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**NUMERICAL ACCURACY OF LINEAR TRIANGULAR
FINITE ELEMENTS IN MODELING
MULTI-HOLED STRUCTURES**

by
R. M. SULLIVAN and J. E. GRIFFEN

DATE PUBLISHED: JUNE 1980

GENERAL ATOMIC COMPANY

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R. M. SULLIVAN and J. E. GRIFFEN**

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ABSTRACT

A study has been performed to quantify the accuracy of linear triangular finite elements for modeling temperature and stress fields in structures with multiple holes. The purpose of the study was to evaluate the use of these elements for the analysis of HTGR fuel blocks, which may contain up to 325 holes. Since an accurate full scale analysis was not feasible with existing methods, a representative small scale benchmark problem containing only seven holes was selected. The finite element codes used in this study were TEPC-2D for thermal analysis and SAFIRE for stress analysis. It was concluded that linear triangular finite elements are too inefficient for this application. An accurate analysis of stresses in HTGR fuel blocks will require the use of higher order elements, such as the 8-node quadrilaterals in the new TWOD code.

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1. SUMMARY AND CONCLUSION

This report quantifies the numerical accuracy of linear triangular finite elements used for two-dimensional thermal and stress analyses of graphite components. Accuracies were examined for thermal and mechanical loadings for a hole geometry similar to those found in HTGR fuel elements. A simplified model (the seven hole element shown in Figure 1) was used so that existing linear finite element computer codes could assure a converged solution with adequate mesh fineness. An accurate analysis of the full HTGR fuel element is more expensive and is currently beyond the capability of these codes.

A thermal stress problem with two lines of thermal and structural symmetry (a one-twelfth sector) was examined using seven different meshes. The coarsest mesh employed only four elements to model the web of symmetry between fuel and coolant holes. The most refined mesh had 64 times that number of elements. The differential temperature across the sector predicted by the coarse mesh was ten percent less than that found by the most refined mesh. The resulting peak in-plane tensile and compressive thermal stresses were twenty-one and sixty-two percent less, respectively, than those for the converged solution.

A uniform static load problem with only one line of structural symmetry (a one-half sector) was also examined using several different meshes. Both uniformly and partially refined (embedded) meshes were used in order to test the effectiveness of local refinement techniques. The finest uniformly refined half element mesh had sixteen times as many elements as the coarsest mesh (four elements in the web of symmetry). In addition, segments of this model were extracted, refined, and analyzed using nodal displacements determined from a complete coarse mesh analysis as displacement boundary conditions for the extracted regions. The coarsest half sector mesh predicted only sixty-one percent of the

displacement at the peak stress location and only thirty-five percent of the peak stress, respectively, of those from the most uniformly refined mesh. The extraction and refinement procedure, using the coarse mesh displacement boundary conditions, did not predict any increase in peak stress even for two successive refinements (a factor of 16 on the number of elements) of the extracted region.

The failure of the extraction procedure is attributed to the fact that errors in the coarse mesh displacement field (caused by incorrect stiffness) preclude convergence of the local stress field to the correct solution. The fact that local mesh refinement caused no change in the peak stress may be regarded as incidental, since other less stressed areas showed some increase in stress with refinement. The embedded meshes, on the other hand, produced more accurate results than the extracted and refined meshes. The degree of accuracy depended on the level of refinement in both the local area and the surrounding coarser mesh.

The conclusions that may be drawn from this study are:

1. For applied mechanical loads with few lines of loading and/or structural symmetry, the extraction technique will predict stresses with an error directly proportional to the error in the coarse mesh displacement boundary conditions. In the case of a coarse mesh having four elements in the web of symmetry (a finer mesh than has been used in prior fuel element stress analyses) the calculated peak stress was only 35 percent of that found by the most refined mesh analysis.*

* This does not imply that actual stresses will be three times higher than calculated using existing fuel element meshes. This is simply the numerical error in an elastic solution. Actual stresses resulting from the time-dependent nonlinear material behavior can not be determined until such errors are eliminated. Improved material models (the discussion of which is beyond the scope of this report) will also be required for accurate fuel element stress analysis.

