001604	SIGE	-	001607	SIGL	-	001606	SIG1X	-	001567
SIG3	-	001605	STRA1	-	001076	T	-	000504C02	TIME	-	001577
XATD	-	001557	XCOEF	-	001060	XK	-	001573	XN	-	001602
XMS	-	000505C02	XMS2	-	001207C02	Z	-	001611	ZI	-	001603

START OF CONSTANTS

000732

START OF TEMPORARIES

000764

START OF INDIRECTS

001045

UNUSED COMPILER SPACE

105700

```

SUBROUTINE POLRT(XCOF,COF,M,ROOTR,ROOTI,IER)
C
C .....
C SUPROUTINE POLRT
C
C PURPOSE
C   COMPUTES THE REAL AND COMPLEX ROOTS OF A REAL POLYNOMIAL
C
C USAGE
C   CALL POLRT(XCOF,COF,M,ROOTR,ROOTI,IER)
C
C DESCRIPTION OF PARAMETERS
C   XCOF -VECTOR OF M+1 COEFFICIENTS OF THE POLYNOMIAL
C         ORDERED FROM SMALLEST TO LARGEST POWER
C   COF   -WORKING VECTOR OF LENGTH M+1
C   M     -ORDER OF POLYNOMIAL
C   ROOTR -RESULTANT VECTOR OF LENGTH M CONTAINING THE
C         CORRESPONDING IMAGINARY ROOTS OF THE POLYNOMIAL
C   IER   -ERROR CODE WHERE
C         IER=0 NO ERROR
C         IER=1 M LESS THAN ONE
C         IER=2 M GREATER THAN 36
C         IER=3 UNABLE TO DETERMINE ROOT WITH 500 ITERATIONS
C         IER=4 HIGH ORDER COEFFICIENT IS ZERO
C
C REMARKS
C   LIMITED TO 36TH ORDER POLYNOMIAL OR LESS
C   FLOATING POINT OVERFLOW MAY OCCUR FOR HIGH ORDER POLYNOMIALS
C   BUT WILL NOT AFFECT THE ACCURACY OF THE RESULTS
C
C SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
C   NONE
C
C METHOD
C   NEWTON-RAPHSON ITERATIVE TECHNIQUE. THE FINAL ITERATIONS
C   ON EACH ROOT ARE PERFORMED USING THE ORIGINAL POLYNOMIAL
C   RATHER THAN THE REDUCED POLYNOMIAL TO AVOID ACCUMULATED
C   ERRORS IN THE REDUCED POLYNOMIAL.
C
C .....
C
000007 DIMENSION XCOF(1),COF(1),ROOTR(1),ROOTI(1)
000007 DOUBLE PRECISION XU,YU,X,Y,XPR,YPR,UX,UY,V,YT,XT,U,XI2,YI2,SUMSQ,
10X,DY,TEMP,ALPHA
C
C .....

```


	C		ROOT0470
	C	IF A DOUBLE PRECISION VERSION OF THIS ROUTINE IS DESIRED, THE	ROOT0480
	C	C IN COLUMN ONE SHOULD BE REMOVED FROM THE DOUBLE PRECISION	ROOT0490
	C	STATEMENT WHICH FOLLOWS.	ROOT0500
	C		ROOT0510
	C	DOUBLE PRECISION XCOF, COF, ROOTK, ROOTI	ROOT0520
	C		ROOT0530
	C	THE C MUST ALSO BE REMOVED FROM DOUBLE PRECISION STATEMENTS	ROOT0540
	C	APPEARING IN OTHER ROUTINES USED IN CONJUNCTION WITH THIS ROUTINE.	ROOT0550
	C	THE DOUBLE PRECISION VERSION MAY BE MODIFIED BY CHANGING THE	ROOT0560
	C	CONSTANT IN STATEMENT 7R TO 1.0D-12 AND IN STATEMENT 122 TO	ROOT0570
	C	1.0D-10 THIS WILL PROVIDE HIGHER PRECISION RESULTS AT THE COST	ROOT0580
	C	OF EXECUTION TIME	ROOT0590
	C		ROOT0600
	C		ROOT0610
	C		ROOT0620
000007		IFIT=0	ROOT0630
000010		N=M	ROOT0640
000011		IER=0	ROOT0650
000011		IF (XCOF(N+1)) 5, 20, 5	ROOT0660
000013		5 IF (N) 10, 10, 30	ROOT0670
	C		ROOT0680
	C	SET ERROR CODE TO 1	ROOT0690
	C		ROOT0700
000015		10 IER=1	ROOT0710
000016		15 RETURN	ROOT0720
	C		ROOT0730
	C	SET ERROR CODE TO 4	ROOT0740
	C		ROOT0750
000017		20 IER=4	ROOT0760
000020		GO TO 15	ROOT0770
	C		ROOT0780
	C	SET ERROR CODE TO 2	ROOT0790
	C		ROOT0800
000021		25 IER=2	ROOT0810
000022		GO TO 15	ROOT0820
000023		30 IF (N-36) 35, 35, 25	ROOT0830
000026		35 NX=N	ROOT0840
000030		NXX=N+1	ROOT0850
000032		N2=1	ROOT0860
000033		KJ1=N+1	ROOT0870
000034		DO 40 L=1, KJ1	ROOT0880
000035		MT=KJ1-L+1	ROOT0890
000040		40 COF(MT)=XCOF(L)	ROOT0900
	C		ROOT0910
	C	SET INITIAL VALUES	ROOT0920
	C		ROOT0930

000045	45	XC=0.00500101	ROOT0940
000047		Y0=0.01000101	ROOT0950
	C		ROOT0960
	C	ZERO INITIAL VALUE COUNTER	ROOT0970
	C		ROOT0980
000051		IN=0	ROOT0990
000052	50	X=X0	ROOT1000
	C		ROOT1010
	C	INCRFMET INITIAL VALUES AND COUNTER	ROOT1020
	C		ROOT1030
000055		X0=10.0*Y0	ROOT1040
000062		Y0=10.0*X	ROOT1050
	C		ROOT1060
	C	SET X AND Y TO CURRENT VALUE	ROOT1070
	C		ROOT1080
000070		X=X0	ROOT1090
000072		Y=Y0	ROOT1100
000075		IN=IN+1	ROOT1110
000076		GO TO 60	ROOT1120
000077	55	IF I=1	ROOT1130
000100		XPR=X	ROOT1140
000103		YPR=Y	ROOT1150
	C		ROOT1160
	C	EVALUATE POLYNOMIAL AND DERIVATIVES	ROOT1170
	C		ROOT1180
000105	60	ICT=0	ROOT1190
000106	65	UX=0.0	ROOT1200
000110		UY=0.0	ROOT1210
000111		V=0.0	ROOT1220
000113		YT=0.0	ROOT1230
000114		XT=1.0	ROOT1240
000116		U=COF(N+1)	ROOT1250
000121		IF(U) 70, 145, 70	ROOT1260
000123	70	DO 75 I=1,N	ROOT1270
000125		L=N-I+1	ROOT1280
000130		TEMP=COF(L)	ROOT1290
000133		XT2=X*XT-Y*YT	ROOT1300
000150		YT2=X*YT+Y*XT	ROOT1310
000166		U=U+TEMP*XT2	ROOT1320
000200		V=V+TEMP*YT2	ROOT1330
000212		FI=I	ROOT1340
000213		UX=UX+FI*XT1*TEMP	ROOT1350
000230		UY=UY-FI*YT*TEMP	ROOT1360
000244		X1=XT2	ROOT1370
000247	75	YT=YT2	ROOT1380
000254		SUMSQ=UX*UX+UY*UY	ROOT1390
000267		IF(SUMSQ) 80, 120, 80	ROOT1400

000271	80	DX=(V*UY-U*UX)/SUMSQ	ROOT1410
000322		X=X+DX	ROOT1420
000331		DY=-(U*UY+V*UX)/SUMSQ	ROOT1430
000361		Y=Y+DY	ROOT1440
000370	85	IF(DABS(DY)+DABS(DX)-1.0D-05) 110, 90, 90	ROOT1450
	C		ROOT1460
	C	STEP ITERATION COUNTER	ROOT1470
	C		ROOT1480
000417	90	ICT=ICT+1	ROOT1490
000421		IF(ICT-500) 65, 95, 95	ROOT1500
000423	95	IF(IFIT) 110, 100, 110	ROOT1510
000424	100	IF(IN-5) 50, 105, 105	ROOT1520
	C		ROOT1530
	C	SET ERROR CODE TO 3	ROOT1540
	C		ROOT1550
000427	105	IER=3	ROOT1560
000430		GO TO 15	ROOT1570
000431	110	DO 115 L=1,NXX	ROOT1580
000433		MT=KJ1-L+1	ROOT1590
000436		TFMP=XCOF(MT)	ROOT1600
000441		XCOF(MT)=COF(L)	ROOT1610
000444	115	COF(L)=TFMP	ROOT1620
000453		ITEMP=N	ROOT1630
000454		N=NX	ROOT1640
000455		NX=ITEMP	ROOT1650
000456		IF(IFIT) 130, 55, 130	ROOT1660
000460	120	IF(IFIT) 125, 50, 125	ROOT1670
000461	125	X=XPR	ROOT1680
000464		Y=YPR	ROOT1690
000466	130	IFIT=0	ROOT1700
000467	135	IF(DABS(Y/X)-1.0D-04) 150, 140, 140	ROOT1710
000517	140	ALPHA= X/X	ROOT1720
000525		SUMSQ=X*X+Y*Y	ROOT1730
000540		N=N-2	ROOT1740
000542		GO TO 155	ROOT1750
000542	145	X=0.0	ROOT1760
000544		NX=NX-1	ROOT1770
000545		NXX=NXX-1	ROOT1780
000546	150	Y=0.0	ROOT1790
000550		SUMSQ=0.0	ROOT1800
000551		ALPHA=X	ROOT1810
000554		N=N-1	ROOT1820
000555	155	COF(2)=COF(2)+ALPHA*COF(1)	ROOT1830
000566	160	DO 165 I=2,N	ROOT1840
000570	165	COF(L+1)=COF(L+1)+ALPHA*COF(L)-SUMSQ*COF(L-1)	ROOT1850
000615	170	ROOTI(N2)=Y	ROOT1860
000622		ROOTR(N2)=X	ROOT1870

ROOT1880
ROOT1890
ROOT1900
ROOT1910
ROOT1920
ROOT1930
ROOT1940

000626
000627
000631
000634
000635
000636
000640
N2=N2+1
IF (SUMSQ) 175, 180, 175
Y=-Y
175
SUMSQ=0.0
GO TO 170
180 IF (N) 15, 15, 45
END

SUBPROGRAM LENGTH
000750

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

5	-	000013	10	-	000015	15	-	000016	20	-	000017
25	-	000021	30	-	000023	35	-	000026	45	-	000045
50	-	000052	55	-	000077	60	-	000105	65	-	000106
70	-	000123	80	-	000271	85	-	000370	90	-	000417
95	-	000423	100	-	000424	105	-	000427	110	-	000431
120	-	000460	125	-	000461	130	-	000466	135	-	000467
140	-	000517	145	-	000542	150	-	000546	155	-	000555
160	-	000566	165	-	000570	170	-	000615	175	-	000631
180	-	000636									

BLOCK NAMES AND LENGTHS

VARIABLE ASSIGNMENTS

ALPHA	-	000731	DX	-	000723	DY	-	000725	FI	▼	000746
I	-	000745	ICT	-	000744	IFIT	-	000733	IN	▼	000743
ITEMP	-	000747	KJ1	-	000740	L	-	000741	MT	-	000742
N	-	000734	NX	-	000735	NXX	-	000736	N2	-	000737
SUMSQ	-	000721	TEMP	-	000727	U	-	000713	UX	-	000701
UY	-	000703	V	-	000705	X	-	000671	X0	-	000665
XPR	-	000675	XT	-	000711	XT2	-	000715	Y	-	000673
Y0	-	000667	YPR	-	000677	YT	-	000707	YT2	-	000717

START OF CONSTANTS
000642

START OF TEMPORARIES
000653

START OF INDIRECTS
000661

UNUSED COMPILER SPACE
106100

CORE P 13.13.42. NORMAL CONTRC 000100 07
 ---TIME---LOAD MODE --L1--L2---TYPE---USER---CALL---FWA LOAD---LW1

FWA LOADER 136562 FWA TABLES 135336

--PROGRAM---ADDRESS--

FATB02 010243

--LAELED---COMMON--

BLOCKA 000100
 BLOK 002013
 BLOCKC 002515
 BLOCK 003217

RUILD 055211
 COUNT 055742
 DEL 055751

BLOK 002013
 BLOCKA 000100
 BLOCKC 002515

POLRT 057574
 SYSTEM 060544
 INPUTC 061532
 OUTPTC 062072
 SORT 062464
 MATRIX 063657

SCOPE2 060544

IROW 062527
 ICOL 063203

FRROR 065471
 ALNLOG 065604
 RBAREX 065673
 EXP 065757
 DAHS 066036
 SIOS 066053
 GETBA 066456
 KPAKER 066475
 KODER 067532
 MASCNT 070730

IROW 062527
 ICOL 063203

RRAIEX 071345

--ENTRY-----ADDRESS--

FATB02 010244

RUILD 055221

REFERENCES

SNATCH 055241

FATB02	012375	012401	012405	012411	012430	01
	012451	013654	013660	013664	013670	
FATB02	012106	012112	012120	012124	012130	01
	012726	012734	012740	012744	012750	01
	013540	013544	013550	013554	013625	01
	014153	014157	014163			

COUNT 055743

RUILD 055267

DEL 055756

FATB02 014523 014531

POLRT 057575

DEL 056540

[illegible]

MATRIX	063664	FATB02	012064	012070	012074	012102	012140	012143
			012164	012170	012176	012202	012210	012222
			012234	012242	012246	012254	012302	012310
			012423	012455	012463	012754	012757	012763
			012775	013003	013007	013015	013034	013042
			013064	013070	013076	013102	013110	013147
			013243	013247	013253	013256	013513	013521
			013563	013567	013575	013601	013607	013613
			013635	013643	013674	013702	013711	013720
			013770	013777	014003	014007	014013	014167
			014176	014204	014210	014216	014243	014251
		DEL	056237	056242				
ERROR	065472	BUILD	055346	055376				
ALOG	065610	DEL	056130	056145	056160	056176	056221	
		RBAREX	065717					
ALOG10	065605							
RBAREX	065674	DEL	056211	056357	056374	056377		
EXP	065760	DEL	056251					
		RBAREX	065722					
DABS	066037	POLRT	060165	060173	060277			
BKSPRU.	066352							
FJ7BAK.	066363							
POSFIL.	066421	OUTPTC	062131					
RNPRU.	066431							
DAT.	066455	INPUTC	061541					
		OUTPTC	062101					
CI01.	066317							
OPEN.	066055	SYSTEM	061222					
		INPUTC	061561					
		OUTPTC	062121					
SIO.	066171	INPUTC	061612					
		OUTPTC	062167					
IRFA	066453	INPUTC	061536					
		OUTPTC	062076					
IRFB	066454	INPUTC	061537					

		OUTPTC	06	'7		
GETBA	066456	INPUTC	061547			
		OUTPIC	062107			
KRAKER	066476	INPUTC	061566	061543		
BCRA	067526	INPUTC	061611			
RDNX	067242	INPUTC	061607	061617	061624	
ARLI	067531	INPUTC	061555	061611	061605	
KODER	067533	OUTPTC	062103	062140		
ARLO	070727	OUTPTC	062115	062141	062165	
WTNX	070515	OUTPTC	062202			
MASONT	070731	MATRIX	063711			
RRATIX	071346	RBAREX	065704			

-----UNSATISFIED EXTERNALS-----

REFERENCES

NO. OF GRIDS = 8
NO. RODS ACROSS FLATS = 9

TOTAL NO. OF FUEL RODS PER ASSEMBLY = 217
FUEL ROD DIAMETER = .250
FUEL ROD WALL THICKNESS = .0160
PITCH TO DIAMETER RATIO = 1.160
FUEL ROD THERMAL COEFF. OF EXPANSION = .000010500
PRE-LOAD IN SPRINGFINGER SUPPORT OF ROD = 3.0 LBS.
NO. SUPPORTS AT EACH GRID PER FUEL ROD = 3
COEF. OF FRICTION BETWEEN SPRINGFINGER AND FUEL ROD = .32

TEMPERATURES BETWEEN REGIONS
SURLENGTH

1	5	742	755	765	771	773	776	780	783	785
	788	789	790	791	790	785	765	735		
2	730	785	810	829	839	846	852	859	865	870
	874	876	881	882	880	870	830	770		
3	745	827	865	894	809	919	924	939	947	955
	963	965	971	974	970	955	895	805		
4	760	870	920	958	978	992	1005	1018	1030	1040
	1048	1056	1062	1065	1060	1040	960	840		
5	781	780	918	951	975	989	1001	1015	1027	1037
	1047	1055	1059	1060	1047	1027	955	867		
6	802	870	917	945	971	985	997	1013	1024	1035
	1046	1054	1053	1055	1034	1013	950	894		
7	823	870	915	938	968	982	994	1010	1020	1032
	1044	1052	1053	1050	1020	1000	945	920		

MODULUS OF ELASTICITY -BY REGION
SUBLLENGTH

1	22020000	21750000	21620000	21520000	21470000	21440000	21410000	21370000	21340000	21320000
	21290000	21280000	21270000	21260000	21270000	21320000	21520000	21820000		
2	21870000	21320000	21060000	20868400	20764400	20691600	20630000	20560000	20500000	20450000
	20410000	20390000	20340000	20330000	20350000	20450000	20858000	21470000		
3	21720000	20889200	20500000	20210000	21076400	19960000	19910000	19760000	19680000	19600000
	19520000	19500000	19440000	19410000	19450000	19600000	20200000	21118000		
4	21570000	20450000	19950000	19570000	19370000	19230000	19125000	19060000	19000000	18950000
	18910000	18882000	18864000	18855000	18870000	18950000	19550000	20754000		
5	21360000	21370000	19970000	19640000	19400000	19260000	19145000	19075000	19015000	18965000
	18915000	18885000	18873000	18870000	18915000	19015000	19600000	20480000		
6	21149200	20450000	19980000	19700000	19440000	19300000	19180000	19085000	19030000	18975000
	18920000	18888000	18891000	18885000	18980000	19085000	19650000	20210000		
7	20930800	20450000	20000000	19770000	19470000	19330000	19210000	19100000	19050000	18990000
	18930000	18894000	18891000	18900000	19050000	19150000	19700000	19950000		

DISPLACEMENT OF CAN

9.0000E-04 1.4000E-03 7.0000E-04 0. -1.2600E-03 -1.3400E-03 -3.9000E-03 -3.7000E-03
1.8000E-02 5.0000E-03 -7.0000E-03 -1.2000E-02 -3.0000E-03 1.9000E-02 5.3000E-02 8.6000E-02

REGION NO.

NO. RODS IN REGION

A-66

2	10
3	11
4	12
5	13
6	14
7	15
8	16
9	17
10	16
11	15
12	14
13	13
14	12
15	11
16	10
17	9

MOMENT OF INERTIA OF INDIVIDUAL FUEL ROD= 8.0842E-05
 AREA OF INDIVIDUAL FUEL ROD= 1.1762E-02
 MOMENT OF INERTIA OF SECTION OF FUEL RODS= 1.7551E-02

TEMPERATURE GRADIENTS
 SURLENGTH

1	107.5	51.8	39.8	19.9	11.9	11.9	15.9	11.9	8.0	11.9
	4.0	4.0	4.0	-4.0	-19.9	-79.6	-119.5			
2	219.0	99.5	75.7	39.8	27.9	23.9	27.9	23.9	19.9	15.9
	8.0	19.9	4.0	-8.0	-39.8	-159.3	-238.9			

3	3.5	151.3	115.5	-338.4	438	19.9	59.7	31.9	31.9	31.9
	8.0	23.9	11.9	-15.9	-59.7	-238.9	-358.4			
4	438.0	199.1	151.3	79.6	55.7	51.8	51.8	47.8	39.8	31.9
	31.9	23.9	11.9	-19.9	-79.6	-318.5	-477.8			
5	-4.0	549.5	131.4	95.6	55.7	47.8	55.7	47.8	39.8	39.8
	31.9	15.0	4.0	-51.8	-79.6	-286.7	-350.4			
6	270.8	187.1	111.5	103.5	55.7	47.8	63.7	43.8	43.8	43.8
	31.9	-4.0	8.0	-83.6	-83.6	-250.8	-223.0			
7	187.1	179.2	91.6	119.5	55.7	47.8	63.7	39.8	47.8	47.8
	31.9	4.0	-11.9	-119.5	-79.6	-219.0	-99.5			

AVE. TEMPERATURE GRADIENT ACROSS ASSEMBLY

SUBLENGTH GRADIENT

1	5.9
2	12.0
3	20.3
4	24.8
5	27.1
6	25.8
7	26.1

LENGTHS OF SUBLENGTHS

1	10.0
2	10.0
3	10.0
4	10.0
5	10.0
6	10.0
7	10.0

RELATIVE DISPLACEMENTS

I	THETA(I)	DELTA(I)
1	6.2311E-04	3.1156E-03
2	1.2649E-03	6.3245E-03
3	2.1328E-03	1.0664E-02
4	2.6005E-03	1.3003E-02
5	2.8429E-03	1.4214E-02
6	2.7094E-03	1.3547E-02
7	2.7457E-03	1.3728E-02

TOTAL THERMAL DISPLACEMENTS

SUBLENGTH DELTA Y THETA X

1	0.	0.
2	3.1156E-03	6.2311E-04
3	1.5671E-02	1.8880E-03
4	4.5216E-02	4.0209E-03
5	9.8427E-02	6.6214E-03
6	1.7886E-01	9.4643E-03
7	2.8705E-01	1.2174E-02
8	4.2251E-01	1.4919E-02

STIFFNESS MATRIX - SUBLENGTH NO. 1

1	6.9270E+02	3.4635E+02	-1.0391E+02	1.0391E+02
2	3.4635E+02	6.9270E+02	-1.0391E+02	1.0391E+02
3	-1.0391E+02	-1.0391E+02	2.0781E+01	-2.0781E+01
4	1.0391E+02	1.0391E+02	-2.0781E+01	2.0781E+01

STIFFNESS MATRIX - SUBLENGTH NO. 2

1	6.6775E+02	3.3387E+02	-1.0016E+02	1.0016E+02
2	3.3387E+02	6.6775E+02	-1.0016E+02	1.0016E+02
3	-1.0016E+02	-1.0016E+02	2.0032E+01	-2.0032E+01
4	1.0016E+02	1.0016E+02	-2.0032E+01	2.0032E+01

STIFFNESS MATRIX - SUBLENGTH NO. 3

1	6.4507E+02	3.2253E+02	-9.6760E+01	9.6760E+01
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2	3.2253E+02	6.4507E+02	9.6760E+01	9.6760E+01
3	-9.6760E+01	-9.6760E+01	1.9352E+01	-1.9352E+01
4	9.6760E+01	9.6760E+01	-1.9352E+01	1.9352E+01

STIFFNESS MATRIX - SUBLENGTH NO. 4

1	6.2303E+02	3.1152E+02	-9.3455E+01	9.3455E+01
2	3.1152E+02	6.2303E+02	-9.3455E+01	9.3455E+01
3	-9.3455E+01	-9.3455E+01	1.8691E+01	-1.8691E+01
4	9.3455E+01	9.3455E+01	-1.8691E+01	1.8691E+01

STIFFNESS MATRIX - SUBLENGTH NO. 5

1	6.2474E+02	3.1237E+02	-9.3712E+01	9.3712E+01
2	3.1237E+02	6.2474E+02	-9.3712E+01	9.3712E+01
3	-9.3712E+01	-9.3712E+01	1.8742E+01	-1.8742E+01
4	9.3712E+01	9.3712E+01	-1.8742E+01	1.8742E+01

STIFFNESS MATRIX - SUBLENGTH NO. 6

1	6.2393E+02	3.1196E+02	-9.3589E+01	9.3589E+01
2	3.1196E+02	6.2393E+02	-9.3589E+01	9.3589E+01
3	-9.3589E+01	-9.3589E+01	1.8718E+01	-1.8718E+01
4	9.3589E+01	9.3589E+01	-1.8718E+01	1.8718E+01

STIFFNESS MATRIX - SUBLENGTH NO. 7

1	6.2442E+02	3.1221E+02	-9.3662E+01	9.3662E+01
2	3.1221E+02	6.2442E+02	-9.3662E+01	9.3662E+01
3	-9.3662E+01	-9.3662E+01	1.8732E+01	-1.8732E+01
4	9.3662E+01	9.3662E+01	-1.8732E+01	1.8732E+01

CODE MATRIX

1	2	9	10
2	3	10	11
3	4	11	12
4	5	12	13

5	6	13	14
6	7	14	15
7	8	15	16

TOTAL STIFFNESS

1	6.9270E+02	3.4635E+02	0.	0.	0.	0.	0.	0.	0.	0.	0.
-1.0391E+02	1.0391E+02	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
2	3.4635E+02	1.3604E+03	3.3387E+02	0.	0.	0.	0.	0.	0.	0.	0.
-1.0391E+02	3.7432E+00	1.0016E+02	0.	0.	0.	0.	0.	0.	0.	0.	0.
3	0.	3.3387E+02	1.3128E+03	3.2253E+02	0.	0.	0.	0.	0.	0.	0.
0.	-1.0016E+02	3.4018E+00	9.6760E+01	0.	0.	0.	0.	0.	0.	0.	0.
4	0.	0.	3.2253E+02	1.2681E+03	3.1152E+02	0.	0.	0.	0.	0.	0.
0.	0.	-9.6760E+01	3.3050E+00	9.3455E+01	0.	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	3.1152E+02	1.2478E+03	3.1237E+02	0.	0.	0.	0.	0.
0.	0.	0.	-9.3455E+01	-2.5672E-01	9.3712E+01	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	3.1237E+02	1.2487E+03	3.1196E+02	0.	0.	0.	0.
0.	0.	0.	0.	-9.3712E+01	1.2266E-01	9.3589E+01	0.	0.	0.	0.	0.
7	0.	0.	0.	0.	0.	3.1196E+02	1.2483E+03	3.1221E+02	0.	0.	0.
0.	0.	0.	0.	0.	0.	-9.3589E+01	-7.3335E-02	9.3662E+01	0.	0.	0.
8	0.	0.	0.	0.	0.	0.	3.1221E+02	6.2442E+02	0.	0.	0.
0.	0.	0.	0.	0.	0.	0.	-9.3662E+01	9.3662E+01	0.	0.	0.
9	-1.0391E+02	-1.0391E+02	0.	0.	0.	0.	0.	0.	0.	0.	0.
2.0781E+01	-2.0781E+01	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
10	1.0391E+02	3.7432E+00	-1.0016E+02	0.	0.	0.	0.	0.	0.	0.	0.
-2.0781E+01	4.0013E+01	-2.0032E+01	0.	0.	0.	0.	0.	0.	0.	0.	0.
11	0.	1.0016E+02	3.4018E+00	-9.6760E+01	0.	0.	0.	0.	0.	0.	0.
0.	-2.0032E+01	3.9384E+01	-1.9352E+01	0.	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	9.6760E+01	3.3050E+00	-9.3455E+01	0.	0.	0.	0.	0.	0.
0.	0.	-1.9352E+01	3.8043E+01	-1.8691E+01	0.	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	9.3455E+01	-2.5672E-01	-9.3712E+01	0.	0.	0.	0.	0.
0.	0.	0.	-1.8691E+01	3.7433E+01	-1.8742E+01	0.	0.	0.	0.	0.	0.

14	0.	0.	0.	0.	0.	9.3712E+01	1.2266E-01	-9.3589E+01	0.
0.	0.	0.	0.	0.	0.	-1.8742E+01	3.7460E+01	-1.8718E+01	0.
15	0.	0.	0.	0.	0.	0.	9.3589E+01	-7.3335E-02	-9.3662E+01
0.	0.	0.	0.	0.	0.	0.	-1.8718E+01	3.7450E+01	-1.8732E+01
16	0.	0.	0.	0.	0.	0.	0.	9.3662E+01	9.3662E+01
0.	0.	0.	0.	0.	0.	0.	0.	-1.8732E+01	1.8732E+01

STIFFNESS MATRIX - SUBLENGTH NO. 1

1	1.5032E+05	7.5158E+04	-2.2547E+04	2.2547E+04
2	7.5158E+04	1.5032E+05	-2.2547E+04	2.2547E+04
3	-2.2547E+04	-2.2547E+04	4.5095E+03	-4.5095E+03
4	2.2547E+04	2.2547E+04	-4.5095E+03	4.5095E+03

STIFFNESS MATRIX - SUBLENGTH NO. 2

1	1.4490E+05	7.2450E+04	-2.1735E+04	2.1735E+04
2	7.2450E+04	1.4490E+05	-2.1735E+04	2.1735E+04
3	-2.1735E+04	-2.1735E+04	4.3470E+03	-4.3470E+03
4	2.1735E+04	2.1735E+04	-4.3470E+03	4.3470E+03

STIFFNESS MATRIX - SUBLENGTH NO. 3

1	1.3998E+05	6.9990E+04	-2.0997E+04	2.0997E+04
2	6.9990E+04	1.3998E+05	-2.0997E+04	2.0997E+04
3	-2.0997E+04	-2.0997E+04	4.1994E+03	-4.1994E+03
4	2.0997E+04	2.0997E+04	-4.1994E+03	4.1994E+03

STIFFNESS MATRIX - SUBLENGTH NO. 4

1	1.3520E+05	6.7599E+04	-2.0280E+04	2.0280E+04
2	6.7599E+04	1.3520E+05	-2.0280E+04	2.0280E+04
3	-2.0280E+04	-2.0280E+04	4.0559E+03	-4.0559E+03
4	2.0280E+04	2.0280E+04	-4.0559E+03	4.0559E+03

STIFFNESS MATRIX - RIX - SUBLENGTH NO. 5

1	1.3557E+05	6.7785E+04	-2.0335E+04	2.0335E+04
2	6.7785E+04	1.3557E+05	-2.0335E+04	2.0335E+04
3	-2.0335E+04	-2.0335E+04	4.0671E+03	-4.0671E+03
4	2.0335E+04	2.0335E+04	-4.0671E+03	4.0671E+03

STIFFNESS MATRIX - SUBLENGTH NO. 6

1	1.3539E+05	6.7696E+04	-2.0309E+04	2.0309E+04
2	6.7696E+04	1.3539E+05	-2.0309E+04	2.0309E+04
3	-2.0309E+04	-2.0309E+04	4.0618E+03	-4.0618E+03
4	2.0309E+04	2.0309E+04	-4.0618E+03	4.0618E+03

STIFFNESS MATRIX - SUBLENGTH NO. 7

1	1.3550E+05	6.7749E+04	-2.0325E+04	2.0325E+04
2	6.7749E+04	1.3550E+05	-2.0325E+04	2.0325E+04
3	-2.0325E+04	-2.0325E+04	4.0649E+03	-4.0649E+03
4	2.0325E+04	2.0325E+04	-4.0649E+03	4.0649E+03

CODE MATRIX

3	4	1	11
4	5	11	12
5	6	12	13
6	7	13	14
7	8	14	15
8	9	15	16
9	10	16	2

TOTAL STIFFNESS

1	4.5095E+03	0.	-2.2547E+04	-2.2547E+04	0.	0.	0.	0.	0.
0.	0.	-4.5095E+03	0.	0.	0.	0.	0.	0.	0.
2	0.	4.0649E+03	0.	0.	0.	0.	0.	0.	0.
2.0325E+04	2.0325E+04	0.	0.	0.	0.	0.	0.	-4.0649E+03	0.

3	-2.2547E+04	0.	1.5032E+05	7.5158E+04	0.	0.	0.	0.	0.
0.	0.		2.2547E+04	0.	0.	0.	0.	0.	0.
4	-2.2547E+04	0.	7.5158E+04	2.9522E+05	7.2450E+04	0.	0.	0.	0.
0.	0.		8.1227E+02	2.1735E+04	0.	0.	0.	0.	0.
5	0.	0.	0.	7.2450E+04	2.8488E+05	6.9990E+04	0.	0.	0.
0.	0.		-2.1735E+04	7.3820E+02	2.0997E+04	0.	0.	0.	0.
6	0.	0.	0.	0.	6.9990E+04	2.7518E+05	6.7599E+04	0.	0.
0.	0.		0.	-2.0997E+04	7.1718E+02	2.0280E+04	0.	0.	0.
7	0.	0.	0.	0.	0.	6.7599E+04	2.7077E+05	6.7785E+04	0.
0.	0.		0.	0.	-2.0280E+04	-5.5709E+01	2.0335E+04	0.	0.
8	0.	0.	0.	0.	0.	0.	6.7785E+04	2.7096E+05	0.
6.7696E+04	0.		0.	0.	0.	-2.0335E+04	2.6616E+01	2.0309E+04	0.
9	0.	2.0325E+04	0.	0.	0.	0.	0.	6.7696E+04	0.
2.7089E+05	6.7749E+04	0.	0.	0.	0.	0.	-2.0304E+04	-1.5914E+01	0.
10	0.	2.0325E+04	0.	0.	0.	0.	0.	0.	0.
6.7749E+04	1.3550E+05	0.	0.	0.	0.	0.	0.	-2.0325E+04	0.
11	-4.5095E+03	0.	2.2547E+04	8.1227E+02	-2.1735E+04	0.	0.	0.	0.
0.	0.		8.8565E+03	-4.3470E+03	0.	0.	0.	0.	0.
12	0.	0.	0.	2.1735E+04	7.3820E+02	-2.0997E+04	0.	0.	0.
0.	0.		-4.3470E+03	8.5464E+03	-4.1994E+03	0.	0.	0.	0.
13	0.	0.	0.	0.	2.0997E+04	7.1718E+02	-2.0280E+04	0.	0.
0.	0.		0.	-4.1994E+03	8.2553E+03	-4.0559E+03	0.	0.	0.
14	0.	0.	0.	0.	0.	2.0280E+04	-5.5709E+01	-2.0335E+04	0.
0.	0.		0.	0.	-4.0559E+03	8.1230E+03	-4.0671E+03	0.	0.
15	0.	0.	0.	0.	0.	0.	2.0335E+04	2.6616E+01	0.
-2.0309E+04	0.		0.	0.	0.	-4.0671E+03	8.1289E+03	-4.0618E+03	0.
16	0.	-4.0649E+03	0.	0.	0.	0.	0.	2.0309E+04	0.
-1.5914E+01	-2.0325E+04	0.	0.	0.	0.	0.	-4.0618E+03	8.1267E+03	0.

1 ROD TEMPS. 7.2850E+02 7.4850E+02 7.6000E+02 7.6750E+02 7.7150E+02 7.7450E+02 7.7800E+02 7.8150E+02
7.8400E+02 7.8650E+02 7.8850E+02 7.8950E+02 7.9050E+02 7.9050E+02 7.8750E+02 7.7500E+02
7.5000E+02

LINEAR TEMPS. 7.1618E+02 7.1735E+02 7.1853E+02 7.1971E+02 7.2088E+02 7.2206E+02 7.2324E+02 7.2441E+02
7.2559E+02 7.2676E+02 7.2794E+02 7.2912E+02 7.3029E+02 7.3147E+02 7.3265E+02 7.3382E+02
7.3500E+02

TEMP. DIFF. 1.2324E+01 3.1147E+01 4.1471E+01 4.7794E+01 5.0618E+01 5.2441E+01 5.4765E+01 5.7088E+01
5.8412E+01 5.9735E+01 6.0559E+01 6.0382E+01 6.0206E+01 5.9029E+01 5.4853E+01 4.1176E+01
1.5000E+01

2 ROD TEMPS. 7.5750E+02 7.9750E+02 8.1950E+02 8.3400E+02 8.4250E+02 8.4900E+02 8.5550E+02 8.6200E+02
8.6750E+02 8.7200E+02 8.7500E+02 8.7850E+02 8.8150E+02 8.8100E+02 8.7500E+02 8.5000E+02
8.0000E+02

LINEAR TEMPS. 7.3235E+02 7.3471E+02 7.3706E+02 7.3941E+02 7.4176E+02 7.4412E+02 7.4647E+02 7.4882E+02
7.5118E+02 7.5353E+02 7.5588E+02 7.5824E+02 7.6059E+02 7.6294E+02 7.6529E+02 7.6765E+02
7.7000E+02

TEMP. DIFF. 2.5147E+01 6.2794E+01 8.2441E+01 9.4588E+01 1.0074E+02 1.0488E+02 1.0903E+02 1.1318E+02
1.1632E+02 1.1847E+02 1.1912E+02 1.2026E+02 1.2091E+02 1.1806E+02 1.0971E+02 8.2353E+01
3.0000E+01

3 ROD TEMPS. 7.8600E+02 8.4600E+02 8.7950E+02 8.5150E+02 8.6400E+02 9.2150E+02 9.3150E+02 9.4300E+02
9.5100E+02 9.5900E+02 9.6400E+02 9.6800E+02 9.7250E+02 9.7200E+02 9.6250E+02 9.2500E+02
8.5000E+02

LINEAR TEMPS. 7.4853E+02 7.5206E+02 7.5559E+02 7.5912E+02 7.6265E+02 7.6618E+02 7.6971E+02 7.7324E+02
7.7676E+02 7.8029E+02 7.8382E+02 7.8735E+02 7.9088E+02 7.9441E+02 7.9794E+02 8.0147E+02
8.0500E+02

TEMP. DIFF. 3.7471E+01 9.3941E+01 1.2391E+02 9.2382E+01 1.0135E+02 1.5532E+02 1.6179E+02 1.6976E+02
1.7424E+02 1.7871E+02 1.8018E+02 1.8065E+02 1.8162E+02 1.7759E+02 1.6456E+02 1.2353E+02
4.5000E+01

4 ROD TEMPS. 8.1500E+02 8.9500E+02 9.3900E+02 9.6800E+02 9.8500E+02 9.9850E+02 1.0115E+03 1.0240E+03
1.0350E+03 1.0440E+03 1.0520E+03 1.0590E+03 1.0635E+03 1.0625E+03 1.0500E+03 1.0000E+03
9.0000E+02

LINEAR TEM. , 7.6471E+02 7.6941E+02 7.7412E+02 7.782E+02 7.8353E+02 7.8824E+02 7.9294E 7.9765E+0
8.0235E+02 8.0706E+02 8.1176E+02 8.1647E+02 8.2118E+02 8.2588E+02 8.3059E+02 8.3529E+02
8.4000E+02

TEMP. DIFF. 5.0294E+01 1.2559E+02 1.6488E+02 1.8418E+02 2.0147E+02 2.1626E+02 2.1856E+02 2.2635E+02
2.3265E+02 2.3694E+02 2.4024E+02 2.4253E+02 2.4237E+02 2.3662E+02 2.1941E+02 1.6471E+02
6.0000E+01

5 ROD TEMPS. 7.8050E+02 8.4900E+02 9.3450E+02 9.6300E+02 9.8200E+02 9.9500E+02 1.0080E+03 1.0210E
1.0320E+03 1.0420E+03 1.0510E+03 1.0570E+03 1.0595E+03 1.0535E+03 1.0370E+03 9.9100E+02
9.1100E+02

LINEAR TEMPS. 7.8606E+02 7.9112E+02 7.9618E+02 8.0124E+02 8.0629E+02 8.1135E+02 8.1641E+02 8.2147E+0
8.2653E+02 8.3159E+02 8.3665E+02 8.4171E+02 8.4676E+02 8.5182E+02 8.5688E+02 8.6194E+02
8.6700E+02

TEMP. DIFF. -5.5588E+00 5.7882E+01 1.3832E+02 1.6176E+02 1.7571E+02 1.8365E+02 1.9159E+02 1.9953E+02
2.0547E+02 2.1041E+02 2.1435E+02 2.1529E+02 2.1274E+02 2.0168E+02 1.8012E+02 1.2906E+02
4.4000E+01

6 ROD TEMPS. 8.3600E+02 8.9350E+02 9.3100E+02 9.5800E+02 9.7800E+02 9.9100E+02 1.0050E+03 1.0185E
1.0295E+03 1.0405E+03 1.0500E+03 1.0535E+03 1.0540E+03 1.0445E+03 1.0235E+03 9.8150E+02
9.2200E+02

LINEAR TEMPS. 8.0741E+02 8.1282E+02 8.1824E+02 8.2365E+02 8.2906E+02 8.3447E+02 8.3988E+02 8.4529E+0
8.5071E+02 8.5612E+02 8.6153E+02 8.6694E+02 8.7235E+02 8.7776E+02 8.8318E+02 8.8859E+02
8.9400E+02

TEMP. DIFF. 2.8588E+01 8.0676E+01 1.1276E+02 1.3435E+02 1.4894E+02 1.5653E+02 1.6512E+02 1.7321E+02
1.7879E+02 1.8438E+02 1.8847E+02 1.8656E+02 1.8165E+02 1.6674E+02 1.4032E+02 9.2912E+01
2.8000E+01

7 ROD TEMPS. 8.4650E+02 8.9250E+02 9.2650E+02 9.5300E+02 9.7500E+02 9.8800E+02 1.0020E+03 1.0150E
1.0260E+03 1.0380E+03 1.0480E+03 1.0525E+03 1.0515E+03 1.0350E+03 1.0100E+03 9.7250E+02
9.3250E+02

LINEAR TEMPS. 8.2871E+02 8.3441E+02 8.4012E+02 8.4582E+02 8.5153E+02 8.5724E+02 8.6294E+02 8.6865E+0
8.7435E+02 8.8006E+02 8.8576E+02 8.9147E+02 8.9718E+02 9.0288E+02 9.0859E+02 9.1429E+02

9.2000E+01

TEMP. DIFF.	1.7794E+01	5.8088E+01	8.6382E+01	1.0718E+02	1.2347E+02	1.3076E+02	1.3906E+02	1.4635E+02
	1.5165E+02	1.5794E+02	1.6224E+02	1.6103E+02	1.5432E+02	1.3212E+02	1.0141E+02	5.8206E+01
	1.2500E+01							

CODE MATRIX

1	0	9	17
0	2	17	10
2	0	10	18
0	3	18	11
3	0	11	19
0	4	19	12
4	0	12	20
0	5	20	13
5	0	13	21
0	6	21	14
6	0	14	22
0	7	22	15
7	0	15	23
0	8	23	16

ROD REGION 3. 1

GRID	DELTA	THETA	MOMENT	SHEAR
1	.0180000	.0009000	-2.197278	.031172
2	.0050000	.0014000	-1.986437	-.001123
3	-.0070000	.0007000	-1.989388	-.001021
4	-.0120000	0.0000000	-1.443954	-.079494
5	-.0030000	-.0012600	8.140433	-.118215
6	.0190000	-.0013400	-2.539568	.022682
7	.0530000	-.0039000	1.198221	.239661
8	.0860000	-.0037000	2.630324	-.093662

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COMPONENTS OF DISPLACEMENTS

GRID	DELTA	THETA	MECHANICAL	DELTA	THETA
1	0.0000000	-0.0000000	.018000	.000900	
2	.0564410	-.0112882	-.051441	.012688	
3	.2842952	-.0342827	-.291295	.034983	
4	.7985351	-.0685653	-.810535	.068565	

5	1.7141330	-0.1145543	-1.717133	0.113294
6	2.8575852	-0.1141362	-2.838585	0.112796
7	4.1410946	-0.1425657	-4.088095	0.138666
8	5.6650007	-0.1622155	-5.579001	0.158516

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ROD REGION GRID	0. 2 DELTA	THETA	MOMENT	SHEAR
1	.0180000	.0009000	-1.183661	.031172
2	.0050000	.0014000	-.906265	-.001123
3	-.0070000	.0007000	-1.116585	-.001021
4	-.0120000	0.0000000	-.503368	-.079494
5	-.0030000	-.0012600	-4.843242	-.118215
6	.0190000	-.0013400	7.906402	.022682
7	.0530000	-.0039000	-.040725	.239661
8	.0860000	-.0037000	2.499796	-.003662

COMPONENTS OF DISPLACEMENTS THERMAL		MECHANICAL	
GRID	DELTA	THETA	DELTA
1	0.0000000	-0.0000000	.018000
2	.0271753	-.0054351	-.022175
3	.1337860	-.0158871	-.140786
4	.3720923	-.0317742	-.384092

5	.7943543	-.0526782	-.797354	.051418
6	1.6096127	-.1103734	-1.590613	.109033
7	2.8115963	-.1300233	-2.758596	.126123
8	4.2058972	-.1488369	-4.119897	.145137

ROD REGION GRID	J. 3 DELTA	THETA	MOMENT	SHEAR
1	.0180000	.0009000	-.966457	.031172
2	.0050000	.0014000	-.704711	-.001123
3	-.0070000	.0007000	-.928539	-.001021
4	-.0120000	0.0000000	-.328735	-.079494
5	-.0030000	-.0012600	1.231669	-.118215
6	.0190000	-.0013400	2.289105	.022682
7	.0530000	-.0039000	.156039	.239661
8	.0860000	-.0037000	1.063985	-.093662

COMPONENTS OF DISPLACEMENTS				
THERMAL, GRID	DELTA	THETA	MECHANICAL	
			DELTA	THETA
1	0.0000000	-0.0000000	.018000	.000900
2	.0209041	-.0041808	-.015904	.005581
3	.1024299	-.0121244	-.109430	.012824
4	.2842952	-.0242487	-.296295	.024249

5	.6062178	-.0401358	-.609218	.038876
6	1.0765592	-.0539325	-1.057559	.052592
.7	1.6744153	-.0656388	-1.621415	.061739
8	2.3788822	-.0752546	-2.292882	.071555

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ROD REGION GRID	0. 4	DELTA	THETA	MOMENT	SHEAR
1		.0180000	.0009000	-.604451	.031172
2		.0050000	.0014000	-.438581	-.001123
3		-.0070000	.0007000	6.129495	-.001021
4		-.0120000	0.0000000	-6.842753	-.079494
5		-.0030000	-.0012600	.647202	-.118215
6		.0190000	-.0013400	1.831844	.022682
7		.0530000	-.0039000	-.431237	.239661
8		.0860000	-.0037000	1.520834	-.003662

COMPONENTS OF DISPLACEMENTS THERMAL			MECHANICAL		
GRID	DELTA	THETA	DELTA	THETA	
1	0.0000000	-0.0000000	.018000	.000900	
2	.0104520	-.0020904	-.005452	.003490	
3	.0522602	-.0062712	-.059260	.006971	
4	-.0627122	.0292657	.050712	-.029266	

5	-.3135609	.0209041	.310561	-.022164
6	-.4724318	.0108701	.491432	-.012210
7	-.5267823	-.0000000	.579782	-.003900
8	-.4640702	-.0125424	.550070	.008842

ROD REGIO GRID	VO. 5	DELTA	THETA	MOMENT	SHEAR
1		.0180000	.0009000	-.459649	.031172
2		.0050000	.0014000	-.374004	-.001123
3		-.0070000	.0007000	-7.227282	-.001021
4		-.0120000	0.0000000	6.695363	-.079494
5		-.0030000	-.0012600	.909469	-.118215
6		.0190000	-.0013400	1.961416	.022682
7		.0530000	-.0039000	-.169567	.239661
8		.0860000	-.0037000	.476607	-.093662