2. The error in the temperature, displacement, and stress fields calculated using the extraction procedure was found to be insensitive to the level of local mesh refinement. That is, local refinement with the resultant increased model flexibility did not offset the error introduced through the displacement boundary conditions as caused by a too stiff or coarse mesh representation of the entire model. The extraction technique as currently formulated is not reliable and should be discontinued.
3. An embedded mesh with the same level of refinement is more accurate than an extracted mesh. The error depends upon the ratio of the refined to coarse mesh areas and upon the level of overall mesh fineness. In the mechanical load analysis an embedded mesh having only twenty-three percent as many elements as the most uniformly refined mesh found over ninety percent of the peak stress.
4. For multiholed structures such as fuel elements, linear finite element codes are too inefficient for accurate stress calculations. To obtain an accuracy of within ten percent, a fuel element mesh would require nearly 100,000 linear triangular elements. A higher ordered quadrilateral element, currently being programmed in the new TWOD code, should dramatically reduce this.

2. INTRODUCTION

HTGR fuel elements are graphite hexagonal right prisms with arrays of fuel, coolant, and burnable poison holes. The major structural loads are those due to differential thermal and irradiation strains and those from seismic excitations of the core. The resulting temperature and stress fields arising from these loads are typically analyzed using two dimensional triangular finite element codes with linear temperature and displacement fields. Since strains are combinations of displacement derivatives, these are constant strain elements. For a linear constitutive (stress-strain) law, these are also constant stress elements.

In the past, owing to limited computer capability, rather coarse finite element meshes have been used for temperature and structural evaluations of fuel elements. Detailed analysis has been performed using a coarse mesh model to determine displacement boundary conditions for a locally refined analysis of a critical area (the so called extraction technique). The accuracy of this technique, which depends upon the accuracy of the coarse mesh displacement field, had never been quantified. The primary purpose of this study is to assess how the accuracy of the temperature and stress fields varies with mesh fineness and to quantify the errors of the extraction technique.

The seven hole element illustrated in Fig. 1 provides a relatively simple geometry for evaluating the numerical accuracy of these codes while retaining the essential features of the HTGR fuel element such as local and overall temperature fields and complicated load paths. This element has the same fuel/coolant hole pitch and hole sizes as the 10-row FSV fuel element and approximately similar thermal loadings between the fuel and coolant holes.

Fig. 1. Seven hole element (Mesh A1)

The mesh shown in Figure 1 is constructed with the same level of mesh refinement, hence numerical accuracy, as that used in some recent fuel element stress analyses. The Figure 1 mesh is coarser than those used in the present study, in which the coarsest mesh has finite element boundaries at all lines of geometric symmetry and contains about twice the number of finite elements as in Figure 1. Three additional levels of mesh refinement were required to achieve a converged solution.

3. ANALYSIS AND RESULTS

The numerical accuracy study was performed for both thermal and mechanical loads using symmetrical sectors of the seven hole element. The thermal load arises from the spatially varying temperature field between the center coolant hole and the six surrounding fuel holes. A one-twelfth symmetrical sector of the seven hole element was used for the thermal problem as this allowed extremely detailed mesh fineness. A one-half sector was used to examine the more asymmetrical mechanical load.

3.1 ONE-TWELFTH SECTOR THERMAL ANALYSIS

A one-twelfth sector of the element was analyzed for temperatures via the TEPC-2D linear finite element code (Reference 1). The thermal boundary conditions consisted of a uniform heat flux on the surface of the fuel hole, convective cooling on the coolant hole surface, and adiabatic boundaries on the geometrical lines of symmetry and the outer surface, as illustrated in Figure 2.

The seven finite element meshes used in the analysis are shown in Appendix A (figures A1 through A7). They consist of two series of mesh refinements created with the REFINE code (Reference 2). Each series starts from coarse meshes referred to respectively as B1 and C1. Each refinement quadruples the number of elements, and since mesh C1 has about twice the number of elements as B1, the two initial meshes yield a series (B1, C1, B2, C2, etc.) with approximately twice the number of elements in each successive mesh in the series. Mesh B1 has only boundary nodes, while mesh C1 has interior nodes at places of interest and, consequently, has a different element pattern. The series terminates with mesh B4 which has 64 times the number of elements as mesh B1. For structural comparisons, the polygonal holes were sized to preserve the cross sectional area. The heat flux on the fuel hole surface and the heat transfer coefficient on the coolant hole surface were modified

Fig. 2. One-twelfth sector of seven hole element (Mesh C1)

appropriately as their perimeters varied. The details of the thermal analyses are given in Appendix B.

A contour plot of the resultant temperature field is shown in Figure 3 for the finest mesh (B4). The maximum temperature difference across the sector as predicted by all seven meshes is shown in Figure 4. As depicted in this figure, mesh B3 predicts the maximum temperature different within one percent of mesh B4, while mesh B1 underpredicts it by ten percent. This underprediction leads to lower estimates of the thermal stress.

The temperatures on the exterior boundaries of the one-twelfth sector are shown in Figures 5 through 8 for all meshes. The temperature profiles along the coolant and fuel hole surfaces are shown in Figures 5 and 6, respectively while the profiles along the x axis and the 30 degree line of symmetry are depicted in Figures 7 and 8. Convergence of the temperature field is indicated at mesh fineness level B3.

The effect of using the linear interpolation/extrapolation part of the extraction technique in finding the nodal temperatures for a uniform refinement of the entire one-twelfth model was also examined. The nodal temperatures from mesh B2 were used to find those for mesh B3 via linear interpolation and compared to those calculated via TEPC for mesh B3 directly.

The maximum temperature difference across the sector was found to increase by only 1.5°F via linear interpolation/extrapolation while the direct calculation yielded an increase of 17.1°F. Most of the error occurred in underpredicting the hottest temperature which lies on the surface of the fuel hole furthest from the center coolant hole and on the 30 degree line of symmetry. For this analysis, the total area was preserved during mesh refinement. This caused the nodes along the

Fig. 3. Temperature field (°F) (1/12th sector - Mesh B4)

Fig. 4. Maximum temperature differences (1/12th sector)

Fig. 5. Coolant hole circumference temperature profiles (1/12th sector)

Fig. 6. Fuel hole circumference temperature profiles (1/12th sector)

Fig. 7. X-Axis temperature profiles (1/12th sector)

Fig. 8. Thirty degree line of symmetry temperature profiles (1/12th sector)

fuel hole surface to move towards the hole center so a linear extrapolation was actually employed. The error in the maximum temperature difference, however, is most likely not due to any error in this extrapolation process but rather results from the use of the inaccurate coarse mesh temperature field.

3.2. ONE-TWELTH SECTOR THERMAL STRESS ANALYSIS

The SAFIRE code (Reference 3) was used to find the resultant thermal stress arising in the one-twelfth sector due to the nonuniform temperature field between the fuel and coolant holes. Generalized plane strain analyses were performed for all seven meshes using the nodal temperatures found via the TEPC-2D analyses. The H-451 graphite material property module built into the SAFIRE code was utilized. For this elastic analysis, only the temperature dependent elastic moduli, linear coefficients of thermal expansion, and Poisson's ratios for both axial and in-plane directions were required.

The adiabatic boundaries along the x-axis and the 30° line of symmetry were treated as lines of structural symmetry (zero shear stress, zero net transverse force, and zero rotation of the line) as shown in Figure 9 for mesh B4. The details of the SAFIRE analyses including sample data input listings are given in Appendix C.

Contour plots for the axial (SZZ) stress and the three plane (SXX, SYY, SXY) stress components for mesh B4 are shown in Figures 10 through 13. The maximum tensile stresses for both the axial and in-plane (radial) directions occur at the coolant hole surface on the 30° line of symmetry: the coolest point in the sector. This maximum in-plane stress is the hoop stress around the coolant hole. The maximum compressive stresses for both the axial and in-plane directions occur at the hottest point in the sector: at the outer edge of the fuel hole on the 30° line of symmetry. This maximum in-plane stress is the hoop stress around the fuel hole. The locations of these peak stress values are indicated in Figure 9.