COMPONENTS OF DISPLACEMENTS
THERMAL

THERMAL GRID	DELTA	THETA	MECHANICAL	DELTA	THETA
1	0.0000000	-0.0000000		.018000	.000900
2	.0062712	-.0012542		-.001271	.002654
3	.0334465	-.0041808		-.040446	.004881
4	.3051993	-.0501697		-.317199	.050170

5	.8361625	-.0560229	-.839162	.054763
6	1.4256570	-.0618760	-1.406657	.060536
7	2.0736829	-.0677292	-2.020683	.063829
8	2.7802402	-.0735823	-2.694240	.069882

GRID	DELTA	THETA	MOMENT	SHEAR
1	.0180000	.0009000	-.459649	.031172
2	.0050000	.0014000	-.304211	-.001123
3	-.0070000	.0007000	-.217707	-.001021
4	-.0120000	0.0000000	-.318885	-.079494
5	-.0030000	-.0012600	.974947	-.118215
6	.0190000	-.0013400	1.961245	.022682
7	.0530000	-.0039000	-.169465	.239661
8	.0860000	-.0037000	.346079	-.093662

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COMPONENTS OF DISPLACEMENTS

THERMAL GRID	DELTA	THETA	MECHANICAL	DELTA	THETA
1	0.0000000	-0.0000000		.018000	.000900
2	.0062712	-.0012542		-.001271	.002654
3	.0313561	-.0037627	.	-.038356	.004463
4	.0794354	-.0058531		-.091435	.005853

5	.1651421	-.0112882	-.168142	.010028
6	.3031089	-.0163052	-.284109	.014965
7	.4912454	-.0213221	-.438245	.017422
8	.7295517	-.0263391	-.643552	.022639

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ROD REGION GRID	7 DELTA	THETA	MOMENT	SHEAR
1	.0180000	.0009000	-.532050	.031172
2	.0050000	.0014000	-.301603	-.001123
3	-.0070000	.0007000	-.822139	-.001021
4	-.0120000	0.0000000	.355340	-.079494
5	-.0030000	-.0012600	.844350	-.118215
6	.0190000	-.0013400	1.830989	.022682
7	.0530000	-.0039000	-.169669	.239661
8	.0860000	-.0037000	.607135	-.093662

COMPONENTS OF DISPLACEMENTS				
THERMAL				
GRID	DELTA	THETA	MECHANICAL DELTA	THETA
1	0.0000000	-0.0000000	.018000	.000900
2	.0083616	-.0016723	-.003362	.003072
3	.0397177	-.0045989	-.046718	.005299
4	.1170627	-.0108701	-.129063	.010870

5	.2529391	-.0163052	-.255939	.015045
6	.4452565	-.0221583	-.426257	.020818
7	.7002861	-.0288476	-.647286	.024948
8	1.0222086	-.0355369	-.936209	.031837

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ROD REGION 3. 8 GRID	DELTA	THETA	MOMENT	SHEAR
1	.0180000	.0009000	-.459649	.071172
2	.0050000	.0014000	-.304211	-.001123
3	-.0070000	.0007000	-.419974	-.001021
4	-.0120000	0.0000000	-.051498	-.079494
5	-.0030000	-.0012600	.909827	-.118215
6	.0190000	-.0013400	2.026458	.022682
7	.0530000	-.0039000	-.104149	.279661
8	.0860000	-.0037000	.215550	-.093662

COMPONENTS OF DISPLACEMENTS
THERMAL

GRID	DELTA	THETA	MECHANICAL DELTA	THETA
1	0.0000000	-0.0000000	.018000	.000900
2	.0062712	-.0012542	-.001271	.002654
3	.0313561	-.0037627	-.038356	.004463
4	.0857067	-.0071074	-.097707	.007107

5	.1818653	-.0121244	-.184865	.010864
6	.3281938	-.0171413	-.309194	.015801
7	.5226015	-.0217402	-.469602	.017840
8	.7609078	-.0259210	-.674908	.022221

ROD REGIO GRID	NO. 9	DELTA	THETA	MOMENT	SHEAR
1		.0180000	.0009000	-.387247	.031172
2		.0050000	.0014000	-.306820	-.001123
3		-.0070000	.0007000	-.489767	-.001021
4		-.0120000	0.0000000	.078741	-.079494
5		-.0030000	-.0012600	.910185	-.118215
6		.0190000	-.0013400	1.895861	.022682
7		.0530000	-.0039000	-.234678	.239661
8		.0860000	-.0037000	.346079	-.093662

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COMPONENTS OF DISPLACEMENTS			MECHANICAL		
THERMAL GRID	DELTA	THETA	DELTA	THETA	
1	0.0000000	-0.0000000	.018000	.000900	
2	.0041808	-.0008362	.000819	.002236	
3	.0229945	-.0029266	-.029994	.003627	
4	.0689834	-.0062712	-.080983	.006271	

5	.1525996	-.0104520	-.155600	.009192
6	.2780240	-.0146328	-.259024	.013293
7	.4473469	-.0192317	-.394347	.015332
8	.6647492	-.0242487	-.578749	.020549

ROD REGI(NO. 10 GRID	DELTA	THETA	MOMENT	SHEAR
1	.0180000	.0009000	-.459649	.031172
2	.0050000	.0014000	-.164625	-.001123
3	-.0070000	.0007000	-.559560	-.001021
4	-.0120000	0.0000000	.204981	-.079494
5	-.0030000	-.0012600	.779945	-.118215
6	.0190000	-.0013400	1.495861	.022682
7	.0530000	-.0039000	-.234678	.239661
8	.0860000	-.0037000	.346079	-.093662

COMPONENTS OF DISPLACEMENTS

GRID	DELTA	THETA	MECHANICAL DELTA	THETA
1	0.0000000	-0.0000000	.018000	.000900
2	.0062712	-.0012542	-.001271	.002654
3	.0271753	-.0029266	-.034175	.003627
4	.0731642	-.0062712	-.085164	.006271

5	.1525996	-.0096159	-.155600	.008356
6	.2696624	-.0137967	-.250662	.012457
7	.4306237	-.0183956	-.377624	.014496
8	.6396643	-.0234125	-.553664	.019713

ROD REGIL GRID	NO. 11	DELTA	THETA	MOMENT	SHEAR
1		.0180000	.0009000	-.314846	.031172
2		.0050000	.0014000	-.169842	-.001123
3		-.0070000	.0007000	-.294611	-.001021
4		-.0120000	0.0000000	-.195555	-.079494
5		-.0030000	-.0012600	.910542	-.118215
6		.0190000	-.0013400	1.960903	.022682
7		.0530000	-.0039000	-.169260	.239661
8		.0860000	-.0037000	.085022	-.093662

COMPONENTS OF DISPLACEMENTS

THERMAL				MECHANICAL	
GRID	DELTA	THETA		DELTA	THETA
1	0.0000000	-0.0000000		.018000	.000900
2	.0020904	-.0004181		.002910	.001818
3	.0104520	-.0012542		-.017452	.001954
4	.0271753	-.0020904		-.039175	.002090

5	.0648026	-.0054351	-.067803	.004175
6	.1358764	-.0087797	-.116876	.007440
7	.2403967	-.0121244	-.187397	.008224
8	.3783635	-.0154690	-.292364	.011769

RON RFGIO. 10. 12 GRID	DELTA	THETA	MOMENT	SHEAR
1	.0180000	.0009000	-.314846	.031172
2	.0050000	.0014000	-.379221	-.001123
3	-.0070000	.0007000	-.354922	-.001021
4	-.0120000	0.0000000	.204375	-.079494
5	-.0030000	-.0012600	1.041497	-.118215
6	.0190000	-.0013400	2.286626	.022682
7	.0530000	-.0039000	-.299329	.239661
8	.0860000	-.0037000	-.371827	-.093662

COMPONENTS OF DISPLACEMENTS

THERMAL GRID	DELTA	THETA	MECHANICAL	DELTA	THETA
1	0.0000000	-0.0000000		.018000	.000900
2	.0020904	-.0004181		.002910	.001818
3	.0167232	-.0025085		-.023723	.003208
4	.0543506	-.0050170		-.066351	.005017

5	.1170627	-.0075255	-.120063	.006265
6	.2006790	-.0091978	-.181679	.007858
7	.2905665	-.0087797	-.237566	.004880
8	.3804539	-.0091978	-.294454	.005498

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ROD REF GRID	J NO. 13	DELTA	THETA	MOMENT	SHEAR
1		.0180000	.0009000	-.314846	.031172
2		.0050000	.0014000	-.100049	-.001123
3		-.0070000	.0007000	-.431826	-.001021
4		-.0120000	0.0000000	.197466	-.079494
5		-.0030000	-.0012600	1.042034	-.118215
6		.0190000	-.0013400	1.895091	.022682
7		.0530000	-.0039000	.157367	.239661
8		.0860000	-.0037000	-.632884	-.093662

COMPONENTS OF DISPLACEMENTS

THERMAL GRID	DELTA	THETA	MECHANICAL	DELTA	THETA
1	0.0000000	-0.0000000		.018000	.000900
2	.0020904	-.0004181		.002910	.001818
3	.0083616	-.0008362		-.015362	.001536
4	.0279945	-.0020904		-.034994	.002090

5	.0501697	-.0033446	-.053170	.002085
6	.0857067	-.0037627	-.066707	.002423
7	.1275148	-.0045989	-.074515	.000699
8	.1672325	-.0033446	-.081232	-.000355

ROD RFGIO NO. 14 GRID	DELTA	THETA	MOMENT	SHEAR
1	.0180000	.0009000	-.170044	.031172
2	.0050000	.0014000	-.035473	-.001123
3	-.0070000	.0007000	-.169247	-.001021
4	-.0120000	0.0000000	.246465	-.079494
5	-.0030000	-.0012600	1.435256	-.118215
6	.0190000	-.0013400	2.480812	.022682
7	.0530000	-.0039000	.419599	.239661
8	.0860000	-.0037000	-2.395016	-.003662

COMPONENTS OF DISPLACEMENTS
THERMAL

THERMAL GRID	DELTA	THETA	MECHANICAL	DELTA	THETA
1	0.0000000	-0.0000000		.018000	.000900
2	-.0020904	.0004181		.007090	.000982
3	-.0104520	.0012542		.003452	-.000554
4	-.0313561	.0029266		.019356	-.002927

5	-.0710738	.0050170	.068074	-.006277
6	-.1484188	.0104520	.167419	-.011792
7	-.2968377	.0192317	.349838	-.023132
8	-.5518672	.0317742	.637867	-.035474

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ROD REC GRID	V NO. 15	DELTA	THETA	MOMENT	SHEAR
1		.0180000	.0009000	.119561	.031172
2		.0050000	.0014000	.233266	-.001123
3		-.0070000	.0007000	.014057	-.001021
4		-.0120000	0.0000000	.481612	-.079494
5		-.0030000	-.0012600	.915551	-.118215
6		.0190000	-.0013400	2.023723	.022682
7		.0530000	-.0039000	-.233043	.239661
8		.0860000	-.0037000	-1.742375	-.093662

COMPONENTS OF DISPLACEMENTS

THERMAL GRID	DELTA	THETA	MECHANICAL DELTA	THETA
1	0.0000000	-0.0000000	.018000	.000900
2	-.0104520	.0020904	.015452	-.000690
3	-.0522602	.0062712	.045260	-.005571
4	-.1463284	.0125424	.134328	-.012542

5	- .3135609	.0209041	.310561	- .022164
6	- .5644097	.0292657	.583410	- .030606
7	- .9009650	.0380454	.953965	- .041945
8	- 1.3232271	.0464070	1.409227	- .050107

ROD REGI GRID	NO. 16	DELTA	THETA	MOMENT	SHEAR
1		.0180000	.0009000	1.205580	.031172
2		.0050000	.0014000	1.241037	-.001123
3		-.0070000	.0007000	.954283	-.001021
4		-.0120000	0.0000000	1.354776	-.079494
5		-.0030000	-.0012600	.403896	-.118215
6		.0190000	-.0013400	1.367148	.022682
7		.0530000	-.0039000	-.687745	.239661
8		.0860000	-.0037000	-4.026620	-.093662

COMPONENTS OF DISPLACEMENTS			MECHANICAL	
THERMAL GRID	DELTA	THETA	DELTA	THETA
1	0.0000000	-0.0000000	.018000	.000900
2	-.0418081	.0083616	.046808	-.006962
3	-.2090406	.0250449	.202041	-.024385
4	-.5853137	.0501697	.573314	-.050170

5	-1.2542437	.0836162	1.251244	-.084876
6	-2.2409154	.1137181	2.259915	-.115058
7	-3.5097919	.1400572	3.562792	-.143957
8	-5.0253364	.1630517	5.111336	-.166752

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ROD REG1 GRID	NO. 17	DELTA	THETA	MOMENT	SHEAR
1		.0180000	.0009000	1.929592	.031172
2		.0050000	.0014000	1.912884	-.001123
3		-.0070000	.0007000	1.581101	-.001021
4		-.0120000	0.0000000	1.936885	-.079494
5		-.0030000	-.0012600	-1.156113	-.118215
6		.0190000	-.0013400	-.134120	.022682
7		.0530000	-.0039000	-2.189179	.239661
8		.0860000	-.0037000	-2.068695	-.093662

COMPONENTS OF DISPLACEMENTS
THERMAL
GRID

	DELTA	THETA	MECHANICAL DELTA	THETA
1	0.0000000	-0.0000000	.018000	.000900
2	-.0627122	.0125424	.067712	-.011142
3	-.3135609	.0376273	.306561	-.036927
4	-.8779706	.0752546	.865971	-.075255

5	-1.8813655	.1254244	1.878366	-.126684
6	-3.3195650	.1622155	3.338565	-.163556
7	-5.0587829	.1856281	5.111783	-.189528
8	-6.9673237	.1960801	7.053324	-.199780

MOMENTS FUEL RODS
ROD REGION

1	-2.197	-3.872	-5.561	-6.715	.921	-3.305	-3.567	.000
	-1.886	-3.572	-5.271	-7.219	-.766	-4.765	-2.630	
2	-1.184	-1.778	-2.594	-2.807	-8.155	-1.936	-3.436	.000
	-.872	-1.478	-2.304	-3.312	-9.842	-3.396	-2.500	
3	-.966	-1.359	-1.988	-2.026	-1.299	-.697	-2.001	.000
	-.655	-1.059	-1.697	-2.531	-2.986	-2.157	-1.064	
4	-.604	-.731	5.699	-.854	-.711	-.566	-2.457	-.000
	-.293	-.431	5.989	-1.358	-2.398	-2.026	-1.521	
5	-.460	-.522	-7.449	-.463	-.058	.216	-1.413	.000
	-.148	-.221	-7.158	-.968	-1.745	-1.244	-.477	
6	-.460	-.452	-.369	-.398	.072	.347	-1.283	.000
	-.148	-.152	-.079	-.903	-1.614	-1.113	-.346	
7	-.532	-.522	-1.044	-.398	-.058	.086	-1.544	-.000
	-.220	-.221	-.753	-.903	-1.745	-1.374	-.607	
8	-.460	-.452	-.572	-.333	.072	.412	-1.152	.000
	-.148	-.152	-.281	-.838	-1.614	-1.048	-.216	
9	-.387	-.382	-.572	-.203	.203	.412	-1.283	.000

	-.076	-.082	-.281	-.707	-1.484	-1.048	-.346	
10	-.460	-.313	-.572	-.072	.203	.412	-1.283	.000
	-.148	-.012	-.281	-.577	-1.484	-1.048	-.346	
11	-.315	-.173	-.167	-.072	.334	.608	-1.022	.000
	-.003	.128	.123	-.577	-1.353	-.852	-.085	
12	-.315	-.382	-.437	.058	.595	1.105	-.565	.000
	-.003	-.082	-.147	-.447	-1.092	-.265	.372	
13	-.315	-.103	-.235	.253	.791	.999	-.304	.000
	-.003	.197	.056	-.251	-.896	-.461	.633	
14	-.170	.106	.237	.774	1.705	2.499	1.458	-.000
	.142	.407	.528	.270	.018	1.039	2.395	
15	.120	.665	.979	1.751	2.162	2.499	.806	-.000
	.431	.965	1.260	1.246	.475	1.039	1.742	
16	1.206	2.758	4.013	5.658	5.557	5.238	3.090	-.000
	1.517	3.059	4.303	5.153	3.871	3.778	4.027	
17	1.930	4.154	6.036	8.263	6.602	4.781	1.132	-.000
	2.241	4.455	6.326	7.758	4.915	3.321	2.069	

AXIAL LOA	IN RODS
SUR-LENGTH	LOAD

1	2.880
2	5.760
3	8.640
4	11.520
5	8.640
6	5.760
7	2.880

ROD DEFLECTIONS
AXIAL LOAD = 0.0

	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 1					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 2					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 3					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 4					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 5					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 6					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 7					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 8					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 9					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 10					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 11					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 12					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 13					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 14					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 15					

.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 16					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500
	TOTAL CENTER SPAN DEFLECTION OF RODS IN REGION 17					
.0006250	-.0008750	-.0008750	-.0015750	-.0001000	-.0032000	.0002500

LENGTH NO. 1

AXIAL LOAD = 2.9 LBS

UPPER GRID DEFLECTION (GRID NO. 1) = .0180000 INS

LOWER GRID DEFLECTION (GRID NO. 2) = .0050000 INS

POD ROW / NO.	MOMENTS GRID 1	IN GRID 2	RODS / TOTAL LOCAL / CENTER DEFLECTION	MAXIMUM LOC. CREEP / DEFLECTION	CENTER DEFL. / RELATIVE TO EARTH	FLOW / CHANNEL CHANGE	/ CRITICAL / AXIAL LOAD / COMPONENT	CREEP / DEFLECTION	/ STRUT BUCKLIN M.S.
1	-2.197	-1.886	.0025363	.0159868	.0140363		17.749	.0004113	5.16
2	-1.184	-.872	.0024697	.0159868	.0139697	-.0000666	20.624	.0003447	6.16
3	-.966	-.655	.0024581	.0159868	.0139581	-.0000117	21.246	.0003331	6.38
4	-.604	-.293	.0024408	.0159868	.0139408	-.0000173	22.251	.0003158	6.73
5	-.460	-.148	.0024347	.0159868	.0139347	-.0000060	22.629	.0003097	6.86
6	-.460	-.148	.0024341	.0159868	.0139341	-.0000006	22.671	.0003091	6.87
7	-.532	-.220	.0024368	.0159868	.0139368	.0000027	22.502	.0003118	6.81
8	-.460	-.148	.0024341	.0159868	.0139341	-.0000027	22.671	.0003091	6.87
9	-.387	-.076	.0024315	.0159868	.0139315	-.0000026	22.839	.0003065	6.93
10	-.460	-.148	.0024328	.0159868	.0139328	.0000013	22.753	.0003078	6.90
11	-.315	-.003	.0024277	.0159868	.0139277	-.0000051	23.090	.0003027	7.02
12	-.315	-.003	.0024295	.0159868	.0139295	.0000019	22.967	.0003045	6.97
13	-.315	-.003	.0024271	.0159868	.0139271	-.0000025	23.131	.0003021	7.03
14	-.170	.142	.0024216	.0159868	.0139216	-.0000055	23.509	.0002966	7.16
15	.120	.431	.0024324	.0159868	.0139324	.0000109	22.779	.0003074	6.91
16	1.206	1.517	.0024893	.0159868	.0139893	.0000549	19.667	.0003643	5.83
17	1.930	2.241	.0025378	.0159868	.0140378	.0000485	17.694	.0004128	5.14

ENGTH NO. 2

UPPER GRID DEFLECTION (GRID NO. 2) = .0050000 INS.

XIAL LOAD = 5.8 LBS

LOWER GRID DEFLECTION (GRID NO. 3) = -.0070000 INS.

ROW / NO.	ROD / GRID 2	MOMENTS IN GRID 3	TOTAL LOCAL DEFLECTION	MAXIMUM LOC. DEFLECTION	CREEP DEFLECTION	CENTER DEFL./ RELATIVE TO EARTH	FLOW / CHANNEL / CHANGE	/CRITICAL/ AXIAL / DEFLECTION/BUCKLING LOAD/COMPONENT	CREEP /STRUT M.S.
1	-3.872	-3.572	-.0038435	.0226088	-.0048435		15.012	-.0014685	1.61
2	-1.778	-1.478	-.0033833	.0226088	-.0043833	.0004601	19.289	-.0010083	2.35
3	-1.359	-1.059	-.0033178	.0226088	-.0043178	.0000655	20.234	-.0009428	2.51
4	-.731	-.431	-.0032883	.0226088	-.0042883	.0000296	20.705	-.0009133	2.59
5	-.522	-.221	-.0034546	.0226088	-.0044546	-.0001663	18.389	-.0010796	2.19
6	-.452	-.152	-.0031892	.0226088	-.0041892	.0002654	22.532	-.0008142	2.91
7	-.522	-.221	-.0032152	.0226088	-.0042152	-.0000260	22.011	-.0008402	2.82
8	-.452	-.152	-.0031950	.0226088	-.0041950	.0000202	22.413	-.0008200	2.89
9	-.382	-.082	-.0031889	.0226088	-.0041889	.0000061	22.538	-.0008139	2.91
10	-.313	-.012	-.0031870	.0226088	-.0041870	.0000019	22.577	-.0008120	2.92
11	-.173	.128	-.0031643	.0226088	-.0041643	.0000228	23.064	-.0007893	3.00
12	-.382	-.082	-.0031831	.0226088	-.0041831	-.0000198	22.660	-.0008081	2.93
13	-.103	.197	-.0031623	.0226088	-.0041623	.0000208	23.107	-.0007873	3.01
14	.106	.407	-.0031828	.0226088	-.0041828	-.0000204	22.667	-.0008078	2.94
15	.665	.965	-.0032476	.0226088	-.0042476	-.0000648	21.406	-.0008726	2.72
16	2.758	3.059	-.0036105	.0226088	-.0046105	-.0003629	16.782	-.0012355	1.91
17	4.154	4.455	-.0040054	.0226088	-.0050054	-.0003949	14.077	-.0016304	1.44

LENGTH NO. 3

AXIAL LOAD = 8.6 LBS

UPPER GRID DEFLECTION (GRID NO. 3) = -.0070000 INS

LOWER GRID DEFLECTION (GRID NO. 4) = -.0120000 INS

POD NO.	MOMENTS GRID 3	IN GRID 4	RODS / TOTAL DEFLECTION	LOCAL / CENTER DEFLECTION	MAXIMUM / CREEP DEFLECTION	LOC./CENTER / RELATIVE TO EARTH	DEFL./ CHANNEL CHANGE	FLOW / CRITICAL/ AXIAL LOAD	CREEP / DEFLECTION/ COMPONENT	STRUT / BUCKLIN M.S.
1	-5.561	-5.271	-.0077534	.0276900	-.0172534		11.985	-.0053784	.39	
2	-2.594	-2.304	-.0046382	.0276900	-.0141382	.0031153	17.589	-.0022632	1.04	
3	-1.988	-1.697	-.0043548	.0276900	-.0138548	.0002833	18.907	-.0019798	1.19	
4	5.699	5.989	-.0048075	.0276900	-.0143075	-.0004527	16.944	-.0024325	.96	
5	-7.449	-7.158	-.0057394	.0276900	-.0152394	-.0009319	14.521	-.0033644	.68	
6	-.369	-.079	-.0038775	.0276900	-.0133775	.0018620	22.232	-.0015025	1.57	
7	-1.044	-.753	-.0039742	.0276900	-.0134742	-.0000967	21.400	-.0015992	1.48	
8	-.572	-.281	-.0038996	.0276900	-.0133996	.0000746	22.032	-.0015246	1.55	
9	-.572	-.281	-.0038865	.0276900	-.0133865	.0000131	22.150	-.0015115	1.56	
10	-.572	-.281	-.0038736	.0276900	-.0133736	.0000129	22.267	-.0014986	1.58	
11	-.167	.123	-.0038166	.0276900	-.0133166	.0000570	22.812	-.0014416	1.64	
12	-.437	-.147	-.0038528	.0276900	-.0133528	-.0000362	22.462	-.0014778	1.60	
13	-.235	.056	-.0038322	.0276900	-.0133322	.0000206	22.659	-.0014572	1.62	
14	.237	.528	-.0039408	.0276900	-.0134408	-.0001086	21.675	-.0015658	1.51	
15	.979	1.269	-.0041796	.0276900	-.0136796	-.0002387	19.926	-.0018046	1.31	
16	4.013	4.303	-.0062094	.0276900	-.0157094	-.0020298	13.723	-.0038344	.59	
17	6.036	6.326	-.0099993	.0276900	-.0194993	-.0037899	10.472	-.0076243	.21	

LENGTH NO. 4

AXIAL LOAD = 11.5 LBS

UPPER GRID DEFLECTION (GRID NO. 4) = -.0120000 IN

LOWER GRID DEFLECTION (GRID NO. 5) = -.0030000 IN

ROW / NO.	ROD / GRID 4	MOMENTS IN GRID 5	RODS / TOTAL	LOCAL / CENTER	MAXIMUM / CHFEF	LOC./CENTER DEFL./ RELATIVE TO / EARTH	FLOW / CHANNEL / CHANGE	/CRITICAL/ AXIAL / LOAD/COMPONENT	CHFEF / DEFLECTION/HUCKLE	STRUT M.S.
1	-6.715	-7.219	-.0142443	.0319737	-.0217443		12.899	-.0111693	.12	
2	-2.807	-3.312	-.0129871	.0319737	-.0204871	.0012572	13.643	-.0099121	.18	
3	-2.026	-2.531	-.0080899	.0319737	-.0155899	.0048973	18.127	-.0050149	.57	
4	-.854	-1.358	-.0068342	.0319737	-.0143342	.0012557	20.654	-.0037592	.79	
5	-.463	-.968	-.0084955	.0319737	-.0159955	-.0016613	17.536	-.0054205	.52	
6	-.398	-.903	-.0064789	.0319737	-.0139789	.0020145	21.678	-.0034039	.88	
7	-.398	-.903	-.0066339	.0319737	-.0141339	-.0001549	21.208	-.0035589	.84	
8	-.333	-.838	-.0064923	.0319737	-.0139923	.0001416	21.636	-.0034173	.88	
9	-.203	-.707	-.0064209	.0319737	-.0130209	.0000714	21.865	-.0033459	.90	
10	-.072	-.577	-.0063748	.0319737	-.0138748	.0000461	22.018	-.0032998	.91	
11	-.072	-.577	-.0062837	.0319737	-.0137837	.0000911	22.333	-.0032087	.94	
12	.058	-.447	-.0062618	.0319737	-.0137618	.0000220	22.411	-.0031868	.95	
13	.253	-.251	-.0063959	.0319737	-.0138959	-.0001342	21.948	-.0033209	.91	
14	.774	.270	-.0068811	.0319737	-.0143811	-.0004852	20.532	-.0038061	.78	
15	1.751	1.246	-.0077186	.0319737	-.0152186	-.0008375	18.745	-.0046436	.63	
16	5.658	5.153	-.0160388	.0319737	-.0235388	-.0083202	11.910	-.0129638	.03	
17	8.263	7.758	-.0215592	.0319737	-.0290592	-.0055204	8.946	-.0184842	-.22	

LENGTH NO. 5

AXIAL LOAD = 8.6 LRS

UPPER GRID DEFLECTION (GRID NO. 5) = -.0030000 INS

LOWER GRID DEFLECTION (GRID NO. 6) = .0190000 INS

ROD NO.	/ MOMENTS / GRID	IN 5	RODS 6	/ TOTAL LOCAL / DEFLECTION	/ MAXIMUM LOC. / DEFLECTION	/ CENTER DEFL. / EARTH	/ FLOW / CHANNEL / CHANGE	/ CRITICAL/ / AXIAL LOAD	/ CREEP / COMPONENT	/ SLOPE / M.S.
1	.921	-.766	-.0032492	.0276900	.0047508		16.962	-.0016492	.96	
2	-8.155	-9.842	-.0064298	.0276900	.0015702	-.0031806	11.152	-.0048298	.29	
3	-1.299	-2.986	-.0029959	.0276900	.0050041	.0034339	18.496	-.0013959	1.14	
4	-.711	-2.398	-.0028249	.0276900	.0051751	.0001710	19.886	-.0012249	1.30	
5	-.058	-1.745	-.0026875	.0276900	.0053125	.0001375	21.319	-.0010875	1.47	
6	.072	-1.614	-.0026652	.0276900	.0053348	.0000223	21.586	-.0010652	1.50	
7	-.058	-1.745	-.0026907	.0276900	.0053093	-.0000256	21.281	-.0010907	1.46	
8	.072	-1.614	-.0026590	.0276900	.0053410	.0000318	21.663	-.0010590	1.51	
9	.203	-1.484	-.0026407	.0276900	.0053593	.0000182	21.892	-.0010407	1.53	
10	.203	-1.484	-.0026348	.0276900	.0053652	.0000059	21.969	-.0010348	1.54	
11	.334	-1.353	-.0026145	.0276900	.0053855	.0000203	22.237	-.0010145	1.57	
12	.595	-1.092	-.0025832	.0276900	.0054168	.0000313	22.671	-.0009832	1.62	
13	.791	-.896	-.0025995	.0276900	.0054005	-.0000163	22.441	-.0009995	1.60	
14	1.705	.018	-.0027923	.0276900	.0052077	-.0001927	20.197	-.0011923	1.34	
15	2.162	.475	-.0029132	.0276900	.0050868	-.0001209	19.124	-.0013132	1.21	
16	5.557	3.871	-.0049973	.0276900	.0030027	-.0020841	12.518	-.0033473	.45	
17	6.602	4.915	-.0068829	.0276900	.0011171	-.0018856	10.847	-.0052829	.26	

LENGTH NO. 6

AXIAL LOAD = 5.8 LBS

UPPER GRID DEFLECTION (GRID NO. 6) = .0190000 INS

LOWER GRID DEFLECTION (GRID NO. 7) = .0530000 INS

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POD / ROW / NO.	MOMENTS IN GRID 6	RODS / GRID 7	TOTAL LOCAL / CENTER DEFLECTION	MAXIMUM LOC./ CHFEF DEFLECTION	CENTER DEFL./ /RELATIVE TO / EARTH	FLOW / CHANNEL / CHANGE	/CRITICAL/ AXIAL / LOAD/	CREEP /DEFLECTION/ COMPONENT	/STRUT /HUCKLIN / M.S.
1	-3.305	-4.765	-.0072332	.0226088	.0287668		16.240	-.0025332	1.82
2	-1.936	-3.396	-.0081436	.0226088	.0278564	-.0009104	13.306	-.0034436	1.31.
3	-.697	-2.157	-.0067724	.0226088	.0292276	.0013712	18.665	-.0020724	2.24
4	-.566	-2.026	-.0067390	.0226088	.0292610	.0000334	18.882	-.0020390	2.28
5	.216	-1.244	-.0064916	.0226088	.0295084	.0002473	20.739	-.0017916	2.60
6	.347	-1.113	-.0064568	.0226088	.0295432	.0000349	21.042	-.0017568	2.65
7	.086	-1.374	-.0065186	.0226088	.0294814	-.0000618	20.513	-.0018186	2.56
8	.412	-1.048	-.0064398	.0226088	.0295602	.0000788	21.194	-.0017398	2.68
9	.412	-1.048	-.0064398	.0226088	.0295602	.0000000	21.194	-.0017398	2.68
10	.412	-1.048	-.0064398	.0226088	.0295602	.0000000	21.194	-.0017398	2.68
11	.608	-.852	-.0063906	.0226088	.0296094	.0000492	21.652	-.0016906	2.76
12	1.195	-.265	-.0062817	.0226088	.0297183	.0001088	22.763	-.0015817	2.95
13	.999	-.461	-.0062782	.0226088	.0297218	.0000035	22.802	-.0015782	2.96
14	2.499	1.039	-.0065495	.0226088	.0294505	-.0002713	20.261	-.0018495	2.52
15	2.499	1.039	-.0065356	.0226088	.0294644	.0000139	20.373	-.0018356	2.54
16	5.238	3.778	-.0077083	.0226088	.0282917	-.0011727	14.498	-.0030083	1.52
17	4.781	3.321	-.0074508	.0226088	.0285492	.0002575	15.371	-.0027508	1.67

LENGTH NO. 7

AXIAL LOAD = 2.9 LBS

UPPER GRID DEFLECTION (GRID NO. 7) = .0530000 INS

LOWER GRID DEFLECTION (GRID NO. 8) = .0860000 INS

ROD ROW / NO.	MOMENTS IN		RODS	TOTAL LOCAL	MAXIMUM LOC.	CENTER DEFL.	FLOW	CRITICAL	CREEP	STRUT
	GRID 7	GRID 8		DEFLECTION	DEFLECTION	RELATIVE TO	CHANNEL	AXIAL	DEFLECTION	BUCKLING
						EARTH	CHANGE	LOAD/COMPONENT		M.S.
1	-3.567	-2.630	.0021351	.0159868	.0716351			15.960	.0003851	4.54
2	-3.436	-2.500	.0021103	.0159868	.0716103	-.0000248		16.860	.0003603	4.85
3	-2.001	-1.064	.0020461	.0159868	.0715461	-.0000642		19.896	.0002961	5.91
4	-2.457	-1.521	.0020588	.0159868	.0715588	.0000127		19.194	.0003088	5.66
5	-1.413	-.477	.0020214	.0159868	.0715214	-.0000374		21.443	.0002714	6.45
6	-1.283	-.346	.0020170	.0159868	.0715170	-.0000044		21.749	.0002670	6.55
7	-1.544	-.607	.0020259	.0159868	.0715259	.0000089		21.139	.0002759	6.34
8	-1.152	-.216	.0020133	.0159868	.0715133	-.0000127		22.017	.0002633	6.64
9	-1.283	-.346	.0020165	.0159868	.0715165	.0000032		21.787	.0002665	6.56
10	-1.283	-.346	.0020165	.0159868	.0715165	0.0000000		21.787	.0002665	6.56
11	-1.022	-.085	.0020086	.0159868	.0715086	-.0000079		22.362	.0002586	6.76
12	-.565	.372	.0019942	.0159868	.0714942	-.0000144		23.512	.0002442	7.16
13	-.304	.633	.0019971	.0159868	.0714971	.0000029		23.269	.0002471	7.08
14	1.458	2.395	.0020563	.0159868	.0715563	.0000592		19.327	.0003063	5.71
15	.806	1.742	.0020368	.0159868	.0715368	-.0000195		20.444	.0002868	6.10
16	3.090	4.027	.0021554	.0159868	.0716554	.0001185		15.304	.0004054	4.31
17	1.132	2.069	.0020705	.0159868	.0715705	-.0000849		18.600	.0003205	5.46

DEFLECTION. WITH MISFITS REVERSED FOR MOST DAMAGE

LENGTH NO. 1

AXIAL LOAD = 2.9 LBS

UPPER GRID DEFLECTION (GRID NO. 1) = .0180000 INS

LOWER GRID DEFLECTION (GRID NO. 2) = .0050000 INS

ROD NO.	MOMENTS / GRID	IN / 1	PODS / GRID	TOTAL LOCAL / 2	MAXIMUM LOC. / CENTER	LOC. / CREEP	CENTER DEFL. / RELATIVE TO	FLOW / CHANNEL	CRITICAL / AXIAL	CREEP / DEFLECTION	STRUT / BUCKLIN
NO.	GRID	1	GRID	2	DEFLECTION	DEFLECTION	EARTH	CHANGE	LOAD/COMPONENT	/ M.S.	
1	-2.197	-1.886	-.0010445	.0159868	.0104555				17.749	-.0031695	5.16
2	-1.184	-.872	-.0010170	.0159868	.0104830	.0000275			20.624	-.0031420	6.16
3	-.966	-.655	-.0010122	.0159868	.0104878	.0000048			21.246	-.0031372	6.38
4	-.604	-.293	-.0010051	.0159868	.0104949	.0000071			22.251	-.0031301	6.73
5	-.460	-.148	-.0010026	.0159868	.0104974	.0000025			22.629	-.0031276	6.86
6	-.460	-.148	-.0010023	.0159868	.0104977	.0000003			22.671	-.0031273	6.87
7	-.532	-.220	-.0010034	.0159868	.0104966	-.0000011			22.502	-.0031284	6.81
8	-.460	-.148	-.0010023	.0159868	.0104977	.0000011			22.671	-.0031273	6.87
9	-.387	-.076	-.0010012	.0159868	.0104988	.0000011			22.839	-.0031262	6.93
10	-.460	-.148	-.0010018	.0159868	.0104982	-.0000006			22.753	-.0031268	6.90
11	-.315	-.003	-.0009997	.0159868	.0105003	.0000021			23.090	-.0031247	7.02
12	-.315	-.003	-.0010004	.0159868	.0104996	-.0000008			22.967	-.0031254	6.97
13	-.315	-.003	-.0009994	.0159868	.0105006	.0000010			23.131	-.0031244	7.03
14	-.170	.142	-.0009972	.0159868	.0105028	.0000023			23.509	-.0031222	7.16
15	.120	.431	-.0010016	.0159868	.0104984	-.0000045			22.779	-.0031266	6.91
16	1.206	1.517	-.0010251	.0159868	.0104740	-.0000235			19.667	-.0031501	5.83
17	1.930	2.241	-.0010451	.0159868	.0104549	-.0000200			17.694	-.0031701	5.14

LENGTH NO. 2

AXIAL LOAD = 5.8 LRS

UPPER GRID DEFLECTION (GRID NO. 2) = .0050000 INS.

LOWER GRID DEFLECTION (GRID NO. 3) = -.0070000 INS.

POD ROW NO.	MOMENTS / GRID 2	IN RODS / GRID 3	TOTAL LOCAL / CENTER DEFLECTION	MAXIMUM LOC. / CREEP DEFLECTION	CENTER DEFL. / RELATIVE TO EARTH	FLOW / CHANNEL CHANGE	CRITICAL / AXIAL LOAD/COMPONENT	CREEP / DEFLECTION	STRUT / BUCKLING M.S.
1	-3.872	-3.572	.0010139	.0226088	.0000139		15.012	.0033889	1.61
2	-1.778	-1.478	.0008910	.0226088	-.0001090	-.0001229	19.289	.0032660	2.35
3	-1.359	-1.059	.0008737	.0226088	-.0001263	-.0000174	20.234	.0032487	2.51
4	-.731	-.431	.0008658	.0226088	-.0001342	-.0000078	20.705	.0032408	2.59
5	-.522	-.221	.0009100	.0226088	-.0000900	.0000441	18.389	.0032850	2.19
6	-.452	-.152	.0008396	.0226088	-.0001604	-.0000704	22.532	.0032146	2.91
7	-.522	-.221	.0008465	.0226088	-.0001535	.0000069	22.011	.0032215	2.82
8	-.452	-.152	.0008411	.0226088	-.0001589	-.0000053	22.413	.0032161	2.89
9	-.382	-.082	.0008395	.0226088	-.0001605	-.0000016	22.538	.0032145	2.91
10	-.313	-.012	.0008390	.0226088	-.0001610	-.0000005	22.577	.0032140	2.92
11	-.173	.128	.0008330	.0226088	-.0001670	-.0000060	23.064	.0032080	3.00
12	-.382	-.082	.0008380	.0226088	-.0001620	.0000050	22.660	.0032130	2.93
13	-.103	.197	.0008325	.0226088	-.0001675	-.0000055	23.107	.0032075	3.01
14	.106	.407	.0008379	.0226088	-.0001621	.0000054	22.667	.0032129	2.94
15	.665	.965	.0008551	.0226088	-.0001449	.0000172	21.406	.0032301	2.72
16	2.758	3.059	.0009515	.0226088	-.0000485	.0000965	16.782	.0033265	1.91
17	4.154	4.455	.0010576	.0226088	.0000576	.0001061	14.077	.0034326	1.44

LENGTH NO. 3

AXIAL LOAD = 8.6 LBS

UPPER GRID DEFLECTION (GRID NO. 3) = -.0070000 INS

LOWER GRID DEFLECTION (GRID NO. 4) = -.0120000 INS

ROW / NO.	MOMENTS IN GRID 3	RODS / GRID 4	TOTAL LOCAL / CENTER DEFLECTION	MAXIMUM LOC. / CREEP DEFLECTION	CENTER DEFL. / RELATIVE TO EARTH	FLOW / CHANNEL CHANGE	CRITICAL / AXIAL LOAD/COMPONENT	CREEP / DEFLECTION/HUCKLIN M.S.	STRUT
1	-5.561	-5.271	.0022202	.0276900	-.0072798		11.985	.0045952	.39
2	-2.594	-2.304	.0012279	.0276900	-.0082721	-.0009923	17.589	.0036029	1.04
3	-1.988	-1.697	.0011506	.0276900	-.0083494	-.0000773	18.907	.0035256	1.19
4	5.699	5.989	.0012746	.0276900	-.0082254	.0001240	16.944	.0036496	.96
5	-7.449	-7.158	.0015407	.0276900	-.0079593	.0002661	14.521	.0039157	.68
6	-.369	-.079	.0010222	.0276900	-.0084778	-.0005105	22.232	.0033072	1.57
7	-1.044	-.753	.0010480	.0276900	-.0084520	.0000259	21.400	.0034230	1.48
8	-.572	-.281	.0010281	.0276900	-.0084710	-.0000200	22.032	.0034031	1.55
9	-.572	-.281	.0010246	.0276900	-.0084754	-.0000035	22.150	.0033996	1.54
10	-.572	-.281	.0010211	.0276900	-.0084789	-.0000034	22.267	.0033961	1.58
11	-.167	.123	.0010059	.0276900	-.0084941	-.0000152	22.812	.0033809	1.64
12	-.437	-.147	.0010156	.0276900	-.0084844	.0000097	22.462	.0033906	1.60
13	-.235	.056	.0010101	.0276900	-.0084899	-.0000055	22.659	.0033851	1.62
14	.237	.528	.0010391	.0276900	-.0084609	.0000290	21.675	.0034141	1.51
15	.979	1.269	.0011032	.0276900	-.0083968	.0000641	19.926	.0034782	1.31
16	4.013	4.303	.0016831	.0276900	-.0078169	.0005799	13.723	.0040581	.59
17	6.036	6.326	.0034095	.0276900	-.0060905	.0017264	10.472	.0057845	.21

LENGTH NO. 4

AXIAL LOAD = 11.5 LRS

UPPER GRID DEFLECTION (GRID NO. 4) = -.0120000 INS

LOWER GRID DEFLECTION (GRID NO. 5) = -.0030000 INS

POD / ROW / NO.	/ MOMENTS IN		PODS / TOTAL LOCAL /	MAXIMUM LOC./CENTER DEFL./	FLOW /CRITICAL/	CREEP /STRUT			
GRID 4 / GRID 5 /	DEFLECTION /	CREEP /	DEFLECTION /	RELATIVE TO /	CHANNEL /	AXIAL /DEFLECTION/BUCKLIN			
				EARTH /	CHANGE /	LOAD/COMPONENT / M.S.			
1	-6.715	-7.219	-.0142443	.0319737	-.0217443	12.899	-.0111693	.12	
2	-2.807	-3.312	-.0129871	.0319737	-.0204871	.0012572	13.643	-.0099121	.18
3	-2.026	-2.531	-.0080899	.0319737	-.0155899	.0048973	18.127	-.0050149	.57
4	-.854	-1.358	-.0068342	.0319737	-.0143342	.0012557	20.654	-.0037592	.79
5	-.463	-.968	-.0084955	.0319737	-.0159955	-.0016613	17.536	-.0054205	.52
6	-.398	-.903	-.0064789	.0319737	-.0139789	.0020165	21.678	-.0034039	.88
7	-.398	-.903	-.0066339	.0319737	-.0141339	-.0001549	21.208	-.0035589	.84
8	-.333	-.838	-.0064923	.0319737	-.0139923	.0001416	21.636	-.0034173	.88
9	-.203	-.707	-.0064209	.0319737	-.0139209	.0000714	21.865	-.0033459	.90
10	-.072	-.577	-.0063748	.0319737	-.0138748	.0000461	22.018	-.0032998	.91
11	-.072	-.577	-.0062837	.0319737	-.0137837	.0000911	22.333	-.0032087	.94
12	.058	-.447	-.0062618	.0319737	-.0137618	.0000220	22.411	-.0031868	.95
13	.253	-.251	-.0063959	.0319737	-.0138959	-.0001342	21.948	-.0033209	.91
14	.774	.270	-.0068811	.0319737	-.0143811	-.0004852	20.532	-.0038061	.78
15	1.751	1.246	-.0077186	.0319737	-.0152186	-.0008375	18.745	-.0046436	.63
16	5.658	5.153	-.0160388	.0319737	-.0235388	-.0083202	11.910	-.0129638	.03
17	8.263	7.758	-.0215592	.0319737	-.0290592	-.0055204	8.946	-.0184842	-.22

LENGTH NO. 5

AXIAL LOAD = 8.6 LRS

UPPER GRID DEFLECTION (GRID NO. 5) = -.0030000 INC

LOWER GRID DEFLECTION (GRID NO. 6) = .0190000 INC

ROD / MOMENTS IN RODS / TOTAL LOCAL / MAXIMUM LOC. / CENTER DEFL. / FLOW / CRITICAL / CREEP / STRUT	ROW /	GRID 5 /	GRID 6 /	CENTER /	CREEP /	RELATIVE TO /	CHANNEL /	AXIAL /	DEFLECTION /	BUCKLING /
NO. /				DEFLECTION /	DEFLECTION /	EARTH /	CHANGE /	LOAD /	COMPONENT /	M.S. /
1	.921	-.766	.0028455	.0276900	.0108455		.0028867	16.962	.0044455	.96
2	-8.155	-9.842	.0057322	.0276900	.0137322		-.0031094	11.152	.0073322	.29
3	-1.299	-2.986	.0026228	.0276900	.0106228		-.0001501	18.496	.0042228	1.14
4	-.711	-2.398	.0024727	.0276900	.0104727		-.0001206	19.886	.0040727	1.30
5	-.058	-1.745	.0023521	.0276900	.0103521		-.0000196	21.319	.0039521	1.47
6	.072	-1.614	.0023326	.0276900	.0103326		.0000224	21.586	.0039326	1.50
7	-.058	-1.745	.0023550	.0276900	.0103550		-.0000279	21.281	.0039550	1.46
8	.072	-1.614	.0023271	.0276900	.0103271		-.0000160	21.663	.0039271	1.51
9	.203	-1.484	.0023111	.0276900	.0103111		-.0000052	21.892	.0039111	1.53
10	.203	-1.484	.0023059	.0276900	.0103059		-.0000178	21.969	.0039059	1.54
11	.334	-1.353	.0022881	.0276900	.0102881		-.0000274	22.237	.0038881	1.57
12	.595	-1.092	.0022607	.0276900	.0102607		.0000143	22.671	.0038607	1.62
13	.791	-.896	.0022750	.0276900	.0102750		.0001690	22.441	.0038750	1.60
14	1.705	.018	.0024440	.0276900	.0104440		.0001061	20.197	.0040440	1.34
15	2.162	.475	.0025501	.0276900	.0105501		.0018537	19.124	.0041501	1.21
16	5.557	3.871	.0044038	.0276900	.0124038		.0017619	12.518	.0060038	.45
17	6.602	4.915	.0061657	.0276900	.0141657			10.847	.0077657	.26

ENGTH NO. 6

XIAL LOAD = 5.8 LBS

UPPER GRID DEFLECTION (GRID NO. 6) = .0190000 INS.

LOWER GRID DEFLECTION (GRID NO. 7) = .0530000 INS.