Fig. 9. Finite element grid (1/12th sector - Mesh B4)

Fig. 10. SZZ stress (1/12th sector)

Fig. 11. SXX stress (1/12th sector)

Fig. 12. SY Y stress (1/12th sector)

Fig. 13. SXY stress (1/12th sector)

Figure 14 shows the peak stress values in both tension and compression as calculated with the seven meshes. The percent error in the maximum temperature difference and in the peak tensile and compressive stresses for all meshes compared to those predicted by mesh B4 is given in Figure 15. As seen in this figure, the peak stress values are predicted to within about ten percent of the mesh B4 values at mesh fineness level B3, while the coarsest mesh B1 has a sixty-two percent error in predicting the compressive stress near the fuel hole and a twenty-one percent error in predicting the tensile stress near the coolant hole.

The peak stresses are plotted versus the maximum temperature difference for all meshes in Figure 16. The axial stress is seen to be nearly linear with increasing temperature difference. In actuality, the axial stress is directly proportional to the difference between the element mean temperature and the temperature at the point of interest which for this problem is approximately one-half of the maximum temperature difference; therefore, the linearity of the stress-temperature difference relation is nearly maintained. (The in-plane stress is also proportional to the temperature difference but the shape of the temperature field affects the relation.) Finally, in Figure 17, the percent error in peak stress values is plotted versus the percent error in the maximum temperature difference where the error is again defined relative to the mesh B4 values.

Figures 16 and 17 together illustrate the resulting error in stress prediction due to the combined errors in temperature prediction and in mesh fineness. In order to separate the effect of the temperature error from the structural stiffness error, it is noted that if the structural mesh were fully refined, yet the coarse mesh temperature field were used in the stress analysis, the percent error in the stresses would be nearly equal to the percent error in the temperature differences. Thus, it is approximately correct to assume that any percent error in excess of the temperature error is due solely to the structural modeling. Thus, the error in the fuel hole hoop stress of eleven percent for mesh B3 is primarily due to mesh coarseness and not due to the associated one per-

Fig. 14. Peak stress values (1/12th sector)

Fig. 15. Peak stress and maximum temperature difference errors (1/12th sector)

Fig. 16. Peak stress vs maximum temperature difference (1/12th sector)

Fig. 17. Percent error - peak stress vs max temperature difference (1/12th sector)

cent error in temperature difference (see Figure 17). Table 1 (page 3-51) gives a summary of the error for the maximum temperature differential and peak stress values for all meshes.

The test for convergence for the stress field (a tensor variable) is more complex than that for temperature (a scalar variable) and requires an examination of the entire field rather than just the peak values. Although the values of the resolved scalar displacements, DELX, along the x-axis (Figure 18) and DELR, along the 30° line of symmetry (Figure 19) reveal no anomalies for all meshes, plots of the scalar components of the stress tensor along the x-axis do. Figure 20 shows the value of SYX (the stress component on the face of a stress cube with constant Y coordinate value and acting in the Y direction) along the x-axis. (This stress component becomes the hoop stress around the center coolant hole.) The discontinuity in this variable that occurs at the x coordinate value of 0.64 inches (as shown in Figure 20 and in more detail in the blow up of this region in Figure 21) is related to the change in the finite element pattern or orientation at this location (see Figure 9). It results primarily from the difference in mechanical and free thermal strains (in the y direction) between adjacent elements; the mechanical strain is controlled by the y displacement of the common node off the x-axis (the common node on the x-axis has zero y displacement), but the free thermal strain has a variation between elements. One way to avoid this is to maintain a consistent element slash pattern.

The magnitude of any such discontinuity decreases with increasing mesh fineness and is only 70 psi or five percent of the peak SYX value at mesh level B4. The value of the SXX stress component along the x-axis also reveals this discontinuity as well as smaller ones for x values of 0.44 inches and 0.85 inches as shown in Figure 22. The axial stress component, SZZ, along the x-axis varies smoothly with no jumps and appears well predicted for meshes finer than B2 as shown in Figure 23. The in-plane shear stress component, SXY, which should be zero along the x-axis since it is a line of structural symmetry, is shown in Figure 24 for all meshes.