ROD ROW / NO.	MOMENTS / GRID 6	IN / GRID 7	RODS / TOTAL LOCAL / / CENTER / DEFLECTION /	MAXIMUM LOC. / / CREEP / DEFLECTION /	CENTER DEFL. / / RELATIVE TO / EARTH /	FLOW / CHANNEL CHANGE	/ CRITICAL / / AXIAL / LOAD / COMPONENT	CREEP / DEFLECTION / BUCKLING	STRUT / M.S.
1	-3.305	-4.765	-.0072332	.0226088	.0287668		16.240	-.0025332	1.82
2	-1.936	-3.396	-.0081436	.0226088	.0278564	-.0009104	13.306	-.0034436	1.31
3	-.697	-2.157	-.0067724	.0226088	.0292276	.0013712	18.665	-.0020724	2.24
4	-.566	-2.026	-.0067390	.0226088	.0292610	.0000334	18.882	-.0020390	2.28
5	.216	-1.244	-.0064916	.0226088	.0295084	.0002473	20.739	-.0017916	2.60
6	.347	-1.113	-.0064568	.0226088	.0295432	.0000349	21.042	-.0017568	2.65
7	.086	-1.374	-.0065186	.0226088	.0294814	-.0000618	20.513	-.0018186	2.56
8	.412	-1.048	-.0064398	.0226088	.0295602	.0000788	21.194	-.0017398	2.68
9	.412	-1.048	-.0064398	.0226088	.0295602	.0000000	21.194	-.0017398	2.68
10	.412	-1.048	-.0064398	.0226088	.0295602	.0000000	21.194	-.0017398	2.68
11	.608	-.852	-.0063906	.0226088	.0296094	.0000492	21.652	-.0016906	2.76
12	1.195	-.265	-.0062817	.0226088	.0297183	.0001088	22.763	-.0015817	2.95
13	.999	-.461	-.0062782	.0226088	.0297218	.0000035	22.802	-.0015782	2.96
14	2.499	1.039	-.0065495	.0226088	.0294505	-.0002713	20.261	-.0018495	2.52
15	2.499	1.039	-.0065356	.0226088	.0294644	.0000139	20.373	-.0018356	2.54
16	5.238	3.778	-.0077083	.0226088	.0282917	-.0011727	14.498	-.0030083	1.52
17	4.781	3.321	-.0074508	.0226088	.0285492	.0002575	15.371	-.0027508	1.67

LENGTH NO. 7

AXIAL LOAD = 2.9 LBS

UPPER GRID DEFLECTION (GRID NO. 7) = .0530000 IN

LOWER GRID DEFLECTION (GRID NO. 8) = .0860000 IN

ROD ROW NO.	MOMENTS / GRID 7	IN / GRID 8	RODS / CENTER DEFLECTION	TOTAL LOCAL / CENTER DEFLECTION	MAXIMUM LOC. / CREEP DEFLECTION	CENTER DEFL. / RELATIVE TO EARTH	FLOW / CHANNEL CHANGE	CRITICAL / AXIAL LOAD/COMPONENT	CREEP / DEFLECTION / HUCKLIN	STRUT / M.S.
1	-3.567	-2.630	-.0015251	.0159868	.0679749	15.960	-.0032751	4.54		
2	-3.436	-2.500	-.0015074	.0159868	.0679926	.0000177	16.860	-.0032574	4.85	
3	-2.001	-1.064	-.0014615	.0159868	.0680385	.0000459	19.896	-.0032115	5.91	
4	-2.457	-1.521	-.0014706	.0159868	.0680294	-.0000091	19.194	-.0032206	5.66	
5	-1.413	-.477	-.0014439	.0159868	.0680561	.0000267	21.443	-.0031939	6.45	
6	-1.283	-.346	-.0014408	.0159868	.0680592	.0000031	21.749	-.0031908	6.55	
7	-1.544	-.607	-.0014471	.0159868	.0680529	-.0000064	21.139	-.0031971	6.34	
8	-1.152	-.216	-.0014381	.0159868	.0680619	.0000090	22.017	-.0031881	6.64	
9	-1.283	-.346	-.0014404	.0159868	.0680596	-.0000023	21.787	-.0031904	6.56	
10	-1.283	-.346	-.0014404	.0159868	.0680596	0.0000000	21.787	-.0031904	6.56	
11	-1.022	-.085	-.0014348	.0159868	.0680652	.0000056	22.362	-.0031848	6.76	
12	-.565	.372	-.0014245	.0159868	.0680755	.0000103	23.512	-.0031745	7.16	
13	-.304	.633	-.0014265	.0159868	.0680735	-.0000021	23.269	-.0031765	7.08	
14	1.458	2.395	-.0014688	.0159868	.0680312	-.0000423	19.327	-.0032188	5.71	
15	.806	1.742	-.0014549	.0159868	.0680451	.0000139	20.444	-.0032049	6.10	
16	3.090	4.027	-.0015397	.0159868	.0679603	-.0000847	15.304	-.0032897	4.31	
17	1.132	2.069	-.0014789	.0159868	.0680211	.0000607	18.600	-.0032289	5.46	

LENGTH NO. 1

AXIAL LOAD = 2.9 LRS

UPPER GRID DEFLECTION (GRID NO. 1) = .0180000 INS

LOWER GRID DEFLECTION (GRID NO. 2) = .0050000 INS

ROW / NO.	ROD / GRID 1	MOMENTS IN RODS / GRID 2	TOTAL LOCAL / CENTER DEFLECTION	MAXIMUM LOC. / CREEP DEFLECTION	CENTER DEFL. / RELATIVE TO EARTH	FLOW / CHANNEL CHANGE	CRITICAL / AXIAL LOAD	CREEP / DEFLECTION COMPONENT	STRUT BUCKLING M.S.
1	-2.197	-1.886	.0025363	.0159868	.0140363		17.749	0.0000000	5.16
2	-1.184	-.872	-.0010170	.0159868	.0104830	-.0035533	20.624	0.0000000	6.16
3	-.966	-.655	.0024581	.0159868	.0139581	.0034751	21.246	0.0000000	6.38
4	-.604	-.293	-.0010051	.0159868	.0104949	-.0034631	22.251	0.0000000	6.73
5	-.460	-.148	.0024347	.0159868	.0139347	.0034398	22.629	0.0000000	6.86
6	-.460	-.148	-.0010023	.0159868	.0104977	-.0034371	22.671	0.0000000	6.87
7	-.532	-.220	.0024368	.0159868	.0139368	.0034391	22.502	0.0000000	6.81
8	-.460	-.148	-.0010023	.0159868	.0104977	-.0034391	22.671	0.0000000	6.87
9	-.387	-.076	.0024315	.0159868	.0139315	.0034338	22.839	0.0000000	6.93
10	-.460	-.148	-.0010018	.0159868	.0104982	-.0034333	22.753	0.0000000	6.90
11	-.315	-.003	.0024277	.0159868	.0139277	.0034295	23.090	0.0000000	7.02
12	-.315	-.003	-.0010004	.0159868	.0104996	-.0034281	22.967	0.0000000	6.97
13	-.315	-.003	.0024271	.0159868	.0139271	.0034275	23.131	0.0000000	7.03
14	-.170	.142	-.0009972	.0159868	.0105028	-.0034242	23.509	0.0000000	7.16
15	.120	.431	.0024324	.0159868	.0139324	.0034296	22.779	0.0000000	6.91
16	1.206	1.517	-.0010251	.0159868	.0104749	-.0034575	19.667	0.0000000	5.83
17	1.930	2.241	.0025378	.0159868	.0140378	.0035629	17.694	0.0000000	5.14

LENGTH NO. 2

AXIAL LOAD = 5.8 LBS

UPPER GRID DEFLECTION (GRID NO. 2) = .0050000 INS

LOWER GRID DEFLECTION (GRID NO. 3) = -.0070000 INS

ROD ROW / NO.	MOMENTS / GRID 2	IN / GRID 3	RODS / TOTAL / CENTER / DEFLECTION	LOCAL / CREEP / DEFLECTION	MAXIMUM LOC. / RELATIVE TO / EARTH	CENTER DEFL. / CHANNEL / CHANGE	FLOW / CRITICAL / AXIAL	DEFLECTION / DEFLECTION / COMPONENT	HUCKLIN / M.S.
1	-3.872	-3.572	.0010139	.0226088	.0000139	15.012	0.0000000	1.61	
2	-1.778	-1.478	-.0033833	.0226088	-.0043833	19.289	0.0000000	2.35	
3	-1.359	-1.059	.0008737	.0226088	-.0001263	20.234	0.0000000	2.51	
4	-.731	-.431	-.0032883	.0226088	-.0042883	20.705	0.0000000	2.59	
5	-.522	-.221	.0009100	.0226088	-.0000900	18.389	0.0000000	2.19	
6	-.452	-.152	-.0031892	.0226088	-.0041892	22.532	0.0000000	2.91	
7	-.522	-.221	.0008465	.0226088	-.0001535	22.011	0.0000000	2.82	
8	-.452	-.152	-.0031950	.0226088	-.0041950	22.413	0.0000000	2.89	
9	-.382	-.082	.0008395	.0226088	-.0001605	22.538	0.0000000	2.91	
10	-.313	-.012	-.0031870	.0226088	-.0041870	22.577	0.0000000	2.92	
11	-.173	.128	.0008330	.0226088	-.0001670	23.064	0.0000000	3.00	
12	-.382	-.082	-.0031831	.0226088	-.0041831	22.660	0.0000000	2.93	
13	-.103	.197	.0008325	.0226088	-.0001675	23.107	0.0000000	3.01	
14	.106	.407	-.0031828	.0226088	-.0041828	22.667	0.0000000	2.94	
15	.665	.965	.0008551	.0226088	-.0001449	21.406	0.0000000	2.72	
16	2.758	3.059	-.0036105	.0226088	-.0046105	16.782	0.0000000	1.91	
17	4.154	4.455	.0010576	.0226088	.0000576	14.077	0.0000000	1.44	

LENGTH NO. 3

UPPER GRID DEFLECTION (GRID NO. 3) = -.0070000 INS

AXIAL LOAD = 8.6 LRS

LOWER GRID DEFLECTION (GRID NO. 4) = -.0120000 INS

ROD ROW / NO. /	MOMENTS GRID 3	IN GRID 4	PODS / TOTAL LOCAL / CENTER / DEFLECTION	MAXIMUM LOC. / CREEP / DEFLECTION	CENTER DEFL. / RELATIVE TO / EARTH	FLOW CHANNEL CHANGE	/ CRITICAL / AXIAL / LOAD /	CREEP DEFLECTION / COMPONENT	/ STRUT HUCKLIN M.S.
1	-5.561	-5.271	.0022202	.0276900	-.0072798		11.985	0.0000000	.39
2	-2.594	-2.304	-.0046382	.0276900	-.0141382	-.0068583	17.589	0.0000000	1.04
3	-1.988	-1.697	.0011506	.0276900	-.0087494	.0057888	18.907	0.0000000	1.19
4	5.699	5.989	-.0048075	.0276900	-.0143075	-.0059581	16.944	0.0000000	.96
5	-7.449	-7.158	.0015407	.0276900	-.0079593	.0063492	14.521	0.0000000	.68
6	-.369	-.079	-.0038775	.0276900	-.0133775	-.0054181	22.232	0.0000000	1.57
7	-1.044	-.753	.0010480	.0276900	-.0084520	.0049255	21.400	0.0000000	1.48
8	-.572	-.281	-.0038996	.0276900	-.0133996	-.0049476	22.032	0.0000000	1.55
9	-.572	-.281	.0010246	.0276900	-.0084754	.0049242	22.150	0.0000000	1.56
10	-.572	-.281	-.0038736	.0276900	-.0133736	-.0048982	22.267	0.0000000	1.58
11	-.167	.123	.0010059	.0276900	-.0084941	.0048795	22.812	0.0000000	1.64
12	-.437	-.147	-.0038528	.0276900	-.0133528	-.0048597	22.462	0.0000000	1.60
13	-.235	.056	.0010101	.0276900	-.0084899	.0048629	22.659	0.0000000	1.62
14	.237	.528	-.0039408	.0276900	-.0134408	-.0049509	21.675	0.0000000	1.51
15	.979	1.269	.0011032	.0276900	-.0083968	.0050440	19.926	0.0000000	1.31
16	4.013	4.303	-.0062094	.0276900	-.0157094	-.0073126	13.723	0.0000000	.59
17	6.036	6.326	.0034095	.0276900	-.0060905	.0096189	10.472	0.0000000	.21

LENGTH NO. 4

AXIAL LOAD = 11.5 LBS

UPPER GRID DEFLECTION (GRID NO. 4) = -.0120000 INS

LOWER GRID DEFLECTION (GRID NO. 5) = -.0030000 INS

ROD ROW / NO.	MOMENTS / GRID 4	IN / GRID 5	RODS / TOTAL LOCAL / / CENTER / / DEFLECTION	MAXIMUM LOC. / / CREEP / / DEFLECTION	CENTER DEFL. / / RELATIVE TO / / EARTH	FLOW / CHANNEL / / CHANGE	CRITICAL / / AXIAL / / LOAD	CREEP / / DEFLECTION / / COMPONENT	STRUT / HUCKLIN / / M.S.
1	-6.715	-7.219	-.0006994	.0319737	-.0081994		12.899	0.0000000	.12
2	-2.807	-3.312	-.0129871	.0319737	-.0204871	-.0122877	13.643	0.0000000	.18
3	-2.026	-2.531	-.0002058	.0319737	-.0077058	.0127814	18.127	0.0000000	.57
4	-.854	-1.358	-.0068342	.0319737	-.0143342	-.0066284	20.654	0.0000000	.79
5	-.463	-.968	-.0002186	.0319737	-.0077186	.0066156	17.536	0.0000000	.52
6	-.398	-.903	-.0064789	.0319737	-.0139789	-.0062603	21.678	0.0000000	.88
7	-.398	-.903	-.0001642	.0319737	-.0076642	.0063148	21.208	0.0000000	.84
8	-.333	-.838	-.0064923	.0319737	-.0139923	-.0063281	21.636	0.0000000	.88
9	-.203	-.707	-.0001585	.0319737	-.0076585	.0063338	21.865	0.0000000	.90
10	-.072	-.577	-.0063748	.0319737	-.0138748	-.0062163	22.018	0.0000000	.91
11	-.072	-.577	-.0001549	.0319737	-.0076549	.0062199	22.333	0.0000000	.94
12	.058	-.447	-.0062618	.0319737	-.0137618	-.0061069	22.411	0.0000000	.95
13	.253	-.251	-.0001579	.0319737	-.0076579	.0061039	21.948	0.0000000	.91
14	.774	.270	-.0068811	.0319737	-.0143811	-.0067233	20.532	0.0000000	.78
15	1.751	1.246	-.0001946	.0319737	-.0076946	.0066866	18.745	0.0000000	.63
16	5.658	5.153	-.0160388	.0319737	-.0235388	-.0158442	11.910	0.0000000	.03
17	8.263	7.758	-.0153171	.0319737	-.0228171	.0007218	8.946	0.0000000	-.22

ENGTH NO. 5

XIAL LOAD = 8.6 LBS

UPPER GRID DEFLECTION (GRID NO. 5) = -.0030000 INS.

LOWER GRID DEFLECTION (GRID NO. 6) = .0190000 INS.

ROW / NO.	GRID 5	GRID 6	TOTAL LOCAL / CENTER DEFLECTION	MAXIMUM LOC./ CREEP DEFLECTION	CENTER DEFL./ RELATIVE TO EARTH	FLOW / CHANNEL CHANGE	CRITICAL / AXIAL LOAD	CREEP / DEFLECTION COMPONENT	STRUT / BUCKLING M.S.
1	.921	-.766	.0028455	.0276900	.0108455		16.962	0.0000000	.96
2	-8.155	-9.842	-.0064298	.0276900	.0015702	-.0092753	11.152	0.0000000	.29
3	-1.299	-2.986	.0026228	.0276900	.0106228	.0090526	18.496	0.0000000	1.14
4	-.711	-2.398	-.0028249	.0276900	.0051751	-.0054477	19.886	0.0000000	1.30
5	-.058	-1.745	.0023521	.0276900	.0103521	.0051770	21.319	0.0000000	1.47
6	.072	-1.614	-.0026652	.0276900	.0053348	-.0050173	21.586	0.0000000	1.50
7	-.058	-1.745	.0023550	.0276900	.0103550	.0050201	21.281	0.0000000	1.46
8	.072	-1.614	-.0026590	.0276900	.0053410	-.0050139	21.663	0.0000000	1.51
9	.203	-1.484	.0023111	.0276900	.0103111	.0049701	21.892	0.0000000	1.53
10	.203	-1.484	-.0026348	.0276900	.0053652	-.0049459	21.969	0.0000000	1.54
11	.334	-1.353	.0022881	.0276900	.0102881	.0049229	22.237	0.0000000	1.57
12	.595	-1.092	-.0025832	.0276900	.0054168	-.0048713	22.671	0.0000000	1.62
13	.791	-.896	.0022750	.0276900	.0102750	.0048502	22.441	0.0000000	1.60
14	1.705	.018	-.0027923	.0276900	.0052077	-.0050673	20.197	0.0000000	1.34
15	2.162	.475	.0025501	.0276900	.0105501	.0053424	19.124	0.0000000	1.21
16	5.557	3.871	-.0049973	.0276900	.0030027	-.0075475	12.518	0.0000000	.45
17	6.602	4.915	.0061657	.0276900	.0141657	.0111630	10.847	0.0000000	.26

LENGTH NO. 6

AXIAL LOAD = 5.8 LBS

UPPER GRID DEFLECTION (GRID NO. 6) = .0190000 INS

LOWER GRID DEFLECTION (GRID NO. 7) = .0530000 INS

ROW / NO.	MOMENTS IN GRID 6 / GRID 7		TOTAL LOCAL / CENTER / DEFLECTION		MAXIMUM LOC. / CREEP / DEFLECTION		LOC. / CENTER DEFL. / RELATIVE TO / CHANNEL		FLOW / CRITICAL / CHANGE / AXIAL / DEFLECTION		CREEP / STRUT LOAD / COMPONENT / M.S.	
1	-3.305	-4.765	-.0026319	.0226088	.0333681				16.240	0.0000000	1.82	
2	-1.936	-3.396	-.0081436	.0226088	.0278564	-.0055117			13.306	0.0000000	1.31	
3	-.697	-2.157	-.0024575	.0226088	.0335425	.0056860			18.665	0.0000000	2.24	
4	-.566	-2.026	-.0067390	.0226088	.0292610	-.0042814			18.882	0.0000000	2.28	
5	.216	-1.244	-.0023530	.0226088	.0336470	.0043860			20.739	0.0000000	2.60	
6	.347	-1.113	-.0064568	.0226088	.0295432	-.0041038			21.042	0.0000000	2.65	
7	.086	-1.374	-.0023630	.0226088	.0336370	.0040938			20.513	0.0000000	2.56	
8	.412	-1.048	-.0064398	.0226088	.0295602	-.0040768			21.194	0.0000000	2.68	
9	.412	-1.048	-.0023337	.0226088	.0336663	.0041060			21.194	0.0000000	2.68	
10	.412	-1.048	-.0064398	.0226088	.0295602	-.0041060			21.194	0.0000000	2.68	
11	.608	-.852	-.0023155	.0226088	.0336845	.0041242			21.652	0.0000000	2.76	
12	1.195	-.265	-.0062817	.0226088	.0297143	-.0039662			22.763	0.0000000	2.95	
13	.999	-.461	-.0022741	.0226088	.0337259	.0040077			22.802	0.0000000	2.96	
14	2.499	1.039	-.0065495	.0226088	.0294505	-.0042754			20.261	0.0000000	2.52	
15	2.499	1.039	-.0023692	.0226088	.0336300	.0041803			20.373	0.0000000	2.54	
16	5.238	3.778	-.0077083	.0226088	.0282917	-.0053300			14.498	0.0000000	1.52	
17	4.781	3.321	-.0027156	.0226088	.0332844	.0049927			15.371	0.0000000	1.67	

ENGTH NO. 7

IAL LOAD = 2.9 LBS

UPPER GRID DEFLECTION (GRID NO. 7) = .0530000 INS.

LOWER GRID DEFLECTION (GRID NO. 8) = .0860000 INS.

ROW / NO.	ROD / GRID 7	MOMENTS IN RODS / GRID 8	TOTAL LOCAL / CENTER DEFLECTION	MAXIMUM LOC. / CREEP DEFLECTION	CENTER DEFL. / RELATIVE TO EARTH	FLOW / CHANNEL CHANGE	/ CRITICAL / AXIAL / LOAD /	CREEP / DEFLECTION / COMPONENT	STRUT / BUCKLING M.S.
1	-3.567	-2.630	.0021351	.0159868	.0716351		15.960	0.0000000	4.54
2	-3.436	-2.500	-.0015074	.0159868	.0679926	-.0036425	16.860	0.0000000	4.85
3	-2.001	-1.064	.0020461	.0159868	.0715461	.0035535	19.896	0.0000000	5.91
4	-2.457	-1.521	-.0014706	.0159868	.0680294	-.0035167	19.194	0.0000000	5.66
5	-1.413	-.477	.0020214	.0159868	.0715214	.0034920	21.443	0.0000000	6.45
6	-1.283	-.346	-.0014408	.0159868	.0680592	-.0034622	21.749	0.0000000	6.55
7	-1.544	-.607	.0020259	.0159868	.0715259	.0034667	21.139	0.0000000	6.34
8	-1.152	-.216	-.0014381	.0159868	.0680619	-.0034640	22.017	0.0000000	6.64
9	-1.283	-.346	.0020165	.0159868	.0715165	.0034546	21.787	0.0000000	6.56
10	-1.283	-.346	-.0014404	.0159868	.0680596	-.0034569	21.787	0.0000000	6.56
11	-1.022	-.085	.0020086	.0159868	.0715086	.0034490	22.362	0.0000000	6.76
12	-.565	.372	-.0014245	.0159868	.0680755	-.0034331	23.512	0.0000000	7.16
13	-.304	.633	.0019971	.0159868	.0714971	.0034216	23.269	0.0000000	7.08
14	1.458	2.395	-.0014688	.0159868	.0680312	-.0034660	19.327	0.0000000	5.71
15	.806	1.742	.0020368	.0159868	.0715368	.0035057	20.444	0.0000000	6.10
16	3.090	4.027	-.0015397	.0159868	.0679603	-.0035765	15.304	0.0000000	4.31
17	1.132	2.069	.0020705	.0159868	.0715705	.0036101	18.600	0.0000000	5.46

D INPUT *ENDFILE*INPUT

ROR NUMBFR 0065 DETECTED BY INPUTC AT ADDRESS 061576

DATA CARDS FOR SAMPLE PROBLEM - FA1H02

.020							
.0015							
2	1	1					
1.6	25600000.	.0000008	1.0				
8	9	1					
217.	.25	.016	1.16	.0000105	3.	3.	.32
1.	10.	20.	30.	40.	50.	60.	70.
15.	742.	765.	765.	770.	773.	776.	780.
33.	785.	788.	789.	790.	791.	790.	785.
35.	735.						
30.	795.	810.	829.	835.	846.	852.	859.
35.	870.	874.	876.	881.	882.	880.	870.
30.	770.						
45.	827.	865.	894.	899.	919.	924.	939.
47.	955.	963.	965.	971.	974.	970.	955.
35.	865.						
30.	870.	920.	958.	978.	992.	1005.	1018.
130.	1040.	1049.	1056.	1062.	1065.	1060.	1060.
30.	840.						
31.	780.	918.	951.	975.	989.	1001.	1015.
127.	1037.	1047.	1055.	1059.	1060.	1067.	1067.
35.	867.						
12.	870.	917.	945.	971.	985.	997.	1013.
124.	1035.	1046.	1054.	1053.	1055.	1034.	1013.
30.	894.						
23.	870.	915.	938.	968.	982.	994.	1010.
120.	1032.	1044.	1052.	1053.	1050.	1029.	1000.
45.	920.						
700.	50.						
11							
22170000.	21670000.	21170000.	20650000.	20150000.	19650000.	19150000.	18900000.
18750000.	18600000.	18400000.					
.0009	.0014	.0007	0.	-.00126	-.00134	-.0039	-.0037
.018	.005	-.007	-.012	-.003	.019	.053	.006

301
7779.

.02

G-H

•	4.228F-06	8.455E-06	1.268E-05	1.691E-05	2.114E-05	2.537E-05	.03 1
•959E-05	3.384E-05	3.821E-05	4.258E-05	4.696E-05	5.133E-05	5.570E-05	.03 2
•008E-05	6.445E-05	6.887E-05	7.334E-05	7.781E-05	8.229E-05	8.676E-05	.03 3
•123E-05	9.570E-05	1.002E-04	1.047E-04	1.093E-04	1.13E-04	1.184E-04	.03 4
•229E-04	1.275E-04	1.320E-04	1.366E-04	1.412E-04	1.458E-04	1.504E-04	.03 5
•551E-04	1.597E-04	1.643E-04	1.689E-04	1.735E-04	1.782E-04	1.829E-04	.03 6
•876E-04	1.922E-04	1.969E-04	2.016E-04	2.063E-04	2.111E-04	2.157E-04	.03 7
•205E-04	2.252E-04	2.299E-04	2.346E-04	2.394E-04	2.441E-04	2.489E-04	.03 8
•537E-04	2.584E-04	2.632E-04	2.680E-04	2.728E-04	2.776E-04	2.824E-04	.03 9
•872E-04	2.920E-04	2.968E-04	3.016E-04	3.064E-04	3.111E-04	3.159E-04	.03 10
•209E-04	3.258E-04	3.306E-04	3.355E-04	3.403E-04	3.452E-04	3.501E-04	.03 11
•550E-04	3.598E-04	3.647E-04	3.696E-04	3.745E-04	3.794E-04	3.843E-04	.03 12
•892E-04	3.941E-04	3.991E-04	4.040E-04	4.089E-04	4.138E-04	4.187E-04	.03 13
•237E-04	4.287E-04	4.336E-04	4.386E-04	4.435E-04	4.485E-04	4.535E-04	.03 14
•585E-04	4.634E-04	4.684E-04	4.734E-04	4.784E-04	4.834E-04	4.884E-04	.03 15
•934E-04	4.984E-04	5.034E-04	5.084E-04	5.134E-04	5.185E-04	5.235E-04	.03 16
•285E-04	5.335E-04	5.386E-04	5.436E-04	5.487E-04	5.537E-04	5.588E-04	.03 17
•638E-04	5.689E-04	5.740E-04	5.790E-04	5.841E-04	5.892E-04	5.942E-04	.03 18
•993E-04	6.044E-04	6.095E-04	6.146E-04	6.197E-04	6.248E-04	6.299E-04	.03 19
•350E-04	6.401E-04	6.453E-04	6.504E-04	6.555E-04	6.606E-04	6.657E-04	.03 20
•709E-04	6.760E-04	6.812E-04	6.863E-04	6.914E-04	6.965E-04	7.017E-04	.03 21
•069E-04	7.121E-04	7.172E-04	7.224E-04	7.276E-04	7.327E-04	7.379E-04	.03 22
•431E-04	7.483E-04	7.535E-04	7.587E-04	7.638E-04	7.690E-04	7.742E-04	.03 23
•794E-04	7.847E-04	7.899E-04	7.951E-04	8.003E-04	8.055E-04	8.107E-04	.03 24
•160E-04	8.212E-04	8.264E-04	8.316E-04	8.368E-04	8.420E-04	8.472E-04	.03 25
•530E-04	8.533E-04	8.586E-04	8.638E-04	8.690E-04	8.742E-04	8.794E-04	.03 26
•009E-04	9.118E-04	9.227E-04	9.337E-04	9.447E-04	9.557E-04	9.667E-04	.03 27
•950E-04	1.014E-03	1.034E-03	1.055E-03	1.081E-03	1.107E-03	1.135E-03	.03 28
•166E-03	1.198E-03	1.233E-03	1.270E-03	1.310E-03	1.352E-03	1.397E-03	.03 29
•445E-03	1.495E-03	1.548E-03	1.604E-03	1.664E-03	1.726E-03	1.791E-03	.03 30
•860E-03	1.932E-03	2.007E-03	2.086E-03	2.168E-03	2.254E-03	2.344E-03	.03 31
•438E-03	2.535E-03	2.636E-03	2.742E-03	2.851E-03	2.965E-03	3.083E-03	.03 32
•206E-03	3.333E-03	3.465E-03	3.601E-03	3.743E-03	3.889E-03	4.040E-03	.03 33
•197E-03	4.354E-03	4.526E-03	4.699E-03	4.878E-03	5.063E-03	5.253E-03	.03 34
•450E-03	5.653E-03	5.862E-03	6.078E-03	6.301E-03	6.530E-03	6.767E-03	.03 35
•011E-03	7.262E-03	7.521E-03	7.787E-03	8.062E-03	8.344E-03	8.635E-03	.03 36
•935E-03	9.243E-03	9.560E-03	9.887E-03	1.022E-02	1.057E-02	1.092E-02	.03 37
•129E-02	1.167E-02	1.205E-02	1.245E-02	1.286E-02	1.328E-02	1.371E-02	.03 38
•416E-02	1.461E-02	1.504E-02	1.557E-02	1.607E-02	1.658E-02	1.710E-02	.03 39
•764E-02	1.820E-02	1.877E-02	1.936E-02	1.994E-02	2.051E-02	2.122E-02	.03 40
•188E-02	2.256E-02	2.325E-02	2.397E-02	2.471E-02	2.546E-02	2.624E-02	.03 41
•705E-02	2.787E-02	2.873E-02	2.960E-02	3.051E-02	3.144E-02	3.239E-02	.03 42
•338E-02	3.440E-02	3.545E-02	3.654E-02	3.765E-02	3.881E-02	4.000E-02	.03 43
•000000	1.6190E-10	7500.	2.0278				
500.	1.250.	15000.	.00187	.0128			

10050.

APPENDIX B

ISOC2 CODE

LOW STRAIN RATE STRESS-STRAIN CURVE GENERATION

```

      PROGRAM TS002(INPUT,OUTPUT,PUNCH)
C
C                                     **INPUT DATA**
C
C      YOUNGS MODULOUS OF STATIC STRESS STRAIN CURVE - EE
C      LINEAR ELASTIC LIMIT STRESS -AA
C
C      CONSTANTS OF STATIC STRESS-STRAIN CURVE
C      OF FORM
C      STRAIN = STRESS/EE + XK * (STRESS - AA)**NM
C              -EE,XK,AA,BR
C
C      STRAIN RATE -SR-
C      TOTAL NUMBER OF M(T) -MM-
C      *** TO TEST CONVERGENCE OF STRESS
C      VALUE AT EACH INTERVAL **
C      NUMBER OF SEGMENTS PER INTERVAL - M(1)-
C      MAXIMUM STRAIN VALUE ON CURVE -EP-
C      EXPONENT OF T FOR STRESS RELAXATION FORMULA -TXPO-
C      MULTIPLIER OF T FOR STRESS RELAXATION FORMULA -TMULT-
C
C      *** STRESS RELAXATION FORMULA ***
C      STRESS= INITIAL STRESS +((STRESS INCREMENT)*(1.-TMULT*T**TXPO)
C
C      ** OUTPUT DATA **
C      POINT IDENTIFICATION NUMBER -I-
C      STRESS AT SPECIFIED POINT -SIG(IZ)-
C
000003      DIMENSION M(10),SIG(15000),STR(301)
000003      COMMON/BLOCKA/ EE,XK,AA,BR
C      STEP NO. 1
000003      READ 15,EE,XK,AA,BR
000017      READ 5,M,N,(M(T),I=1,MM)
000036      5 FORMAT(12I5)
000036      10 READ 15,SR,EP,IXPO,TMULT
000042      IF(SR.EQ.0.) GOTO 95
000053      15 FORMAT(2F10.0)
000053      DO 50 I1=1,MM
000055      I2 = N* M(I1)
C      STEP NO. 2
000060      DO 20 K=1,I2

```

```

KS)0010
KS)0020
KS)0030
KS)0040
KS)0050
KS)0060
KS)0070
KS)0080
KS)0090
KS)0100
KS)0110
KS)0120
KS)0130
KS)0140
KS)0150
KS)0160
KS)0170
KS)0180
KS)0190
KS)0200
KS)0210
KS)0220
KS)0230
KS)0240
KS)0250
KS)0260
KS)0270
KS)0280
KS)0290
KS)0300
KS)0310
KS)0320
KS)0330
KS)0340
KS)0350
KS)0360
KS)0370
KS)0380
KS)0390
KS)0400
KS)0410
KS)0420
KS)0430
KS)0440
KS)0450
KS)0460

```

```

000061      SIG(K) = 0.                                KS))0470
000062      20 CONTINUE                                KS))0480
000064      X = I2                                       KS))0490
C          STEP NO. 3                                KS))0500
000065      DT = ER* 8760./ (X*SR)                    KS))0510
000070      EIN = ER/X                                  KS))0520
C          STEP NO. 4                                KS))0530
000072      DO 30 I=1,I2                               KS))0540
000073      SIGO = FT(SIG(I))*EIN                      KS))0550
000077      DO 25 J=1,I2                               KS))0560
000101      XJ = J+1-I                                 KS))0570
000104      T = XJ *DT                                 KS))0580
000106      SIG(J) = SIG(J) +SIGO *().-TMULT*T**TXPO ) KS))0590
000116      25 CONTINUE                                KS))0600
000120      30 CONTINUE                                KS))0610
000122      PRINT 35,M(I1),SR,ER,N                     KS))0620
000136      35 FORMAT(1H),* NUMBER OF SEGMENTS PER INTERVAL =*I2,/* STRAIN RATE=*KS))0630
      IF 10.3.* 1N/IN/YEAR/* MAXIMUM STRAIN ON CURVE =*F10.3,/* NUMBER OF KS))0640
      2POINTS ON CURVE =* J5///* POINT*10X,* STRESS*///) KS))0650
000136      DO 40 I=1,N                                 KS))0660
000140      IZ = I*M(I1)                                 KS))0670
000143      PRINT 45,I,SIG(IZ)                          KS))0680
000153      40 CONTINUE                                KS))0690
000156      45 FORMAT(13,10X,F10.1/)                  KS))0700
000156      50 CONTINUE                                KS))0710
C          STEP NO. 5                                KS))0720
000160      N2=N*M                                       KS))0730
000163      DO 55 J=1,N2                                 KS))0740
000164      IF (SIG(J+1).LT.SIG(J)) GO TO 60            KS))0750
000167      55 CONTINUE                                KS))0760
000171      60 SIGMAX =SIG(J)                            KS))0770
000173      SIGEN = SIGMAX/300.                          KS))0780
000175      KZ=1                                         KS))0790
000176      NZ = J                                       KS))0800
000177      STR( 1)=0.0                                  KS))0810
000200      DO 75 K=2,301                                KS))0820
000201      DO 65 KI=KZ,NZ                              KS))0830
000203      IF ((K-1)*SIGEN.LT.SIG(KI)) GO TO 70      KS))0840
000211      65 CONTINUE                                KS))0850
000213      70 KZ = KI                                    KS))0860
000215      IF (KI.EQ.1) STR(K) = EIN + EIN * ((K-1)*SIGEN-SIG(KI)) / SIG(KI) KS))0870
000226      IF (KI.EQ.1) GO TO 75                        KS))0880
000230      STR( K) =(K-1)*EIN+EIN*(((K-1)*SIGEN-SIG(KI))/(SIG(KI)-SIG(KI- KS))0890
      1)))                                             KS))0900
000246      STR(K) = STR(K) + EIN                      KS))0910
000247      75 CONTINUE                                KS))0920
000251      DO 85 I = 1,43                             KS))0930

```


000253	I/0=7*(I-1)	KS))0940
000256	PUNCH 80, (STR(I/0 +J),J=1,7),SR,1	KS))0950
000274	80 FORMAT (7F10.3,4X,F3.2,1X,12)	KS))0960
000274	85 CONTINUE	KS))0970
000276	PUNCH 90, SIGMAX,SR	KS))0980
000306	90 FORMAT(2F20.3)	KS))0990
000306	GOTO 10	KS))1000
000307	95 CALL EXIT	KS))1010
000310	END	KS))1020

4
J

PROGRAM LENGTH INCLUDING I/O BUFFERS
044452

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

5	-	000322	10	-	000036	15	-	000324	35	-	000331
45	-	000354	60	-	000171	70	-	000213	75	-	000247
80	-	000361	90	-	000365	95	-	000367			

BLOCK NAMES AND LENGTHS

BLOCKA - 000004

VARIABLE ASSIGNMENTS

AA	-	000002C01	BP	-	000003C01	DT	-	036347	FF	-	000000C01
EIN	-	036350	FR	-	036340	I	-	036330	I/	-	036355
IZD	-	036343	II	-	036343	12	-	036344	J	-	036352
K	-	036345	FI	-	036362	KZ	-	036361	P	-	000415
MM	-	036335	P	-	036334	NZ	-	036356	SIG	-	000427
SIGEN	-	036360	SIGMAX	-	036357	SIG0	-	036361	SP	-	036337
STR	-	036357	T	-	036354	TROU I	-	036342	TXP0	-	036341
X	-	036346	AD	-	036353	AK	-	000001C01			

START OF CO STENTS

000312

START OF TEMPORARIES

000367

START OF INDIRECTS

000407

UNUSED COMPILER SPACE

107500

B-5

	FUNCTION ET(SIG)	0010
00003	COMMON/BLOCKA/ EF,X ,A ,B	0020
00003	ET= EF	0030
00005	IF (SIG.GT.A) ET= EF/(1.+EF*X*(SIG-A)**(B-1.))	0040
00021	RETURN	0050
00023	END	0060

SUBPROGRAM LENGTH

000041

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

BLOCK NAMES AND LENGTHS

BLOCKA - 000004

VARIABLE ASSIGNMENTS

A - 000002C01 R

X - 000001C01

- 000003C01 EF

- 000000C01 F1

- 000040

START OF CONSTANTS

000025

START OF TEMPORARIES

000027

START OF INDIRECTS

000040

UNUSED COMPILER SPACE

110600

ORE MAP 10 3.39. NORMAL CONTROL 00010 051217
 ---TIME---LOAD MODE ---L1---L2---TYPE-----USEP---+---CALL-----FNA LOAD---LWA LOAD---

FNA LOADER 137005 FNA TABLES 136510

---PROGRAM---ADDRESS---

---LABELLED---COMMON---

ISOC2	000104		BLOCKA	000100
ET	044556		BLOCKA	000100
SYSTEM	044617			
INPUTC	045534			
RRAREX	046117			
OUTPTC	046203			
GETFA	046562			
XPCI	046601			
KRAKER	046606			
ALNLOG	047623			
EXP	047712			
RRATEX	047771			
KODER	050022			

---ENTRY---ADDRESS---

REFERENCES

ISOC2	000105							
ET	044557	ISOC2	000200					
CENTRY	044620	ISOC2	000106					
SYSTEM	044763	INPUTC	045562					
		RRAREX	046163					
		OUTPTC	046217					
		KRAKER	047425					
		ALNLOG	047663	047665				
		RRATEX	050007					
		KODER	051030					
SYSTEMC	044730							
SYSTEMP	044756							
END	044654	ISOC2	000415					
		ET	044602					
STOP	044703							
EXIT	044675	ISOC2	000413					
ABNORMAL	044713	INPUTC	045563					
		OUTPTC	046220					
		KRAKER	047426					
		KODER	051031					
INPUTC	045536	ISOC2	000111	000113	000115	000117	000121	000122
			000127	000131	000135	000141	000144	000146
			000152	000154	000155			

RR. EX	046120	ISOC2	000213					
		ET	044571					
OUTPTC	046205	ISOC2	000230	000232	000234	000236	000240	000241
			000253	000255	000256	000364	000370	000374
			000377	000404	000406	000410	000411	
		KRAKER	041313	041377	047402			
GETHA	046562	INPUTC	045544					
		OUTPTC	046213					
XHCL	046601	INPUTC	045512	045615				
		OUTPTC	046224	046270	046273			
KRAKER	046607	INPUTC	045540	045555				
AI OG	047627	WHAREX	046143					
AI OF10	047524							
FXP	047713	WHAREX	046146					
RSATIX	047772	WHAREX	046130					
KONFR	050023	OUTPTC	046207	046232				

-----UNSATISFIED EXTERNALS-----

REFR RES

NUMBER (SEGMENTS PER INTERVAL = 20
 STRAIN RATE = .050 IN/IN/YEAR
 MAXIMUM STRAIN ON CURVE = .060
 NUMBER OF POINTS ON CURVE = 20

POINT	STRESS
-------	--------

1	13544.3
2	14658.5
3	15788.0
4	16945.5
5	16401.2
6	16788.4
7	17125.8
8	17425.1
9	17694.3
10	17938.7
11	18162.7
12	18369.1
13	18560.6
14	18734.1
15	18906.0
16	19062.7
17	19210.3
18	19349.7
19	19481.7

B-10

20

19506.9

B-11

NUMBER SEGMENTS PER INTERVAL = 20
STRAIN RATE = .100 IN/IN/YEAR
MAXIMUM STRAIN ON CURVE = .120
NUMBER OF POINTS ON CURVE = 20

POINT	STRESS
-------	--------

1	16869.0
---	---------

2	18898.0
---	---------

3	20364.3
---	---------

4	21551.2
---	---------

5	22565.2
---	---------

6	23459.3
---	---------

7	24264.6
---	---------

8	25000.8
---	---------

9	25681.4
---	---------

10	26316.1
----	---------

11	26912.1
----	---------

12	27475.0
----	---------

13	28009.2
----	---------

14	28518.2
----	---------

15	29004.8
----	---------

16	29471.3
----	---------

17	29919.4
----	---------

18	30352.2
----	---------

19	30769.6
----	---------

20

31173.4

B-13

DATA CARDS FOR SAMPLE PROBLEM - ISOC2

18000000.	3.666E-13	10000.	2.6277
20	1	20	
.05	.06	.15978489	.1537925
.10	.12	.07488116	.1204167

Card 1 (8F10.0)

EE
 XK
 AA
 BB

$$\left\{ \begin{array}{l} \text{Constants of output of ISOCUR of equation} \\ \epsilon = \frac{\sigma}{E} + XK (\sigma - AA)^{BB} \text{ Describing the elastic-plastic} \\ \text{stress-strain curve.} \end{array} \right.$$
Card 2 (I5,5X,I5) *(Place a 1 in Col. 10)*

cc 3-5 Number of points for which we print values of stress-N
 cc 13-15 Number of strain increments into which each of the N
 increments is divided. - M ($M \cdot N \leq 15000$)

Card 3 (8F10.0)

cc 1-10 Strain rate for curve output (0.03 = 3 percent/year)-SR
 cc 11-20 Maximum strain value on output curve (0.03 = 3 percent
 strain)-ER
 cc 21-30 TXPO { Constants of our stress relation, where
 cc 31-40 TMULT { $\sigma_2 = \sigma_1 (1. - TMULT(TIME)^{TXPO})$

Repeat card 3 for each addition case desired. Follow last card by a blank card.

This program generates low strain rate curves.

Step 1

Read EE, XK, AA, BB, N, M
SR, ER, TXPO, TMULT

$$\epsilon = \begin{cases} \frac{\sigma}{EE} & \sigma \leq AA \\ \frac{\sigma}{EE} + XK (\sigma - AA)^{BB} & \sigma \geq AA \end{cases}$$

Step 2

Initialize all stresses. $SIG(K) = 0$ $1 \leq K \leq M \cdot N$

Step 3

$$\Delta T = \frac{\epsilon_R \times 8760}{N \cdot M \cdot SR}$$

$$\epsilon_{IN} = \frac{\epsilon_R}{N \cdot M}$$

Step 4

For each increment in term, follow the elastic curve from the initial stress₁ and compute the decayed stress at every increment above, using the relaxation formula

$$\sigma_0 = E_T \epsilon_{IN}$$

$$E_T = E_T (\sigma_I)$$

$$\sigma_j = \sigma_j + \sigma_0 \times (1 - At^B)$$

$$t = (J-I+1)\Delta t$$

Print the stress value at the N constant strain increments to ϵ_R .

Step 5

Go up the isochronous curve until there is a negative slope. Call the maximum stress up to this point SIGMAX. This is divided into 300 constant stress increments and the strains are found at each point. These values of strains are then punched out on 7E10.3 followed by the value of SIGMAX, on card 44.

Step 5

Go up the isochronous curve until there is a negative slope. Call the maximum stress up to this point SIGMAX. This is divided into 300 constant stress increments and the strains are found at each point. These values of strains are then punched out on 7E10.3 followed by the value of SIGMAX, on card 44.