Fig. 18. Displacement (in.) along X-Axis in X direction (1/12th sector)

Fig. 19. Radial displacement (in.) along thirty degree line of symmetry (1/12th sector)

Fig. 20. SYX stress (PSI) along X-Axis (1/12th sector)

Fig. 21. Detailed blowup of SYX stress (1/12th sector)

Fig. 22. SXX stress along X-Axis (1/12th sector)

Fig. 23. SZZ stress along X-Axis (1/12th sector)

Fig. 24. SXY stress along X-Axis (1/12th sector)

Finally, to provide perspective, all four stress components are plotted along the x-axis for mesh level B4 in Figure 25.

To provide more insight to the stress field along the 30° line of symmetry, the in-plane cartesian stress components SXX, SYY, and SXY may be transformed to the in-plane polar coordinate stress components SRR, STT, and SRT via the stress transformation laws (Reference 4). The radial stress component, SRR, should vanish at the hole boundaries and the STT stress component becomes the peak tensile hoop stress for the coolant hole and the peak compressive hoop stress for the fuel hole at radii of 0.31 inches and 0.99 inches, respectively. These components are shown in Figures 26 and 27 for all meshes and are seen to be strong functions of the radius. These figures illustrate the difficulty in accurate stress calculations without extremely fine meshes. Figure 28 shows the axial stress component, SZZ, for all meshes along this line of symmetry. Finally, for additional perspective, all four stress components are shown in Figure 29 along the upper boundary of the one-twelfth sector (30° line plus fuel hole boundary) for mesh B4.

3.3 ONE-HALF SECTOR MECHANICAL LOAD

To assess the accuracy in predicting displacements and stresses under mechanical loading, a one-half sector of the seven hole element was used as the model. Two series of uniformly refined meshes were created by first successively flipping the one-twelfth sector meshes B1 and C1 about their lines of symmetry (referred to as HB1 and HC1, respectively) and then refining these two meshes. The most refined mesh, HC3, has 16 times the number of elements (2304) as mesh HC1 (144) and about 38 times as many elements as mesh HB1 (60). In addition, local refinement of the center regions of HB1 and HC1 was used to create two series of embedded fine meshes. The center region of HB1 was also extracted and thrice refined to obtain a series of extracted meshes. All these meshes are shown in Appendix A.

Fig. 25. Thermal stress along X-Axis (1/12th Sector - Mesh B4)

Fig. 26. SRR stress along thirty degree line of symmetry (1/12th sector)

Fig. 27. STT stress along thirty degree line of symmetry (1/12th sector)

Fig. 28. SZZ stress along thirty degree line of symmetry (1/12th sector)

Fig. 29. Thermal stress along thirty degree line of symmetry (1/12th sector - Mesh B4)

The loading, restraint, and symmetry conditions applicable to the half element analyses are shown in Figure 30 for mesh HC1. The load consisted of a uniform pressure of 100 psi on one face which is restrained on the opposite side by a rigid frictionless surface. In retrospect, a one-quarter element model with symmetrical loading would probably have sufficed for this study and allowed a finer mesh pattern. The SAFIRE code was used to find the resultant displacement and stress fields for all cases. The details of the analysis along with sample listings of data input and code output are presented in Appendix D.

The undeformed and deformed meshes for mesh HC3 under the 100 psi static pressure load are presented for comparison in Figures 31 and 32, respectively. The deformations in Figure 32 are 100 times true size. Contour plots of the in-plane stress components, SXX, SYX, and SXY are shown in Figures 33, 34, and 35, respectively. The peak in-plane tensile stress is the SYX (hoop) stress that occurs at the surface of the center coolant hole on the x-axis as shown in Figure 34. Peak values for the in-plane compressive stresses are also hoop stresses that occur on both coolant and fuel holes. These are also shown in Figure 34. For additional insight to the stress field, the values of the three in-plane stress components for mesh HC3 along the positive x-axis are shown in Figure 36.