APPENDIX C

ISOCUR CODE

ISOCHRONOUS STRESS-STRAIN CURVE GENERATION

```

PROGRAM ISOCUR(INPUT,OUTPUT)
000003 DIMENSION XATD(3,4),SIG(3),EP(3),TI(3)
000003 DIMENSION T(10),EPS(200,10),EPSC(200)

C
C
C *** STRAIN = STRESS / E + A * (STRESS - A)**B + K2*(STRESS-AA)**N*T
C
C
C PRIMARY CREEP = K * (STRESS - A)**B
C SECONDARY CREEP = K2 * (STRESS-AA)**N * (TIME)
C
C
C SIG(I) = TWO VALUES OF STRESS INPUT (ON CURVES)
C EP(I) = STRAIN
C TI(I) = TIME
C E = YOUNG'S MODULUS
C SIGMAX = MAXIMUM VALUE OF STRESS ON OUTPUT CURVES
C NS = NUMBER OF STRESSES IN OUTPUT
C NT = NUMBER OF TIMES FOR WHICH STRAINS ARE COMPUTED
C T(I) = VALUES OF TIME FOR WHICH ADDITIONAL CURVES ARE CALCULATED
C
C *****
C
C THIS PROGRAM FORMS ISOCHRONOUS STRESS-
C STRAIN CURVES (CREEP SENSITIVE STRESS
C -STRAIN CURVES)
C
C *****
C
000003 STEP NO. 1
000013 READ 65,E,SIGMAX
000035 READ 65,AA,(SIG(I),I=1,2),(EP(I),I=1,2)
000037 DO 5 J=1,2
000041 XATD(I,1) = 1.
000046 XATD(J,2) = ALOG(SIG(I)-AA)
000055 XATD(I,3) = ALOG(EP(I)-SIG(I)/E)
000057 5 CONTINUE
000066 CALL MATRIX (10,2,3,0,XATD,3,DET)
000074 PRINT 34,DET
000077 XK1 = EXP(XATD(1,3))
000100 H = XATD(2,3)
000110 PRINT 10,XK1,H
10 FORMAT(/////* K =*E12.4,/* B =*E12.4//)

```

```

E 0010
F 0020
E 0030
E 0040
F 0050
F 0060
E 0070
E 0080
E 0090
E 0100
E 0110
E 0120
E 0130
E 0140
E 0150
E 0160
E 0170
F 0180
E 0190
E 0200
E 0210
F 0220
E 0230
E 0240
E 0250
E 0260
E 0270
F 0280
E 0290
E 0300
E 0310
F 0320
E 0330
F 0340
F 0350
E 0360
E 0370
E 0380
E 0390
E 0400
F 0410
F 0420
E 0430
E 0440
E 0450
F 0460

```


	STEP NO. 2	E	0470
000110	READ 65,AAA,(SIG(I),I=1,2),(FP(I),I=1,2),(TI(I),I=1,2)	F	0480
000140	DO 15 I=1,2	F	0490
000142	XATD(I,1) = 1.0	F	0500
000144	XATD(I,2) = ALOG(SIG(I)-AAA)	F	0510
000151	IF(SIG(I).LE.AA) XATD(I,3)=ALOG(FP(I)-SIG(I)/E) -ALOG(TI(I))	E	0520
000167	IF(SIG(I).GT.AA) XATD(I,3)=ALOG(FP(I)-SIG(I)/E-XK1*(SIG(I)-AA)**R)	F	0530
	1 -ALOG(TI(I))	F	0540
000215	15 CONTINUE	F	0550
000217	20 IF(XATD(1,2).EQ.XATD(2,2))	F	0560
000221	GOTO 30	F	0570
000222	25 XATD(1,2) = XATD(2,2) * 0.999	F	0580
000224	30 CONTINUE	F	0590
000224	CALL MATRIX(10,2,3,0,XATD,3,DET)	E	0600
000233	PRINT 35,DET	F	0610
000241	35 FORMAT(///* THE DETERMINANT OF THE MATRIX OF COEFFICIENTS IS FOUR	E	0620
	1AL TO *F12.4///)	F	0630
000241	A = EXP(XATD(1,3))	F	0640
000244	X ^T = XATD(2,3)	E	0650
000245	PRINT 40,A,XM	F	0660
000255	40 FORMAT(/** A =*F12.4,/* M =*E12.4)	F	0670
000255	PRINT 45	E	0680
000261	450FORMAT (1H1,//////40X,*COORDINATES OF INPUT DATA*//25X,*POINT*10X,	E	0690
	1*TIME*10X,*STRESS*10X,*STRAIN*//)	F	0700
000261	DO 50 I=1,2	F	0710
000263	PRINT 55,I,TI(I),SIG(I),FP(I)	F	0720
000276	50 CONTINUE	E	0730
000300	55 FORMAT (26X,I1,10X,F6.3, 9X,F6.0,8X,F8.6)	F	0740
	C STEP NO. 3	E	0750
000300	READ 60,NT,NS	E	0760
000310	READ 65,(T(I),I=1,NT)	F	0770
000323	60 FORMAT(12I5)	E	0780
000323	65 FORMAT(8F10.0)	F	0790
000323	SIGIN = SIGMAX/ NS	F	0800
000326	DO 90 I=1,NT	F	0810
000327	DO 75 J=1,NS	F	0820
000330	XJ=J	F	0830
000331	IF(J.EQ.1) GOTO 70	E	0840
000333	IF(EPS(J-1,I).GT.0.1) GOTO 80	F	0850
000340	70 S = XJ * SIGIN	F	0860
000342	IF(S.LE.AAA) EPS(J,I) = S/E	F	0870
000351	IF(S.LE.AA.AND.S.GT.AAA) EPS(J,I) = S/E +A*(S-AAA)**XM*T(I)	F	0880
000374	IF(S.GT.AA) EPS(J,I)=S/E+XK1*(S-AA)**R+A*(S-AAA)**XM*T(I)	F	0890
000421	75 CONTINUE	F	0900
000424	GOTO 90	E	0910
000424	80 DO 85 K=J,NS	F	0920
000426	85 EPS(K,I) = 0.	F	0930

000434	90 CONTINUE	E	0940
000437	NXQ=AA/SIGIN	F	0950
000441	DO 95 J=1,NS	F	0960
000443	XJ = J	F	0970
000444	EPSC(J)=XJ*SIGIN/E	E	0980
000447	IF (J.GT.NXQ) EPSC(J)=XJ*SIGIN/F+XK1*(XJ*SIGIN-AA)**R	F	0990
000462	95 CONTINUE	F	1000
000465	PRINT 100,(I(I),I=1,NT)	F	1010
000477	100 FORMAT(1H1,* TIME*15X,10F11.2///)	E	1020
000477	PRINT 105	F	1030
000503	105 FORMAT(* STRESS*4X,* PRIMARY*20X,* STRAINS*/10X,* STRAIN*/10X,* CRF	F	1040
	1EEP*)	F	1050
000503	NTM = NT - 1	E	1060
000505	DO 120 I=1,NS	F	1070
000507	S = I*SIGIN	F	1080
000512	IF(EPS(I,1).EQ.0.) GOTO 125	F	1090
000513	NZ = NT	F	1100
000515	DO 110 K=1,NTM	F	1110
000516	IF(EPS(I,NT+1-K).EQ.0.) NZ = NT-K	F	1120
000523	110 CONTINUE	F	1130
000526	PRINT 115,S,EPSC(I),(EPS(I,J),J=1,N/)	E	1140
000546	115 FORMAT(F6.0,4XF11.8,4X,,9F11.8/)	E	1150
000546	120 CONTINUE	F	1160
000551	CALL EXIT	E	1170
000552	125 DO 130 IZ=I,NS	F	1180
000554	S = IZ*SIGIN	E	1190
000557	PRINT 115,S,EPSC(IZ)	E	1200
000566	130 CONTINUE	F	1210
000571	CALL EXIT	F	1220
000572	END	E	1230

PROGRAM LENGTH INCLUDING I/O BUFFERS
011321

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

10	-	000611	15	-	000215	20	-	000217	25	-	000222
30	-	000224	35	-	000620	40	-	000631	45	-	000635
55	-	000650	60	-	000655	65	-	000657	70	-	000340
75	-	000421	80	-	000424	85	-	000426	90	-	000434
95	-	000462	100	-	000662	105	-	000666	110	-	000523
115	-	000676	125	-	000552						

BLOCK NAMES AND LENGTHS

VARIABLE ASSIGNMENTS

A	-	005240	AA	-	005232	AAA	-	005237	H	-	005236
DET	-	005234	F	-	005230	EP	-	000760	FPS	-	001000
EPSC	-	004720	I	-	005233	I/	-	005254	J	-	005245
K	-	005250	IS	-	005243	NT	-	005242	NTM	-	005252
NXG	-	005251	NZ	-	005253	S	-	005247	SJG	-	000755
SIGIN	-	005244	SIGMAX	-	005231	T	-	000765	TI	-	000763
XAID	-	000741	XJ	-	005246	XK1	-	005235	X	-	005241

START OF CONSTANTS

000574

START OF TEMPORARIES

000702

START OF INDIRECTS

000724

UNUSED COMPILER SPACE

106400

CORE MAP 0' 8.16. NORMAL CONTROL 0001. 021514
 ---TIME---LOAD MODE ---L1---L2---TYPE-----USER---+---CALL-----FWA LOAD---LKA LOAD---

FWA LOADER 137005 FWA TABLES 136402

PROGRAM---ADDRESS-

--LABELLED--COMMON--

ISOCUR 000100
 SYSTEM 011421
 INPUTC 012336
 ALNLOG 012721
 MATRIX 014140

IROW 013010
 ICOL 013464

OUTPTC 016023
 EXP 016402
 PHAREX 016401
 GETRA 016545
 XRCI 016564
 KPAKER 016571
 MASNT 017606

IROW 000000
 ICOL 013010
 ICOL 013464

SCRT 020223
 KODER 020266
 PHAIEX 021463

ENTRY---ADDRESS-

REFERENCES

ISOCUR 000101
 ORNTRY 011422

ISOCUR 000102

SYSTEM 011565

INPUTC 012364
 ALNLOG 012761 012763
 OUTPTC 016037
 EXP 016435
 PHAREX 016525
 SCRT 020250
 KODER 021274
 PHAIEX 021501

SYSTEMC 011532
 SYSTEMP 011560
 END 011456

ISOCUR 000673
 MATRIX 015602

STOP 011505
 EXIT 011477

ISOCUR 000651 000671

ARNORML 011515

INPUTC 012365
 OUTPTC 016040
 KPAKER 011411
 KODER 021275

INPUTC	012340	ISOCUR	000105 000131 000237 000422	000107 000134 000402	000111 000212 000404	000112 000214 000406	000115 000220 000407	000117 000226 000412
ALOG	012725	ISOCUR	000143	000152	000246	000255	000263	000273
		RRAREX	016505					
ALOG10	012722							
MATRIX	014145	ISOCUR	000162	000165	000327	000332		
OUTPTC	016025	ISOCUR	000170 000335 000357 000375 000631 000665	000172 000337 000360 000566 000633	000173 000340 000364 000572 000641	000202 000347 000366 000576 000645	000204 000351 000370 000601 000660	000205 000353 000372 000602 000662
		KRAKER	017356	017362	017365			
EXP	016403	ISOCUR	000175	000342				
		RRAREX	016510					
RRAREX	016462	ISOCUR	000301	000467	000506	000511	000555	
GFTBA	016545	INPUTC	012346					
		OUTPTC	016033					
XPCI	016564	INPUTC	012414	012417				
		OUTPTC	016044	016110	016113			
KRAKER	016572	INPUTC	012342	012357				
MASCNT	017607	MATRIX	014172					
SORT	020224	MATRIX	014242 015314	014357	014420	015177	015261	015276
KRAKER	020267	OUTPTC	016027	016052				
RRAREX	021464	RRAREX	016472					

-----UNSATISFIED EXTERNALS-----

REFERENCES

THE DETERMINANT OF THE MATRIX OF COEFFICIENTS IS EQUAL TO 6.2861E-01

K = 1.6190E-10
R = 2.0278E+00

THE DETERMINANT OF THE MATRIX OF COEFFICIENTS IS EQUAL TO -4.7000E-01

A = 6.5244E-12
M = 2.5258E+00

COORDINATES OF INPUT DATA

POINT	LINE	STRESS	STRAIN
1	.500	13000	.030500
2	.500	10000	.009000

[illegible]

6600	.00036667	.00038605	.00040543	.042481	.00046357	.00048246	.00050234
6750	.00037500	.00039930	.00042361	.00044792	.00049652	.00052083	.00054513
6900	.00038333	.00041325	.00044317	.00047308	.00053241	.00056283	.00059274
7050	.00039167	.00042741	.00046415	.00050041	.00057289	.00060914	.00064538
7200	.00040000	.00044332	.00048655	.00052997	.00061001	.00065944	.00070325
7350	.00040833	.00045950	.00051070	.00056187	.00066421	.00071540	.00076657
7500	.00041667	.00047649	.00053634	.00059617	.00071582	.00077664	.00083550
7650	.00042919	.00049850	.00056784	.00063715	.00077578	.00084512	.00091443
7800	.00045640	.00053006	.00060975	.00068540	.00084871	.00092740	.00100805
7950	.00046051	.00057139	.00066230	.00075418	.00093494	.00102585	.00111673
8100	.00051961	.00062262	.00072567	.00082067	.00103469	.00113773	.00124074
8250	.00056778	.00068364	.00079995	.00091602	.00114815	.00126625	.00138032
8400	.00062506	.00075514	.00088527	.00101534	.00127549	.00140502	.00153570
8550	.00069152	.00083658	.00099817	.00112777	.00141689	.00156201	.00170707
8700	.00076719	.00092823	.00108935	.00125039	.00157248	.00173360	.00189464
8850	.00085209	.00103614	.00120827	.00138032	.00174242	.00192055	.00209860
9000	.00094628	.00114237	.00133855	.00153465	.00192684	.00212362	.00231412
9150	.00104976	.00126496	.00148026	.00169547	.00212588	.00234117	.00255034
9300	.00115256	.00139796	.00163346	.00186886	.00233966	.00257515	.00281055
9450	.00125472	.00154141	.00179822	.00205491	.00256830	.00282510	.00305180
9600	.00141624	.00169536	.00197459	.00225371	.00281194	.00309117	.00337029
9750	.00155715	.00185983	.00216264	.00246532	.00307058	.00337349	.00367640
9900	.00170747	.00203488	.00236242	.00268583	.00334405	.00367219	.00399560
10050	.00186721	.00222053	.00257399	.00292731	.00363395	.00396741	.00430073
10200	.00203639	.00241682	.00279740	.00317783	.00393869	.00431524	.00466071
10350	.00221542	.00262378	.00303271	.00344147	.00425910	.00466743	.00507669
10500	.00240312	.00284145	.00327990	.00371824	.00459496	.00503347	.00547180
10650	.00260070	.00308986	.00353921	.004006837	.00494608	.00541604	.00588519
10800	.00280777	.00330903	.00381050	.00431176	.00531428	.00581574	.00631700
10950	.00302435	.00355900	.00409388	.00462853	.00560784	.00623271	.00678730
11100	.00325045	.00381981	.00438940	.00495375	.00604746	.00666705	.00723641
11250	.00348660	.00409146	.00466510	.00530248	.00651325	.00711080	.00772427
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11550	.00398597	.00466746	.00534924	.006003073	.00730371	.008007549	.00875690
11700	.00425025	.00497185	.00569376	.00641536	.00785876	.00856147	.00930267
11850	.00452410	.00528721	.00605053	.00681374	.00833996	.0090910334	.00986649
12000	.00480753	.00561355	.00641951	.00722504	.00883794	.00964435	.01045037
12150	.00510055	.00595091	.00680163	.00765200	.00935273	.01020240	.01105382
12300	.00540316	.00629931	.00719584	.00809190	.00995824	.01078082	.01167097
12450	.00571538	.00665878	.00760250	.00854506	.01043275	.01137654	.01231003
12600	.00603722	.007072433	.008082105	.00901397	.01099819	.01190071	.01295202
12750	.00636868	.00741099	.008445375	.00949606	.01158070	.01262345	.01366577
12900	.00670976	.007800374	.008894820	.009999230	.01218036	.01327485	.01436888
13050	.00706049	.00820775	.00935544	.01051275	.01270726	.01394500	.01509220
13200	.00742086	.00862208	.00982244	.01102744	.01343140	.01483602	.01583504
13350	.00779088	.00906422	.01030804	.01156643	.014008312	.01534194	.01600133
13500	.00817056	.00948678	.01080350	.01211978	.01475223	.01606100	.01730523

•01819085
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•01989471
•02073316
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•02346589
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•01916916
•01999919
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•01646493

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•01484430

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•00945892
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•00978400
•0101407
•01095184
•01119931
•01155449
•01202338
•01250000

13650
13800
13950
14100
14250
14400
14550
14700
14850
15000

DATA CARDS FOR SAMPLE PROBLEM - ISOCUR

18000000.	15000.					
7500.	11500.	15000.	.0039	.0125		
5000.	13000.	10000.	.0305	.009	.5	.5
6 100						
.02397	.04795	.07192	.11986	.14384	.16781	

C-2

INPUT DESCRIPTION FOR ISOCUR

Card 1

(8F10)

cc 1-10

Modulus of elasticity in elastic range - E

cc 11-20

Maximum value of stress for which strains are calculated - SIGMAX

Card 2

(8F10.0)

cc 1-10

Elastic limit stress - AA

cc11-20-SIG(1)

cc21-30-SIG(2)

cc31-40-EP(1)

cc41-50-EP(2)

Stress coordinates of input points for elastic-plastic - primary creep curve: strain coordinates of input points for elastic-plastic - primary creep curves

Card 3

(8F10.0)

cc 1-10

Minimum value of stress for secondary creep-AAA

cc 11-70

Stress, strain and time coordinates of input

SIG (1)

isochronous stress strain curve.

SIG (2)

EP (1)

EP (2)

TI (1)

TI (2)

Card 4

(12I5)

Col. 4-5

Number of times for which strains are calculated
(10 max.) -NT

cc 8-10

Number of stress values for which strains are calculated. (max. 200) -NS

Card 5

(8F10.0)

Values of time for which strains are calculated

$(1 \leq T \leq NT)$

$(NT \leq 10)$

$T(I)$

This program fits an equation of the form

$$\epsilon = \frac{\sigma}{E} + K_1 (\sigma - A)^B + K_2 (\sigma - A_2)^{B_2} T$$

to experimental data so that we can generate isochronous stress-strain curves for different times. The $K_1 (\sigma - A)^B$ is the plastic-primary creep portion of the strain and the $K_2 (\sigma - A_2)^{B_2} T$ is the secondary creep portion of the strain. The complete expression for strain is given by

$$\epsilon = \begin{cases} \frac{\sigma}{E} & \sigma \leq A_2 \\ \frac{\sigma}{E} + K_2 (\sigma - A_2)^{B_2} T & A_2 \leq \sigma \leq A \\ \frac{\sigma}{E} + K_1 (\sigma - A)^B + K_2 (\sigma - A_2)^{B_2} T & A \leq \sigma \end{cases}$$

Step 1 Determine K_1 and B

From the elastic-plastic-primary creep curve, we pick what we judge to be $\underline{A}$, the linear elastic limit. We then pick two other points on the curve which the curve must fit, and read in the coordinates of these points (these points should be chosen so that they best represent the curve above $\underline{A}$ knowing that the curve must pass through A).

We then have two equations in stress and strain.

$$\epsilon_1 = \frac{\sigma_1}{E} + K_1 (\sigma_1 - A)^B$$

$$\epsilon_2 = \frac{\sigma_2}{E} + K_1 (\sigma_2 - A)^B$$

and from these, $\underline{K}_1$ and $\underline{B}$ are determined.

Step 2 Determine K_2 and B_2

From experimental data, pick the stress level at which secondary creep seems to take effect. Use this value for A_2 . Pick two other points -- preferably at constant time which best represent that particular curve above A_2 . Read in A_2 , and the coordinates (σ, ϵ, t) of the two points.

Again we have two equation to solve for K_2 and B_2 .

Step 3 Calculate Values of ϵ at Constant σ Increments for Different Values of Time

Read $\underline{NS}$, NT , $\underline{T(I)}$ $I \leq I \leq NT$

Calculate by using the strain formula, the strains for each $T(I)$ at constant increments of stress equal to $\underline{SIGMAX}$ divided up to $\epsilon = 0.1$.

A(2)	- K_2
AA(1)	- A
AAA(2)	- A_2
B(1)	- B
E(1)	- Young's modulus (input)
EP(1,2)	- Strain coordinate of input points
EPS(3)	- Calculated value of strain for time T and stress σ
EPSC(3)	- Calculated value of elastic-plastic-primary creep strain for stress σ
NS(3)	- No. of points of stress read out for calculated stress-strain curves
NT(3)	- No. of times for which a curve is calculated
SIG(1,2)	- Stress coordinate of input points
SIGIN	- Stress increment for which strain is calculated
SIGMAX	- Maximum value of stress for which strain is calculated
T(I) (3)	- Values of time for which strain is calculated
TI(2)	- Time coordinates of input points

APPENDIX D
SISINUC CODE
SWELLING-INDUCED STRAINING OF A NONUNIFORM CLADDING

1. STRUCTURAL MODEL

(See Figure 4-7 for fuel tube/shear web geometry)

$$\phi_0 = \frac{W}{2 \cdot R} \quad (1)$$

Divide the $\pi - \phi_0$ area into n segments.

$$\phi = \frac{1}{n} (\pi - \phi_0) \quad (2)$$

$$\ell_j = R \cdot \phi \quad (3)$$

Circumferential translation of segment j relative to the pellet can be produced by each of three mechanisms:

- (a) shear deformation of the cladding
- (b) shear deformation of the pellet
- (c) sliding between pellet and cladding

The contribution of mechanisms (a) and (b) is considered negligible relative to contribution (c); therefore, only mechanism (c) is included in the structural model.

The limiting value of shear flow, q_j , is obtained as:

$$q_j = P \cdot \mu \quad (4)$$

Figure D-1. Structural Model

Figure D-2. Low Strain Rate Stress-Strain Curves

The load balance equation for element j is thus obtained:

$$F_j + q_j \cdot \ell_j - F_{j-1} = 0 \quad (5)$$

The segment circumferential translation is assumed to be described by a stick/slip model; i.e., under the load system described by Eq. (5), segment j is free to slide over the pellet surface in the direction j to $j-1$. Neglecting thinning of the cladding due to straining the segment, mean stress σ_j is obtained:

$$\sigma_j = \frac{F_j + F_{j-1}}{2 \cdot t} \quad j \neq 0 \quad (6)$$

Fuel swelling in the axial direction is assumed to be accommodated by dished recesses in the pellet ends; in this swelling model, therefore, axial stresses are assumed to be zero.

The membrane stress in segment 0 is obtained:

$$\sigma_0 = \frac{F_0}{t + x} \quad (7)$$

Let the swelling strain in an equivalent uniform tube be ϵ_{IR} . The strain in segment j is ϵ_j . Consider the equilibrium of the overall tube section. Figure D-2 represents a series of low-strain-rate stress-strain curves. In these curves the stress corresponding to a given strain is obtained from the short-time stress-strain curve by subtracting the integrated effect of stress relaxation over the loading period (see Section 4.5.1).

Curve S_0 represents the short-time stress-strain curve. Curves S_1 , S_2 , etc. correspond to straining rates of S_1 , S_2 , etc. in./in./year. Let the time over which strain ϵ_{IR} is produced by U_{IT} years.

$$S_k = \frac{\epsilon_{IR}}{U_{IT}} \quad (8)$$

Entering the k^{th} low-strain-rate stress-strain curve with strain ϵ_{IR} , membrane stress σ_R is obtained.

$$P = \frac{\sigma_R \cdot t}{R} \quad (9)$$

At some point remote from the effect of the shear web stiffening, there will exist a segment k in which the stress and strain correspond to σ_R and ϵ_{IR} , respectively, and shear flow q_k is zero. This segment is found by iteration.

Membrane elongation of the cladding contained in arc θ_{k-1} is by definition of segment k given as:

$$\delta_{0k} = E_{IR} \cdot R \cdot \theta_{k-1} \quad (10)$$

Consider the deflection of a string of k segments:

$$F_{k-1} = \sigma_R \cdot t \quad (11)$$

$$F_0 = F_{k-1} + \sum_{j=1}^{j=k-1} q_j \ell_j \quad (12)$$

$$F_j = F_{j-1} - q_j \ell_j \quad (13)$$

Using Eq. (6) obtain σ_j . The corresponding strains ϵ_j are given by the low-strain-rate stress-strain curves as a function of both stress σ_j and strain rate S .

$$\epsilon = f(\sigma, S) \quad (14)$$

Unfortunately, a long-running computer code (ISOC2) is needed for a direct evaluation of this function at each (σ, S) . The only practical alternative is to generate a library of discrete points satisfying (14), $\epsilon_{jk} = f(\sigma_j, S_k)$, by running ISOC2 once for a wide range of (σ_j, S_k) , and then interpolate between points in this library each time (Eq. 14) must be evaluated in SISINUC. This

interpolation is performed in two steps. First, $\epsilon_k(\sigma)$ is obtained by linear interpolation between points of constant S_k :

Choose j such that $\sigma_j < \sigma < \sigma_{j+1}$,

$$\text{Then } \epsilon_k(\sigma) = f(\sigma_j, S_k) + [f(\sigma_{j+1}, S_k) - f(\sigma_j, S_k)] \frac{\sigma - \sigma_j}{\sigma_{j+1} - \sigma_j} \quad (14A)$$

The second interpolation, between input strain rates, is more complicated since linear interpolation is inaccurate. A much better result is obtained by approximating $\log f(\sigma, S)$ by a polynomial in $\log S$. SISINUC uses a second-order polynomial of the form.

$$\log f(\sigma, S) \approx \log g(\sigma, S) \equiv a_0(\sigma) + a_1(\sigma) \log S + a_2(\sigma) (\log S)^2 \quad (15)$$

The coefficients $a_i(\sigma)$ are determined by requiring that $g(\sigma, S_k) = \epsilon_k(\sigma)$ exactly for three consecutive input strain rates S_k .

Since all cladding strains occur in the same time U , the strain rate in a segment with strain ϵ is $S = \epsilon/U$. Thus, (Eq. 14) fully defines ϵ (implicitly) as a function only of σ , for a given U . Using (Eq. 15) to approximate $f(\sigma, S)$, (Eq. 14) can be solved explicitly for the unique strain corresponding to any stress.

$$\begin{aligned} \log \epsilon = & - \frac{a_1(\sigma) - 1 - a_2(\sigma) \log U}{2a_2(\sigma)} - \frac{1}{2a_2(\sigma)} \{ (a_1(\sigma) - 1 - 2a_2(\sigma) \log U)^2 \\ & - 4a_2(\sigma) [a_0(\sigma) - a_1(\sigma) \log U + a_2(\sigma) (\log U)^2] \}^{1/2} \quad (16) \end{aligned}$$

The three input strain rates, S_k , S_{k+1} , and S_{k+2} , used in the interpolation should be close to the actual straining rate, ϵ/U . It would appear that it is impossible to make such a choice, since ϵ is the unknown variable.

However, it can be shown that:

$$S_k \leq \epsilon/U \leq S_{k+1} \quad (17)$$

if, and only if, $\epsilon_k(\sigma) \geq U \cdot S_k$ and $\epsilon_{k+1}(\sigma) \leq U \cdot S_{k+1}$. SISINUC searches for that value of k for which these inequalities are satisfied. For extremely high or low ϵ , (Eq. 17) cannot be satisfied for any input strain rate S_k . In these cases, the code uses the three highest or the three lowest strain rates available and extrapolates to the required rate.

A unique real solution given by (Eq. 16) is guaranteed provided that $\epsilon/U \leq (S_k)_{\max}$. Solutions may be obtained for higher strain rates, but for maximum accuracy the range of input curves should span the entire range of strain rates anticipated in the solution.

The error in the approximation $g(\sigma, S)$ to $f(\sigma, S)$ cannot be evaluated theoretically. Several test cases were run using eight input curves generated by ISOC2 corresponding to strain rates of 1, 2, 3, 4, 6, 8, and 10 percent per year. The object of these tests was to generate each of the known curves from three adjacent ones, using the logarithmic interpolation procedure described above. For example, use the 2, 4 and 6 percent per year curves to determine the a_i 's and then using (Eq. 15) with $S = 3$ percent/year to obtain an approximation to $f(\sigma, 3 \text{ percent/year})$. The error in this test approximation is probably larger than the actual difference between $f(\tau, S)$ and $g(\sigma, S)$ for any S from 2 percent/year to 4 percent/year, because: (1) the error for rates between 2 and 4 percent per year should be greatest approximately halfway between them, since both $f(\sigma, S)$ and $g(\sigma, S)$ have monotonic curvature; and (2) the actual error will be even smaller when the excluded test curve (in this example, 3 percent/year) is returned to improve the accuracy of the interpolation.

Each of the eight curves was tested in the critical region defined by $f(\sigma, S) \approx S \cdot U$. The maximum error in the approximations in all cases except those which required extrapolation (the 1 percent/year and 10 percent/year curves) was 5.0 percent of the true strain for $U \leq 1.2$ years. In most cases, especially for small values of U , the error was less than 1/2 percent. Cases

with $U > 1.2$ years were not tested. The extrapolation cases were slightly more inaccurate, with maximum errors of 5.2 percent and 9.0 percent respectively for the 1 percent/year and 10 percent/year curves.

As stated above, these test calculations overestimate the error in the approximation to $f(\sigma, S)$ in all cases except those requiring extrapolation. Thus, as long as the input strain rates are spaced as closely as the set which was tested, the logarithmic interpolation procedure will produce accurate results within the range spanned by the input strain rates.

The main iteration routine in SISINUC will be started with k set at two. A set of stresses, σ_j ($j = 0, k-1$) will be calculated from Eqs. (12), (13), and (6). A corresponding set of strains, ϵ_j , will be computed as the approximate solution to $\epsilon_j = f(\sigma_j, \epsilon_j/U)$ by the method described above. At the end of each pass through the loop the cladding elongation δ_{Ak} will be calculated.

$$\delta_{Ak} = \epsilon_0 \cdot W/2 + \sum_{j=1}^{k-1} \epsilon_j l_j \quad (18)$$

and a check will be made to see if it has exceeded δ_0 .

$\delta_{0k} > \delta_{Ak} \longrightarrow$ Return to Eq. 28 (see Figure D2-3)

$\delta_{0k} < \delta_{Ak} \longrightarrow$ Exit loop, go to (19)

Calculate error in solution

$$ER = \left(\frac{\delta_{Ak}}{\delta_{0k}} - 1 \right) 100 \quad (19)$$

This does not include errors caused by interpolation.

Print results: Check all data has been processed

Calculate routing logic

$$\begin{array}{lll} \text{A} & \begin{array}{l} \text{IR} = 0 \\ \text{IR} = \text{IR} + 1 \end{array} & \begin{array}{l} \text{Terminal strain} \\ \end{array} \end{array} \quad (20)$$

$$\begin{array}{lll} \text{B} & \begin{array}{l} \text{IT} = 0 \\ \text{IT} = \text{IT} + 1 \end{array} & \begin{array}{l} \text{Straining time} \\ \end{array} \end{array} \quad (21)$$

$$\begin{array}{lll} \text{C} & \begin{array}{l} \text{IU} = 0 \\ \text{IU} = \text{IU} + 1 \end{array} & \begin{array}{l} \text{Coefficient of friction} \\ \end{array} \end{array} \quad (22)$$

$$\begin{array}{lll} & \begin{array}{l} \text{IU} < \text{NU} \\ \text{IU} \geq \text{NU} \end{array} & \begin{array}{l} \text{C} \\ \text{D} \end{array} \end{array} \quad (23)$$

$$\begin{array}{lll} \text{D} & \begin{array}{l} \text{IT} < \text{NT} \\ \text{IT} \geq \text{NT} \end{array} & \begin{array}{l} \text{B} \\ \text{E} \end{array} \end{array} \quad (24)$$

$$\begin{array}{lll} \text{E} & \begin{array}{l} \text{IR} < \text{NE} \\ \text{IR} \geq \text{NE} \end{array} & \begin{array}{l} \text{A} \\ \text{F} \end{array} \end{array} \quad (25)$$

F Exit program

Calculation of σ_R

The reference stress σ_R is calculated in a straightforward manner if the reference strain rate, ϵ_{IR}/U , happens to correspond exactly to one of the input strain rates. If it falls between two input rates, a second-order logarithmic interpolation procedure similar to that described above is used. The functional relation (14) is inverted to give $\sigma = h(\epsilon, S)$ and an approximate function $c(\epsilon, S)$ is defined as in (15).

$$\log h(\epsilon, S) \approx \log c(\epsilon, S) \equiv a_0(\epsilon) + a_1(\epsilon) \log S + a_2(\epsilon) (\log S)^2 \quad (26)$$

The curves $\sigma_k(\epsilon) \equiv h(\epsilon, S_k)$ for input strain rates S_k are constructed (approximately) by linear interpolation. The three input strain rates S_k, S_{k+1}, S_{k+2} are chosen directly by requiring that $S_k < \epsilon_{IR}/U < S_{k+1}$. The a_i 's are

determined by setting $(\epsilon_{IR}, S_j) = \sigma_j(\epsilon)$ exactly for $j=k, k+1, k+2$. The reference stress is then given approximately by

$$\sigma_R = c(\epsilon_{IR}, \epsilon_{IR}/U) \quad (27)$$

1.1 INNER LOOP ITERATION COUNTERS

$$\begin{array}{l} Q \quad k=1 \\ \quad k=k + 1 \end{array} \quad (28)$$

$$\theta_{k-1} = \phi_0 + (k-1)\phi \quad (29)$$

$$\begin{array}{l} j=0 \\ j=j + 1 \end{array} \quad (30)$$

$$\begin{array}{l} k=0 \\ k=k + 1 \end{array} \quad (31)$$

1.2 SISINUC EXTENSION NO. 1

SISINUC was designed to solve the problem of strain localization due to the presence of a shear web as discussed above. The current version also allows analysis of two further strain localization mechanisms:

- (a) A local defect producing a thinning of the cladding.
- (b) A local increase in temperature causing a local weakening of the cladding.

The effect of axial straining is also to be considered.

Let IN be an indicator to denote the type of problem to be run:

- IN = 1 Shear web problem
- = 2 Local defect problem
- = 3 Local temperature variation

1.3 CODE MODIFICATIONS

The maximum strain will now be located in the reduced thickness section. The segments will slide away from the weak section and the direction of application of the friction loads will be reversed. If we make the assumption that the local temperature perturbation is in the form of a temperature increase (wire-wrap case) the same motion is produced by this case. Insert Eqs. 11a, 12a, and 13a.

$$\begin{array}{ll} \text{If } IN = 1 & \text{Equations 12 and 13} \\ \text{If } IN \neq 1 & \text{Equations 12a and 13a} \end{array} \quad (11a)$$

$$F_0 = F_{k-1} - \sum_{j=1}^{j=k-1} q_j \ell_j \quad (12a)$$

$$F_j = F_{j-1} + q_j \ell_j \quad (13a)$$

These loads can be converted into stresses using the existing code equations. In converting these stresses to strains, however, additional modifications are required for the $IN = 3$ case.

All curves corresponding to the cladding base temperature are read in first, followed by the corresponding curves for the hot-spot temperature. In this case, the number of input curves, NS , for the base temperature must not exceed 13. The number of curves for the hot-spot temperature cannot be greater than $\min(NS, 16-NS)$. Both sets must contain at least three curves. Curves 1 to NS are used to calculate $\epsilon_j (j=1, k-1)$ and the rest are used for ϵ_o .

Figure D-3. Sisine Program Flow Diagram

D3 - CODE INPUT DESCRIPTION

<u>CARD</u>	<u>FORMAT</u>	<u>COLUMNS</u>	<u>NAME</u>	<u>LIMITS</u>	<u>DESCRIPTION</u>
1	I3	1-3	IN	$1 \leq IN \leq 3$	Problem type indicator IN = 1, shear web problem IN = 2, local defect problem IN = 3, hot spot problem
2	I5,4I3	1-5	N	$N \geq 1$	Number of segments in 180° arc
		6-8	NE	$1 \leq NE \leq 10$	Number of reference strains
		9-11	NU	$1 \leq NU \leq 10$	Number of coefficients of friction
		12-14	NT	$1 \leq NT \leq 10$	Number of straining times
		15-17	NS	$3 \leq NS \leq 16$ if $IN \neq 3$ $3 \leq NS \leq 13$ if $IN = 3$	Number of input low strain rate stress-strain curves If $IN = 3$, NS = no. of input curves corresponding to the base temperature
3	4F10.0	1-10	T	$T > 0$	Clad thickness (in.)
		11-20	W	$W > 0$	Width of shear web, defect, or hot spot (in.)
		21-30	R	$R > 0$	Mean radius of clad (in.)
		31-40	X	$-T < x < \infty$	Effective diffusion length of shear web or equivalent increase in thickness at a defect (in)

D3 - CODE INPUT DESCRIPTION (Cont)

<u>CARD</u>	<u>FORMAT</u>	<u>COLUMNS</u>	<u>NAME</u>	<u>LIMITS</u>	<u>DESCRIPTION</u>
4 etc.	8F10.0	1-80 (as needed)	E(IR) IR=1,NE	E(IR) > 0	Reference strains (in/in)
5 etc.	8F10.0	1-80 (as needed)	UU(IU) IU=1,NU	UU (IU) > 0	Coefficients of friction
6 etc.	8F10.0	1-80 (as needed)	TIM(IT) IT=1,NT	TIM(IT) > 0	Straining times (years)

The remaining cards contain the input stress-strain curve information. Curves already read in for the previous case may be retained by substituting card 6' for cards 7 to 10.

6'	A10	1-10			Card 6' contains an asterisk (*) in one of the first ten columns.
----	-----	------	--	--	---

If 6' is not used, then cards 7 to 10 are required.

7 etc.	8F10.0	1-80 (as needed)	SR(IS), IS=1,NS	SR(IS) > 0, SR(IS+1) > SR(IS)	Strain rates (in/in/year) for input curves,
-----------	--------	---------------------	--------------------	-------------------------------------	---

If IN $\neq$ 3, Card 7' is omitted.

7'	8F10.0	1-80 (as needed)	SR(IS), IS=NS+1, α	SR(IS) > 0, SR(IS+1) > SR(IS) $\alpha \leq \min (NS, 16-NS)$	Strain rates (in/in/year) for curves corresponding to the hot spot temperature.
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D3 - CODE INPUT DESCRIPTION (Cont)

<u>CARD</u>	<u>FORMAT</u>	<u>COLUMNS</u>	<u>NAME</u>	<u>LIMITS</u>	<u>DESCRIPTION</u>
8	24I3	1-72 (as needed)	MX(IS), IS=1,NS	$2 \leq \text{MX}(\text{IS}) \leq 301$	Number of points on input curve IS.
If IN $\neq$ 3, Card 8' is omitted.					
8'	8F10.0	1-80 (as needed)	MX(IS)	$2 \leq \text{MX}(\text{IS}) \leq 301$	Number of points on input curve IS
9, etc.	8F10.0	1-80 (as needed)	SIGX(IS), IS=NS+1, α	$\text{SIGX}(\text{IS}) > 0$	Maximum stress on input curve IS(psi).
If IN $\neq$ 3, card 9' is omitted.					
9'	8F10.0	1-80 (as needed)	SIGX(IS), IS=NS+1, α	$\text{SIGX}(\text{IS}) > 0$	Maximum stress on input curve IS(psi).
10, etc.	7F10.0	1-70 (as needed)	E2(IS,IM), IM=1,MX(IS)	$\text{E2}(\text{IS},1)=0$ $\text{E2}(\text{IS},\text{IM}+1)$ $> \text{E2}(\text{IS},\text{IM})$	Strains at constant stress increments curve IS (in/in)

Repeat card(s) 10 for IS = 1 to α .

Repeat cards 1 to 10 for each problem desired.

D-4 DESCRIPTION OF SYMBOLS USED

<u>Symbol</u>	<u>Computer Identification</u>	<u>Description</u>
(a) Input Data		
N	N	No. of segments in 180°
NE	NE	No. of reference strains
NU	NU	No. of coefficients of friction
NT	NT	No. of straining times
NS	NS	No. of input low strain rate stress-strain curves
t,T	T	Tube wall thickness (in.)
w	W	Width of shear web, defect, or hot spot (in.)
R	R	Mean radius of cladding (in.)
X	X	Effective diffusion length of shear web or equivalent increase in thickness at a defect (in.)
ϵ_{IR}	$\epsilon(IR)$	Reference swelling strain (in/in)
μ_{IU}	UU(IU)	Coefficient of friction
U_{IT}	TIM(IT)	Straining time (years)
S_k	SR(*S)	Strain rate for input curve k (in/in/year)
MX(IS)	MX(IS)	No. of points on input curve IS
$\sigma_{max., IS}$	SIGX(IS)	Max. stress on input curve IS
ϵ_{jk}	E2(IS,IM)	Strain corresponding to a stress
		$\frac{(k - 1) \sigma_{max., IS}}{MX(IS) - 1} \text{ on curve } k$

D-4 DESCRIPTION OF SYMBOLS USED (Cont)

Symbol	Computer Identification	Description
(b) Derived Data		
$\sigma_{in, IS}$	SIGIN(IS)	Stress increment on curve IS
ϕ_o	XPO	Angular half-width of shear web, defect or hot spot
ϕ	XP	Angular width of each of N segments
l_j	L	Length of each of N segments
$\sigma_{k(\epsilon)}$	SIGR1, SIGR2, SIGR3	Stress corresponding to strain ϵ when strain rate is S_k
σ_R	SIGR	Reference stress (stress corresponding to reference strain and strain rate)
P	P	Uniform internal pressure
θ_k	THETA	Total angular width of first k segments
F_j	F(j)	Axial force in segment j
δ_{ok}	DELTAOK	Required total elongation of first k segments assuming a reference strain ϵ_{IR}
δ_{ak}	DELTAK	Actual elongation of first k segments, with assumption that $F_{k-1} = \sigma_R t$
q_j	XQ	Frictional shear flow in segment j
σ_j	SIG(J)	Computed stress in segment j
$\epsilon_k(\sigma)$	EJ1, EJ2, EJ3	Strain corresponding to stress σ when strain rate is S_k
ϵ_j	EJ(J3)	Computed strain in segment j
ER	ER	Approximate error in solution


```

      PROGRAM SISTNUC (INPUT,OUTPUT)
C
C
C          **INPUT DATA**
C
C  TOTAL NUMBER OF SEGMENTS  -N-
C  TOTAL NUMBER OF POINTS ON ISOCHRONOUS STRESS-STRAIN CURVE  -M-
C  COEFFICIENT OF FRICTION -UU(IU)-
C  NUMBER OF REFERENCE SWELLING STRAINS  -NF-
C  NUMBER OF COEFFICIENTS OF FRICTION  -UU-
C  NUMBER OF ISOCHRONOUS STRESS-STRAIN CURVES  -NS-
C  TUBE WALL THICKNESS  -T-
C  SHEAR WEB THICKNESS  -W-
C  TUBE MEAN RADIUS  -R-
C  SHEAR WEB EFFECTIVE DIFFUSION LENGTH  -A-
C  REFERENCE SWELLING STRAIN  -F(IR)-
C  MAXIMUM STRESS VALUE ON ISOCHRONOUS STRESS-STRAIN CURVE  -SIGX(1S)-
C  PERCENT STRAIN ST CONSTANTLY INCREMENTED STRESS LEVEL  -E2(1S,1M)-
C
C
C          ** PRINTED OUTPUT **
C
C
C  CLAD NOMINAL SWELLING STRAIN  -E(IR)-
C  CONVERGENCE ERROR  -ER-
C  COEFFICIENT OF FRICTION  -RR(IU)-
C  ISOCHRONOUS STRESS-STRAIN CURVE IDENTIFICATION NUMBER  -IS-
C  CLAD MEMBRANE LOAD DISTRIBUTION  -F(J)-
C  CLAD STRAIN DISTRIBUTION  -E(J)-
C  LAST SEGMENT TO HAVE UNIFORM STRAINING  -K-1-
C  ARC OVER WHICH UNIFORM STRAINING OCCURS  -THETA(K-1)-
000003      REAL I
000003      DIMENSION F(10),UU(10),SIGX(16),F2(16,301),F(1800),SIG(1800),
000003      IEJ(1800),SIG-IN(16)
000003      DIMENSION Mx(16),TIM(10),SR(32)
000003      DIMENSION TK(K),TL(10)
000003      DIMENSION IVR(34)
000003      DATA IAPT/5LINPOT/
000003      DATA IVW/
000003      1 340H(1X,*CLAD NOMINAL SWELLING STRAIN = *F10.4/** STRAINING TIME
000003      2  **F10.4,6H YEARS/** NOMINAL STRAIN RATE **F6.4,1H/, F
000003      3 6.4,1H = *F6.
000003      44.5H/YEAR
000003      5 /** COEFFICIENT OF FRICTION = *F10.4/** CONVERGENCE ERROR PER
000003      6CENT **F12.4,/**/
000003      7A = IVR(1K)
000005      8C = IVR(12)

```

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SIS0010
SIS0020
SIS0030
SIS0040
SIS0050
SIS0060
SIS0070
SIS0080
SIS0090
SIS0100
SIS0110
SIS0120
SIS0130
SIS0140
SIS0150
SIS0160
SIS0170
SIS0180
SIS0190
SIS0200
SIS0210
SIS0220
SIS0230
SIS0240
SIS0250
SIS0260
SIS0270
SIS0280
SIS0290
SIS0300
SIS0310
SIS0320
SIS0330
SIS0340
SIS0350
SIS0360
SIS0370
SIS0380
SIS0390
SIS0400
SIS0410
SIS0420
SIS0430
SIS0440
SIS0450
SIS0460

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000006	KJM = 1	SIS0470
000007	IZ = -1	SIS0480
000010	5 CONTINUE	SIS0490
000010	IF (IZ.LT.0) GO TO 10	SIS0500
000012	IN = IZ	SIS0510
000013	IZ = -1	SIS0520
000014	GO TO 20	SIS0530
000014	10 CONTINUE	SIS0540
000014	READ 290, IN	SIS0550
000022	IF (EOF,INPT) 325, 15	SIS0560
000025	15 CONTINUE	SIS0570
000025	20 CONTINUE	SIS0580
000025	IF (IN.LE.0) GO TO 325	SIS0590
000027	READ 285, N,NE,NU,NT,NS	SIS0600
000044	NSG = NS	SIS0610
000046	NSI = NS + 1	SIS0620
000050	IF (IN.EQ.3) NSG = NS + NS	SIS0630
000053	JL = NS + 8	SIS0640
000055	NSG = MIN0(JL,NSG)	SIS0650
000060	NC = 1	SIS0660
000061	READ 280, T,W,K,X,EPS	SIS0670
000076	READ 280, (I(IR),IR=1,NE)	SIS0680
000111	READ 280, (U(IU),IU=1,NU)	SIS0690
000124	READ 280, (T(IT),IT=1,NT)	SIS0700
000137	IK = 0	SIS0710
000140	JT = MIN0(N,NS)	SIS0720
000144	JV = JT * 10	SIS0730
000146	25 CONTINUE	SIS0740
000146	READ 300, (IK(I),I=1,8)	SIS0750
000160	IF (IK.EQ.1) GO TO 40	SIS0760
000162	DECODE(10, 245,TK) (TL(I),I=1,10)	SIS0770
000176	DO 30 J = 1,10	SIS0780
000200	IF (TL(J).EQ.1H*) GO TO 35	SIS0790
000202	IF (TL(J).EQ.1H*) GO TO 65	SIS0800
000204	30 CONTINUE	SIS0810
000206	GO TO 50	SIS0820
000207	35 CONTINUE	SIS0830
000207	DECODE(JV, 280,TK) (SR(IS),IS=1,JT)	SIS0840
000224	IF (NS.GT.P) READ 280, (SR(IS),IS=9,NS)	SIS0850
000241	IK = 1	SIS0860
000242	IF (IN.EQ.3) GO TO 25	SIS0870
000244	GO TO 55	SIS0880
000245	40 CONTINUE	SIS0890
000246	JX = NSG + NS	SIS0900
000247	JX = JX * 10	SIS0910
000261	DECODE(JX, 280,TK) (SR(IS),IS=NSI,NSG)	SIS0920
000266	DO 45 IS = 1,NSI,NSG	SIS0930

000270	IF (SR(IS).GT.0.0) GO TO 45	SIS0940
000273	MSG = IS - 1	SIS0950
000274	GO TO 55	SIS0960
000275	45 CONTINUE	SIS0970
000300	GO TO 55	SIS0980
000300	50 CONTINUE	SIS0990
000300	DECODE (2, 290, 1X) 12	SIS1000
000310	GO TO 65	SIS1010
000311	55 CONTINUE	SIS1020
000311	READ 290, (AX(IS), IS=1, NS)	SIS1030
000324	IF (IN.EC.3) READ 290, (PX(IS), IS=NS1, MSG)	SIS1040
000341	READ 280, (SIGX(IS), IS=1, NS)	SIS1050
000354	IF (IN.EC.3) READ 280, (SIGX(IS), IS=NS1, MSG)	SIS1060
000371	DO 60 IS = 1, NSG	SIS1070
000373	N = NX(IS)	SIS1080
000375	READ 305, (F2(IS, IM), IM=1, M)	SIS1090
000411	60 CONTINUE	SIS1100
000414	65 CONTINUE	SIS1110
000414	PRINT 215	SIS1120
000420	PRINT 250, N, MF, NT, NU, NS, T, W, R, X	SIS1130
000446	PRINT 265, (F(IR), IR=1, MF)	SIS1140
000461	XNC=NC	SIS1150
000463	DO 70 IR=1, MF	SIS1160
000464	70 F(IR)=F(IR)/XNC	SIS1170
000471	PRINT 225, (TIM(IT), IT=1, NT)	SIS1180
000503	PRINT 230, (UU(IU), IU=1, NU)	SIS1190
000516	PRINT 235, (SIGX(IS), IS=1, NS)	SIS1200
000531	IF (IN.EC.3) PRINT 235, (SIGX(IS), IS=NS1, MSG)	SIS1210
000546	PRINT 240	SIS1220
000552	DO 75 IS = 1, NSG	SIS1230
000554	M = NX(IS)	SIS1240
000556	SIGIN(IS) = SIGX(IS) / (FLOAT(M) - 1.)	SIS1250
000561	75 PRINT 260, IS, (E2(IS, IM), IM=1, M)	SIS1260
000603	IR=0	SIS1270
000604	80 IR=IR+1	SIS1280
000606	IT = 0	SIS1290
000607	85 IT = IT + 1	SIS1300
000611	TM = TIM(IT)	SIS1310
000613	IU=0	SIS1320
000614	90 IU=IU+1	SIS1330
000616	XP0=W/(2.*R)	SIS1340
000621	XP=1./FLOAT(N)*(3.14159-XP0)	SIS1350
000625	I = R*XP	SIS1360
000626	DO 95 IS = 1, NS	SIS1370
000630	IF (F(IR)/TM.LT.SG(IS)) GO TO 100	SIS1380
000634	95 CONTINUE	SIS1390
000636	100 IF (IS.GT.1) IS = IS - 1	SIS1400