This displacement in the x direction, DELX, along the x-axis is shown in Figure 37 for the six uniformly refined meshes (URM) HB1, HC1, etc. The displacement along this axis in the Y direction is, of course, zero since this is a line of structural symmetry. The stress component, SYX, along the x-axis for these same six meshes is shown in Figure 38. This stress becomes the hoop stress at the edge of the center hole, and Figure 38 illustrates its highly peaked nature and consequent poor evaluation with coarse mesh analyses. The hoop stress around the center hole may be found via the stress transformation laws from cartesian to polar coordinates. The STT or hoop stress component versus

Fig. 30. One half seven hole element (Mesh HC1)

Fig. 31. Finite element grid (1/2 element - Mesh HC3)

Fig. 32. Deformation field (100 x true size) of one-half element under 100 PSI load (Mesh HC3)

Fig. 33. SXX stress (1/2 element)

Fig. 34. SYY stress (1/2 element)

Fig. 35. SXY stress (1/2 element)

Fig. 36. Stresses along X-Axis for 100 PSI load (1/2 element)

Fig. 37. Displacement along X-Axis for 100 PSI load (1/2 element)

Fig. 38. SYX stress along X-Axis for 100 PSI load (1/2 element)

angular coordinate, θ , for the positive X, Y quadrant is shown in Figure 39 as calculated using the six meshes.

The percent error in the peak tensile hoop stress and in the x displacements for the points on the x-axis at the load face (LF) and at the coolant hole (CH) edge, relative to the HC3 values, are shown in Figure 40 for all six meshes. As this figure illustrates, the coarsest mesh, HB1, underpredicts the peak tensile stress by about sixty-six percent while underpredicting the x displacement at the same location by about thirty-nine percent. In Figure 41, the ratio of the peak stress predicted by each mesh relative to that by HC3 is plotted versus the ratio of the x displacement prediction relative to that from HC3. When allowance is taken for the differences between the HB and HC mesh patterns, two straight lines result. The cause of this linearity is not obvious but may relate in a general way to the load/deflection relation for a linear elastic spring.

The peak in-plane tensile stress predicted by the series of uniformly refined meshes (URM) HB1, HC1, etc., is shown in Figure 42. As indicated in this figure, the solution probably has not converged but for purposes of this study, mesh HC3 was taken as the reference case. Also indicated in this figure is the peak tensile stress as calculated using the so-called embedded meshes which have local refinement of the center regions of the HB series of meshes (HB1EMB1, HB2EMB2, etc.) and the peak stress as calculated using the extracted and refined meshes (HB1EXT1, HB2EXT2, etc.).

As Figure 42 illustrates, the embedded mesh concept can provide a means of obtaining relatively accurate results with far fewer elements and less expense, e.g. the embedded mesh HB2EMB2 calculates over ninety percent of the peak stress predicted by mesh HC3 but has only twenty-three

Fig. 39. STT (Hoop) stress around center hole for 100 PSI load (1/2 element)

Fig. 40. Percent error in peak stress and displacements for 100 PSI load (1/2 element)

Fig. 41. Percent error - peak stress vs Y displacement for 100 PSI load (1/2 element)

Fig. 42. Peak stress for 100 PSI load for all one half element meshes

percent as many finite elements. The difficulty in using the method occurs in assessing its accuracy which depends both upon the ratio of embedded to total area and upon the fineness of mesh outside and inside the embedded region. The latter effect is indicated by the curves for HB1EMB and HB2EMB. The embedded to total area ratio in this study was about 0.23 for all cases. Accuracy would improve as this ratio approaches unity.

Finally, the curves for HB1EXT and HB2EXT indicate that the solutions using the extraction technique as currently formulated depend greatly upon the accuracy of the overall coarse mesh displacement field from which the displacement boundary conditions for the extracted mesh analyses are derived.

TABLE 1
ONE-TWELTH SECTOR ANALYSIS ACCURACY RESULTS

Model	No. of Elements	No. of Nodes	$\Delta T_{\max}$	Error (%) ⁽¹⁾		Peak Axial Stress	
				Peak In-Plane Stress		Tensile	Compressive
				Tensile	Compressive		
B1	10	12	-10.6	-21.1	-62.0	-18.5	-41.5
C1	24	23	-5.6	-15.9	-37.9	-10.3	-22.9
B2	40	33	-3.4	-7.1	-33.2	-6.3	-18.5
C2	96	69	-1.4	-6.9	-13.1	-3.6	-6.4
B3	160	105	-0.7	-2.1	-10.9	-1.6	-4.9
C3	384	233	-0.1	-2.0	-1.0	-0.9	-0.3
B4	640	369	0	0	0	0	0

Notes: (1) Minus (-) sign indicates under prediction.