000642	IS1 = IS + 1	SIS1410
000644	IS2 = IS + 2	SIS1420
000646	IF (IS2.GT.NS) IS2 = IS - 1	SIS1430
000652	IX0Z = IS	SIS1440
000654	M = MX(1S)	SIS1450
000655	DO 105 L3 = 2,M	SIS1460
000657	XL3 = L3 - 1	SIS1470
000661	IF (F(1R).LE.F2(1S,L3)) GO TO 110	SIS1480
000666	105 CONTINUE	SIS1490
000671	110 SIGR1 = XL3*SIGIN(1S)-SIGIN(1S)*(F2(1S,L3)-F(1R))/(E2(1S,L3)-F2(1S,L3-1))	SIS1500
000706	M = MX(1S1)	SIS1510
000710	DO 115 L4 = 2,M	SIS1520
000712	XL4 = L4 - 1	SIS1530
000714	IF (F(1R).LE.E2(1S1,L4)) GO TO 120	SIS1540
000721	115 CONTINUE	SIS1550
000724	120 SIGR2 = XL4*SIGIN(1S1)-SIGIN(1S1)*(F2(1S1,L4)-F(1R))/(E2(1S1,L4)-F2(1S1,L4-1))	SIS1560
000741	M = MX(1S2)	SIS1570
000743	DO 125 L5 = 2,M	SIS1580
000746	XL5 = L5 - 1	SIS1590
000747	IF (F(1R).LE.E2(1S2,L5)) GO TO 130	SIS1600
000754	125 CONTINUE	SIS1610
000757	130 SIGR3 = XL5*SIGIN(1S2) - SIGIN(1S2)*(F2(1S2,L5)-F(1R)) / (F2(1S2,L5)-F2(1S2,L5-1))	SIS1620
000774	Y1 = ALOG(SIGR1)	SIS1630
000777	Y2 = ALOG(SIGR2)	SIS1640
001001	Y3 = ALOG(SIGR3)	SIS1650
001003	X1 = ALOG(SF(1S))	SIS1660
001006	X2 = ALOG(SF(1S1))	SIS1670
001011	X3 = ALOG(SF(1S2))	SIS1680
001014	D = (X1-X2)*(X2-X3)*(X3-X1)	SIS1690
001023	A = (Y1*(X2-X3) + Y2*(X3-X1) + Y3*(X1-X2)) / (-D)	SIS1700
001037	B = (Y1*(X2*X2-X3*X3) + Y2*(X3*X3-X1*X1) + Y3*(X1*X1-X2*X2)) / D	SIS1710
001053	C = (Y1*X2*X3*(X2-X3) + Y2*X3*X1*(X3-X1) + Y3*X1*X2*(X1-X2)) / (-D)	SIS1720
001073	FP = C + F*ALOG(F(1R)/1F) + A*ALOG(F(1R)/TM)*ALOG(E(1R)/TM)	SIS1730
001104	SIGR = EXP(FP)	SIS1740
001107	P = SIGR * T / (K-0.5*T)	SIS1750
001113	XQ = P*DD(TU)	SIS1760
001115	IF (IN.NE.1) XQ = -XQ	SIS1770
001120	K = 1	SIS1780
001121	INC = N / 100	SIS1790
001124	135 K = K + INC	SIS1800
001126	IS = IX0Z	SIS1810
001127	IS1 = IS + 1	SIS1820
001131	THETA = XQ0+(K-1)*XQ	SIS1830
001136	DELTAK=F(1R)*R* THETA	SIS1840

001141	F(K-1)=SIGR*T	SIS1880
001143	KK=K-1	SIS1890
001145	Q1=0.0	SIS1900
001146	AKK=KK	SIS1910
001147	Q1=AKK*X0*L	SIS1920
001152	F0=F(K-1)+Q1	SIS1930
001154	F(1)=F0-X0*L	SIS1940
001157	K2=K-2	SIS1950
001161	DO 140 J2=2,K2	SIS1960
001162	140 F(J2)=F(J2-1)-X0*L	SIS1970
001170	DO 145 J=2,KK	SIS1980
001171	145 SIG(J)=(F(J)+F(J-1))/(2.*T)	SIS1990
001200	SIG(1)=(F(1)+F0)/(2.*T)	SIS2000
001204	SIG0=F0/(T+X)	SIS2010
001206	SIG(K)=SIG0	SIS2020
001210	DO 180 J3=1,K	SIS2030
001212	K0M=0	SIS2040
001213	I0M=0	SIS2050
001214	I01=1	SIS2060
001215	I02=NS	SIS2070
001216	IF (IM.F0.3.AND.J3.EQ.K) I01=NS+1	SIS2080
001230	IF (IM.F0.3.AND.J3.EQ.K) I02=NS+1	SIS2090
001240	IF (IM.F0.3.AND.J3.EQ.K) IS=NS+1	SIS2100
001251	IS1=IS+1	SIS2110
001253	AHC=1.0	SIS2120
001255	TEMP=F(IR)	SIS2130
001257	150 M=MX(IS)	SIS2140
001261	K0M=K0M+1	SIS2150
001263	L1=(SIG(J3)+SIGIN(IS))/SIGIN(IS)	SIS2160
001266	L1=L1+1	SIS2170
001270	IF (L1.LT.2) L1=2	SIS2180
001273	IF (L1.GT.M) L1=M	SIS2190
001276	XL1=L1-1	SIS2200
001300	155 FJ1=F2(IS,L1)-(F2(IS,L1)-F2(IS,L1-1))*(XL1*SIGIN(IS)-SIG(J3))/	SIS2210
	SIGIN(IS)	SIS2220
001314	M=MX(IS1)	SIS2230
001316	L2=(SIG(J3)+SIGIN(IS1))/SIGIN(IS1)	SIS2240
001322	L2=L2+1	SIS2250
001324	IF (L2.LT.2) L2=2	SIS2260
001327	IF (L2.GT.M) L2=M	SIS2270
001332	XL2=L2-1	SIS2280
001334	160 FJ2=F2(IS1,L2)-(F2(IS1,L2)-F2(IS1,L2-1))*(XL2*SIGIN(IS1)-SIG(J	SIS2290
	13))/SIGIN(IS1)	SIS2300
001350	IF (FJ1.LT.IM*SR(IS)) GO TO 170	SIS2310
001354	IF (FJ2.GT.IM*SR(IS1)) GO TO 175	SIS2320
001361	165 CONTINUE	SIS2330
001361	IS2=IS+2	SIS2340

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001363 IF(I52*G1.102) I52 = I5 - 1
001367 K = M*(I52)
001371 L03 = (SIG(J3) + SIGN(I52)) / SIGN(I52)
001375 L03 = L03 + 1
001377 IF(L03*1.1.2) L03 = 2
001402 IF(L03*G1.102) L03 = M
001405 X103 = I03 - 1
001407 F03 = E2(I52,L03) - (E2(I52,L03)-E2(I52,L03-1))*(X103*SIGN(I52))-S
S152420
S152430 IG(J3) / SIGN(I52)
X1 = ALG(S*(I5))
X2 = ALG(S*(I51))
X3 = ALG(S*(I52))
X4 = ALG(S*(I5))
Y1 = ALG(FJ3)
Y2 = ALG(FJ2)
Y3 = ALG(FJ3)
U = (X1-X2)*(X2-X3)*(X3-X1)
V = (Y1*(X2-X3) + Y2*(X3-X1) + Y3*(X1-X2)) / (-U)
H = (Y1*(X2*X3-X3*X2) + Y2*(X3*X3-X1*X1) + Y3*(X1*X1-X2*X2)) / (-U)
C = (Y1*X2*X3*(X2-X3) + Y2*X3*X3*(X3-Y1) + Y3*X1*X1*(X1-X2)) / (-U)
H1 = H - 1.0 - C*(A*ALOG(I1M))
CL = C - H*(I1M) + A*ALOG(I1M)*ALOG(I1)
F0 = (-0.5/π) * (H1 + SORT(H1*H1 - 4.*A*C))
FJ(J4) = F0(F0)
GO TO 185
170 IF(I5.F0.101) GO TO 165
I5 = I5 - 1
I51 = I5 + 1
GO TO 150
175 IF(I51.F0.102) GO TO 165
I5 = I5 + 1
GO TO 150
180 CONTINUE
F0 = FJ(K)
SUM = 0.0
DO 185 J4=1,K
SUM = FJ(J4) * L + SUM
185
OTLAK = F0*W/2.0*SUM
IF(I5.F0.1.100000*OTLAK*G1.OTLAK) GO TO 135
IF(I5.F0.1.100000*OTLAK*G1.OTLAK) GO TO 135
FM = (OTLAK/OTLAK-1.0)*100.
FM = ABS(FM)
IF(MC.F0.1) GO TO 100
K = K - 1
K = K - 1
TIC = TIC / 10
IF(I5.F0.1.1) TIC = 1
S152350
S152360 K = M*(I52)
S152370 L03 = (SIG(J3) + SIGN(I52)) / SIGN(I52)
S152380 L03 = L03 + 1
S152390 IF(L03*1.1.2) L03 = 2
S152400 IF(L03*G1.102) L03 = M
S152410 X103 = I03 - 1
S152420 F03 = E2(I52,L03) - (E2(I52,L03)-E2(I52,L03-1))*(X103*SIGN(I52))-S
S152430
S152440 X1 = ALG(S*(I5))
S152450 X2 = ALG(S*(I51))
S152460 X3 = ALG(S*(I52))
S152470 X4 = ALG(S*(I5))
S152480 Y1 = ALG(FJ3)
S152490 Y2 = ALG(FJ2)
S152500 Y3 = ALG(FJ3)
S152510 U = (X1-X2)*(X2-X3)*(X3-X1)
S152520 V = (Y1*(X2-X3) + Y2*(X3-X1) + Y3*(X1-X2)) / (-U)
S152530 H = (Y1*(X2*X3-X3*X2) + Y2*(X3*X3-X1*X1) + Y3*(X1*X1-X2*X2)) / (-U)
S152540 C = (Y1*X2*X3*(X2-X3) + Y2*X3*X3*(X3-Y1) + Y3*X1*X1*(X1-X2)) / (-U)
S152550 H1 = H - 1.0 - C*(A*ALOG(I1M))
S152560 CL = C - H*(I1M) + A*ALOG(I1M)*ALOG(I1)
S152570 F0 = (-0.5/π) * (H1 + SORT(H1*H1 - 4.*A*C))
S152580 FJ(J4) = F0(F0)
S152590 GO TO 185
S152600 IF(I5.F0.101) GO TO 165
S152610 I5 = I5 - 1
S152620 I51 = I5 + 1
S152630 GO TO 150
S152640 IF(I51.F0.102) GO TO 165
S152650 I5 = I5 + 1
S152660 GO TO 150
S152670 CONTINUE
S152680 F0 = FJ(K)
S152690 SUM = 0.0
S152700 DO 185 J4=1,K
S152710 SUM = FJ(J4) * L + SUM
S152720
S152730 OTLAK = F0*W/2.0*SUM
S152740 IF(I5.F0.1.100000*OTLAK*G1.OTLAK) GO TO 135
S152750 IF(I5.F0.1.100000*OTLAK*G1.OTLAK) GO TO 135
S152760 FM = (OTLAK/OTLAK-1.0)*100.
S152770 FM = ABS(FM)
S152780 IF(MC.F0.1) GO TO 100
S152790 K = K - 1
S152800 K = K - 1
S152810 TIC = TIC / 10
S152820 IF(I5.F0.1.1) TIC = 1
S152830

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001644      GO TO 175                                SIS2820
001645 190 CONTINUE                                SIS2830
001645      PRINT 220                                SIS2840
001651      KK=K-1                                    SIS2850
001653      PRINT 245, KK, THETA                      SIS2860
001663      F(IR)=X/C*F(IR)                            SIS2870
001666      SS = F(IR) / TIM(IT)                        SIS2880
001670      IR = ALOG10(TIM(IT))                        SIS2890
001673      IR = MAX0(IR,0)                            SIS2900
001676      IF (IR.GT.3) IVR(I2) = IC = 1              SIS2910
001702      IF (IR.LE.3) IVR(IR) = IA + IR             SIS2920
001706      IF (IR.GT.3) IVR(IR) = IA - 1094           SIS2930
001712      PRINT IVR, F(IR), TIM(IT), F(IR), TIM(IT), SS, UU(IT), FR SIS2940
001734      F(IR)=F(IR)/ANC                            SIS2950
001737      PRINT 270                                    SIS2960
001742      PRINT 275, FO, EU                          SIS2970
001752      DO 195 J=1, KK                            SIS2980
001754 195 PRINT 275, F(J), FJ(J)                    SIS2990
001766 200 FORMAT (10X, *XP= *F10.4, //10X, *SIG(I) (JS)=*F12.4, //10X, *SIGR=*F12.4 SIS3000
      A, //10X, *D=*F12.4, //)
001766 205 FORMAT (20X, *DELTA K=*F12.4, 10X, *DELTA OK=*F12.4) SIS3020
001766 210 FORMAT (10X, *J3= *J3, 10X, * KJ= *J5, //15X, *FJ(J3, JS)=*F12.4, 6X, *FJ(J SIS3030
      A, JS)=*F12.4)
001766 215 FORMAT (1H, 30X, *INPUT DATA*///)          SIS3050
001766 220 FORMAT (///40X, *OUTPUT DATA*///)          SIS3060
001766 225 FORMAT (/// * STRAINING TIMES (YEARS)*1X, 10F9.4) SIS3070
001766 2300 FORMAT (/// * COEFFICIENTS OF FRICTION*// * BETWEEN TUBE AND PELLETS* SIS3080
      110F8.5)
001766 235 FORMAT (/// * MAXIMUM STRESS VALUES*// * OF THE ISOCHRONOUS*// * STRESS-S SIS3100
      TRAIN CURVES (PSI)*10F12.0, ///)
001766 2400 FORMAT (///20X, * STRAIN AT CONSTANTLY INCREMENTED STRESS LEV SIS3120
      *FI*//)
001766 2450 FORMAT (* LAST SEGMENT TO HAVE UNIFORM STRAINING* 16, // * ARC OVER SIS3140
      WHICH NON-UNIFORM STRAINING OCCURS*F12.4, //)
001766 2500 FORMAT (* TOTAL NUMBER OF SEGMENTS *16, // * NUMBER OF REFERENCE SIS3160
      1
      2 SWELLING STRAINS *16, // * NUMBER OF STRAINING TIMES*16, // * SUM SIS3180
      3 OF COEFFICIENTS OF FRICTION *16, // * NUMBER OF ISOCHRONOUS
      4 STRESS-STRAIN CURVES *16, // * TUBE WALL THICKNESS (IN.)*F10.5, // * SIS3200
      5 SHEAR FR THICKNESS (IN.)*F10.5, // * TUBE MEAN RADIUS (IN.)*F10.5, // * SIS3210
      6 SHEAR WR EFFECTIVE DIFFUSION LENGTH (IN.)*F10.5, //)
001766 255 FORMAT (2X, * REFERENCE*// * SWELLING STRAIN *S*4X, 10F9.4, //) SIS3230
001766 2600 FORMAT (1/35X, * ISOCHRONOUS STRESS-STRAIN CURVE NUMBER*15, //10F11.6, SIS3240
      110F11.6)
001766 265 FORMAT (1X, * CLAD NOMINAL SWELLING STRAIN = *F10.4, // * STRAINING TIM SIS3260
      1 * *F10.4, 5X, YEARS, // * NOMINAL STRAIN RATE = *F6.4, 1H / , F6.4, 3H = , F6.4,
      24 // * COEFFICIENT OF FRICTION = *F10.4, // * CONVERGENCE ERROR PSD SIS3280