TABLE 2
ONE HALF ELEMENT ANALYSIS ACCURACY RESULTS 100 PSI LOAD

Model	Number of Elements	Number of Nodes	Error (%) ⁽¹⁾⁽²⁾	
			Displacement Along X Axis At Center Hole	Peak Stress
HB1	60	50	39.3	64.9
HB1EXT1	96	71	39.4	64.9
HB1EMB1	138	97	25.6	37.5
HC1	144	106	23.4	56.2
HB2	240	162	18.8	30.4
HB1EXT2	384	237	39.5	65.1
HB2EXT1	384	237	18.9	31.9
HB1EMB2	438	263	17.0	19.6
HB2EMB1	540	328	9.1	9.7
HC2	576	358	8.3	20.0
HB3	960	556	4.1	5.0
HB2EXT2	1536	857	19.0	30.6
HB1EMB3	1614	883	14.2	14.7
HB2EMB2	1716	948	5.9	4.2
HC3	2304	1294	0	0

Notes: (1) Percent error is relative to HC3 values.
(2) All values are under predictions.

4. REFERENCES

1. Tzung, F., and C. Charman, "TEPC-2D A User's Manual for the Two Dimensional Finite Element Computer Program for Thermal-Elastic-Plastic-Creep Analysis," Gulf- GA-A-A12753, November 7, 1973.
2. Plaehn, M.H., D. Pelessone, and P.D. Smith, "REFINE, A Computer Program to Locally Refine Triangular Finite Element Meshes," Doc. No. 904423/1, November, 1979.
3. Tang, P.Y., and P.D. Smith, "SAFIRE A Two Dimensional Computer Program for the Viscoelastic/Cracking Analysis of Graphite Structures: Part 1 - User's Manual," GA-A14652, September, 1977.
4. Huges, W.F., and E.W. Gaylord, Basic Equations of Engineering Science, Schaum's Outline Series, McGraw-Hill Co., New York, 1964, pp 87-88.
5. Zienkiewicz, O.C., The Finite Element Method in Engineering Science, McGraw-Hill Co., London, 1971.

APPENDIX A FINITE ELEMENT MESHES

Figs. A1 through A7 show the finite element meshes used for the one-twelfth sector thermal and stress analyses. Figs. A8 through A21 show the meshes used for the one-half element mechanical load analysis. The total area is preserved in all refinements for both the one-twelfth sector and the one-half element meshes.

Fig. A1. One twelfth sector of seven hole element (Mesh B1)

Fig. A2. One-twelfth sector of seven hole element (Mesh C1)

Fig. A3. One twelfth sector of seven hole element (Mesh B2)

Fig. A4. One-twelfth sector of seven hole element (Mesh C2)

Fig. A5. One-twelfth sector of seven hole element (Mesh B3)

Fig. A6. One-twelfth sector - seven hole element (Mesh C3)

Fig. A7. One-twelfth sector - seven hole element (Mesh B4)

Fig. A8. One-half seven hole element (Mesh HB1)

Fig. A9. One-half seven hole element (Mesh HC1)

Fig. A10. One-half seven hole element (Mesh HB2)

Fig. A11. One-half seven hole element (Mesh HC2)

Fig. A12. One-half seven hole element (Mesh HB3)

Fig. A13. One-half seven hole element (Mesh HC3)

Fig. A14. One-half seven hole element (Mesh HB1EMB1)

Fig. A15. One-half seven hole element (Mesh HB1EMB2)

Fig. A16. One-half seven hole element (Mesh HB1EMB3)

Fig. A17. One-half seven hole element (Mesh HB2EMB1)

Fig. A18. One-half seven hole element (Mesh HB2EMB2)