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          3CENT =*F12.4,/)
001766 2700FORMAT (10X,* CLAD MEMBRANE*30X,* CLAD STRAIN*/10X,* LOAD DISTRIBUTION*26X,* DISTRIBUTION*/16X,* (LPS)*/)
          275 FORMAT (12X,F10.4,32X,F12.4)
001766          IF (IU.LT.NU) GO TO 90
001770          IF (IT.LT.NT) GO TO 85
001773          IF (IR.LT.NE) GO TO 80
          280 FORMAT (F10.0)
          285 FORMAT (15,2013)
          290 FORMAT (2413)
          295 FORMAT (10A1)
          300 FORMAT (8A10)
          305 FORMAT (7F10.3)
          310 FORMAT (1X,3I4,2F18.6,18,2F18.6)
          KJM = 0
          GO TO 5
          315 PRINT 320
          320 FORMAT (* PROBLEM TERMINATED-----IMPOSSIBLE TO EXTRAPOLATE TO REQUIRED STRAIN RATE USING PRESENT SET OF ISOCRONOUS CURVES*)
          KJM = 0
          GO TO 5
          325 CONTINUE
          CALL EXIT
          END

```

SIS3290
 SIS3300
 SIS3310
 SIS3320
 SIS3330
 SIS3340
 SIS3350
 SIS3360
 SIS3370
 SIS3380
 SIS3390
 SIS3400
 SIS3410
 SIS3420
 SIS3430
 SIS3440
 SIS3450
 SIS3460
 SIS3470
 SIS3480
 SIS3490
 SIS3500
 SIS3510
 SIS3520

PROGRAM LENGTH INCLUDING I/O BUFFERS
033110

FUNCTION ASSIGNMENTS

STATEMENT ASSIGNMENTS

5	-	000010	10	-	000014	15	-	000025	20	-	000025
25	-	000146	35	-	000207	40	-	000245	45	-	000275
50	-	000300	55	-	000311	65	-	000414	70	-	000465
80	-	000504	85	-	000607	90	-	000614	100	-	000636
110	-	000671	120	-	000724	130	-	000757	135	-	001124
140	-	001162	145	-	001171	150	-	001257	155	-	001300
160	-	001334	165	-	001361	170	-	001556	175	-	001563
180	-	001570	185	-	001576	190	-	001645	200	-	002032
205	-	002044	210	-	002052	215	-	002063	220	-	002067
225	-	002073	230	-	002100	235	-	002110	240	-	002123
245	-	002133	250	-	002147	255	-	002224	260	-	002233
265	-	002244	270	-	002272	275	-	002305	280	-	002311
285	-	002313	290	-	002316	295	-	002320	300	-	002322
305	-	002324	310	-	002326	315	-	001776	320	-	002332
325	-	002004									

BLOCK NAMES AND LENGTHS

VARIABLE ASSIGNMENTS

A	-	026770	ARC	-	027020	B	-	026771	BI	-	027033
C	-	026772	CL	-	027034	D	-	026767	DELTA	-	027040
DELTAOK	-	027002	F	-	002467	FJ	-	023073	FI	-	027024
FJ2	-	027027	FJ3	-	027032	FO	-	027035	FP	-	026773
EPS	-	026725	FR	-	027041	F2	-	002433	F	-	014053
FO	-	027006	I	-	026734	IA	-	026743	IR	-	027043
IBM	-	027015	IC	-	026704	IK	-	026731	IM	-	026740
IN	-	026707	INC	-	027000	INPT	-	026702	IOI	-	027016
IO2	-	027017	IR	-	026726	IS	-	026735	ISI	-	026745
IS2	-	026746	IT	-	026730	IU	-	026727	IVK	-	026637
IXQZ	-	026747	IZ	-	026706	J	-	027011	JI	-	026717
JT	-	026732	JV	-	026733	JX	-	026736	JZ	-	027010
J3	-	027013	J4	-	027037	K	-	026777	KIM	-	026705
KK	-	027003	KOA	-	027014	K2	-	027007	L	-	026666
L03	-	027030	LI	-	027022	L2	-	027025	L3	-	026750
L4	-	026753	LS	-	026756	M	-	026737	MX	-	026523
N	-	026710	NC	-	026720	NE	-	026711	NS	-	026714
NSG	-	026715	NSI	-	026716	NT	-	026713	NU	-	026712
P	-	026775	OI	-	027004	R	-	026723	STG	-	017463
SIGIN	-	026503	SIGN	-	027012	SIGH	-	026774	STGR1	-	026752

SIGR2	-	026755	SIGR3	-	026760	SIGX	-	026761	SW	-	026555
SS	-	027042	SUW	-	027036	T	-	026721	TEMP	-	027021
THETA	-	027001	TI	-	026543	TA	-	026615	TI	-	026625
TM	-	026742	UU	-	002501	W	-	026722	X	-	026724
XKK	-	027005	XL03	-	027031	XL1	-	027023	XL2	-	027026
XL3	-	026751	XL4	-	026754	XL5	-	026757	XAC	-	026741
XP	-	026744	XPO	-	026743	XQ	-	026776	X1	-	026764
X2	-	026765	X3	-	026766	YJ	-	026761	Y2	-	026762
Y3	-	026763									

START OF CONSTANTS

002007

START OF TEMPORARIES

002347

START OF INDIRECTS

002453

UNUSED COMPILER SPACE

107600

CORE MAP 1(30.54. NORMAL CONTROL

TIME	LOAD MODE	L1	L2	TYPE	USER	CALL	FPA LOAD	LWA LOAD
FPA LOADER	145005	FPA TABLES	144431				0001	040064

PROGRAM-----ADDRESS-----LABELLED-----COMMON-----

SISINUC 000100
 SYSTEM 033210
 INPUTC 034125
 IFFENDF 034510
 INPUTS 034533
 OUTPUTC 035036
 ALNLOG 035415
 EXP 035506
 SORT 035563
 GETRA 035626
 XRCI 035645
 KRAKER 035652
 KOFER 035667

ENTRY-----ADDRESS-----
 SISINUC 000101
 ENTRY 033211

SYSTEM 033356

SISINUC 000102
 INPUTC 034153
 IFFENDF 034524
 INPUTS 034550
 OUTPUTC 035052
 ALNLOG 035455
 SORT 035610
 KRAKER 035671
 KOFER 035675

REFERENCES

035457

SYSTEMC 033321
 SYSTEMP 033347
 END 033245
 STOP 033274
 EXIT 033266
 ARNORMI 033304

SISINUC 002106
 SISINUC 002104
 INT 034154
 IFFENDF 034525
 INPUTS 034561
 OUTPUTC 035053
 KRAKER 035472
 KOFER 035676

INPUTC 034127

SISINUC	000116	000120	000121	000130	000132	000134
	000140	000142	000143	000162	000164	000166
	000172	000174	000175	000200	000204	000210

			00 7	000223	000224	000232	0002	000250
			000257	000330	000334	000340	000413	000417
			000430	000434	000440	000443	000447	000453
			000464	000470	000476	000504	000510	
IFFNDF	034511	SISINUC	000123					
INPUTS	034535	SISINUC	000264	000266	000272	000275	000311	000313
			000323	000353	000355	000361	000365	000402
			000406	000407				
OUTPTC	035040	SISINUC	000516	000517	000522	000524	000526	000530
			000534	000536	000540	000542	000544	000545
			000554	000560	000572	000576	000602	000605
			000615	000620	000624	000630	000635	000641
			000650	000651	000663	000665	000673	000677
			001750	001755	001757	001761	001762	002014
			002020	002022	002024	002025	002030	002032
			002040	002041	002044	002046	002050	002051
			002057	002061	002062	002100	002101	
		KRAKER	035437	035443	036446			
ALOG	035421	SISINUC	001075	001077	001101	001104	001107	001112
			001524	001527	001532	001534	001536	001540
			001627					
ALOG10	035416	SISINUC	001771					
EXP	035505	SISINUC	001205	001652				
SQRT	035566	SISINUC	001645					
GETFA	035625	INPUTC	034135					
		IFFNDF	034514					
		OUTPTC	035046					
XRCI	035645	INPUTC	034203	034206				
		OUTPTC	035057	035123	035126			
KRAKER	035653	INPUTC	034131	034140				
		INPUTS	034640	034655				
KODER	036670	OUTPTC	035042	035065				

----UNSATISFIED EXTERNALS----

REFERENCES

INPUT DATA

TOTAL NUMBER OF SEGMENTS 1800
 NUMBER OF REFERENCE SWELLING STRAINS 2
 NUMBER OF STRAINING TIMES 1
 NUMBER OF COEFFICIENTS OF FRICTION 1
 NUMBER OF ISOCHRONOUS STRESS-STRAIN CURVES 4
 TUBE WALL THICKNESS(IN.) .01600
 SHEAR WEB THICKNESS(IN) .02000
 TUBE MEAN RADIUS(IN) .11700
 SHEAR WEB EFFECTIVE DIFFUSION LENGTH(IN) .00700

REFERENCE
 SWELLING STRAINS .0100 .0200

STRAINING TIMES(YEARS) 1.0000

COEFFICIENTS OF FRICTION
 BETWEEN TUBE AND PELLET .40000

MAXIMUM STRESS VALUES
 ON THE ISOCHRONOUS
 STRESS-STRAIN CURVES(PST) 15427 16607 17779 18743 19578 20678 2143

STRAIN AT CONSTANTLY INCREMENTED STRESS LEVEL

ISOCHRONOUS STRESS-STRAIN CURVE NUMBER 1									
0.000000	.000004	.000008	.000011	.000015	.000019	.000023	.000027	.000031	.000035
.000039	.000043	.000047	.000051	.000055	.000059	.000063	.000067	.000071	.000075

.000079	.000083	.000088	.000092	.0000	.000100	.000104	.000109	.000113	.00011
.000121	.000126	.000130	.000134	.000138	.000143	.000147	.000151	.000156	.00016
.000164	.000169	.000173	.000178	.000182	.000186	.000191	.000195	.000200	.00020
.000209	.000213	.000217	.000222	.000226	.000231	.000235	.000240	.000244	.00024
.000253	.000258	.000262	.000267	.000271	.000276	.000280	.000285	.000290	.00029
.000299	.000303	.000308	.000313	.000317	.000322	.000326	.000331	.000336	.00034
.000345	.000350	.000354	.000359	.000364	.000369	.000373	.000378	.000382	.00038
.000392	.000396	.000401	.000406	.000410	.000415	.000420	.000425	.000429	.00043
.000439	.000444	.000448	.000453	.000458	.000463	.000468	.000473	.000477	.00048
.000487	.000492	.000497	.000501	.000506	.000511	.000516	.000521	.000526	.00053
.000535	.000540	.000545	.000550	.000555	.000560	.000564	.000569	.000574	.00057
.000584	.000589	.000594	.000599	.000604	.000609	.000614	.000619	.000623	.00062
.000633	.000638	.000643	.000648	.000653	.000658	.000663	.000668	.000673	.00067
.000683	.000688	.000693	.000698	.000703	.000708	.000713	.000718	.000723	.00072
.000733	.000738	.000744	.000748	.000754	.000759	.000764	.000769	.000774	.00077
.000784	.000789	.000794	.000799	.000804	.000809	.000815	.000820	.000825	.00083
.000835	.000840	.000845	.000850	.000856	.000861	.000866	.000871	.000876	.00088
.000886	.000892	.000897	.000902	.000907	.000912	.000918	.000923	.000928	.00093
.000938	.000944	.000949	.000954	.000960	.000964	.000970	.000976	.000982	.00099
.001014	.001025	.001038	.001051	.001067	.001083	.001101	.001121	.001142	.00116
.001191	.001218	.001246	.001280	.001314	.001351	.001390	.001432	.001477	.00152
.001577	.001631	.001689	.001750	.001814	.001882	.001954	.002030	.002110	.00219
.002282	.002374	.002471	.002573	.002679	.002791	.002907	.003029	.003156	.00328
.003428	.003573	.003724	.003881	.004045	.004217	.004395	.004581	.004775	.00497
.005187	.005406	.005635	.005872	.006120	.006377	.006646	.006926	.007217	.00752
.007837	.008167	.008511	.008870	.009244	.009635	.010040	.010470	.010910	.01138
.011870	.012380	.012910	.013470	.014060	.014680	.015320	.016010	.016730	.01749
.018290	.019140	.020040	.021000	.022020	.023110	.024280	.025540	.026900	.02838
.030000									

ISOCHRONOUS STRESS-STRAIN CURVE NUMBER 2

0.000000	.000004	.000008	.000012	.000016	.000020	.000024	.000028	.000032	.000036
.000040	.000044	.000048	.000053	.000057	.000061	.000065	.000069	.000074	.000078
.000082	.000086	.000091	.000095	.000099	.000104	.000108	.000112	.000117	.000121
.000125	.000130	.000134	.000138	.000143	.000147	.000152	.000156	.000161	.000165
.000170	.000174	.000178	.000183	.000187	.000192	.000196	.000201	.000205	.000210
.000214	.000219	.000223	.000228	.000233	.000237	.000242	.000246	.000251	.000255
.000260	.000265	.000269	.000274	.000278	.000283	.000288	.000292	.000297	.000301
.000306	.000311	.000315	.000320	.000325	.000329	.000334	.000339	.000344	.000348
.000353	.000358	.000362	.000367	.000372	.000377	.000381	.000386	.000391	.000395
.000400	.000405	.000410	.000414	.000419	.000424	.000429	.000434	.000438	.000443
.000448	.000453	.000458	.000462	.000467	.000472	.000477	.000482	.000487	.000491
.000496	.000501	.000506	.000511	.000516	.000521	.000525	.000530	.000535	.000540
.000545	.000550	.000555	.000560	.000564	.000569	.000574	.000579	.000584	.000588
.000594	.000599	.000604	.000609	.000614	.000619	.000623	.000628	.000633	.000638
.000643	.000648	.000653	.000658	.000663	.000668	.000673	.000678	.000683	.000688

.000693	.000698	.000703	.000708	.000713	.000718	.000723	.000728	.000733	.000738
.000743	.000748	.000753	.000758	.000763	.000768	.000773	.000778	.000783	.000788
.000794	.000799	.000804	.000809	.000814	.000819	.000824	.000829	.000834	.000839
.000844	.000849	.000854	.000859	.000864	.000869	.000874	.000879	.000884	.000889
.000899	.000904	.000909	.000914	.000919	.000924	.000929	.000934	.000939	.000944
.001005	.001010	.001015	.001020	.001025	.001030	.001035	.001040	.001045	.001050
.001248	.001253	.001258	.001263	.001268	.001273	.001278	.001283	.001288	.001293
.001717	.001722	.001727	.001732	.001737	.001742	.001747	.001752	.001757	.001762
.002493	.002498	.002503	.002508	.002513	.002518	.002523	.002528	.002533	.002538
.003666	.003671	.003676	.003681	.003686	.003691	.003696	.003701	.003706	.003711
.005348	.005353	.005358	.005363	.005368	.005373	.005378	.005383	.005388	.005393
.007694	.007699	.007704	.007709	.007714	.007719	.007724	.007729	.007734	.007739
.010920	.010925	.010930	.010935	.010940	.010945	.010950	.010955	.010960	.010965
.015330	.015335	.015340	.015345	.015350	.015355	.015360	.015365	.015370	.015375
.021420	.021425	.021430	.021435	.021440	.021445	.021450	.021455	.021460	.021465
.030000	.030005	.030010	.030015	.030020	.030025	.030030	.030035	.030040	.030045

ISOCHRONOUS STRESS-STRAIN CURVE NUMBER 2

.000000	.000004	.000008	.000013	.000017	.000021	.000025	.000030	.000034	.000038
.000043	.000047	.000051	.000056	.000060	.000064	.000069	.000073	.000078	.000082
.000087	.000091	.000096	.000100	.000105	.000109	.000114	.000118	.000123	.000127
.000132	.000137	.000141	.000146	.000150	.000155	.000160	.000164	.000169	.000173
.000178	.000183	.000188	.000192	.000197	.000202	.000206	.000211	.000216	.000220
.000225	.000230	.000235	.000239	.000244	.000249	.000254	.000258	.000263	.000267
.000273	.000278	.000282	.000287	.000292	.000297	.000302	.000306	.000311	.000315
.000321	.000326	.000331	.000336	.000340	.000345	.000350	.000355	.000360	.000364
.000370	.000374	.000379	.000384	.000389	.000394	.000399	.000404	.000409	.000413
.000419	.000424	.000429	.000434	.000439	.000444	.000449	.000454	.000459	.000463
.000468	.000473	.000478	.000483	.000488	.000493	.000498	.000503	.000508	.000512
.000519	.000523	.000528	.000533	.000538	.000543	.000548	.000553	.000558	.000562
.000569	.000574	.000579	.000584	.000589	.000594	.000599	.000604	.000609	.000613
.000620	.000625	.000630	.000635	.000640	.000645	.000650	.000655	.000660	.000664
.000671	.000676	.000681	.000686	.000691	.000696	.000701	.000706	.000711	.000715
.000722	.000727	.000732	.000737	.000742	.000747	.000752	.000757	.000762	.000766
.000774	.000779	.000784	.000789	.000794	.000799	.000804	.000809	.000814	.000818
.000826	.000831	.000836	.000841	.000846	.000851	.000856	.000861	.000866	.000870
.000885	.000890	.000895	.000900	.000905	.000910	.000915	.000920	.000925	.000930
.001014	.001019	.001024	.001029	.001034	.001039	.001044	.001049	.001054	.001059
.001310	.001315	.001320	.001325	.001330	.001335	.001340	.001345	.001350	.001355
.001860	.001865	.001870	.001875	.001880	.001885	.001890	.001895	.001900	.001905
.002742	.002747	.002752	.002757	.002762	.002767	.002772	.002777	.002782	.002787
.004040	.004045	.004050	.004055	.004060	.004065	.004070	.004075	.004080	.004085
.005862	.005867	.005872	.005877	.005882	.005887	.005892	.005897	.005902	.005907
.008344	.008349	.008354	.008359	.008364	.008369	.008374	.008379	.008384	.008389
.011670	.011675	.011680	.011685	.011690	.011695	.011700	.011705	.011710	.011715
.015070	.015075	.015080	.015085	.015090	.015095	.015100	.015105	.015110	.015115

.021880	.022560	.023250	.023970	.02471	.025460	.026240	.027050	.027800	.028730
.029600	.030510	.031440	.032390	.033380	.034400	.035450	.036540	.037650	.038810
.040000									

ISOCHRONOUS STRESS-STRAIN CURVE NUMBER 4

0.000000	.000004	.000009	.000013	.000018	.000022	.000027	.000031	.000036	.000041
.000045	.000049	.000054	.000058	.000063	.000068	.000072	.000077	.000081	.000086
.000091	.000095	.000100	.000105	.000109	.000114	.000119	.000124	.000128	.000133
.000138	.000143	.000147	.000152	.000157	.000162	.000166	.000171	.000176	.000181
.000186	.000191	.000196	.000200	.000205	.000210	.000215	.000220	.000225	.000230
.000235	.000240	.000244	.000249	.000254	.000259	.000264	.000269	.000274	.000279
.000284	.000289	.000294	.000299	.000304	.000309	.000314	.000319	.000324	.000329
.000334	.000339	.000344	.000349	.000354	.000359	.000364	.000369	.000374	.000379
.000384	.000389	.000394	.000400	.000405	.000410	.000415	.000420	.000425	.000430
.000435	.000440	.000445	.000450	.000455	.000461	.000466	.000471	.000476	.000481
.000487	.000492	.000497	.000502	.000507	.000512	.000518	.000523	.000528	.000533
.000538	.000543	.000549	.000554	.000559	.000564	.000569	.000575	.000580	.000585
.000590	.000596	.000601	.000606	.000611	.000616	.000622	.000627	.000632	.000637
.000643	.000648	.000653	.000659	.000664	.000669	.000674	.000680	.000685	.000690
.000696	.000701	.000706	.000712	.000717	.000722	.000727	.000733	.000738	.000743
.000749	.000754	.000759	.000765	.000770	.000775	.000781	.000786	.000792	.000797
.000802	.000808	.000813	.000818	.000824	.000829	.000835	.000841	.000847	.000852
.000856	.000866	.000873	.000882	.000893	.000903	.000914	.000927	.000942	.000957
.000976	.000994	.001016	.001038	.001064	.001090	.001119	.001151	.001185	.001221
.001260	.001301	.001345	.001392	.001441	.001490	.001540	.001592	.001670	.001731
.001803	.001874	.001940	.002028	.002110	.002197	.002285	.002379	.002476	.002577
.002683	.002792	.002906	.003024	.003147	.003274	.003406	.003543	.003684	.003830
.003982	.004138	.004300	.004468	.004640	.004810	.005003	.005193	.005389	.005591
.005800	.006015	.006236	.006464	.006699	.006941	.007190	.007447	.007710	.007982
.008261	.008549	.008844	.009148	.009460	.009781	.010110	.010450	.010800	.011160
.011520	.011900	.012290	.012690	.013100	.013520	.013950	.014390	.014840	.015310
.015790	.016280	.016780	.017300	.017830	.018370	.018940	.019510	.020100	.020700
.021320	.021960	.022610	.023280	.023970	.024670	.025400	.026140	.026900	.027680
.028480	.029310	.030150	.031020	.031910	.032830	.033770	.034730	.035720	.036740
.037790	.038860	.039970	.041100	.042270	.043470	.044700	.045970	.047270	.048620
.050000									

ISOCHRONOUS STRESS-STRAIN CURVE NUMBER 5

0.000000	.000005	.000009	.000014	.000019	.000023	.000028	.000032	.000037	.000042
.000046	.000051	.000056	.000061	.000065	.000070	.000075	.000080	.000085	.000090
.000094	.000099	.000104	.000109	.000114	.000119	.000123	.000128	.000133	.000138
.000143	.000148	.000153	.000158	.000163	.000168	.000173	.000178	.000183	.000188
.000193	.000197	.000203	.000208	.000213	.000219	.000223	.000228	.000233	.000238
.000243	.000249	.000253	.000258	.000263	.000269	.000273	.000279	.000284	.000290
.000295	.000300	.000306	.000311	.000317	.000322	.000328	.000333	.000339	.000345

.000345	.000351	.000356	.000361	.000366	.000371	.000377	.000382	.000387	.000392
.000397	.000403	.000408	.000413	.000418	.000424	.000429	.000434	.000439	.000445
.000450	.000455	.000460	.000466	.000471	.000476	.000481	.000487	.000492	.000497
.000503	.000508	.000513	.000519	.000524	.000529	.000535	.000540	.000545	.000551
.000556	.000561	.000567	.000572	.000577	.000583	.000588	.000594	.000599	.000605
.000610	.000615	.000620	.000626	.000631	.000637	.000642	.000647	.000653	.000658
.000664	.000669	.000675	.000680	.000685	.000691	.000696	.000702	.000707	.000711
.000718	.000723	.000729	.000734	.000740	.000745	.000751	.000756	.000762	.000767
.000773	.000778	.000784	.000789	.000795	.000800	.000806	.000811	.000817	.000822
.000828	.000833	.000839	.000844	.000850	.000855	.000860	.000866	.000871	.000877
.000882	.000888	.000893	.000899	.000904	.000910	.000915	.000921	.000926	.000931
.000937	.000942	.000948	.000953	.000959	.000964	.000969	.000975	.000980	.000985
.000991	.000996	.001002	.001007	.001013	.001018	.001023	.001029	.001034	.001039
.001045	.001050	.001056	.001061	.001066	.001072	.001077	.001082	.001088	.001093
.001098	.001104	.001109	.001114	.001120	.001125	.001130	.001136	.001141	.001146
.001151	.001157	.001162	.001167	.001173	.001178	.001183	.001188	.001194	.001199
.001204	.001209	.001215	.001220	.001225	.001231	.001236	.001241	.001247	.001252
.001257	.001262	.001268	.001273	.001278	.001284	.001289	.001294	.001300	.001305
.001310	.001315	.001321	.001326	.001331	.001337	.001342	.001347	.001353	.001358
.001363	.001368	.001374	.001379	.001384	.001390	.001395	.001400	.001406	.001411
.001416	.001422	.001427	.001432	.001438	.001443	.001448	.001453	.001459	.001464
.001469	.001474	.001480	.001485	.001490	.001496	.001501	.001506	.001512	.001517
.001522	.001527	.001533	.001538	.001543	.001548	.001554	.001559	.001564	.001569
.001575	.001580	.001585	.001591	.001596	.001601	.001606	.001612	.001617	.001622
.001627	.001632	.001638	.001643	.001648	.001653	.001659	.001664	.001669	.001674
.001680	.001685	.001690	.001696	.001701	.001706	.001712	.001717	.001722	.001727
.001732	.001738	.001743	.001748	.001753	.001759	.001764	.001769	.001774	.001779
.001785	.001790	.001795	.001801	.001806	.001811	.001816	.001822	.001827	.001832
.001837	.001843	.001848	.001853	.001859	.001864	.001869	.001874	.001880	.001885
.001890	.001895	.001901	.001906	.001911	.001917	.001922	.001927	.001932	.001937
.001943	.001948	.001953	.001959	.001964	.001969	.001974	.001980	.001985	.001990
.001996	.002001	.002006	.002012	.002017	.002022	.002027	.002032	.002038	.002043
.002048	.002053	.002059	.002064	.002069	.002074	.002079	.002085	.002090	.002095
.002100	.002106	.002111	.002116	.002122	.002127	.002132	.002137	.002143	.002148
.002153	.002159	.002164	.002169	.002174	.002180	.002185	.002190	.002196	.002201
.002206	.002212	.002217	.002222	.002227	.002233	.002238	.002243	.002248	.002254
.002259	.002264	.002269	.002275	.002280	.002285	.002290	.002296	.002301	.002306
.002311	.002317	.002322	.002327	.002332	.002338	.002343	.002348	.002353	.002359
.002364	.002369	.002374	.002380	.002385	.002390	.002396	.002401	.002406	.002411
.002417	.002422	.002427	.002432	.002438	.002443	.002448	.002453	.002459	.002464
.002469	.002474	.002480	.002485	.002490	.002496	.002501	.002506	.002511	.002517
.002522	.002527	.002532	.002538	.002543	.002548	.002553	.002559	.002564	.002569
.002574	.002580	.002585	.002590	.002596	.002601	.002606	.002611	.002617	.002622
.002627	.002632	.002638	.002643	.002648	.002653	.002659	.002664	.002669	.002674
.002680	.002685	.002690	.002696	.002701	.002706	.002711	.002717	.002722	.002727
.002732	.002738	.002743	.002748	.002753	.002759	.002764	.002769	.002774	.002779
.002785	.002790	.002795	.002801	.002806	.002811	.002816	.002822	.002827	.002832
.002837	.002843	.002848	.002853	.002859	.002864	.002869	.002874	.002880	.002885
.002890	.002895	.002901	.002906	.002911	.002917	.002922	.002927	.002932	.002937
.002943	.002948	.002953	.002959	.002964	.002969	.002974	.002980	.002985	.002990
.002996	.003001	.003006	.003012	.003017	.003022	.003027	.003032	.003038	.003043
.003048	.003053	.003059	.003064	.003069	.003074	.003079	.003085	.003090	.003095
.003100	.003106	.003111	.003116	.003122	.003127	.003132	.003137	.003143	.003148
.003153	.003159	.003164	.003169	.003174	.003180	.003185	.003190	.003196	.003201
.003206	.003211	.003217	.003222	.003227	.003232	.003238	.003243	.003248	.003254
.003259	.003264	.003269	.003274	.003280	.003285	.003290	.003296	.003301	.003306
.003311	.003317	.003322	.003327	.003332	.003338	.003343	.003348	.003353	.003359
.003364	.003369	.003374	.003380	.003385	.003390	.003396	.003401	.003406	.003411
.003417	.003422	.003427	.003432	.003438	.003443	.003448	.003453	.003459	.003464
.003469	.003474	.003480	.003485	.003490	.003496	.003501	.003506	.003511	.003517
.003522	.003527	.003532	.003538	.003543	.003548	.003553	.003559	.003564	.003569
.003574	.003580	.003585	.003590	.003596	.003601	.003606	.003611	.003617	.003622
.003627	.003632	.003638	.003643	.003648	.003653	.003659	.003664	.003669	.003674
.003680	.003685	.003690	.003696	.003701	.003706	.003711	.003717	.003722	.003727
.003732	.003738	.003743	.003748	.003753	.003759	.003764	.003769	.003774	.003779
.003785	.003790	.003795	.003801	.003806	.003811	.003816	.003822	.003827	.003832
.003837	.003843	.003848	.003853	.003859	.003864	.003869	.003874	.003880	.003885
.003890	.003895	.003901	.003906	.003911	.003917	.003922	.003927	.003932	.003937
.003943	.003948	.003953	.003959	.003964	.003969	.003974	.003980	.003985	.003990
.003996	.004001	.004006	.004012	.004017	.004022	.004027	.004032	.004038	.004043
.004048	.004053	.004059	.004064	.004069	.004074	.004079	.004085	.004090	.004095
.004100	.004106	.004111	.004116	.004122	.004127	.004132	.004137	.004143	.004148
.004153	.004159	.004164	.004169	.004174	.004180	.004185	.004190	.004196	.004201
.004206	.004211	.004217	.004222	.004227	.004232	.004238	.004243	.004248	.004254
.004259	.004264	.004269	.004274	.004280	.004285	.004290	.004296	.004301	.004306
.004311	.004317	.004322	.004327	.004332	.004338	.004343	.004348	.004353	.004359
.004364	.004369	.004374	.004380	.004385	.004390	.004396	.004401	.004406	.004411
.004417	.004422	.004427	.004432	.004438	.004443	.004448	.004453	.004459	.004464
.004469	.004474	.004480	.004485	.004490	.004496	.004501	.004506	.004511	.004517
.004522	.004527	.004532	.004538	.004543	.004548	.004553	.004559	.004564	.004569
.004574	.004580	.004585	.004590	.004596	.004601	.004606	.004611	.004617	.004622
.004627	.004632	.004638	.004643	.004648	.004653	.004659	.004664	.004669	.004674
.004680	.004685	.004690	.004696	.004701	.004706	.004711	.004717	.004722	.004727
.004732	.004738	.004743	.004748	.004753	.004759	.004764	.004769	.004774	.004779
.004785	.004790	.004795	.004801	.004806	.004811	.004816	.004822	.004827	.004832
.004837	.004843	.004848	.004853	.004859	.004864	.004869	.004874	.004880	.004885
.004890	.004895	.004901	.004906	.004911	.004917	.004922	.004927	.004932	.004937
.004943	.004948	.004953	.004959	.004964	.004969	.004974	.004980	.004985	.004990
.004996	.005001	.005006	.005012	.005017	.005022	.005027	.005032	.005038	.005043
.005048	.005053	.005059	.005064	.005069	.005074	.005079	.005085	.005090	.005095
.005100	.005106	.005111	.005116	.005122	.005127	.005132	.005137	.005143	.005148
.005153	.005159	.005164	.005169	.005174	.005180	.005185	.005190	.005196	.005201
.005206	.005211	.005217	.005222	.005227	.005232	.005238	.005243	.005248	.005254
.005259	.005264	.005269	.005274	.005280	.005285	.005290	.005296	.005301	.005306
.005311	.005317	.005322	.005327	.005332	.005338	.005343	.005348	.005353	.005359
.005364	.005369	.005374	.005380	.005385	.005390	.005396	.005401	.005406	.005411
.005417	.005422	.005427	.005432	.005438	.005443	.005448	.005453	.005459	.005464
.005469	.005474	.005480	.005485	.005490	.005496	.005501	.005506	.005511	.005517
.005522	.005527	.005532	.005538	.005543	.005548	.005553	.005559	.005564	.005569
.005574	.005580	.005585	.005590	.005596	.005601	.005606	.005611	.005617	.005622
.005627	.005632	.005638	.005643	.005648	.005653	.005659	.005664	.005669	.005674
.005680	.005685	.005690	.005696	.005701	.005706	.005711	.005717	.005722	.005727
.005732	.005738	.005743	.005748	.005753	.005759	.005764	.005769	.005774	.005779
.005785	.005790	.005795	.005801	.005806	.005811	.005816	.005822	.005827	.005832
.005837	.005843	.005848	.005853	.005859	.005864	.005869	.005874	.005880	.005885
.005890	.005895	.005901	.005906	.005911	.005917	.005922	.005927	.005932	.005937
.005943	.005948	.005953	.005959	.005964	.005969	.005974	.005980	.005985	.005990
.005996	.006001	.006006	.006012</						

.003619	.003772	.003930	.004094	.00426	.004439	.004619	.004807	.005000	.005199
.005405	.005618	.005837	.006062	.006295	.006535	.006782	.007036	.007298	.007567
.007844	.008130	.008423	.008725	.009035	.009353	.009681	.010020	.010360	.010720
.011080	.011460	.011840	.012240	.012640	.013050	.013480	.013920	.014370	.014830
.015300	.015780	.016280	.016790	.017310	.017840	.018390	.018950	.019530	.020120
.020720	.021340	.021970	.022620	.023280	.023970	.024660	.025380	.026110	.026860
.027630	.028410	.029220	.030040	.030880	.031750	.032630	.033540	.034470	.035420
.036390	.037390	.038410	.039450	.040520	.041620	.042740	.043890	.045070	.046280
.047520	.048780	.050080	.051410	.052780	.054170	.055600	.057070	.058580	.060120
.061700	.063330	.064990	.066700	.068460	.070250	.072100	.074000	.075950	.077950
.080000									

ISOCHRONOUS STRESS-STRAIN CURVE NUMBER 7

0.000000	.000005	.000010	.000016	.000021	.000026	.000031	.000035	.000042	.000047
.000052	.000057	.000062	.000068	.000073	.000078	.000083	.000089	.000094	.000099
.000105	.000110	.000115	.000121	.000126	.000132	.000137	.000142	.000148	.000153
.000158	.000164	.000169	.000175	.000180	.000186	.000191	.000197	.000202	.000208
.000213	.000219	.000224	.000230	.000235	.000241	.000246	.000252	.000257	.000263
.000269	.000274	.000280	.000285	.000291	.000296	.000302	.000309	.000313	.000319
.000325	.000330	.000336	.000341	.000347	.000353	.000359	.000364	.000370	.000375
.000381	.000387	.000392	.000398	.000404	.000409	.000415	.000421	.000426	.000432
.000438	.000444	.000449	.000455	.000461	.000467	.000472	.000478	.000484	.000490
.000495	.000501	.000507	.000513	.000519	.000524	.000530	.000536	.000542	.000547
.000553	.000559	.000565	.000571	.000576	.000582	.000588	.000594	.000600	.000605
.000611	.000617	.000623	.000629	.000635	.000641	.000646	.000652	.000658	.000664
.000670	.000676	.000682	.000688	.000693	.000699	.000705	.000711	.000717	.000723
.000729	.000735	.000741	.000747	.000752	.000758	.000764	.000770	.000776	.000782
.000788	.000794	.000800	.000806	.000812	.000817	.000824	.000830	.000838	.000844
.000850	.000870	.000891	.000892	.000903	.000914	.000933	.000955	.000977	.001000
.001031	.001061	.001094	.001132	.001171	.001215	.001261	.001311	.001365	.001421
.001482	.001546	.001614	.001686	.001761	.001841	.001925	.002013	.002106	.002203
.002304	.002410	.002520	.002636	.002755	.002881	.003010	.003145	.003286	.003431
.003582	.003739	.003901	.004069	.004242	.004422	.004608	.004800	.004998	.005203
.005415	.005633	.005858	.006090	.006329	.006576	.006829	.007091	.007360	.007637
.007921	.008214	.008516	.008825	.009144	.009471	.009807	.010150	.010510	.010870
.011240	.011630	.012020	.012430	.012840	.013250	.013700	.014150	.014600	.015070
.015560	.016050	.016550	.017070	.017600	.018140	.018700	.019270	.019850	.020450
.021060	.021690	.022330	.022980	.023650	.024340	.025040	.025750	.026500	.027250
.028020	.028810	.029610	.030430	.031250	.032100	.033020	.033920	.034840	.035780
.036750	.037730	.038740	.039770	.040820	.041900	.043000	.044130	.045250	.046450
.047660	.048890	.050140	.051430	.052750	.054090	.055470	.056870	.058310	.059780
.061290	.062830	.064400	.066010	.067650	.069350	.071070	.072840	.074640	.076490
.078380	.080320	.082300	.084330	.086410	.088540	.090720	.092960	.095250	.097500
.100000									

ISOCHRONOUS STRESS-STRAIN CURVE NUMBER 8

0.000000	.000005	.000011	.000016	.000022	.000027	.000033	.000038	.000044	.000049
.000055	.000060	.000065	.000071	.000076	.000082	.000087	.000093	.000098	.000104
.000109	.000115	.000121	.000126	.000132	.000137	.000143	.000149	.000154	.000160
.000166	.000171	.000177	.000183	.000188	.000194	.000199	.000205	.000211	.000217
.000222	.000228	.000234	.000240	.000245	.000251	.000257	.000263	.000268	.000274
.000280	.000286	.000292	.000297	.000303	.000309	.000315	.000321	.000327	.000333
.000338	.000344	.000350	.000356	.000362	.000367	.000373	.000379	.000385	.000391
.000397	.000403	.000409	.000414	.000420	.000426	.000432	.000438	.000444	.000450
.000456	.000462	.000468	.000474	.000480	.000486	.000492	.000498	.000504	.000510
.000515	.000522	.000528	.000533	.000539	.000546	.000552	.000558	.000564	.000570
.000576	.000582	.000588	.000594	.000600	.000606	.000612	.000618	.000624	.000630
.000636	.000642	.000648	.000654	.000660	.000666	.000672	.000678	.000685	.000691
.000697	.000703	.000709	.000715	.000721	.000727	.000733	.000739	.000745	.000751
.000758	.000764	.000770	.000776	.000782	.000788	.000794	.000801	.000807	.000813
.000824	.000832	.000840	.000848	.000856	.000863	.000871	.000879	.000887	.000895
.000909	.000936	.000962	.000988	.001020	.001057	.001093	.001136	.001181	.001229
.001282	.001338	.001397	.001462	.001529	.001600	.001677	.001757	.001842	.001931
.002024	.002122	.002224	.002332	.002444	.002561	.002683	.002810	.002942	.003080
.003223	.003372	.003526	.003686	.003852	.004024	.004202	.004385	.004577	.004774
.004977	.005187	.005405	.005629	.005860	.006093	.006344	.006597	.006858	.007127
.007404	.007688	.007982	.008283	.008593	.008912	.009239	.009576	.009922	.010280
.010640	.011020	.011400	.011790	.012200	.012610	.013040	.013480	.013930	.014390
.014850	.015340	.015830	.016340	.016860	.017390	.017930	.018490	.019060	.019640
.020240	.020850	.021470	.022110	.022770	.023440	.024120	.024830	.025540	.026280
.027030	.027790	.028590	.029380	.030200	.031030	.031890	.032780	.033660	.034570
.035500	.036460	.037430	.038430	.039440	.040480	.041540	.042630	.043740	.044870
.046020	.047200	.048410	.049640	.050900	.052190	.053500	.054840	.056210	.057610
.059040	.060500	.061990	.063510	.065070	.066660	.068280	.069940	.071630	.073360
.075130	.076940	.078780	.080670	.082600	.084570	.086580	.088640	.090740	.092890
.095090	.097330	.099630	.102000	.104400	.106800	.109400	.111400	.114600	.117200
.120000									

OUTPUT DATA

LAST SEGMENT TO HAVE UNIFORM STRAINING 127

ARC OVER WHICH NON-UNIFORM STRAINING OCCURS .3011

CLAD NOMINAL SWELLING STRAIN = .0100

STRAINING TIME = 1.0000 YEARS

NOMINAL STRAIN RATE = .0100/1.0000 = .0100/YEAR

COEFFICIENT OF FRICTION = .4000

CONVERGENCE ERROR PER CENT = .2489

CLAD MEMBRANE
LOAD DISTRIBUTION
(LBS)

248.0274
247.8824
247.6964
247.5314
247.3850
247.2004
247.0350
246.8695
246.7040
246.5385
246.3730
246.2075
246.0420
245.8766
245.7111
245.5456
245.3801
245.2146
245.0491
244.8836
244.7181
244.5527
244.3872
244.2217
244.0562
243.8907
243.7252
243.5597
243.3942
243.2288
243.0633
242.8978
242.7323
242.5668
242.4013
242.2358
242.0703

CLAD STRAIN
DISTRIBUTION

1.2879E-02
1.1253E-02
1.1101E-02
1.7124E-02
1.7006E-02
1.7002E-02
1.6938E-02
1.6876E-02
1.6814E-02
1.6751E-02
1.6687E-02
1.6623E-02
1.6550E-02
1.6490E-02
1.6437E-02
1.6375E-02
1.6312E-02
1.6249E-02
1.6188E-02
1.6126E-02
1.6064E-02
1.6002E-02
1.5938E-02
1.5876E-02
1.5814E-02
1.5751E-02
1.5689E-02
1.5625E-02
1.5564E-02
1.5503E-02
1.5443E-02
1.5382E-02
1.5320E-02
1.5259E-02
1.5194E-02
1.5138E-02
1.5077E-02

241.9049
 241.7394
 241.5739
 241.4084
 241.2429
 241.0774
 240.9119
 240.7465
 240.5810
 240.4155
 240.2500
 240.0845
 239.9190
 239.7535
 239.5880
 239.4226
 239.2571
 239.0916
 238.9261
 238.7606
 238.5951
 238.4296
 238.2641
 238.0987
 237.9332
 237.7677
 237.6022
 237.4367
 237.2712
 237.1057
 236.9402
 236.7748
 236.6093
 236.4438
 236.2783
 236.1128
 235.9473
 235.7818
 235.6164
 235.4509
 235.2854
 235.1199
 234.9544
 234.7889
 234.6234
 234.4579
 234.2925

1.5015F-02
 1.4954F-02
 1.4893F-02
 1.4833F-02
 1.4772F-02
 1.4711F-02
 1.4650F-02
 1.4591F-02
 1.4532F-02
 1.4472F-02
 1.4412F-02
 1.4353F-02
 1.4294F-02
 1.4236F-02
 1.4177F-02
 1.4117F-02
 1.4058F-02
 1.3999F-02
 1.3941F-02
 1.3883F-02
 1.3824F-02
 1.3765F-02
 1.3707F-02
 1.3649F-02
 1.3591F-02
 1.3533F-02
 1.3474F-02
 1.3417F-02
 1.3359F-02
 1.3301F-02
 1.3244F-02
 1.3186F-02
 1.3128F-02
 1.3072F-02
 1.3015F-02
 1.2958F-02
 1.2902F-02
 1.2845F-02
 1.2788F-02
 1.2731F-02
 1.2674F-02
 1.2617F-02
 1.2560F-02
 1.2503F-02
 1.2447F-02
 1.2390F-02

234.1270	1.2247E-02
233.9615	1.2232E-02
233.7960	1.2176E-02
233.6305	1.2120E-02
233.4650	1.2066E-02
233.2995	1.2012E-02
233.1340	1.1957E-02
232.9686	1.1902E-02
232.8031	1.1847E-02
232.6376	1.1793E-02
232.4721	1.1740E-02
232.3066	1.1686E-02
232.1411	1.1632E-02
231.9756	1.1577E-02
231.8101	1.1524E-02
231.6447	1.1472E-02
231.4792	1.1419E-02
231.3137	1.1366E-02
231.1482	1.1312E-02
230.9827	1.1259E-02
230.8172	1.1204E-02
230.6517	1.1155E-02
230.4863	1.1102E-02
230.3208	1.1049E-02
230.1553	1.0997E-02
229.9898	1.0945E-02
229.8243	1.0893E-02
229.6588	1.0840E-02
229.4933	1.0787E-02
229.3278	1.0736E-02
229.1624	1.0684E-02
228.9969	1.0633E-02
228.8314	1.0581E-02
228.6659	1.0528E-02
228.5004	1.0478E-02
228.3349	1.0428E-02
228.1694	1.0378E-02
228.0039	1.0328E-02
227.8384	1.0277E-02
227.6730	1.0227E-02
227.5075	1.0177E-02
227.3420	1.0126E-02
227.1765	1.0075E-02
227.0110	1.0024E-02

OUTPUT DATA

LAST SEGMENT TO HAVE UNIFORM STRAINING 139
 ARC OVER WHICH NON-UNIFORM STRAINING OCCURS .3215
 CLAD NOMINAL SWELLING STRAIN = .0200
 STRAINING TIME = 1.0000 YEARS
 NOMINAL STRAIN RATE = .0200/1.0000 = .0200/YEAR
 COEFFICIENT OF FRICTION = .4000
 CONVERGENCE ERROR PER CENT = .2419

CLAD MEMBRANE LOAD DISTRIBUTION (LBS)

280.8841
 280.6482
 280.5123
 280.3264
 280.1405
 279.4545
 279.7686
 279.5827
 279.3968
 279.2109
 279.0249
 278.8390
 278.6531
 278.4672
 278.2812
 278.0953
 277.9094
 277.7235
 277.5375
 277.3516
 277.1657
 276.9798
 276.7939
 276.6080
 276.4220

CLAD STRAIN DISTRIBUTION

2.4057E-03
 3.3102E-02
 3.2942E-02
 3.2883E-02
 3.2773E-02
 3.2664E-02
 3.2554E-02
 3.2445E-02
 3.2335E-02
 3.2230E-02
 3.2122E-02
 3.2013E-02
 3.1905E-02
 3.1799E-02
 3.1692E-02
 3.1585E-02
 3.1477E-02
 3.1369E-02
 3.1265E-02
 3.1160E-02
 3.1054E-02
 3.0949E-02
 3.0843E-02
 3.0738E-02
 3.0634E-02

276.2361
 276.0502
 275.8643
 275.6744
 275.4924
 275.3065
 275.1206
 274.9347
 274.7488
 274.5628
 274.3769
 274.1910
 274.0051
 273.8192
 273.6332
 273.4473
 273.2614
 273.0755
 272.8896
 272.7036
 272.5177
 272.3318
 272.1459
 271.9599
 271.7740
 271.5881
 271.4022
 271.2163
 271.0303
 270.8444
 270.6585
 270.4726
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 270.1007
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 269.7289
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 269.1711
 268.9852
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 268.6134
 268.4275
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 268.0556
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 267.6838

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 3.0213F-02
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 2.8943F-02
 2.8837F-02
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 2.8201F-02
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 2.7459F-02
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 2.6505F-02
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 2.6293F-02
 2.6187F-02
 2.6081F-02
 2.5975F-02

267.4970
267.3119
267.1260
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266.5682
266.3823
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266.0105
265.8246
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265.2668
265.0809
264.8950
264.7090
264.5231
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264.1513
263.9654
263.7794
263.5935
263.4076
263.2217
263.0358
262.8498
262.6639
262.4780
262.2921
262.1062
261.9202
261.7343
261.5484
261.3625
261.1766
260.9906
260.8047
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260.4329
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260.0610
259.8751
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2.5375F-02
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2.4734F-02
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2.4278F-02
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2.4097F-02
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2.3917F-02
2.3826F-02
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2.2068F-02
2.1982F-02
2.1896F-02
2.1810F-02

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258.0159
257.8300
257.6441
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256.1567
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255.5990
255.4130
255.2271
255.0412

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2.1552E-02
2.1457E-02
2.1382E-02
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2.1210E-02
2.1127E-02
2.1044E-02
2.0960E-02
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2.0290E-02
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2.0125E-02
2.0041E-02

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 15.26.02. 0044331. ALR5105. FT2A 31601 STARR 21
 15.26.03. 0044331. REQUEST SNATL (RRSNATL.SNATL)
 15.28.36. 0044331. SNATL.
 15.29.44. 0044331. STOP
 15.29.45. 0044331. RUN(S,,,TAPE 2,,,100000,,)
 15.29.52. 0044331. LG0.
 15.30.03. 0044331. MAXIMUM FL TF NO COMPILE **** 043600
 15.30.13. 0044331. EXIT
 15.30.14. 0044331. CP 015.915 SEC.
 15.30.14. 0044331. PP 012.096 SEC.
 15.38.59. 08/29/68 *FC 6416 SYS 2.70 UPDT 55, 05/01/68.

DATA CARDS FOR SAMPLE PROBLEM - SISINUC

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1.0
0.01 0.02 0.03 0.04 0.05 0.06 0.08 0.10
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15427.465 16606.864 17778.695 18743.254 19578.118 20678.436 21936.866 23026.334
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2.680E-05 3.078E-05 3.475E-05 3.873E-05 4.270E-05 4.668E-05 5.067E-05 .01 2
5.475E-05 5.884E-05 6.292E-05 6.700E-05 7.108E-05 7.517E-05 7.933E-05 .01 3
8.350E-05 8.767E-05 9.183E-05 9.600E-05 1.002E-04 1.044E-04 1.086E-04 .01 4
1.129E-04 1.171E-04 1.214E-04 1.256E-04 1.299E-04 1.342E-04 1.385E-04 .01 5
1.428E-04 1.471E-04 1.514E-04 1.558E-04 1.601E-04 1.645E-04 1.688E-04 .01 6
1.732E-04 1.776E-04 1.820E-04 1.864E-04 1.908E-04 1.952E-04 1.996E-04 .01 7
2.040E-04 2.085E-04 2.129E-04 2.174E-04 2.218E-04 2.263E-04 2.308E-04 .01 8
2.352E-04 2.397E-04 2.442E-04 2.487E-04 2.532E-04 2.578E-04 2.623E-04 .01 9
2.668E-04 2.714E-04 2.759E-04 2.805E-04 2.850E-04 2.896E-04 2.942E-04 .01 10
2.987E-04 3.033E-04 3.079E-04 3.125E-04 3.171E-04 3.217E-04 3.264E-04 .01 11
3.310E-04 3.356E-04 3.403E-04 3.449E-04 3.495E-04 3.542E-04 3.589E-04 .01 12
3.636E-04 3.682E-04 3.729E-04 3.776E-04 3.823E-04 3.870E-04 3.917E-04 .01 13
3.964E-04 4.011E-04 4.058E-04 4.105E-04 4.153E-04 4.200E-04 4.247E-04 .01 14
4.295E-04 4.343E-04 4.390E-04 4.438E-04 4.485E-04 4.533E-04 4.581E-04 .01 15
4.629E-04 4.677E-04 4.725E-04 4.773E-04 4.821E-04 4.869E-04 4.917E-04 .01 16
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9.781E-03	1.011E-02	1.045E-02	1.080E-02	1.116E-02	1.152E-02	1.190E-02	.04 36
1.229E-02	1.269E-02	1.310E-02	1.352E-02	1.395E-02	1.439E-02	1.484E-02	.04 37
1.531E-02	1.579E-02	1.628E-02	1.678E-02	1.730E-02	1.783E-02	1.838E-02	.04 38
1.894E-02	1.951E-02	2.010E-02	2.070E-02	2.132E-02	2.196E-02	2.261E-02	.04 39
2.328E-02	2.397E-02	2.467E-02	2.540E-02	2.614E-02	2.690E-02	2.768E-02	.04 40
2.848E-02	2.931E-02	3.015E-02	3.102E-02	3.191E-02	3.283E-02	3.377E-02	.04 41

3.473E-01	3.572E-02	3.674E-02	3.779E-02	3.886E-02	997E-02	4.110E-02	.04	42
4.227E-02	4.347E-02	4.470E-02	4.597E-02	4.727E-02	4.862E-02	5.000E-02	.04	43
0.	4.634E-06	9.267E-06	1.390E-05	1.853E-05	2.317E-05	2.780E-05	.05	1
3.243E-05	3.707E-05	4.170E-05	4.634E-05	5.100E-05	5.579E-05	6.058E-05	.05	2
6.537E-05	7.016E-05	7.495E-05	7.974E-05	8.453E-05	8.932E-05	9.411E-05	.05	3
9.890E-05	1.038E-04	1.087E-04	1.136E-04	1.185E-04	1.233E-04	1.282E-04	.05	4
1.331E-04	1.380E-04	1.429E-04	1.478E-04	1.526E-04	1.577E-04	1.627E-04	.05	5
1.677E-04	1.727E-04	1.776E-04	1.826E-04	1.876E-04	1.926E-04	1.975E-04	.05	6
2.026E-04	2.076E-04	2.126E-04	2.177E-04	2.227E-04	2.278E-04	2.328E-04	.05	7
2.379E-04	2.429E-04	2.480E-04	2.530E-04	2.581E-04	2.633E-04	2.684E-04	.05	8
2.735E-04	2.786E-04	2.837E-04	2.888E-04	2.939E-04	2.990E-04	3.041E-04	.05	9
3.093E-04	3.144E-04	3.196E-04	3.248E-04	3.299E-04	3.351E-04	3.402E-04	.05	10
3.454E-04	3.505E-04	3.557E-04	3.609E-04	3.661E-04	3.714E-04	3.766E-04	.05	11
3.818E-04	3.870E-04	3.922E-04	3.974E-04	4.026E-04	4.078E-04	4.131E-04	.05	12
4.183E-04	4.236E-04	4.288E-04	4.341E-04	4.393E-04	4.446E-04	4.498E-04	.05	13
4.551E-04	4.604E-04	4.657E-04	4.710E-04	4.763E-04	4.815E-04	4.868E-04	.05	14
4.921E-04	4.974E-04	5.027E-04	5.080E-04	5.134E-04	5.187E-04	5.240E-04	.05	15
5.293E-04	5.347E-04	5.400E-04	5.453E-04	5.506E-04	5.560E-04	5.614E-04	.05	16
5.667E-04	5.721E-04	5.774E-04	5.828E-04	5.882E-04	5.935E-04	5.989E-04	.05	17
6.043E-04	6.097E-04	6.150E-04	6.204E-04	6.258E-04	6.312E-04	6.366E-04	.05	18
6.420E-04	6.474E-04	6.528E-04	6.582E-04	6.637E-04	6.691E-04	6.745E-04	.05	19
6.799E-04	6.854E-04	6.908E-04	6.962E-04	7.016E-04	7.071E-04	7.126E-04	.05	20
7.180E-04	7.235E-04	7.289E-04	7.344E-04	7.398E-04	7.453E-04	7.507E-04	.05	21
7.562E-04	7.617E-04	7.672E-04	7.727E-04	7.782E-04	7.836E-04	7.891E-04	.05	22
7.946E-04	8.001E-04	8.056E-04	8.111E-04	8.166E-04	8.221E-04	8.276E-04	.05	23
8.332E-04	8.387E-04	8.442E-04	8.497E-04	8.552E-04	8.608E-04	8.663E-04	.05	24
8.884E-04	8.981E-04	9.078E-04	9.176E-04	9.274E-04	9.372E-04	9.470E-04	.05	25
1.002E-03	1.026E-03	1.051E-03	1.080E-03	1.110E-03	1.143E-03	1.178E-03	.05	26
1.216E-03	1.256E-03	1.299E-03	1.346E-03	1.395E-03	1.447E-03	1.502E-03	.05	27
1.560E-03	1.622E-03	1.686E-03	1.754E-03	1.826E-03	1.901E-03	1.980E-03	.05	28
2.062E-03	2.148E-03	2.238E-03	2.332E-03	2.430E-03	2.532E-03	2.638E-03	.05	29
2.748E-03	2.863E-03	2.982E-03	3.106E-03	3.234E-03	3.367E-03	3.505E-03	.05	30
3.647E-03	3.795E-03	3.948E-03	4.106E-03	4.269E-03	4.438E-03	4.613E-03	.05	31
4.793E-03	4.979E-03	5.170E-03	5.368E-03	5.572E-03	5.782E-03	5.999E-03	.05	32
6.222E-03	6.452E-03	6.689E-03	6.932E-03	7.183E-03	7.441E-03	7.707E-03	.05	33
7.980E-03	8.260E-03	8.549E-03	8.846E-03	9.151E-03	9.464E-03	9.786E-03	.05	34
1.012E-02	1.046E-02	1.080E-02	1.116E-02	1.153E-02	1.191E-02	1.229E-02	.05	35
1.269E-02	1.310E-02	1.352E-02	1.395E-02	1.439E-02	1.484E-02	1.530E-02	.05	36
1.578E-02	1.626E-02	1.676E-02	1.727E-02	1.780E-02	1.834E-02	1.889E-02	.05	37
1.945E-02	2.003E-02	2.062E-02	2.123E-02	2.186E-02	2.249E-02	2.315E-02	.05	38
2.382E-02	2.451E-02	2.521E-02	2.593E-02	2.667E-02	2.743E-02	2.820E-02	.05	39
2.900E-02	2.981E-02	3.065E-02	3.151E-02	3.238E-02	3.328E-02	3.420E-02	.05	40
3.515E-02	3.611E-02	3.711E-02	3.812E-02	3.916E-02	4.023E-02	4.133E-02	.05	41
4.245E-02	4.360E-02	4.478E-02	4.599E-02	4.724E-02	4.851E-02	4.982E-02	.05	42
5.116E-02	5.254E-02	5.395E-02	5.541E-02	5.690E-02	5.843E-02	6.000E-02	.05	43
0.	4.917E-06	9.834E-06	1.475E-05	1.961E-05	2.459E-05	2.950E-05	.06	1
3.442E-05	3.934E-05	4.425E-05	4.917E-05	5.409E-05	5.901E-05	6.392E-05	.06	2

6.892E-01	.400E-05	7.909E-05	8.417E-05	8.926E-05	.35E-05	9.943E-05	.06	3
1.045E-04	1.096E-04	1.147E-04	1.198E-04	1.249E-04	1.300E-04	1.351E-04	.06	4
1.403E-04	1.455E-04	1.507E-04	1.559E-04	1.611E-04	1.663E-04	1.715E-04	.06	5
1.767E-04	1.819E-04	1.871E-04	1.923E-04	1.975E-04	2.027E-04	2.080E-04	.06	6
2.133E-04	2.186E-04	2.239E-04	2.292E-04	2.345E-04	2.398E-04	2.450E-04	.06	7
2.503E-04	2.556E-04	2.609E-04	2.662E-04	2.716E-04	2.769E-04	2.823E-04	.06	8
2.877E-04	2.930E-04	2.984E-04	3.038E-04	3.091E-04	3.145E-04	3.198E-04	.06	9
3.252E-04	3.306E-04	3.360E-04	3.414E-04	3.468E-04	3.523E-04	3.577E-04	.06	10
3.631E-04	3.685E-04	3.740E-04	3.794E-04	3.848E-04	3.902E-04	3.957E-04	.06	11
4.011E-04	4.066E-04	4.121E-04	4.176E-04	4.231E-04	4.285E-04	4.340E-04	.06	12
4.395E-04	4.450E-04	4.505E-04	4.560E-04	4.615E-04	4.669E-04	4.725E-04	.06	13
4.780E-04	4.836E-04	4.891E-04	4.946E-04	5.002E-04	5.057E-04	5.112E-04	.06	14
5.168E-04	5.223E-04	5.279E-04	5.334E-04	5.390E-04	5.446E-04	5.501E-04	.06	15
5.557E-04	5.613E-04	5.669E-04	5.725E-04	5.781E-04	5.837E-04	5.892E-04	.06	16
5.948E-04	6.004E-04	6.060E-04	6.117E-04	6.173E-04	6.229E-04	6.285E-04	.06	17
6.342E-04	6.398E-04	6.454E-04	6.511E-04	6.567E-04	6.623E-04	6.680E-04	.06	18
6.736E-04	6.793E-04	6.850E-04	6.906E-04	6.963E-04	7.020E-04	7.076E-04	.06	19
7.133E-04	7.190E-04	7.246E-04	7.303E-04	7.360E-04	7.417E-04	7.474E-04	.06	20
7.531E-04	7.588E-04	7.645E-04	7.702E-04	7.760E-04	7.817E-04	7.874E-04	.06	21
7.931E-04	7.988E-04	8.046E-04	8.105E-04	8.164E-04	8.223E-04	8.282E-04	.06	22
8.341E-04	8.400E-04	8.459E-04	8.518E-04	8.577E-04	8.636E-04	8.735E-04	.06	23
8.878E-04	9.021E-04	9.163E-04	9.306E-04	9.510E-04	9.727E-04	9.944E-04	.06	24
1.021E-03	1.049E-03	1.079E-03	1.113E-03	1.149E-03	1.187E-03	1.229E-03	.06	25
1.274E-03	1.322E-03	1.373E-03	1.428E-03	1.485E-03	1.547E-03	1.611E-03	.06	26
1.680E-03	1.752E-03	1.827E-03	1.907E-03	1.990E-03	2.078E-03	2.170E-03	.06	27
2.265E-03	2.365E-03	2.469E-03	2.578E-03	2.692E-03	2.809E-03	2.932E-03	.06	28
3.059E-03	3.191E-03	3.329E-03	3.471E-03	3.619E-03	3.772E-03	3.930E-03	.06	29
4.094E-03	4.263E-03	4.438E-03	4.619E-03	4.807E-03	5.000E-03	5.199E-03	.06	30
5.405E-03	5.618E-03	5.837E-03	6.062E-03	6.295E-03	6.535E-03	6.782E-03	.06	31
7.036E-03	7.298E-03	7.567E-03	7.844E-03	8.130E-03	8.423E-03	8.725E-03	.06	32
9.035E-03	9.353E-03	9.681E-03	1.002E-02	1.036E-02	1.072E-02	1.108E-02	.06	33
1.146E-02	1.184E-02	1.224E-02	1.264E-02	1.306E-02	1.348E-02	1.392E-02	.06	34
1.437E-02	1.483E-02	1.530E-02	1.578E-02	1.628E-02	1.679E-02	1.731E-02	.06	35
1.784E-02	1.839E-02	1.895E-02	1.953E-02	2.012E-02	2.072E-02	2.134E-02	.06	36
2.197E-02	2.262E-02	2.328E-02	2.397E-02	2.466E-02	2.538E-02	2.611E-02	.06	37
2.686E-02	2.763E-02	2.841E-02	2.922E-02	3.004E-02	3.088E-02	3.175E-02	.06	38
3.263E-02	3.354E-02	3.447E-02	3.542E-02	3.639E-02	3.734E-02	3.841E-02	.06	39
3.945E-02	4.052E-02	4.162E-02	4.274E-02	4.389E-02	4.507E-02	4.628E-02	.06	40
4.752E-02	4.878E-02	5.008E-02	5.141E-02	5.278E-02	5.417E-02	5.560E-02	.06	41
5.707E-02	5.858E-02	6.012E-02	6.170E-02	6.333E-02	6.499E-02	6.670E-02	.06	42
6.846E-02	7.025E-02	7.210E-02	7.400E-02	7.595E-02	7.795E-02	8.000E-02	.06	43
0.	5.201E-06	1.040E-05	1.560E-05	2.081E-05	2.601E-05	3.121E-05	.08	1
3.641E-05	4.161E-05	4.681E-05	5.201E-05	5.721E-05	6.242E-05	6.762E-05	.08	2
7.282E-05	7.802E-05	8.322E-05	8.859E-05	9.397E-05	9.935E-05	1.047E-04	.08	3
1.101E-04	1.155E-04	1.209E-04	1.262E-04	1.316E-04	1.370E-04	1.424E-04	.08	4
1.478E-04	1.531E-04	1.585E-04	1.639E-04	1.693E-04	1.748E-04	1.803E-04	.08	5
1.858E-04	1.913E-04	1.968E-04	2.023E-04	2.078E-04	2.133E-04	2.188E-04	.08	6

2.243E-04	.298E-04	2.353E-04	2.408E-04	2.463E-04	2.18E-04	2.574E-04	.08	7
2.630E-04	2.686E-04	2.742E-04	2.798E-04	2.853E-04	2.909E-04	2.965E-04	.08	8
3.021E-04	3.077E-04	3.133E-04	3.189E-04	3.245E-04	3.301E-04	3.357E-04	.08	9
3.413E-04	3.470E-04	3.527E-04	3.584E-04	3.640E-04	3.697E-04	3.754E-04	.08	10
3.810E-04	3.867E-04	3.924E-04	3.980E-04	4.037E-04	4.094E-04	4.150E-04	.08	11
4.207E-04	4.265E-04	4.322E-04	4.379E-04	4.437E-04	4.494E-04	4.551E-04	.08	12
4.609E-04	4.666E-04	4.723E-04	4.781E-04	4.838E-04	4.895E-04	4.953E-04	.08	13
5.010E-04	5.068E-04	5.126E-04	5.184E-04	5.242E-04	5.300E-04	5.358E-04	.08	14
5.416E-04	5.474E-04	5.532E-04	5.590E-04	5.648E-04	5.705E-04	5.763E-04	.08	15
5.821E-04	5.880E-04	5.938E-04	5.997E-04	6.055E-04	6.114E-04	6.172E-04	.08	16
6.231E-04	6.289E-04	6.348E-04	6.406E-04	6.464E-04	6.523E-04	6.581E-04	.08	17
6.640E-04	6.699E-04	6.758E-04	6.817E-04	6.876E-04	6.934E-04	6.993E-04	.08	18
7.052E-04	7.111E-04	7.170E-04	7.229E-04	7.288E-04	7.347E-04	7.406E-04	.08	19
7.465E-04	7.524E-04	7.584E-04	7.643E-04	7.703E-04	7.762E-04	7.821E-04	.08	20
7.881E-04	7.940E-04	8.000E-04	8.059E-04	8.119E-04	8.178E-04	8.237E-04	.08	21
8.297E-04	8.356E-04	8.416E-04	8.475E-04	8.535E-04	8.594E-04	8.654E-04	.08	22
9.028E-04	9.137E-04	9.328E-04	9.552E-04	9.775E-04	9.999E-04	1.031E-03	.08	23
1.061E-03	1.094E-03	1.132E-03	1.171E-03	1.215E-03	1.261E-03	1.311E-03	.08	24
1.365E-03	1.421E-03	1.482E-03	1.546E-03	1.614E-03	1.686E-03	1.761E-03	.08	25
1.841E-03	1.925E-03	2.013E-03	2.106E-03	2.203E-03	2.304E-03	2.410E-03	.08	26
2.520E-03	2.636E-03	2.755E-03	2.881E-03	3.010E-03	3.145E-03	3.286E-03	.08	27
3.431E-03	3.582E-03	3.739E-03	3.901E-03	4.069E-03	4.242E-03	4.422E-03	.08	28
4.608E-03	4.800E-03	4.998E-03	5.203E-03	5.415E-03	5.633E-03	5.858E-03	.08	29
6.090E-03	6.329E-03	6.576E-03	6.829E-03	7.091E-03	7.360E-03	7.637E-03	.08	30
7.921E-03	8.214E-03	8.516E-03	8.825E-03	9.144E-03	9.471E-03	9.807E-03	.08	31
1.015E-02	1.051E-02	1.087E-02	1.124E-02	1.163E-02	1.202E-02	1.243E-02	.08	32
1.284E-02	1.326E-02	1.370E-02	1.415E-02	1.460E-02	1.507E-02	1.556E-02	.08	33
1.605E-02	1.655E-02	1.707E-02	1.760E-02	1.814E-02	1.870E-02	1.927E-02	.08	34
1.985E-02	2.045E-02	2.106E-02	2.169E-02	2.233E-02	2.298E-02	2.365E-02	.08	35
2.434E-02	2.504E-02	2.576E-02	2.650E-02	2.725E-02	2.802E-02	2.881E-02	.08	36
2.961E-02	3.043E-02	3.128E-02	3.214E-02	3.302E-02	3.392E-02	3.484E-02	.08	37
3.578E-02	3.675E-02	3.773E-02	3.874E-02	3.977E-02	4.082E-02	4.190E-02	.08	38
4.300E-02	4.413E-02	4.528E-02	4.645E-02	4.766E-02	4.889E-02	5.014E-02	.08	39
5.143E-02	5.275E-02	5.409E-02	5.547E-02	5.687E-02	5.831E-02	5.978E-02	.08	40
6.129E-02	6.283E-02	6.440E-02	6.601E-02	6.766E-02	6.935E-02	7.107E-02	.08	41
7.284E-02	7.464E-02	7.649E-02	7.838E-02	8.032E-02	8.230E-02	8.433E-02	.08	42
8.641E-02	8.854E-02	9.072E-02	9.296E-02	9.525E-02	9.760E-02	1.000E-01	.08	43
0.	5.450E-05	1.090E-05	1.635E-05	2.180E-05	2.725E-05	3.270E-05	.10	1
3.815E-05	4.360E-05	4.905E-05	5.450E-05	5.995E-05	6.540E-05	7.085E-05	.10	2
7.629E-05	8.174E-05	8.719E-05	9.264E-05	9.809E-05	1.037E-04	1.093E-04	.10	3
1.149E-04	1.206E-04	1.262E-04	1.318E-04	1.375E-04	1.431E-04	1.487E-04	.10	4
1.544E-04	1.600E-04	1.656E-04	1.713E-04	1.769E-04	1.825E-04	1.882E-04	.10	5
1.938E-04	1.994E-04	2.052E-04	2.109E-04	2.167E-04	2.224E-04	2.282E-04	.10	6
2.340E-04	2.397E-04	2.455E-04	2.512E-04	2.570E-04	2.627E-04	2.685E-04	.10	7
2.742E-04	2.800E-04	2.858E-04	2.915E-04	2.973E-04	3.031E-04	3.089E-04	.10	8
3.148E-04	3.206E-04	3.265E-04	3.323E-04	3.382E-04	3.441E-04	3.499E-04	.10	9
3.558E-04	3.616E-04	3.675E-04	3.733E-04	3.792E-04	3.850E-04	3.909E-04	.10	10

3.967E-04	4.026E-04	4.086E-04	4.145E-04	4.204E-04	4.263E-04	4.323E-04	.10 11
4.382E-04	4.442E-04	4.501E-04	4.560E-04	4.620E-04	4.679E-04	4.738E-04	.10 12
4.798E-04	4.857E-04	4.916E-04	4.976E-04	5.035E-04	5.095E-04	5.155E-04	.10 13
5.215E-04	5.275E-04	5.335E-04	5.395E-04	5.456E-04	5.516E-04	5.576E-04	.10 14
5.636E-04	5.696E-04	5.756E-04	5.816E-04	5.876E-04	5.936E-04	5.996E-04	.10 15
6.056E-04	6.117E-04	6.178E-04	6.238E-04	6.299E-04	6.360E-04	6.420E-04	.10 16
6.481E-04	6.542E-04	6.602E-04	6.663E-04	6.723E-04	6.784E-04	6.845E-04	.10 17
6.905E-04	6.966E-04	7.027E-04	7.088E-04	7.149E-04	7.211E-04	7.272E-04	.10 18
7.333E-04	7.394E-04	7.455E-04	7.517E-04	7.578E-04	7.639E-04	7.700E-04	.10 19
7.761E-04	7.823E-04	7.884E-04	7.945E-04	8.008E-04	8.066E-04	8.165E-04	.10 20
8.243E-04	8.322E-04	8.400E-04	8.479E-04	8.557E-04	8.635E-04	8.714E-04	.10 21
8.792E-04	8.871E-04	8.949E-04	9.028E-04	9.106E-04	9.185E-04	9.263E-04	.10 22
1.020E-03	1.057E-03	1.093E-03	1.130E-03	1.167E-03	1.204E-03	1.241E-03	.10 23
1.338E-03	1.397E-03	1.462E-03	1.524E-03	1.600E-03	1.677E-03	1.757E-03	.10 24
1.842E-03	1.930E-03	2.024E-03	2.122E-03	2.224E-03	2.332E-03	2.444E-03	.10 25
2.561E-03	2.683E-03	2.810E-03	2.942E-03	3.080E-03	3.223E-03	3.372E-03	.10 26
3.526E-03	3.686E-03	3.852E-03	4.024E-03	4.202E-03	4.386E-03	4.577E-03	.10 27
4.774E-03	4.977E-03	5.187E-03	5.405E-03	5.629E-03	5.860E-03	6.098E-03	.10 28
6.344E-03	6.597E-03	6.858E-03	7.127E-03	7.404E-03	7.688E-03	7.982E-03	.10 29
8.283E-03	8.593E-03	8.912E-03	9.239E-03	9.576E-03	9.922E-03	1.028E-02	.10 30
1.064E-02	1.102E-02	1.140E-02	1.179E-02	1.220E-02	1.261E-02	1.304E-02	.10 31
1.348E-02	1.393E-02	1.438E-02	1.485E-02	1.534E-02	1.583E-02	1.634E-02	.10 32
1.686E-02	1.739E-02	1.793E-02	1.849E-02	1.906E-02	1.964E-02	2.024E-02	.10 33
2.085E-02	2.147E-02	2.211E-02	2.277E-02	2.344E-02	2.412E-02	2.483E-02	.10 34
2.554E-02	2.628E-02	2.703E-02	2.779E-02	2.858E-02	2.938E-02	3.020E-02	.10 35
3.103E-02	3.189E-02	3.276E-02	3.366E-02	3.457E-02	3.550E-02	3.646E-02	.10 36
3.743E-02	3.843E-02	3.944E-02	4.048E-02	4.154E-02	4.263E-02	4.374E-02	.10 37
4.487E-02	4.602E-02	4.720E-02	4.841E-02	4.964E-02	5.090E-02	5.219E-02	.10 38
5.350E-02	5.484E-02	5.621E-02	5.761E-02	5.904E-02	6.050E-02	6.199E-02	.10 39
6.351E-02	6.507E-02	6.666E-02	6.828E-02	6.994E-02	7.163E-02	7.336E-02	.10 40
7.513E-02	7.694E-02	7.878E-02	8.067E-02	8.260E-02	8.457E-02	8.658E-02	.10 41
8.864E-02	9.074E-02	9.289E-02	9.509E-02	9.733E-02	9.963E-02	1.020E-01	.10 42
1.044E-01	1.068E-01	1.094E-01	1.119E-01	1.146E-01	1.172E-01	1.200E-01	.10 43

APPENDIX E
STRESS ANALYSIS OF THE GRID

1. GENERAL APPROACH

Grid loading due to flow induced pressure drops and friction interaction with the fuel rods is combined as an equivalent pressure. The grid static analysis is based on this pressure. Stresses produced by temperature gradients through the fuel assembly are included in the thermal analysis. The static and thermal stresses are then combined in a fatigue analysis.

1.1 Notation

D	inch	Diameter.
E	lb/inch ²	Elastic modulus.
F	1/hr	Frequency of load application.
G	lb/inch ²	Shear modulus.
h	inch	Height of the grid.
I	inch ⁴	Moment of inertia.
J	inch ⁴	Polar moment of inertia.
k		Springstiffness in lb/inch, ductility or constants.
l	inch	Length.
L	lb	Load.
M	lb/inch	Moment.
m	lb/inch	Moment per unit length.
P	lb/inch ²	Pressure.
p	lb/inch ²	Radial pressure.
q	lb/inch	Shear force per unit length.
Q	lb	Shear force.
r	inch	Radius.
R	inch	Outside radius of the grid.
R _m	inch	Mean radius of the can.

RA		Reduction of area.
R.F.		Reserve factor, Design stress/Applied stress
S		Section modulus in inch ³ or fatigue strength inch/lb ² .
Se	lb/inch ²	Endurance limit.
t	inch	Thickness.
T		Temperature °F or torsion moment lb inch.
t _m	inch	Mean thickness.
u	inch	Radial deflection.
V	lb	Force on hinge.
W	lb/inch	Load.
Z	inch	Axis.
α	radial	Angle.
δ	inch	Deflection.
θ	radius	Angle of rotation.
μ		Friction coefficient.
ν		Poisson's ratio.
σ	lb/inch ²	Normal stress.
τ	lb/inch ²	Shear stress.

Subscripts

a	amplitude, applied
b	bending
c	critical
f	friction, failure
i	irradiated
L	lateral
m	average or mean
o	center
p	pressure
q	equivalent
r	radial
R	ring
S	static or sodium
t	thermal

u	unirradiated or ultimate
y	yield
x	axis
Z	axis
θ	circumferential

2. DESIGN CRITERIA

2.1 Modes of Failure

The following modes of failure in the grid were investigated:

1. Maximum bending stresses in the cell web.
2. Buckling stresses in the cell web (does not apply to clustered rod grid).
3. Static stresses at the junctions between the webs, both in the parent metal and the braze alloy.
4. The torsion bar in the grid has to transfer shear from the upper flange to the lower flange in the cut out region. It is subjected to high bending stress. The bending stability of the torsion bar is investigated.
5. Thermal stresses in the cell webs at point of maximum thermal stress amplitude and at points of maximum static stress.
6. Fatigue life due to thermal and static stress.
 - a. At discontinuities in the shear webs.
 - b. In the braze alloy.

2.2 Design Stresses

2.2.1 Primary Stresses

The primary stresses shall not exceed the lesser of:

1/3 Ultimate stress	= 53000 lb/inch ²
2/3 Yield stress	= 83500 lb/inch ²
Creep stress for a creep rate of 0.00001 percent/hr	= 35000 lb/inch ²

Data for Inconel 718 at 1100°F are listed in Section 2.3 of this appendix.

The creep criteria therefore limits the design stress under static loading conditions. In addition, the design must include a safety factor of 1.0 against buckling.

2.2.2 Secondary Stresses and Peak Stresses

All thermal stresses are considered secondary stresses because they are self limiting. Thermal stresses and peak stresses resulting from stress concentration are subject to a low cycle fatigue analysis. The cumulative damage usage factors produced by the lifetime loading history shall not exceed 0.8.

The fatigue design curve used has been constructed in Section E-2.4. Figure E-9 shows the fatigue design curve for Inconel 718. Safety factors of 10 on cycles and 1.5 on stress are incorporated into the curve.

2.3 Material Data

Material: Inconel 718

Material data for this material is taken from
References 5 and 6.

Modulus of Elasticity:	$24 \times 10^6 \text{ lb/inch}^2$	Figure E-1
Poisson's ratio:	0.27	Figure E-2
Mean coefficient-linear		
thermal expansion α :	$8 \times 10^6 \text{ inch/inch } ^\circ\text{F}$	Figure E-3
Ultimate stress σ_u :	$160,000 \text{ lb/inch}^2$	Figure E-4
Yield stress, 0.2%, σ_y :	$125,000 \text{ lb/inch}^2$	Figure E-4
Creep stress for a creep rate:		
0.0001%/hr σ_c :	$35,000 \text{ lb/inch}^2$	Figure E-5

All the above data are obtained at 1100°F.

2.4 Low Cycle Fatigue Curve for Inconel 718

2.4.1 Introduction

Low cycle fatigue test data for Inconel 718 at 1100°F including the effects of irradiation in a sodium environment are not available. Two methods will be used to construct low cycle fatigue curves from existing information, which take into account all effects which may reduce the fatigue life.

Method I is applicable if no experimental fatigue data is available which includes the effect of creep irradiation and sodium environments. These effects will be included in the fatigue curve by an approximation procedure.

With Method II a low cycle fatigue curve will be constructed using material data which have been obtained from tensile tests on irradiated specimens at elevated temperatures. This method can be found in a paper by Halford and Manson.^[12]

2.4.2 Method I

2.4.2.1 *The Basic Fatigue Curve*

A fatigue life curve for Inconel 718 is reported in^[13]. The curve which applies to the given temperature is shown in Figure E-6, curve I. It can be described by the function^{[11], [14], [15]},

$$S = \frac{E}{4/N} \times \ln\left(\frac{100}{100-RA}\right) + S_e$$

The ductility $k = \ln\left(\frac{100}{100-RA}\right)$ and the endurance limit S_e have been determined from Figure E-6, curve I as

$$S_e = 55,000 \text{ lb/inch,}$$

$$k = 1.9248.$$

2.4.2.2 *Influence of Irradiation on the Fatigue Strength*

Data for the decrease of the ductility of Inconel 718 at 1200°F due to fast fluence of $4.0 \times 10^{20} \text{ n/cm}^2$ can be found in ^[16], Table 70:

for unirradiated Inconel 718	RA = 24.1%
for irradiated Inconel 718	RA = 10.1%

Since in the actual operation, the fluence will be $\sim 2 \times 10^{23}$, this data is not conservative and the additional reduction will have to be made unless conservatism can be added in other ways, see Figure E-10.

The ductility k in the function $S = \frac{E \times k}{A/N} + S_e$ will be reduced by the same ratio as irradiation has reduced the ductibility in the static tests, thus

$$k_i = \frac{\ln \frac{100}{100-RA_i}}{\ln \frac{100}{100-RA_u}} k_u$$

The fatigue life curve incorporating the reduced ductibility has been plotted in Figure E-6, curve II. The reduction of fatigue strength is significant for a low number of cycles. At high numbers of cycles the applied correction gives no reduction of the fatigue strength due to irradiation. This is in agreement with test results obtained with other materials.^[17]

2.4.2.3 Effect of a Sodium Environment on the Fatigue Strength

No data is available which indicates how a hot sodium environment influences the properties of Inconel 718. Experiments with austenitic stainless steel in a zirconium gettered sodium environment at 1350°F show that the stress rupture strength decreases.^[18] This is due to decarburization of the stainless steel by the zirconium gettered sodium. Decarburization will probably not occur in Inconel 718 to the same extent in the FFTF System. In addition, decarburization is not expected to significantly decrease the strength of Inconel 718 since its strength is dependent on hardening mechanisms not involving carbon. With no other data available, a reduction of the stress rupture strength of Inconel 718 in sodium has been assumed, based upon the test data for stainless steel. Figure E-11 shows the effect of the sodium on stress-rupture properties of stainless steel. In the log-log coordinate system, the stress-rupture line is shifted down parallel.

Halford and Manson^[11] suggested a formula for the determination of the lower bound of the low cycle fatigue life which allows for the effect of the stress-rupture properties on low cycle fatigue:

$$N_F^1 = \frac{N_F}{1 + \frac{k}{A \times F} \times N_F^{(m + 0.12)/m}} \quad (E-3)$$

In this equation the following are defined as:

N_F^1 = lower bound fatigue life

N_F = the fatigue life

A = coefficient in the equation.

Now

$$\sigma_r = 1.75 \times \sigma_u \times \left(\frac{t_r}{A}\right)^m, \quad (E-4)$$

which describes the stress-rupture line in Figure E-12, where,

m = slope of the linear log-log stress-rupture line in Figure E-12.

k, F = constants.

The decrease of the rupture life will be incorporated into the fatigue life curve using Equations E-3 and E-4 in the following way: the ratio of the two coefficients A_u for the stress-rupture curve of unirradiated material, and A_i for irradiated material, can be obtained by forming the ratio of rupture time of both curves at the same stress level as follows:

$$\left(\frac{k}{A_u \times F} \times N^{(m + 0.12)/m}\right) / \left(\frac{k}{A_i \times F} \times N^{(m + 0.12)/m}\right) \approx \frac{A_i}{A_u} = \frac{1}{1.4} \quad (E-5)$$

The fatigue life of a material in a sodium environment, N_s , is approximately

$$N_s \approx \frac{N}{1 + \frac{1}{1.4}} \approx N \times 0.5833, \quad (E-6)$$

where N is the fatigue life of material unexposed to sodium.

The new fatigue life Curve III, Figure E-6, of irradiated Inconel 718 in a sodium environment is obtained by multiplying Curve II by 0.5813. The approximation is based on the assumption that the constants k,F are the same for both fatigue life curves and that the ultimate stress of the material does not change due to irradiation, which gives conservative results.

2.4.2.4 *Stress Relaxation*

Since our basic fatigue curve is obtained by rapid cycling, there may be concern that slow cycling influences this curve. Stress relaxation data in Table E-1^[5] reveals that this influence on low cycle fatigue properties of Inconel 718 is small and therefore can be neglected.

2.4.2.5 *Design Fatigue Curve*

The design fatigue curve IV, Figure E-6, incorporates a safety factor 1.5 on stress or 10 on cycles to failure.

2.4.3 Method II (Halford, Manson)^[12]

Manson gives the following relation for the construction of a fatigue curve:

$$\sigma_F = 3.5 \times \sigma_u \times N_F^{-0.12} + D^{0.6} \times N_F^{-0.6} \quad (E-7)$$

where,

σ_F = fictitious elastic stress amplitude

σ_u = ultimate tensile strength

D = true tensile ductility

N_F = cycles to failure.

Irradiated tensile data of Inconel 718 at 1200°F are obtained from^[16] Table 10 and are tabulated in Table E-2.

The fatigue life curve calculated with Equation E-7 is shown in Figure E-7, Curve I.

TABLE E-1

RELAXATION DATA OF INCONEL 718
 (Hot Rolled 5/8 inch Dia. Bar Stock,
 Initial Stress - 60,000 psi)

Heat Treated 1800°F/1 Hr., W.Q. + 1325°F/16 Hrs., A.C.					
Temp. °F.	Residual Stress, psi., After				
	1 hr.	10 hrs.	100 hrs.	1000 hrs.	10,000 hrs.
1000	60,000	60,000	60,000	62,000	58,000
1100	60,000	60,000	59,600	58,200	51,500
1200	59,000	58,000	56,900	54,400	39,000
1300	57,600	54,200	46,800	28,800	-
Heat Treated 1700°F/1 Hr., W.Q. + 1325°F/16 Hrs., A.C.					
Temp. °F.	Residual Stress, psi., After				
	1 hr.	10 hrs.	100 hrs.	1000 hrs.	10,000 hrs.
1000	60,000	60,000	60,200	61,800	-
1100	60,000	60,000	60,000	60,000	48,500
1200	59,400	58,200	54,000	39,500	-
1300	53,600	47,000	31,800	13,400	-

TABLE E-2

REFERENCE 16, TABLE 10

Test Temp. C	Irradiation Temp. C	Fast Fluence, n/cm ²	Yield Strength 1000 psi		Ultimate Strength 1000 psi		Elongation, percent				Reduction in Area, percent	
			Unirr.	Irr.	Unirr.	Irr.	Uniform		Total		Unirr.	Irr.
650	740	9.2×10^{19}	64	51.5	104	79.6	12.5	5.3	25.6	6.0	24.1	9.7
650	740	2.2×10^{20}	64	62.1	104	89.1	12.5	4.4	25.6	5.0	24.1	11.6
650	740	2.4×10^{20}	64	51.5	104	79.2	12.5	5.0	25.6	5.7	24.1	14.4
650	740	4.0×10^{20}	64	62.8	104	94.4	12.5	6.5	25.6	6.7	24.1	10.1

In extreme cases when the cycle frequency and stress-rupture resistance of the material are low enough that the cycle strain failures are especially time dependent, Halford and Manson emphasize an additional reduction of the fatigue life found by the following formula:

$$N_F^1 = \frac{N_F}{1 + \frac{k}{A \times F} \times N_F^{(m + 0.12)/m}} \quad (E-8)$$

where,

N_F^1 = lower bound fatigue life

k = 0.3

A = coefficient in the stress rupture formula

$\sigma_r = 1.75 \times \sigma_u \times (tr/A)^m$, A can be determined as the time intercept

at an extrapolated value of $\sigma_r = 1.75 \times \sigma_u$

σ_u is the ultimate strength at given temperature

m = slope of the linear log-log stress-rupture line (negative value)

F = frequency of stress application (in cycles per unit time)

N_F = fatigue life calculated from Equation E-3.

Formula E-8 gives the lower bound of the fatigue life if the reduction of the fatigue life is greater than 10 percent. Application of this formula is limited to materials with a negative slope of the stress-rupture line steeper than -0.12.

Data for the stress-rupture properties of Inconel 718 are available only for unirradiated materials. The stress-rupture time for Inconel 718 on log-log coordinates is shown in Figure E-12. The parameters m and A can be found from this chart:

$A = 0.2$ hr.

$m = -0.1092$.

As stated above, Equation E-8 is not applicable for values $m > -0.12$. In this case, according to Halford and Manson, the lower bound of fatigue life should

be determined by using 10 percent N_F as computed with the first formula for σ_F . Before this is done, the damaging effect of sodium has to be incorporated in Curve I.

The same approximation used in Method I, will be used to incorporate the effect of sodium on the fatigue strength of irradiated Inconel 718. Curve III in Figure E-7 shows the result.

2.4.3.1 *Design Fatigue Curve*

The design fatigue Curve V in Figure E-7 incorporates a safety factor 1.5 on stress. Curve IV in the same figure has been constructed with a safety factor of 10 on cycles to failure, as suggested by Halford and Manson above. Since the fatigue strength Curve V is the lowest, it will be used as the final design curve.

2.4.3.2 *The Lower Bound of Fatigue Life Calculated with Formula*

For comparison, a lower bound of the fatigue life given by Equation E-4, Curve I in Figure E-7 will be calculated with an assumed slope of the stress-rupture curve $m = -0.12$. A frequency of stress application

$$F = \frac{1}{24} \text{ (hr.}^{-1}\text{)} \quad (\text{E-9})$$

gives with $k = 0.3$, $A = 0.2$ hr. This formula gives a very low fatigue life (see Figure E-7, Curve VI). Equation E-4 seems not to be applicable if the time of stress application during one cycle increases to very large values, which decreases the fatigue life approximately by the factor $\frac{A \times F}{k}$ if $m = -0.12$. For values $m < -0.12$, only the factor $N_F^{(m = -0.12)/m}$ balances the effect of the frequency. The lower bound curve obtained using this method is considered overly conservative.

2.4.4 The Final Low Cycle Fatigue Design Curve

The fatigue life design curve obtained with Method I, (Curve IV of Figure E-6) and those calculated with Method 2, (Curve V of Figure E-7) have been traced on Figure E-8 which shows also the average life fatigue curves obtained with

both methods. The lower parts of each of the design Curves III and IV blend together in the final design curve shown on Figure E-9.

3. STRESS ANALYSIS UNDER STATIC LOADS

3.1 Stiffness of the Grid Plate

3.1.1 Honeycomb Design

For the analysis of the grid it is necessary to determine the equivalent elastic modulus E^* and Poisson's ratio ν^* of the honeycomb plate with cell dimensions shown in Figure E-13.

In [7], [8], [9], expressions for an equivalent modulus of elasticity and an equivalent Poisson's ratio of a honeycomb plate can be found:

$$E^* = (1 - \nu^*) \times E \times \sigma/8 \quad (E-10)$$

$$\nu^* = 1 - \frac{4}{3 + 2 \times (1 + \nu) \times 1.2 + L^2/(4 \times h^2)}. \quad (E-11)$$

With the material data of Section E-2.3 and the dimensions of the cell, the numbers are:

$$\nu^* = 0.9692$$

$$E^* = \frac{0.0308 \times 24.10^6 \times 0.0075}{0.29} = 19100 \text{ lb/inch}^2$$

$$\frac{E^*}{E} = 0.000797 \quad \text{for } h/\sigma = 0.028$$

$$\frac{E^*}{1 - \nu^*} = 616130 \text{ lb/inch}^2 \quad (E-12)$$

These are the effective values for in-plane and transverse loading of the plate. When applied to transverse bending problems, the plate thickness has to be larger than the hole spacing. This condition is satisfied.

3.1.2 Clustered Rod Grid

The grid supporting the fuel rod clusters can not be treated as a homogeneous plate as was the honeycomb grid. A major part of the transverse load on the wrinkled straps is transferred to the three radial webs, Figure E-14. Analysis of the wrinkled straps and the three radial straps will be treated separately. The grid plate is divided into three rhombus shaped plates.

3.2 Bending Moment and Stresses in the Grid Plate

The grid is loaded by the pressure drop through the grid which is:

$$\begin{aligned}\Delta P &= 6 \text{ lb/inch}^2 && \text{in the honeycomb grid} \\ \Delta P &= 3 \text{ lb/inch}^2 && \text{in the clustered rod grid.}\end{aligned}$$

The total load on the grid plate due to pressure drop is:

$$\begin{aligned}L &= 6 \times 16.2 = 97.2 \text{ lb honeycomb grid} \\ L &= 3 \times 16.2 = 48.6 \text{ lb clustered rod grid.}\end{aligned}$$

Friction, due to relative thermal expansion or contraction between the fuel rods and grid in the axial direction produces a vertical load on the grid plate. This is obtained as follows:

Honeycomb Grid Design

The tubes in each of the 217 cells are assumed clamped by a spring force up to five pounds against two dimples. Loading points are 120 degrees apart as shown in Figure E-15. Assuming a friction coefficient of $\mu = 0.32$ from each tube, a friction force, $L_f = 3 \times 5 \times 0.32 = 4.8 \text{ lb.}$, acts as vertical load on the grid plate. The total friction load of 217 tubes is 1040 lb. The average friction equivalent pressure on the plate is:

$$\frac{1040}{16.2} = 64.2 \text{ lb/inch}^2, \text{ and the total equivalent pressure due to friction and pressure drop is } P = 64.2 + 6 = 70.2 \text{ lb/inch}^2.$$

Clustered Rod Grid

In the clustered rod grid design 48 fuel rod cluster assemblies (four rods brazed together with shear webs form one cluster) are supported at 4 points.

Two springs, each with a force of 5 lb., clamp the cluster at the shear webs against two locating dimples (Figure E-16). Assuming the same coefficient of $\mu = 0.32$ from each cluster, a friction force $L_f = 4 \times 5 \times 0.32 = 6.4$ lb acts as a vertical load on the grid plate. The total friction load of 48 clusters is 306 pounds.

The average friction load on the plate is $\frac{306}{16.2} = 18.8$ lb/inch², and the equivalent pressure due to friction and pressure drop is

$$P = 18.8 + 3 = 21.8 \text{ lb/inch}^2.$$

In calculating the bending moments the analysis can be simplified if the hexagonal plate is replaced by a circular plate with a radius which encloses the hexagonal plate. The circular plate will be loaded by the same equivalent load/inch² as the hexagonal plate.

The boundary of the grid plate is assumed to be simply supported by the can of the fuel assembly. This assumption is conservative, because it gives higher stresses in the middle of the plate.

3.2.1 Honeycomb Design

3.2.1.1 *Bending Moment*

Uniform loading with simply supported edge:

$$m_o = \frac{P_o \times R^2}{16} (3 + \nu^*) \quad . . . \text{bending moment in the center} \quad (E-13)$$

$$m_\theta = \frac{P_o \times R^2}{8} - (1 - \nu^*) \quad . . . \text{tangential bending moment in the edge of the plate} \quad (E-14)$$

With a load of 70.2 lb/inch² (see Section E-3.2) and a radius $\bar{R} = 2.47$ inch (see Figure E-14), the bending moment in the center is:

$$m_o = \frac{70.2 \times 2.47^2 \times 4}{16} = 107 \text{ lb inch/inch} \quad (E-15)$$

$$m_\theta = \frac{70.2 \times 2.47^2 \times 0}{8} = 0 \text{ lb inch/inch} \quad (E-16)$$

The maximum bending moment of 107 lb inch/inch occurs in the center of the simply supported grid plate (Figure E-17).

The bending moment on one web $M = 107 \times 0.29 = 31 \text{ lb-inch}$. The web has to be checked with regard to:

1. bending stresses
2. buckling stresses
3. stresses at the brazed joint

3.2.1.2 *Bending Stresses*

In two webs of each honeycomb cell, a cut out for a spring finger of approximately 60 percent of the height reduces the moment of inertia (Figure E-18). Thus,

$$\sigma = \frac{M \times h \times 6}{(h^3 - (0.6 \times h)^3) \times t} = \frac{M \times 6}{h^2 \times t \times 0.784} \quad (\text{E-17})$$

$$h = 1.125 \text{ inch}$$

$$t = 0.015 \text{ inch}$$

$$\sigma = 13,100 \text{ lb/inch}^2$$

$$\text{R.F.} = \frac{\text{design stress}}{\text{bending stress}} = \frac{35000}{13100} = 2.6. \quad (\text{E-18})$$

3.2.1.3 *Lateral Buckling of the Grid Web*

Assume that the bending moment is applied to the ends of the slotted beam and the ends are free to rotate (Figure E-19). The bending moment limit dictated by lateral buckling is given by:

$$M_{cr} = \frac{\pi}{\ell} \sqrt{E \cdot I \cdot G \cdot J} \quad (\text{E-19})$$

Using 40 percent of the grid height contributions to the stiffness about the axis of smaller flexural rigidity we obtain the following:

$$I \approx \frac{t^3 \times 0.4 \times h}{12} = 0.1265 \times 10^{-6} \text{ inch}^4 \quad (\text{E-20})$$

Torsional stiffness of the upper and lower section alone is:

$$J = 2 \times C_1 \times 0.225^3 = 0.478 \times 10^{-6}$$

$$C_1 = 0.315 \text{ for } \frac{d}{t} = 11.$$

The critical buckling moment is:

$$M_{cr} = 60.37 \text{ lb inch}$$

$$R.F. = \frac{M_{cr}}{M_{appl}} = \frac{60.4}{31} = 1.9.$$

The assumptions made above for torsional stiffness are very conservative.

3.2.1.4 *The Shear Stress in the Torsion Bar Due to Grid Bending*

The shear load in the webs has to be transferred from the upper to the lower strap through the torsion bar (Figure E-20). The radial shear load in a circular plate as function of the radius due to constant loading is:

$$Q = \frac{P \times R}{2} . \quad (E-21)$$

No shear load exists in the plate center. At the boundary the shear load is:

$$Q = \frac{P \times R}{2} = \frac{70.2 \times 2.47}{2} = 86.7 \text{ lb/inch.}$$

One web is loaded by the shear force on pitch width.

Thus,

$$\bar{q} = \frac{P \times R}{2} \times 0.29 = 25.14 \text{ lb.}$$

Due to the cut out, the shear force is concentrated in the torsion bar.

Neglecting the shear force carried by the adjacent webs, the shear load in the torsion bar is approximately:

$$q = \frac{\bar{q} \times a}{b} = \frac{25.14 \times 0.167}{0.9} = 4.638 \text{ lb,}$$

and the shear stress is:

$$\tau = \frac{\bar{q} \times a}{b \times A \times t} = 2,945 \text{ lb/inch}^2$$

The reserve factor is:

$$R.F. = \frac{35,000}{\sqrt{3} \times 2945} = 7.$$

3.2.1.5 *Buckling of the Torsion Bar Due to Shear Load*

A peak bending moment is produced at either end of the torsion bar. In the lateral buckling analysis this moment will be conservatively assumed to be constant along the length of the torsion bar. The end moment is:

$$M_B = \frac{25.14}{2} \times 0.167 = 2.1 \text{ lb.}$$

The critical buckling moment is for clamped ends:

$$M_c = \frac{2\pi}{l} \sqrt{I \cdot E \cdot J \cdot G} \quad (E-22)$$

$$I = \frac{t^3 \times A}{12} = 0.03093 \times 10^{-6} \text{ inch in the plane of smaller flexural rigidity.}$$

$$J = 0.333 \times t^3 \times A = 0.12362 \times 10^{-6} \text{ inch}$$

$$M_c = 8.02 \text{ lb inch}$$

The reserve factor is:

$$R.F. = \frac{M_c}{M_{\text{appl}}} = \frac{8.02}{2.1} = 3.8.$$

3.2.1.6 *Stresses in the Braze Alloy*

At the junction of three webs tensile forces load the braze alloy (Figure E-21). The tensile stress between two matching webs is approximately:

$$\sigma = 11,350 \text{ lb/inch}^2$$

Allowable design stresses for the braze alloy have not yet been fixed.

3.2.2 Clustered Rod Grid

3.2.2.1 *Bending Moment in the Wrinkled Straps*

Bending moments in the wrinkled grid straps are a maximum where they cross the straight radial webs (point F in Figure E-22). A simplified model is used to calculate those bending moments. The strap $\overline{EF}$ in Figure E-22 is assumed to be clamped in point F. The end E is assumed hinged in a grid not surrounded by a can. In the case of a grid surrounded by a can, the grid is clamped to the can at point E. This simplified model neglects the support given by the intersecting straps.

The equivalent pressure on the grid plate due to pressure drop and friction has been calculated in Section E-3.2.,

$$P = 21.4 \text{ lb/inch}^2$$

The load on a strap (e.g. $\overline{EF}$ in Figure E-22) is:

$$L = 21.4 \times 0.594 \times 0.866 = 11 \text{ lb/inch}$$

Figure E-22 shows that the load has to be distributed on the straps in both directions, so that only half the load will be carried by one strap. This simplified model gives conservative results, since it neglects the plate character of the grid.

Maximum bending moments at point F in Figure E-22 are for the grid strap not attached to a grid (see Figure E-23),

$$M = \frac{11 \times 2.375^2}{2 \times 8} = 3.88 \text{ lb/inch}$$

for a grid strap hinged to a can (see Figure E-23),

$$M = \frac{11 \times 2.375^2}{24} = 2.566 \text{ lb/inch}$$

3.2.2.2 Stresses in the Wrinkled Straps Due to Bending

Bending on the wrinkled straps produces both bending stresses and torsional stresses. Maximum stresses due to bending will be found in the section b of the strap (see Figure E-24) where large cut-outs for the torsional springs exist.

It will be assumed that the bending moment $M = 3.88$ lb-inch is applied to a side of a regular mesh shown in Figure E-24. The upper and lower part of the strap are loaded by a compressive and tensile force respectively. The longitudinal forces produce opposite bending about the vertical axis of the upper and lower strap and twist the cross section. The bending moment applied to the wrinkled grid strap is resolved into bending moment and torsion moment effective in each part of the wrinkled strap, (see Figure E-25).

3.2.2.3 Stresses in the Slotted Sections b and c in Figure E-25

Maximum bending stress in section b with height 1.4 inch is:

$$\sigma_b = \frac{M \times 6}{t \times h^2 \times (1-0.6^3)} = \frac{3.88 \times 6}{0.015 \times 1.40^2 \times (1-0.6^3)} = 1010 \text{ lb/inch}^2.$$

The grid height 1.4 inches is dictated by the torsion bar length requirements.

3.2.2.4 Combined Bending and Torsional Stress in Section C (see Figure E-25)

The torsional moment is resolved into two forces bending the upper and the lower part of the strap laterally:

$$P_L = \frac{T_c}{h - d} = \frac{1.94}{(1.4 - 0.28)} = 1.732 \text{ lb};$$

The stress due to lateral bending is:

$$\sigma_{bL} = \frac{P \times 1 \times 6}{t^2 \times d} = \frac{1.94 \times 0.084 \times 6}{0.015^2 \times 0.28} = 13856 \text{ lb/inch}^2$$

The stress due to bending about the axis of greatest flexural rigidity is:

$$\sigma_b = \frac{3.36 \times 6}{0.015 \times 1.4^2 \times (1-0.6^3)} = 874 \text{ lb/inch}$$

The combined bending stress in section is:

$$\sigma = 13856 + 874 = 14730 \text{ lb/inch}^2$$

With the design stress $\sigma = 35,000 \text{ lb/inch}^2$ the reserve factor is:

$$\text{R.F.} = \frac{35000}{14730} = 2.4.$$

3.2.2.5 *The Combined Bending and Torsional Stress in Section A (see Figure E-25)*

The bending stress is the same as in Section C if a cutout of 60 percent of the height is assumed,

$$\sigma_b = 874 \text{ lb/inch}^2$$

The torsional stress is:

$$\tau = \frac{1.94}{1.4 \times 0.015^2 \times 0.333} = 18494 \text{ lb/inch}^2$$

$$\text{R.F.} = \frac{35000}{\sqrt{3} \times 18494} = 1.1.$$

This is the maximum shear stress at the midpoint of the longer side of the cross section, where the bending stresses are zero.

3.2.2.6 *Load on the Straight Radial Webs*

Figure E-22 shows the geometry of a section of the grid plate. The straight web is loaded by the force on the hatched area $\overline{DMB}$ from both sides. The web is assumed hinged to the can and deflects in a symmetric mode about the plate center D. Most of the load is transferred to the web by the wrinkled straps. Figure E-26 shows the load distribution on the straight webs loaded by the pressure on the hatched area $\overline{DMB}$ in Figure E-22 from both sides. The maximum load-intensity is for a load $P = 21.4 \text{ lb/inch}^2$ (see Figure E-26).

$$\bar{W} = 2 \times 1.1875 \times 0.866 \times 21.8 = 44 \text{ lb/inch}$$

Bending moment is a maximum at the clamped end D. For the calculation of the bending moment in point D the load distribution is separated into two triangular distributions L_1 and L_2 (see Figure E-26).

Bending moment in D under load L_1 (see^[20], page 110) is:

$$M_{D_1} = -R \times \ell + \frac{1}{3} \times L_1 \times \ell = 0.171 \times L_1 \times \ell = 10.6 \text{ lb-inch},$$

with

$$L_1 = \frac{1}{4} \times W \times \ell = 26.1 \text{ lb}$$

$$V_1 = \frac{1}{20} \times \frac{L_1}{\ell^3} \left(\frac{15 \times \ell^3}{4} - \frac{4 \times \ell^3}{8} \right) = L_1 \times 0.162 \text{ lb}.$$

Bending moment in D under load L_2 is:

$$M_{D_2} = -V_2 \times \ell + \frac{1}{3} \times L_2 \times \left(\frac{1}{2} + 2 \right) \times \ell = 0.308 \times L_2 \times \ell = 19.1 \text{ lb-inch},$$

with

$$L_2 = 26.1 \text{ lb}$$

$$V_2 = \frac{1}{20} \times L_2 \times \left(\frac{10}{2} + \frac{15}{4} + 5 \right) - \frac{4}{8} - 1 - \frac{3}{4} - 1 = 0.525 \times L_2.$$

The total bending moment at point D is:

$$M_D = 26.1 + 19.1 = 45.2 \text{ lb-inch}$$

The above model neglects the deflection at point D. For a beam loaded by two triangular load distributions and simply supported at its ends (Figure E-27) the bending moment is:

$$L = \frac{\ell \times 44}{2}$$

$$M = L \times \left(-\frac{\ell}{2} + \ell \right) = 62 \text{ lb inch}$$

This is the design moment for the web.

3.2.2.7 Stresses in the Radial Web

Maximum bending stress in the radial web is:

$$\sigma_b = \frac{62 \times 6}{1.4^2 \times 0.015} = \pm 12,653 \text{ lb/inch}^2$$

$$\text{R.F.} = \frac{35000}{12653} = 2.8.$$

3.2.2.8 Lateral Buckling of the Radial Web

A possible mode of failure of the webs is lateral buckling under an end moment. The ends, where the buckling moment is applied, are assumed to be fixed in the horizontal plane. The critical lateral buckling moment is (see^[20], p. 344),

$$M_c = \frac{\pi}{L} \sqrt{E \times I \times G \times J}$$

With the given data (Figure E-28) we find:

$$I = \frac{t^3 \times h}{12} = 0.393 \times 10^{-6} \quad \text{Lateral bending stiffness}$$

$$J = t^3 \times h \times 0.333 = 1.574 \times 10^{-6} \quad \text{Torsional stiffness.}$$

The critical bending moment is:

$$M_c = \frac{2 \times \pi}{0.5937} \times \sqrt{23 \times 0.393 \times 9.4 \times 1.574} = 122 \text{ lb/inch.}$$

The reserve factor is $\text{R.F.} = \frac{122}{61} = 2.$

4. THERMAL STRESS AND STRAINS

4.1 Thermal Loading of the Grid

Figure E-29, curve II shows the temperature distribution across the grid plate, which was used for the calculation of the thermal stress. The edge of the grid plate is attached to the can of the fuel assembly. The surrounding can is at a lower temperature than the grid. For the determination of the thermal stresses in the grid structure the temperature gradient at the grid edge, which is shown in Figure E-30, is assumed to occur as a step change from the grid to

the can. Thermal expansion of the grid produces a tensile stress in the can. The reaction of the can on the grid produces a compressive stress in the grid. The can is approximated to a ring of two times the height of the grid.

Stress analysis of the grid proceeds in three steps:

1. Analysis of the thermal stress on the grid which is free to expand in the radial direction.
2. Interaction between the grid and the surrounding can.
3. Superposition of the stresses of step 1. and step 2.

4.2 Thermal Stress in the Grid

The temperature profile across the grid can be built up by the superposition of two components:

1. A linear gradient across the grid.
2. An axi-symmetric temperature distribution.

Only distribution (2) will be considered in the analysis of the grid thermal stresses.

Formulas for the stress distribution in a circular disk with an axisymmetrical temperature distribution across the disk can be found in^[20], p. 375 or^[21], p. 407.

With the notation of Figure E-30 the stresses in the disk are:

$$\sigma_{\theta} = \alpha \times \bar{E} \times \left(-T + \frac{1}{R^2} \int_0^R T \times r \times dr + \frac{1}{r^2} \int_0^r T \times r \times dr \right) \quad (E-23)$$

$$\sigma_r = \alpha \times \bar{E} \times \left(\frac{1}{R^2} \times \int_0^R T \times r \times dr + \frac{1}{r^2} \int_0^r T \times r \times dr \right), \quad (E-24)$$

and the radial expansion of the disk is:

$$U = \frac{2 \times \alpha}{R} \int_0^R T \times r \times dr. \quad (E-25)$$

$\bar{E}$ is the effective elastic modulus of the disk.

Integration of the temperature distribution in Figure E-29 gives the stresses in the Table E-3 below:

TABLE E-3
RADIAL TEMPERATURE AND DIMENSIONLESS
STRESS IN THE GRID DISK

r"	T [°F]	$\frac{\sigma \cdot R}{E \cdot \alpha}$	$\frac{\sigma_{\theta}}{E \cdot \alpha}$
0"	975	-24.23	-23.23
1"	975	-24.23	-23.23
2"	975	-24.23	-23.23
2.89	975	-24.23	-23.23
3.58	892.5	-21.23	+56.27
4.27	810	0	+117.5

+ tensile stress

- compressive stress

The radial expansion of the grid is $u = 0.03176$ inch.

4.2.1 Stiffness and Thermal Expansion of the Can

Figure E-31 shows a section of the can in the circumferential direction. From room temperature, 70°F, to 810°F the radial expansion of the can is:

$$u_R = \alpha \times R_m \times \Delta T = 8 \times 10^{-6} \times 4.28 \times 740 = 0.025 \text{ inch.}$$

The average thickness of the ring is (see Figure E-31):

$$t_m = 0.070 \text{ inch.}$$

An "internal pressure" of the grid with height h on a ring with height $2 \times h$ produces a radial expansion of:

$$u = \frac{P \times R_m^2}{2 \times t_m \times E}.$$

4.2.2 Interaction Between the Grid and the Surrounding Can

The following relations exist between forces and radial expansion of the grid:

$$u = \frac{P \times R \times (1-\nu^*)}{E^*}. \quad (E-26)$$

The net radial expansion of the grid is:

$$u = \frac{2 \times \alpha}{R} \times \int_0^R T \times r \times dr - \frac{P \times R \times (1-\nu^*)}{E^*}; \quad (E-27)$$

The net radial expansion of the can is:

$$u = R_m \times \alpha \times T + \frac{P \times R_m^2}{2 \times E^* \times t} \quad (E-28)$$

Since the radial expansion of the grid and the can must be compatible, equating the two deflections gives:

$$\underbrace{\frac{2 \times \alpha}{R} \int_0^R T \times r \times dr - \frac{P \times R \times (1 - \nu^*)}{E^*}}_{\text{Grid}} = \underbrace{R_m \times \alpha \times T + \frac{P \times R_m}{2 \times E \times t}}_{\text{Can,}} \quad (E-29)$$

Therefore the grid radial stress is $\sigma = \frac{P \times \rho}{h}$, $\frac{h}{\rho}$ is the relative density of the grid plate.

Substituting P and rearranging terms gives:

$$\frac{\sigma \times h \times r}{P} \times \left(\frac{1 - \mu^*}{E^*} - \frac{R_m^2}{2 \times R \times t \times E} \right) = \frac{2 \alpha}{R} \times \int_0^R T \times r \times dr - R_m \times \alpha \times T \quad (E-30)$$

4.3 Stresses in the Honeycomb Grid

Constants:

$$\frac{h}{\delta} = 0.028 \quad \text{Section E-3.1}$$

$$\frac{E^*}{1 - \nu^*} = 616130 \text{ lb/inch}^2$$

$$E = 24 \times 10^6 \text{ lb/inch}^2 \quad \text{Section E-2.3}$$

$$\alpha = 8 \times 10^{-6} \text{ inch/inch/}^\circ\text{F}$$

$$T = 810 \text{ }^\circ\text{F} \quad \text{Section E-4.2}$$

$$\frac{2 \times \alpha}{R} \times \int_0^R T \times r \times dr = 0.03167 \text{ inch}$$

$$R = 4.268 \text{ inch} \quad \text{Section E-3.1}$$

$$R_m = R + 0.005 = 4.273 \text{ inch} \quad \text{See Figure E-31}$$

Solving Equation E-30 for σ and substitution of the constants gives the stress in the grid

$$\sigma = 0.028 \times 4.268 \times \left(\frac{1}{0.616 \times 10^6} - \frac{4.273^2}{4.2 \times 8 \times 24 \times 10^6} \right)$$

$$\sigma = 23050 \text{ lb/inch}^2 \text{ (compressive).}$$

Superposition of the thermal stress for free radial expansion and the compressive stress produced by the surrounding can give the distribution of the ligament stresses in the grid.

TABLE E-4
LIGAMENT STRESSES IN THE GRID

Stresses in the				
	free expandable grid		canned grid	(lb/inch ²)
r"	σ_r	σ_θ	σ_r	σ_θ
0	-132	-127	-23200	-23200
1"	-132	-127	-23200	-23200
2"	-132	-127	-23200	-23200
2.89	-132	-127	-23200	-23200
3.58	-116	+307	-23150	-22750
4.27	0	+641	-23050	-224000

The ligament stresses are found from Figure E-32 by multiplication of $\frac{\sigma}{E \times \alpha}$ with $(\alpha \times E^*)$ and the relative density of the grid $\frac{\rho}{h}$. Observe that the stresses in the free grid due to the temperature gradient are negligible.

4.3.1 Bucklings of the Web in the Honeycomb Grid

In addition to a static bending moment of $M = 60.4$ lb/inch which is produced by the vertical load in the center of the grid plate, thermal expansion produces longitudinal compressive stresses of 23200 lb/inch².

The critical bending moment has been calculated in Section E-3.2. Interaction between lateral buckling under an applied end moment and buckling under a uniform stress distribution over the cross section can be covered by the following formula (see^[22], p. 97). The maximum allowable stress is:

$$\sigma = \frac{C}{S} \sqrt{M_c^2 + \frac{h^2}{4} \times P_c^2} \quad (E-31)$$

where:

M_c is the critical buckling moment for lateral buckling.

P_c is the Euler buckling load for a constant stress distribution over the cross section.

S is the section modulus across the axis with the largest moment of inertia

$C = 1$ for pin joined ends.

The numerical values are:

Critical bending moment $M_c = 60.37$ lb-inch

Applied bending moment $M_{appl} = 31$ lb-inch

Euler buckling load of the cantilever is:

$$P = \frac{\pi^2 \times (I/2) \times E}{l^2} = \frac{\pi^2 \times 0.1265 \times 10^{-6} \times 24.10^6}{2 \times 0.167^2} = 537 \text{ lb.}$$

The actual axial load is:

$$P = 23200 \times 0.015 \times 0.4 \times 1.125 = 156.6 \text{ lb.}$$

The section modulus is:

$$S = \frac{h^2 \times (1-0.6^3)}{6} \times t = 0.00248 \text{ inch}^3$$

$$\sigma_c = \frac{1}{0.00248} \sqrt{60.37^2 + \frac{1.125^2 \times 537^2}{4}} = 124000 \text{ lb/inch}^2$$

The actual comparable stress is:

$$\sigma_a = \frac{1}{0.00248} \sqrt{31^2 + \frac{1.125^2 \times 156.6}{4}} = 37000 \text{ lb/inch}^2$$

The reserve factor is:

$$R.F. = \frac{124}{37} = 3.35.$$

4.4 The Stiffness of the Can and the Clustered Rod Grid

4.4.1 Can

For a can with the average thickness 0.060 inch (see Figure E-33) and effective height $2h$ (with $h = 1.4$ inch as grid height) an elongation δ is produced by a force

$$P = \frac{E \times 2 \times H \times t}{1} \delta = \frac{23 \times 10^6 \times 2 \times 1.4 \times 0.060 \times \delta}{2.375} = 1626900 \times \delta \text{ (lb).}$$

4.4.2 Radial Web

A compression δ of the straight web is produced by a force

$$P = \frac{E \times H \times t}{1} \times \delta = \frac{23 \times 10^6 \times 1.4 \times 0.015 \times \delta}{2.375} = 203300 \times \delta \text{ (lb)}$$

where,

$$\delta = 4.9188 \times 10^{-6} \times P \text{ (inch).}$$

The straight webs have no cutouts for springfingers. The full height of the grid is assumed to carry load.

4.4.3 Wrinkled Straps

The wrinkled straps are subject to lateral bending moments and longitudinal forces. The elongation δ due to a longitudinal force (see Figure E-34) in one mesh is found by adding the elongation in all segments.

Thus,

$$\begin{aligned} \delta &= \frac{P}{E \times H \times t} \left(\frac{2 \times 0.76}{0.4} + \frac{0.073}{0.4} + 2 \times 0.107 + 0.147 \right) \\ &= \frac{P \times 0.923}{24 \times 10^6 \times 1.4 \times 0.015} = 1.831 \times 10^{-6} \times P. \end{aligned}$$

In four meshes,

$$\delta = 4 \times 1.831 \times 10^{-6} x P = 7.325 \times 10^{-6} x P.$$

4.4.4 Elongations Due to Bending Deformations

Only bending deformations between intersections A-B in Figure E-34 of the straps have to be considered. Figure E-34 shows that bending moments in the brazed part of the straps are balanced by the bending moment of the crossing strap. Balance of the bending moments of crossing straps in the brazed section produces peak tensile stresses in the end of the braze. Bending moment in the joining parts 'a' of the straps produce "peel" deformations in the braze. The deflection of the point A, Figure E-35 is:

$$\delta_A = \frac{P \times 0.043 \times 0.085^2 \times 12 \times \cos 60^\circ}{3 \times E \times t^3 \times h} = 5.473 \times 10^{-6} x P.$$

At point B

$$\delta_B = \delta_A + 2 \times \left(\frac{P \times 0.0193 \times 0.040^2 \times 12}{3 \times E \times t^3 \times h} + P \times 0.0193 \times 0.076 \times 0.004 \right) \times \cos 60^\circ$$

$$\delta_B = [5.473 + 2(1.09 + 0.64) \cos 60^\circ] \times 10^{-6} \times P = 7.203 \times 10^{-6} \times P \text{ (inch)}.$$

The total elongation due to bending and extension of the wrinkled straps is in one side of the mesh where:

$$\delta = (1.831 + 2 \times 7.20) \times 10^{-6} \times P = 16.23 \times 10^{-6} \times P \text{ (inch)},$$

and over the total length of the wrinkled strap where:

$$\delta = 4 \times 16.23 \times 10^{-6} \times P = 64.92 \times 10^{-6} \times P \text{ (inch)}.$$

Figure E-29 shows that the temperature difference between the can and the grid is $\Delta T = 165^\circ\text{F}$. Elongation in the web due to this temperature difference is:

$$\delta = L \times \alpha \times \Delta T = 2.375 \times 8 \times 10^{-6} \times 165 = 0.003135 \text{ inch}$$

where,

$$L = 2.375" \text{ from drawing 6J228.}$$

Radial expansion vertical to the edge is:

$$u = \delta \times \cos 30^\circ = 0.002715 \text{ inch.}$$

4.5 Thermal Stresses in the Clustered Rod Grid

Since the grid is subject to radial compression forces, the can has to sustain a circumferential tensile force. The interaction between the can and the grid has been considered in the following way:

- (a) At the end of the fuel assembly radial deformations of the can around the grid are prevented by an end plate on the fuel assembly (Figure 3-5, drawing 766J223). There the grid is assumed to be surrounded by an infinitely stiff can.
- (b) In the middle of the fuel assembly the sides of the can are assumed to be hinged together, so that the can deforms without elongation of the sides.

4.5.1 Assuming the Grid Surrounded by an Infinitely Stiff Can

Force in the radial web is:

$$P = 0.203 \times 10^6 \times 0.003135 = 635 \text{ lb.}$$

Stress in the radial web is:

$$\sigma = \frac{P}{H \times t} = \frac{0.203 \times 10^6}{1.4 \times 0.015} \times 0.003135 = 30,305 \text{ lb/inch}^2$$

Due to the thermal expansion of the wrinkled straps a longitudinal force is added at the junction with the straps. The increase of the longitudinal forces is transferred by bending of the wrinkled straps (see Figure E-36). A high longitudinal force in the radial web can buckle the web between inter-sections with the wrinkled straps. The buckling stress of the radial web with clamped ends is:

$$\sigma_c = \frac{C \times \pi^2 \times E \times I}{L^2 \times t \times h} = \frac{4 \times \pi^2 \times 24 \times 10^6 \times 0.393 \times 10^{-6}}{0.5937^2 \times 1.4 \times 0.015} = 50,300 \text{ lb/inch}^2$$

The actual longitudinal stress in the radial web is less than 30,300 lb/inch² because the can will deform and relieve some stress in the web. The reserve factor against buckling is greater than.

$$\text{R.F.} = \frac{50,300}{30,300} = 1.7.$$

4.5.1.1 *Stresses in the Wrinkled Straps*

The wrinkled straps have to sustain longitudinal stresses and lateral bending stresses.

The total force is:

$$P = \frac{0.003135}{64.92 \times 10} = 48.3 \text{ lb.}$$

The longitudinal stress in section D, Figure E-35, with slots for the spring in the direction of the load is:

$$\sigma_D = \frac{48.3}{1.4 \times 0.4 \times 0.015} = 5,750 \text{ lb/inch}^2$$

and in point C,

$$\sigma_C = 0.4 \times 5750 = 2,300 \text{ lb/inch}^2$$

The bending stress has a maximum at point C, Figure E-35,

$$\sigma_c = \frac{0.043 \times 48.3 \times 6}{t^2 \times h} = 38,600 \text{ lb/inch}^2$$

The total maximum stress in point C is obtained by adding the bending and longitudinal components,

$$\sigma = 40,900 \text{ lb/inch}^2$$

Another critical point is in the section of the torsional spring, along section D, Figure E-34. The lateral bending stress there is:

$$\sigma_D = \frac{0.0193 \times 48.3 \times 6}{t^2 \times h \times 0.4} = 44,400 \text{ lb/inch}^2$$

The total stress is:

$$\sigma = 44,400 + 5,750 = 50,150 \text{ lb/inch}^2$$

4.5.2 Assuming the Grid is Surrounded by a Flexible Can

The high compression force in the radial web and the low compression forces in the wrinkled strap will produce a distortion of the can. The form of the deformation is shown in Figure E-36. The radial web will push the corner of the can outward, therefore the corner between the radial webs will deflect inward. For simplicity it will be assumed that the sides of the can are inflexible and do not change their length. But instead of being stiff, now the corners will be held together by hinges. The rotation of the side of the can shown in Figure E-36 will bring a stress relief to the radial web, but increase the compressive stress in the wrinkled strap next to the corner between the straight webs.

The rotation of the can side and the stresses produced by this rotation in the straight webs and the wrinkled straps will be calculated using the model shown in Figure E-37. It consists of an inflexible beam supported by springs. The wrinkled straps and the radial web have been replaced by springs with equivalent stiffness.

Before rotation of the beam the radial web is loaded by a radial force of 635 pounds, and the wrinkled straps by 48.4 pounds. In this position the beam is not in equilibrium because the hinged ends of the beam can not transfer a bending moment. The rotation of the beam produced by the unbalanced force of 586.7 pounds, shown in Figure E-37, and the stresses involved will be calculated.

Geometrical compatibility of the can deformation requires that for small angles of rotation the center of rotation is at spring 2. The deflection of the spring due to rotation θ of the can about point 2 is (see Figure E-37).

$$\delta_1 = -\theta \cdot \cos(30^\circ) \cdot 1$$

$$\delta_2 = 0$$

$$\delta_3 = \theta \cdot \cos(30^\circ) \cdot 1$$

$$\delta_4 = 2 \cdot \theta \cdot \cos(30^\circ) \cdot 1$$

The moment about point 2 has to be zero. Spring forces in spring 1, 3, and 4 have to balance the external load applied to point 4. Since the can is rigid, deflections in spring 1 and spring 3 are equal but opposite in direction.

$$\delta_3 = -\delta_1$$

$$\delta_4 = -2 \cdot \delta_1$$

The moment about point 2 has to be zero.

$$\delta_1/k_1 + \delta_1/k_2 + (2 \cdot \delta_1/k_4 - P) = 0$$

Solution for δ_1 gives

$$\delta_1 = \frac{P}{\frac{1}{k_1} + \frac{1}{k_2} + \frac{2}{k_4}} = 0.001341 \text{ inch}$$

where,

$$k_r = k_4 = 4.92 \text{ inch/lb}$$

$$k_1 = k_2 = 64.9 \text{ inch/lb}$$

$$P = 586.7 \text{ lb.}$$

The compression force on spring 1, the wrinkled strap 1, is

$$P_1 = 0.001341 / (64.9 \times 10^{-6}) = 20.67 \text{ lb,}$$

and on the radial web 1, spring 4 is

$$P_4 = 0.001341 / (4.92 \times 10^{-6}) = 545.36 \text{ lb.}$$

4.5.2.1 Forces in the Wrinkled Strap 1

The deflection δ_1 produces in the wrinkled strap a longitudinal force

$$P_1 = 20.67 \text{ lb.}$$

The total force due to thermal expansion and deflection induced by the can is

$$48.3 + 20.7 = 69 \text{ lb.}$$

4.5.2.2 *Thermal Stress in the Wrinkled Strap 1*

Stress in the wrinkled strap 1, produced by the flexible can, may be calculated as above for the rigid can. In Section D, Figure E-35, the longitudinal stress is

$$\sigma = 8219 \text{ lb/inch}^2$$

In Section C

$$\sigma = 3288 \text{ lb/inch}^2$$

The bending stress has a maximum at point C, Figure E-35,

$$\sigma_b = 55,143 \text{ lb/inch}^2$$

The total stress in point is

$$\sigma_C = \sigma + \sigma_B = 58,430 \text{ lb/inch}^2$$

In section D along L_2 the lateral bending stress is

$$\sigma_B = 63,429 \text{ lb/inch}^2$$

The total thermal stress is

$$\sigma_D = \sigma + \sigma_B = 71,648 \text{ lb/inch}^2$$

The actual stress in strap 1 is lower, because deflection of the can walls will reduce the compression of strap 1, and the force in the radial web has to deflect two sides of the can.

4.5.2.3 *Force in the Radial Web*

The deflection of point 4 in Figure E-37 produces a tensile load of 545.5 lb. in the radial web and relieves the high compressive load which is produced by a rigid can. Actually, the tensile force in the radial web is only $\frac{545}{2}$ lb. because the radial compressive force produced by the thermal expansion on the grid has to deflect two sides of the can. The net load in the radial web is

$$P_L = 586.7 - \frac{545.3}{2} + 2 \times 48.3 = 419.7 \text{ lb.}$$

and a stress of

$$\sigma = \frac{419.7}{1.4 \times 0.015} = 19985 \text{ lb/inch}^2$$

4.5.2.4 Buckling of the Radial Web

The buckling load of the radial web has been calculated before.

$$P_C = \frac{4 \cdot \pi^2 \cdot E \cdot I}{l^2} = \frac{4 \times \pi^2 \times 24 \cdot 10^6 \times 0.393 \times 10^{-6}}{0.5937^2} = 1057 \text{ lb.}$$

The radial web is already loaded by a bending moment of $M=62$ lb-inch which is produced by the vertical load on the grid plate. The critical buckling moment of the radial web is $M_{cr} = 122$ lb-inch. Interaction between lateral buckling under an end moment and Euler buckling of a cantilever can be described by the following formula for the critical stress (see^[22], p. 97):

$$\sigma_c = \frac{C}{S_x} \sqrt{M_c^2 + \frac{h^2}{4} \times P_c^2} \quad (\text{E-32})$$

M_c is the critical buckling moment for lateral buckling.

P_c is the Euler buckling load for constant stress distribution over the cross section.

$S_x = \frac{h^2 t}{6} = 0.0049 \text{ m}^3$ is the section modulus across the axis with the largest moment of inertia.

$C = 1$ for pin-jointed ends.

Hence,

$$\sigma_c = \frac{6}{1.4^2 \times 0.015} \sqrt{122^2 + \frac{1.4^2}{4} + 1057^2} = 153,039 \text{ lb/inch}^2$$

The actual stress is:

$$\sigma = \frac{1}{0.0049} \sqrt{61^2 + \frac{1.4^2}{4} \cdot 419.7^2} = 61,236 \text{ lb/inch}$$

The reserve factor is:

$$R.F. = 2.5$$

The actual R.F. is less because the nominal buckling stress is higher than the yield stress.

5. LOW CYCLE FATIGUE

On a permanent static stress in the grid web, a thermal stress is periodically superposed. The cycling stress may cause a low cycle fatigue failure. The discontinuity in the stress distribution at the brazed joint increases the probability of a fatigue failure and, therefore, must be considered. Since no low cycle fatigue data for the given material, Inconel 718, is available, a fatigue design curve has been constructed in section E-2.4. Fatigue analysis will be carried out for compressive and tensile stress conditions. If the oscillating stress is always compressive, the analysis gives the conservative results, because zero mean stress could be used in fatigue analysis. With the available material data it is difficult to decide how conservative the results are.

5.1 Honeycomb Grid Web at Plate Center

Static stress $\sigma_s = \pm 13100 \text{ lb/inch}^2$

Thermal stress $\sigma_t = 23200 \text{ lb/inch}^2$

A uniaxial stress distribution will be assumed. Peak stresses occur at the upper and lower edge of the web.

5.1.1 Stress Concentration Factor

For an idealized joint (see^[10], Figure 57)

$$K_T = 1.7$$

5.1.2 Notch Sensitivity Factor (see [27]) is:

$$q = \frac{1}{1 + \frac{a}{r}}$$

To find r (see Figure E-38).

$$\frac{D}{t} \approx 1.5$$

$$\frac{r}{t} \approx 0.2$$

$$r = 0.2 \cdot 0.015 \text{ inch} = 0.003 \text{ inch}$$

$$a \approx 0.003 \text{ for UTS} = 195000 \text{ lb/inch}^2 \text{ (see}^{[27]} \text{, Figure 10),}$$

$$q = \frac{1}{1 + \frac{0.003}{0.03}} = 0.91.$$

5.1.3 Fatigue Strength Reduction Factor

$$K_F = 1 + q \times (K_T - 1)$$

$$K_F = 1.64$$

With these values the fatigue endurance limit can be calculated:

$$\sigma_{\max} = 1.64 \times (-13,100 + 23,200) = 59,532 \text{ lb/inch}^2$$

$$\sigma_{\min} = 1.64 \times (-13,100) = 21,484 \text{ lb/inch}^2.$$

The mean stress is:

$$\sigma_m = 0.5 \times (-59,532 - 21,484) = 40,508 \text{ lb/inch}^2.$$

Stress amplitude is:

$$\sigma_a = 1.64 \times 0.5 \times 23,200 = 19,024 \text{ lb/inch}^2.$$

$$\sigma_{a'} = \frac{19024 \times 195000}{195000 - 40508} = 24,000 \text{ lb/inch}^2.$$

From the fatigue design curve, Figure E-9, the endurance limit is 30,000 psi, therefore, the usage factor is zero.

$$UF = 0$$

5.2 Fatigue Life of the Braze in the Honeycomb Grid

The honeycomb grid is formed by brazing together wrinkled straps. The braze between adjoining straps is subject to a tensile static stress and a fluctuating compressive stress. Fatigue life of the braze is expected to be considerably lower than the fatigue life of the basic material. The only information on fatigue life in a braze is in^[23]. The loading conditions and parent material relevant to the data is required in this area.

At the junction of three webs the stress is concentrated in the corner (see Section E-3.2.1). The mean tensile stress between two mating webs at the upper and the lower edge of the grid web is approximately:

$$\sigma = \sin 60^\circ \times 13,100 = 11,350 \text{ lb/inch}^2.$$

The fluctuating stress due to thermal expansion of the grid is (see Section E-4.3.1).

$$\sigma = -\sin 60^\circ \times 23200 = 20090 \text{ lb/inch}^2.$$

Assuming for the given configuration a stress concentration factor of:

$$K_T = 1.6 \text{ for } \frac{r}{t} = 0.3 \text{ and } \frac{D}{t} = 2.5 \text{ (see }^{[10]}\text{, Figure 57)}.$$

The maximum stress is:

$$\sigma_{\max} = 1.6 \times 11350 = 18160 \text{ lb/inch}^2.$$

$$\sigma_{\min} = -1.6 \times (23,000 \times 0.866 - 11350) = -13,984 \text{ lb/inch}^2$$

The mean stress is:

$$\sigma_m = (18,160 - 13,984) \times 0.5 = 2,088 \text{ lb/inch}^2$$

and the stress amplitude

$$\sigma_a = 16072 \text{ lb/inch}^2.$$

No correction of the stress amplitude according to the procedure outlined in the ASME Section III can be made because no other material data for the braze is available. The fatigue life of the braze will be estimated from the fatigue life curve reported by Aspden and Feduska^[23], Figure 4, for brazed joints of AISI 347 stainless steel at 1100°F (brazed joints). Figure E-39 shows the test curve and the design curve, which incorporates a safety factor of 10 on cycles and a factor of 1.5 on stress. From Figure E-39 the life time for the given stress amplitude is:

$$N_F = 1.5 \times 10^5 \text{ cycles}$$

$$UF = \frac{30}{1.5 \times 10^5} \approx 0.$$

5.3 Fatigue Life of the Cluster Grid

5.3.1 The Wrinkled Strap

Points of peak stress in the wrinkled strap due to a static preload and thermal compression are points A, B and C in Figure E-35. The static stresses have been calculated in Section E-3, and the thermal stresses at these points in Section E-4.

Point A: static stress is:

$$\sigma_s = \pm 878 \text{ lb/inch}^2 \text{ at the upper and lower edge of the web;}$$

thermal stress is:

$$\sigma_t = -71,730 \text{ lb/inch}^2$$

In the midpoint of the longer side of the cross section the torsional shear stress has a maximum,

$$\tau = 18,494 \text{ lb/inch}^2$$

but there the bending stress is zero.

Point B: static stress is:

$\sigma_s = 14,730 \text{ lb/inch}^2$ at the upper and the lower edge of the web. (The cutout for the spring finger produces this high stress.) The thermal stress is:

$$\sigma_t = -71,730.$$

Point C: static stress is:

$\sigma_s = \pm 878 \text{ lb/inch}^2$ at the upper and the lower edge of the web;

thermal stress is:

$$\sigma_t = -58,430 \text{ lb/inch}^2$$

The above data shows that the critical point B covers all other points. The stresses at this point are high, because this corner is weakened by the cutout for the spring finger.

5.3.2 Stress Concentration Factors

In the knees of the wrinkled straps at point C, Figure E-35, also Figure E-34, stress concentration must be considered. Idealizing the knee as a curved bar, Figure E-40, we find for an assumed ratio of radius/thickness of the web

$\frac{r}{t} = 2.5$, a stress concentration factor of $K_t = 1.4$ (see^[10], Figure 109).

The notch sensitivity factor is:

$$q = \frac{1}{1 - \frac{a}{r}} = 0.93,$$

with $a \approx 0.003$ for UTS = 195000 lb/inch² (see^[27], Figure 10).

The fatigue strength reduction factor is:

$$K_f = 1 + q \times (K_t - 1) = 1.372.$$

With K_f known for the above given stresses in point C of the wrinkled strap the fatigue can now be calculated.

The maximum stress is:

$$\sigma_{\max} = 1.37 \times (14,730 + 71,730) = 118,450 \text{ lb/inch}^2$$

$$\sigma_{\min} = 1.37 \times 14,730 = 20,180 \text{ lb/inch}^2.$$

The maximum stress is below the yield stress of $\sigma_y = 125,000 \text{ lb/inch}^2$. The mean stress is:

$$\sigma_m = 69,315 \text{ lb/inch}^2.$$

The stress amplitude is:

$$\sigma_a = 59,225 \text{ lb/inch}.$$

The corrected amplitude:

$$\sigma_{a'} = \frac{59,225 \times 19,500}{195,000 - 69,315} = 91,887 \text{ lb/inch}^2.$$

The ultimate stress for Inconel 718 at 1100°F is $\sigma_u = 195,000 \text{ lb/inch}^2$.

From the fatigue design curve Figure E-9:

$$N_F = \text{low cycles}$$

$$UF = \frac{30}{1000} = 0.03 < 0.8.$$

5.3.3 Fatigue Life of the Radial Web

Since the radial web is subject to static bending and axial thermal compression, the stress is uniaxial. The static bending stress is

$$\sigma_B = \pm 12,653 \text{ lb/inch}^2.$$

The compressive thermal stress in the radial web of grid with a flexible can is:

$$\sigma_T = 4271 \text{ lb/inch}^2.$$

For this low stress no fatigue failure will occur, thus:

$$N_F > 10^7,$$

$$UF = 0.$$

Figure E-1. Modulus of Elasticity

Figure E-2 Poisson's Ratio

Figure E-3. Thermal Expansion Specific Heat

E-48

Figure E-4. Tensile Properties versus Temperature.

Figure E-5. Inconel "718" Alloy Secondary Creep Rate,% Per Hour

Figure E-6. N-S Curves for Irradiated and Unirradiated Inconel 718 at 1100°F (Based on Experimental Fatigue Life Curve)

Figure E-7. N-S Curves for Irradiated and Unirradiated Inconel 718 at 1200°F
(Computed with a Method by Halford-Manson Material Properties from REIC-Report No. 45, Table 70)

Figure E-8. N-S Curves for Irradiated Inconel 718 in a Sodium Environment (Comparison of two Methods)

Figure E-9. Fatigue Life Design Curve for Inconel 718
at 1100°F in a Sodium Environment

Figure E-10. Effect of Neutron Irradiation on the Mechanical Properties of Inconel 718, Table 70 of Reference (16)

Figure E-11 Biaxial Stress-Rupture Data for Type 316
Stainless Steel in 1350°F Sodium

Figure E-12. Rupture Stress of Unirradiated Inconel 718 at 1100°F (5).

Figure E-13. Honeycomb Design

AREA OF THE GRID PLATE $3 \times 2.495 \times 2.16 = 16.2 \text{ INCH}^2$

Figure E-14. Fuel Rod Assembly

Figure E-15 Spring Force Loading

Figure E 16. Clustered Rod Grid Springfingers

Figure E-17. Bending Moment

Figure E-18. Cutout for Spring Finger

Figure E-19. Lateral Buckling of the Grid Web

Figure E-20. Shear Stress in Torsion Bar

Figure E-21. Stresses in Braze Alloy

Figure E-22. Rhombus Section of the Cluster Grid Plate

Figure E-23. Vertical Loads and Bending Moments on a Wrinkled Strap

Figure E-24. Lateral Bending Forces on the Wrinkled Strap

Figure E-25. Lateral Bending Forces in a Wrinkled Strap

Figure E-26. Load Distribution on Radial Webs

Figure E-27. Load on Other Radial Web Unsupported in D

Figure E-28. Buckling Model for the Straight Web

Figure E-29. Coolant Temperature Distribution across 217 Pin Bundle

Figure E-30. Notation for Stress Calculation of Ring and Grid

Figure E-31. Machined Can Detail

Figure E-32. Thermal Stress across a Circular Plate

Figure E-33. Section of Can for Cluster Grid

Figure E-34. Forces on a Wrinkled Strap
at one Side of a Mesh

Figure E-35. Moment Distribution in Straps of Figure E-34

Figure E-36. Scheme of Grid in Cluster Design ($\frac{1}{3}$ of Grid Plate)

Figure E-37. Model for Can Deflection

Figure E-38. Notch Sensitivity Factor Honeycomb Grid

Figure E-39. Fatigue for Brazed Stainless-Steel Sheet in Bending at 1100°F

Figure E-40. Notch Concentration Factor Wrinkled Straps

APPENDIX F
FLOW-INDUCED VIBRATION OF FUEL RODS

1. INTRODUCTION

Fast-flowing sodium in the reactor excites vibrations of the fuel rods. Their vibration amplitude is a function of the material properties of the sodium and the fuel rods, the flow velocity and the geometric configuration.

Vibration tests with rods in an axial flow have been subjected to a similarity analysis. For given nondimensional parameters, a correlation between the vibration amplitude, the flow velocity, and other pertinent parameters has been found.

The similarity relation of Burgreen^[24] is used to calculate the vibration amplitude. Paidousis^[25] found another empirical formula for calculating the vibration amplitude. Additional tests under simulated in-reactor conditions are required to select the similarity relation relevant to the FFTF fuel assembly design.

Burgreen's analysis is based on simple dimensional evaluations which makes it easier to incorporate the effect of a longitudinal load on the vibration amplitude of a rod. Burgreen derived a similarity relation for rod vibrations without an axial force. A longitudinal force is produced by the friction of rods in the grids during thermal expansion.

2. NOTATION

A	inch ²	crosssection area
D	inch	hydraulic diameter
E	lb/inch ²	elastic modulus
F	lb/inch ²	$\delta V^2/g$ - proportional to fluid force
g	inch/sec ²	gravity
I	inch ⁴	moment of inertia

k		eigen value, clamping constant
ℓ	inch	rod length
L	lb	load on rod
M	lb-inch	moment
P	lb	axial force
P _c	lb	Euler buckling load
R	lb/inch ²	proportional to elastic restoring force
r	inch	rod radius
u		$\frac{\pi}{2} \sqrt{\frac{P}{P_{crit}}}$
δ	inch	deflection of the rod in the center
ω	rad/sec	frequency
ρ _w	lb/inch ³	fluid density
ρ _R	lb/inch ³	rod density
σ	lb/inch ²	stress
Γ Ω ₁		nondimensional parameters

3. ANALYSIS

3.1 Fuel Rods with Hinged Ends

Burgreen derived two nondimensional parameters. The parameter Γ is the ratio of the hydrodynamic forces of the fluid, F, to the elastic restoring force, R, of the rod.

$$\Gamma = \frac{F}{R}$$

The fluid force is proportional to:

$$F \approx \frac{\rho_w \times V^2}{g}$$

where;

ρ_w = Fluid density
V = Fluid velocity
g = Gravity

Elastic restoring forces are proportional to:

$$R \approx EI/\ell^4/\eta(u)$$

The term η has been added to Burgreen's formula and accounts for the effect of the longitudinal forces. It can be derived in the following way. The deflection of a beam with a uniform load and hinged ends is:

$$\delta = \frac{5}{384} \times \frac{L \times \ell^4}{E \times I} \times \eta(u)$$

The factor $\eta(u)$ includes the effect of the axial end load on the deflection. It is unity for zero end load and goes to infinity as the end load approaches the Euler bulking load.

An expression for $\eta(u)$ is:^[21]

$$\eta(u) = \frac{12}{5 \times u^4} (2 \sec(u) - 2 - u^2)$$

where:

$$u = \frac{\pi}{2} \sqrt{\frac{P}{P_c}}$$

P_{crit} is the Euler buckling load.

The other Burgreen nondimensional parameter, Ω , is the ratio of the hydrodynamic forces of the fluid to the damping forces on the rod.

$$\Omega = \frac{\rho_w \times V^2}{\mu \times \omega}$$

where:

μ = fluid viscosity

ω = the frequency of the rod in the fundamental mode.

The fundamental frequency of a rod with hinged ends can be calculated with the following formula:

$$\omega_o = \pi^2 \sqrt{\frac{g \times E \times I}{\rho_R \times A \times \ell^4}}$$

where:

ρ_R = rod density

A = cross sectional area of the rod

A longitudinal force on the rod reduces the frequency, ω_o , according to the following law:^[31]

$$\omega = \sqrt{\left(1 - \frac{P}{P_{crit}}\right) \times \omega_o^2}$$

The deflection of the rod can be found from Burgreen's empirical expression:

$$\left(\frac{\delta}{D}\right)^{1.3} = 0.83 \times 10^{-10} \times k \times \Gamma^{1/2} \times \Omega$$

where:

k = 5 for hinged ends, k = 1 for clamped ends

D = hydraulic diameter

More details of the calculation can be found in Burgreen's paper.^[24] This equation has been programmed with the parameters as input.

3.2 Fuel Rods with Clamped Ends

Clamping the ends of the fuel rods in the grid substantially reduces the vibration amplitude. To include the effect of clamped ends on the vibration amplitude, the increase of the elastic restoring forces and the increase of the eigen-frequency due to the clamping must be incorporated in the analysis.

The elastic restoring force is proportional to $R = EI/(\eta(u))$. The factor $\eta(u)$ takes into account the decrease of R produced by an axial load. For a beam with clamped ends this factor changes to:

$$\eta(u) = \frac{348}{u^4} \left(\frac{u}{2 \times \sin\left(\frac{u}{2}\right)} - \frac{u}{2} \times \cot\left(\frac{u}{2}\right) - \frac{u^2}{8} \right)$$

where:

$$u = 2 \cdot \pi \sqrt{\frac{P}{P_c}}$$

This expression can be derived from a formula cited in Roark^[20] (p. 150), for the deflection of a clamped-clamped beam under axial compression and uniform transverse load.

The eigen-frequency of a beam with clamped ends is:^[28]

$$\omega = 2 \times \pi \times 4.73 \times \sqrt{\frac{g \times E \times I}{\rho_R \times A \times l^4}} \text{ rad/sec}$$

In the final formula for the determination of the vibration amplitude the factor k is now $k = 1$.

3.3 Effective Elastic Modulus During Vibration

To find the vibration amplitudes for a given free length of the fuel rod and a given axial load it is necessary to know the effective elastic modulus.

The equivalent stress in the tube, produced by the tube swelling, has been found for the buckling calculation of the fuel rods as a function of hoop strain rate.

$\sigma = 17,200$ psi for a strain rate of 3%/year, $E_s = 3.44 \times 10^6$ psi

$\sigma = 15,900$ psi for a strain rate of 2%/year, $E_s = 4.18 \times 10^6$ psi

$\sigma = 14,800$ psi for a strain rate of 1%/year, $E_s = 7.10 \times 10^6$ psi

The secant modulus has been chosen as the effective modulus for the vibration of the rod, from the static stress strain curve, Figure F-1.

3.4 Bending Stresses in the Rod Due to Vibrations

Assume elastic deformations of the rod. For a vibration of a beam with hinged ends in its first mode the moment in the center of the rod is:

$$M = EI \cdot \left(\frac{\pi}{\ell}\right)^2 \times \delta$$

The stress is:

$$\sigma = \frac{M}{I} \times r$$

For $\ell = 10$ in. and $E = 20 \times 10^6$ psi

$\delta = 0.001$ in.	$\sigma = 123$ psi
$\delta = 0.002$ in.	$\sigma = 246$ psi
$\delta = 0.005$ in.	$\sigma = 616$ psi
$\delta = 0.010$ in.	$\sigma = 1232$ psi

The above stresses are obtained using the elastic E value, and hence are conservative.

3.5 Results

The vibration amplitude as a function of the free fuel rod length and the axial load for different elastic moduli and two end conditions has been plotted in the Figures F-2 through F-9. The material and geometric parameters are:

Rod diameter (in.)	0.250
Wall thickness (in.)	0.016
Rod density (lb/in.)	0.01641
Gap between rods (in.)	0.00115
Moment of inertia (in. ⁴)	0.000080885

Fluid type	Sodium
Fluid temperature (°F)	1000
Fluid density (lb/in.)	0.0297
Fluid viscosity (lb/ft-hr)	0.570

Comparison of the vibration amplitude of a beam with hinged ends and a beam with clamped ends shows that by clamping the ends the amplitude decreases by a factor of 6.47. This is shown in Figures F-2 and F-3.

This plot also shows the decrease of the vibration amplitude with increasing elastic modulus; the proportionality factor is $\sim 1/E^{0.768}$.

Graphs have been plotted to show the vibration amplitude as a function of the axial compressive load and the rod length. The proposed design length, 9.7 inches, of the rods between other grids is marked (Figure F-4 and F-9).

The maximum axial load on the rod has been calculated with FATBO2 (see Appendix A). The results show that for a hinged support, the axial load exceeded the buckling load. Because the load is strain-limited, the rod will not collapse, but will bend until the stress is released. The vibration of the deformed rod has not been calculated; it would involve nonlinear calculations. The ability of the buckled rod to withstand vibrations is low, and the vibration amplitude of a rod in the post-critical region would be high.

For the fuel rods clamped at the grids, the maximum ratios of the applied load to the buckling load has been calculated using FATBO2 for the different strain rates.

$$\text{Figure F-7 Strain rate } 3\%/ \text{year} \quad \frac{P}{P_{\text{crit}}} = \frac{11.5}{23.6} = 0.487; \quad \delta = 8.3 \times 10^{-4} \text{ inch}$$

$$\text{Figure F-8 Strain rate } 2\%/ \text{year} \quad \frac{P}{P_{\text{crit}}} = \frac{11.5}{28.7} = 0.4 \quad ; \quad \delta = 6.2 \times 10^{-4} \text{ inch}$$

$$\text{Figure F-9 Strain rate } 1\%/ \text{year} \quad \frac{P}{P_{\text{crit}}} = \frac{11.5}{38.9} = 0.29 \quad ; \quad \delta = 3.8 \times 10^{-4} \text{ inch}$$

They show that the vibration amplitude never exceeds the limiting value, 0.001 inch. This value has been chosen as the maximum allowable vibration

amplitude on the basis of trouble-free experience with PWR fuel assembly designs in which vibration amplitudes are limited to similar values. The above results show that effective clamping of the fuel rods by the grid must be provided.

3.6 Clamping Condition of the Fuel Rods in the Grid

The evaluation of the vibration amplitude shows that the fuel rods must be clamped by the grids to keep the vibration amplitude below 0.001 inch. It remains to be shown that the force of the spring finger is sufficient to clamp the rod.

The spring finger of the hexagonal grid presses the fuel rod with a three-pound force against two dimples above and below the spring finger. Figure F-10 shows that the minimum force to overcome the spring load and move the rod in the plane is 2.4 pounds.

If a bending moment of 2.4×0.5 lb/inch is applied, the rod will tilt about the upper or lower of the two dimples, Figure F-11A. Bending moment acting in the same direction may exist on both sides of the grid (Figure F-11B). The bending moment produced by the vibrating rod on the grid must not exceed $M_a = 2.4 \times 0.5/2 = 0.6$ lb inch.

3.6.1 End Moment in a Clamped-Clamped Bar During Vibration

The eigenform of a clamped-clamped rod in vibration is:^[32]

$$Y = C_2 \cdot (\cos kz - \cosh kz) + C_4 \cdot (\sin kz - \sinh kz)$$

The ratio of the constants C_2 and C_4 can be determined from the boundary conditions:

$$Y = 0 \quad ; \quad \frac{\partial Y}{\partial Z} = 0$$

$$Z = 0, \ell \quad ; \quad Z = 0, \ell$$

The boundary conditions yield two equations:

$$C_2 \cdot (\cos k\ell - \cosh k\ell) + C_4 \cdot (\sin k\ell - \sinh k\ell) = 0$$

$$C_2 \cdot (\sin k\ell + \sinh k\ell) + C_4 \cdot (-\cos k\ell + \cosh k\ell) = 0$$

The root for the first vibration modes found from this set of homogeneous equations is $k\ell = 4.730$.^[32]

Inserting $k\ell$ in the two equations above gives:

$$C_2 \cdot (-56.66) + C_4 \cdot (-1 - 56.66) = 0$$

$$C_2 \cdot (+56.66) + C_4 \cdot (1 + 56.66) = 0$$

The ratio of the constants is:

$$\frac{C_2}{C_4} = - \frac{57.66}{56.66} = -1.01756$$

The deflection in the center of the rod is:

$$Y_Z = \ell/2 = C_2 (0.70711 \times (1 + 0.98274) - 5.369 + 0.98274 \times 5.275)$$

$$Y_{\ell/2} = C_2 \times 1.217$$

$Y_{\ell/2}$ is the deflection δ in the center of the rod. For a given deflection δ :

$$C_2 = \frac{\delta}{1.217}$$

We obtain the end moment of the rod from the second derivative of the eigenform:

$$\left[\frac{\partial^2 Y}{\partial Z^2} \right]_{Z=0} = C_2 \left(\frac{k\ell}{\ell} \right)^2 (-1 -1)$$

Inserting C_2 and multiplication with EI gives the end moment:

$$M = -EI \cdot \frac{\delta}{1.271} \cdot \left(\frac{4.730}{\ell}\right)^2 \times 2$$

For the limit deflection of 0.001 in. which must not be exceeded and the parameters

$$I = 0.000080885 \text{ in.}^4$$

Flexural rigidity

$$\ell = 9.7 \text{ in.}$$

Proposed length of fuel rods
between grids

The following end moments have been found as function of the effective elastic modulus of the rod and are all less than 0.6 in/lbs, therefore the fuel rods will not unseat at the grid dimples.

$E = 7 \times 10^3 \text{ psi}$	$M = 0.221 \text{ lb/in.}$	$\frac{0.6}{M} = 2.7$
$E = 4.18 \times 10^3 \text{ psi}$	$M = 0.132 \text{ lb/in.}$	$\frac{0.6}{M} = 4.5$
$E = 3.44 \times 10^3 \text{ psi}$	$M = 0.109 \text{ lb/in.}$	$\frac{0.6}{M} = 5.5$

The vibration amplitude is also lower than 0.001 in all three cases:

$E = 7000 \text{ psi}$	$\delta = 0.00038 \text{ inch}$
$E = 4180 \text{ psi}$	$\delta = 0.00062 \text{ inch}$
$E = 3440 \text{ psi}$	$\delta = 0.00083 \text{ inch}$

Not yet included in the calculation of the end moment of the fuel rod due to vibration is the effect of the axial load. This axial force increases the end moment only by a small amount. For an axial force of $P = 11.5 \text{ lb}$, and a vibration amplitude $\delta = 0.001 \text{ inch}$, the bending moment in midspan of the rod is:

$$M = 0.0115 \text{ lb inch}$$

This is negligible compared to the available clamping moment of 0.6 lb inch.

3.7 Limitation of the Vibration Analysis

The limitations of the published similarity relations for the prediction of fluid-induced vibrations of fuel rods are well known. They are empirical and based on tests with a limited variation of parameters. But they are supposed to include the major influences on fluid-induced vibrations. A rigorous similarity analysis requires full similarity of geometry and flow in the test model and designed fuel assembly.

All published tests have been performed with large pitch-to-diameter ratios. Extrapolation to smaller pitch-to-diameter ratios, as employed in fast breeder reactors, must be confirmed by tests.

Figure F-1. Static Stress-Strain Curve for SS/304 Stainless Steel at 1100°F

Figure F-2. Amplitude of Flow Induced Vibration-Burgreen Theory Fluid Velocity $V = 30$ Ft/Sec for Different Effective E Moduli

Figure F-3. Amplitude of Flow Induced Vibration-Burgreen Theory Fluid Velocity $V = 20$ Ft/Sec for Different Effective "E" Moduli

Figure F-4 Amplitude of Flow Induced Vibration-Burgreen Theory
 Youngs Modulus $E = 3.44 \times 10^6$, 3% Strain Rate Year

Figure F-5. Amplitude of Flow Induced Vibration-Burgreen Theory Youngs Modulus $E = 4.18 \times 10^6$, 2% Strain Rate Year

Figure F-6. Amplitude of Flow Induced Vibration-Burgreen Theory
 Youngs Modulus $E = 7.00 \times 10^6$, 1% Strain Rate/Year

Figure F-7. Amplitude of Flow Induced Vibration-Burgreen Theory
 Youngs Modulus $E = 3.44 \times 10^6$, 3% Strain Rate/Year

Figure F-8. Amplitude of Flow Induced Vibration-Burgreen Theory
 Youngs Modulus $E = 4.18 \times 10^6$, 2% Strain Rate/Year

Figure F-9. Amplitude of Flow Induced Vibration-Burgreen Theory
 Youngs Modulus- $E = 7.0 \times 10^6$, 1% Strain Rate/Year

Figure F-10. Forces at Dimples

A. BENDING MOMENT OF 2.4×0.5 LB-INCH WILL TILT THE ROD ABOUT A DIMPLE

B. VIBRATION MODE OF THE CLAMPED FUEL ROD

Figure F-11. Clamping of Vibrating Fuel Rod in Grid

APPENDIX G

SPRING FINGER ANALYSIS

1. GENERAL APPROACH

For each type of grid (the hexagonal grid, the clustered rod grid and the tri-planar grid), a different spring has been designed (Figure G-1 through G-4). They are essentially torsional springs with a cantilever loading arm of width B. The cantilever arm is attached to the torsion bar of width A at its center. The stiffness of the cantilever arm is made greater than that of the torsion bar so that the stored energy of the spring is mainly contained in the torsion bar. The spring has to provide a preload of three pounds to fix the tubes in the grid and five pounds to hold the fuel rod cluster in position. They have to sustain an additional deflection which is produced by three percent swelling of the fuel rod diameter.

The deflection of the spring finger due to swelling of the rods is determined by the support geometry of the fuel rods or the fuel rod cluster in the grids. Calculation of the deflection due to swelling is the first step in the spring analysis.

The bending deflection of the cantilever and torsion of the torsion bar can be found from readily available formulas. The effective moment applied to the bending cantilever and the torsion bar must be found from the geometry of the grid. With the applied moment known, maximum stresses and bonding stresses in the bending cantilever and in the torsion bar can be calculated.

The width, B, of the cantilever is chosen so that the bending stress and the torsional stress in the torsion bar are of equal percentage of the yield stress limit. At 1100°F, the tension yield stress for Inconel-718 is 125,000 psi and the torsion yield stress is 72,000 psi.

Finally, the derived relationships between stress, deflection, and geometry were solved parametrically and plotted on curves. The discussion of these curves and the selected spring dimensions are given in the main text.

2. NOTATION

A	inch	Width of the torsional spring
B	inch	Width of the bending cantilever
b	inch	Length
C	inch	Length of the torsion bar
D	inch	Pitch of the tube array
E	lb/inch	Youngs modulus
G	lb/inch	Shear modulus
K	.	Torsional constant
k	lb/inch	Spring rate
P	lb	Load
R	inch	Radius
t	inch	Grid thickness
U	inch	Figure G-5
α	o	Angle enclosing the torsional spring (Figure G-4)
β	o	Angle enclosing the bending spring (Figure G-4)
δ	inch	Deflection
θ	rad.	Rotation
σ	lb/inch	Normal stress
τ	lb/inch	Shear stress

Subscripts:

B	Bending
T	Torsion
S	Swelling

3. ANALYSIS

3.1 Torsional Spring Finger for the Honeycomb Grid

Figure G-3 shows the geometry for the notation for a spring in a honeycomb grid.

3.1.1 Deflection Due to Swelling

The deflection of the spring due to three percent swelling of the tube is dictated by the tube support geometry (Figure G-5).

$$\delta_s = 0.03 \cdot R + Z$$

Z is the deflection of the tube center in the direction of the spring force.

With,

$$\Delta R = 0.03 \times R \text{ and the relation } (\Delta R + R^2) = (R \times 0.866)^2 + U^2$$

We find:

$$Z = U - \frac{R}{2} = 0.0072 \text{ and}$$

$$\delta_s = 0.01103$$

3.1.2 Deflection Due to Preload

The bending moment about the root of the bending cantilever is shown in Figure G-6.

$$M_B = P \times b$$

The moment about the center of the torsion bar is

$$M_T = P \times y$$

The distances x and y can be calculated from the dimensions given in Figure G-6.

$$y = D/2 \times \sin 68.5^\circ = 0.46521 \times D$$

D is the pitch of the tube array.

$$b = y - A/2 \times \cos 68.5^\circ = y - 0.18325 \times A$$

The deflection of the cantilever spring of length b under a load P is approximately:

$$\frac{\delta}{P} = \frac{b^3 \times 4}{E \times t^3 \times B}$$

The use of the projected length, b, instead of the developed length of the cantilever spring is conservative, because the actual bending deflection of the spring is higher than calculated. But only 10 percent to 20 percent of the total deflection are contributed by the cantilever.

The angle of twist of the torsion bar under load P is

$$\frac{\theta}{P} = \frac{1}{4} \times \frac{(2 \times C + B/2) \times y}{K \times G}$$

In this formula the effective length of half the torsion bar is assumed to be

$$(C + B/4).$$

The contribution B/4 allows for the diffusion of the load into the parent grid material. The torsional constant, K, is obtained from Roark^[20] (p.194):

$$K = \frac{t^3 \times A}{16} \times \left(\frac{16}{3} - \frac{3.36 \times t}{A} \left(1 - \frac{t^4}{12 \times A^4} \right) \right) .$$

The deflection at the point of the load due to torsion is

$$\frac{\delta}{P} t = \frac{\theta}{P} \times y.$$

The load P has a component on the torsion bar which may produce a bending deflection of the torsion bar. Bending at the torsion bar is prevented by a dimple (Figure G-7) in the middle of the torsion bar.

The deflections due to bending and torsion have to be added

$$\frac{\delta}{P} = \frac{\delta}{P} r + \frac{\delta}{P} \beta.$$

Inversion of δ/P gives the spring rate, k, of the combined springs. With the spring rate obtained, the load produced by the swelling deflection can be calculated ($P_s = k \delta_s$). To obtain the total load, the three-pound preload has to be added,

$$P = k \delta_s + 3.$$

The total deflection of the spring at the point of load application is

$$\delta = \delta_s + 3/k.$$

The force due to preload and swelling deflection produces in the cantilever a maximum bending stress of

$$\sigma_B = \frac{P \times b \times 6}{t^2 \times B}$$

The maximum shear stress in the torsion bar is^[20]:

$$\tau = \frac{P \times Y}{2} \times \left(\frac{3 \times A + 1.8 \times t}{A^2 \times t^2} \right).$$

3.1.3 Optimization of Stresses

Stresses at the clamped end of the cantilever and the maximum stress in the torsion bar due to bending and torsion should be of equal percentage of the yield stress.

$$\sigma_B = \sqrt{3 \cdot \tau}$$

Substitution of σ_B and τ and solving for B gives

$$B = \frac{b}{3xy} \times \frac{L \times A^2}{(3 \times A + 1.8 \times T)}$$

For the given dimensions the result is approximately $B \approx 2A$. Curves in Figures G-8 through G-16 give the results of the geometric analysis. The discussion of these curves and the selected spring dimensions are presented in Section 4.2 of the main text.

3.2 Torsional Spring Finger for the Cluster Grid

For the calculation of the springs in the cluster grid, the notation of the spring in the honeycomb grid can be used. A preload of five pounds is required in each spring to fix the fuel rod cluster in the grid. Deformation of the fuel rod cluster due to swelling of the fuel rods enforces an additional deflection, which increases the spring load. The deflection of the spring due to swelling has to be determined from the support geometry of the fuel rod cluster, see Figure G-17. The cluster is being held by two springs at a and b, Figure G-18, against two opposite dimples, c and d.

The exact deformation of the cluster due to swelling is difficult to predict. Therefore, it will be assumed that deflection of spring a results only from swelling of the distance between spring a and d, whereby the webs at c and b do not contribute to the elongation of the distance $\overline{ad}$. Only the elongation in the direction of the spring force has been taken into account. For instance, of the distance $\overline{ef}$ in Figure G-18, only the part $\overline{gf}$ will elongate due to swelling. The projected distance across the flats of the fuel cluster is

$$\overline{km} = D \times \cos 30^\circ + 2 \times 0.775$$

The distance $2 \times h_i$ had to be subtracted to get the effective distance subject to swelling. Using trigonometric relationships:

$$\overline{gf} = \sqrt{R^2 - 0.0775^2} = 0.098075$$

$$\overline{eg} = \overline{eF} - \overline{gf} = D/2 - 0.098075$$

$$2 \times \overline{h_i} = 2(D/2 - 0.098075)\cos 30^\circ,$$

the total deflection due to swelling is

$$\delta_s = [0.8660 \times D + 0.155 - 2 \times (D/2 - 0.0980) \times 0.8660] \times 0.03$$

The bending moment about the root of the cantilever is (Figure G-18)

$$M_B = P(D/2 - A/2).$$

The moment about the center of the torsion bar is

$$M_T = P \times D/2.$$

The deflection of the cantilever spring of the length $(D - A)$ under a load P is

$$\frac{\delta_B}{P} = \frac{P \times (D-A)^3 \times 4}{8 \times E \times t^3 \times B}$$

The angle of torsion under load P is

$$\frac{\theta}{P} = \frac{1}{4} \times \frac{(2 \cdot C + B/2)}{K \times G} \times \frac{D}{2}.$$

In this formula the effective length of half the torsion bar is assumed to be $(C + B/4)$, because not only the free length of the torsion bar contributes to the deflection but also part of the width B (Figure G-3). The constant for torsional deflection, K, has been used before. The radial deflection at point a due to torsion is

$$\frac{\delta_T}{P} = \frac{\theta}{P} \frac{D}{2}$$

The total deflection due to bending deflection and torsional deflection is

$$\frac{\delta}{P} = \frac{\delta_B}{P} + \frac{\delta_T}{P}.$$

The bending of the torsional bar is prevented by dimples in the middle, above, and below the torsion bar.

Inversion of δ/P gives the spring rate, k, of the combined springs. A preload of $P = 5$ lb produces a deflection $\delta_5 = 5/k$. The total deflection due to preload and swelling deformation of the fuel rod cluster is

$$\delta = \delta_5 + \delta_s.$$

The total spring force under preload and swelling deflection is now

$$P = \delta \times k.$$

This force produces in the cantilever a maximum bending stress of

$$\sigma_B = \frac{P \cdot (D-A)}{2} \frac{6}{t^2 \cdot B} ,$$

and in the torsion bar a torsional stress

$$\tau = \frac{P \times D}{4} \times \frac{(3 \cdot A + 1.8 \cdot t)}{A^2 \cdot t^2}$$

Torsion stress and bending stress in the cantilever are of equal percentage of the yield stress if

$$\sigma_B = \sqrt{3 \cdot \tau} .$$

Combining the equations for σ_B and τ_t and solving for B gives

$$B = \frac{1}{3} \times \frac{(D-A)}{D} \times \frac{(A \cdot t)^2}{(3 \cdot A + 1.8 \cdot t)} \cdot \frac{12}{t^2} .$$

The plots G-19 through G-24 give the result of the parametric analysis. The discussion of this curve and the selected spring dimensions are presented in Section 4.2 of the main text.

3.3 Torsional Spring Finger for the Triplanar Grid

Figures G-17 and G-25 show the geometry and the notation of a spring in the triplanar grid. A preload of three pounds is required to fix the tube in the grid. Swelling in the fuel rod of three percent enforces an additional deflection which increases the spring load. The additional deflection due to a three percent swelling of the tube is (Figure G-26)

$$\delta = 0.03R + Z .$$

Z is the displacement of the tube center in direction of the spring force.

With $\Delta\bar{R} = 0.003\bar{R}$ and the relation (Figure G-26)

$$(\Delta R + R)^2 = \frac{R^2}{2} + U^2 ,$$

we find

$$Z = U - \frac{R}{\sqrt{2}} = 0.0052821 \text{ inch}$$

and

$$\delta = 0.008978 \text{ inch.}$$

Deflection of the cantilever under force P (Ref. 29) is

$$\frac{\delta B}{P} = \frac{R^3 \times 3}{Et^3 B} (2\beta - \sin 2\beta).$$

The torsion moment is $M = P \cdot \sin (\beta + \alpha/2) \cdot R$.

The effective half length of the torsion bar is obtained as $(c + B/4)$. The term $B/4$ is introduced to allow for the diffusion of load into the parent grid material.

The angle of torsion under load P is

$$\frac{\theta}{P} = \frac{\sin (\beta + \alpha/2) \times 1/2 \times R \times (2C + B/2)/2}{K \times G},$$

The term K is identical with that used previously. The radial deflection at the point of the load is

$$\frac{\delta}{P} = R \cdot \sin(\alpha/2 + \beta) \cdot \frac{\theta}{P} .$$

The bending moment at the root of the cantilever is

$$M_B = BR \cdot \sin \beta .$$

The torsion moment in the bar is

$$M_T = P \cdot R \cdot \sin (\beta + \alpha/2) .$$

Maximum bending stress in the cantilever is

$$\sigma_B = \frac{P \cdot R \cdot \sin (\beta) \cdot 6}{t_B^2} ,$$

and the torsion stress in the bar is

$$\tau_t = P \cdot R \sin (\beta + \alpha/2) \frac{1}{2} \frac{(3 \cdot A + 1.8 \cdot t)}{A^2 \cdot t^2} .$$

The torsion stress and maximum bending stress are of equal percentage of the yield stress if $\sigma_B = \tau_T \times \sqrt{3}$. Substituting for σ_B and solving for B gives

$$B = \frac{1}{\sqrt{3}} \times \frac{12 \cdot \sin (\beta)}{\sin (\beta + \alpha/2)} \times \frac{(A \times T)^2}{t^2 \cdot (3 \cdot A + 1.8 \cdot T)}$$

Curves in Figures G-30 through G-35 give the results of the parametric analysis. The discussion of these curves and the selected spring dimensions are presented in Section 4.2 of the main text.

Figure G-1. Cells of Honeycomb Grid

Figure G-2. Cell of Cluster Grid

Figure G-3. Notation of Spring Parameters, Honeycomb and Cluster Design

Figure G-4. Notation of Spring Parameters, Triplanar Grid

Figure G-5. Deflection due to Swelling in Hexagonal Grid

Figure G-6. Geometry of Spring in Hexagonal Grid

Figure G-7. . Forces at Dimples

Figure G-8. Honeycomb Grid Spring Rate for Cantilever Loaded Torsion Spring $T = 0.014$, $D = 0.280$

Figure G-9. Honeycomb Grid Spring for Cantilever Loaded
Torsion Spring $T = 0.015$, $D = 0.280$

Figure G-10. Honeycomb Grid Spring for Cantilever Loaded
Torsion Spring $T = 0.016$, $D = 0.280$

Figure G-11. Honeycomb Grid Spring Rate for Cantilever Loaded Torsion Spring $T = 0.014$, $D = 0.290$

Figure G-12. Honeycomb Grid Spring Rate for Cantilever Loaded Torsion Spring $T = 0.015$, $D = 0.290$

Figure G-13. Honeycomb Grid Spring Rate for Cantilever Loaded Torsion Spring $T = 0.016$, $D = 0.290$

Figure G-14. Honeycomb Grid Spring Rate for Cantilever Loaded Torsion Spring $T = 0.014$, $D = 0.300$

Figure G-15. Honeycomb Grid Spring Rate for Cantilever Loaded Torsion Spring $T = 0.015$, $D = 0.300$

Figure G-16. Honeycomb Grid Spring for Cantilever Loaded Torsion Spring $T = 0.016$, $D = 0.300$

Figure G-17. Spring in the Cluster Grid

Figure G-18. Geometry of Cluster Grid Cell

Figure G-19. Cluster Grid Design, Spring Rate for Cantilever Loaded Torsion Spring $T = 0.014$, $D = 0.280$

Figure G-20. Cluster Grid Design, Spring Rate for Cantilever Loaded Torsion Spring $T = 0.016$, $D = 0.280$

Figure G-21. Cluster Grid Design, Spring Rate for Cantilever Loaded Torsion Spring $T = 0.014$, $D = 0.290$

Figure G-22. Cluster Grid Design for Cantilever Loaded Torsion Spring $T = 0.016$, $D = 0.290$

Figure G-23. Cluster Grid Design Spring Rate for Cantilever Loaded Torsion Spring $T = 0.014$, $D = 0.300$

Figure G-24. Cluster Grid Design Spring Rate for Cantilever Loaded Torsion Spring $T = 0.016$, $D = 0.300$

Figure G-25. Load on Spring in Triplanar Grid

Figure G-26. Deflection due to Swelling in Triplanar Grid

Figure G-27. Selected Spring for Honeycomb Grid Springload versus Deflection

Figure G-28. Selected Spring for Cluster Grid
Springload versus Deflection

Figure G-29. Selected Spring for Triplanar Grid
Spring Load versus Deflection

Figure G-30 Triplanar Grid Spring Rate for Cantilever Loaded Torsion Spring $D = 0.280$, $T = 0.0095$

Figure G-31. Triplanar Grid Spring Rate for Cantilever Loaded Tension Spring $D = 0.280$, $T = 0.0115$

Figure G. Triplanar Grid Spring Rate for
 Cantilever Loaded Torsion Spring $D = 0.290$, $T = 0.0095$

Figure G-33. Triplanar Grid Spring Rate for Cantilever Loaded Torsion Spring $D = 0.290$, $T = 0.0115$

Figure G-34. Triplanar Grid Spring Rate for Cantilever Loaded Torsion Spring $D = 0.300$, $T = 0.0095$

Figure G-35. Triplanar Grid Spring Rate for Cantilever Loaded Torsion Spring $D = 0.200$, $T = 0.0115$