Fig. A19. 1st refine. of extract. from Mesh HB1, Mesh HB1EXT1

Fig. A20. 2nd refine. of extract. from Mesh HB1, Meshes HB1EXT2 and HB2EXT1

Fig. A21. 3rd refine. of extract. from Mesh HB1, Mesh HB2EXT2

APPENDIX B ONE-TWELFTH SECTOR THERMAL ANALYSIS

B.1 INTRODUCTION

The two dimensional finite element code, TEPC-2D, was used for the symmetrical one-twelfth sector analysis. TEPC-2D solves the two dimension heat conduction equation:

$$\nabla \cdot k \nabla T + \dot{q}''' = \frac{d}{dt} \rho c T,$$

where $\nabla = \hat{i} \frac{d}{dx} + \hat{j} \frac{d}{dy}$, the vector differential operator,

k = thermal conductivity, Btu/h-ft-°F,

T = local temperature, °F,

$\dot{q}'''$ = volumetric heat generation rate, Btu/h-ft³,

ρ = material density, lb/ft³,

c = specific heat, Btu/lb °F, and

t = time, hr .

Various boundary conditions (adiabatic, heat flux, etc.) may be imposed. A steady-state solution of this equation for the geometrical web of symmetry with zero axial heat conduction and with constant material properties may be found in Ref. B-1. For the one-twelfth sector no such analytic solution exists, and a numerical solution was used to solve the steady-state problem with zero volumetric heat generation and constant thermal conductivity. The above equation then reduces to the Laplace's equation in T

$$\nabla^2 T = 0 ,$$

where $\nabla^2 = \frac{d^2}{dx^2} + \frac{d^2}{dy^2}$

The boundary conditions employed were convective cooling on the center hole, a surface heat flux on the other hole, and adiabatic conditions on the two lines of symmetry and the outer surface.

B-2 PROBLEM DESCRIPTION

For the seven hole element (Fig. 1), the 0.625 in. diameter center hole was considered as a coolant hole with a mass flow rate of 300 lbm/hr, a centerline coolant temperature of 1200°F, and a convective heat transfer coefficient for fully turbulent flow. The six 0.5 in. diameter surrounding holes on a 0.74 in. pitch circle were considered as fuel holes with uniform surface heat fluxes of 48,800 Btu/hr-ft². All of the thermal and flow data were taken as representative of HTGR conditions; however, for the purposes of this study in which only differential temperatures are important, other values could have been equally well employed.

A one-twelfth sector (Fig. 2) has two lines of geometrical symmetry which were treated as adiabatic boundaries. For simplicity, the outer surface was also considered as adiabatic.

B-3 FLOW AND MATERIAL CONDUCTIVITY DATA

For turbulent flow in the center coolant hole, the following equation from Ref. B-2 was used for the convective heat transfer coefficient, h :

$$h = 0.02 \frac{K_h}{D} N_{Re}^{0.8} N_{Pr}^{0.4} \text{ Btu/hr-ft}^2\text{-}^\circ\text{F (for } N_{Re} > 6000),$$

where K_h = coolant thermal conductivity evaluated at local bulk coolant temperature, T_c , Btu/hr-ft-°F,
 D = coolant hole diameter, ft,

N_{Re} = Dimensionless Reynolds number evaluated at local bulk coolant conditions, and

N_{Pr} = Dimensionless Prandtl number evaluated at local bulk coolant temperature.

The Reynolds number is defined as

$$N_{Re} = VD \rho / \mu,$$

where V = flow velocity, ft/hr ,
 ρ = fluid density, lb_m/ft³, and
 μ = fluid viscosity, lb_m/ft-hr.

Since the mass flow rate, $\dot{M}$, is given by

$$\begin{aligned} \dot{M} &= \rho VA \quad , \quad A = \text{hole area in ft}^2 \quad , \\ &= \rho V \pi D^2/4 \quad , \end{aligned}$$

then $VD \rho = 4\dot{M}/\pi D \quad ,$

so $N_{Re} = 4\dot{M}/\pi \mu D \quad .$

The Prandtl number is defined as

$$N_{Pr} = c_p \mu / K_h \quad ,$$

where c_p = specific heat of fluid, Btu/lb_m-°F .

From Ref. B-2 for helium

$$c_p = 1.242 \quad ,$$

$$\mu = 6.9 * 10^{-4} T_c^{0.674} \quad ,$$

$$K_h = 1.29 * 10^{-3} T_c^{0.674} \quad .$$

The Prandtl number is then

$$N_{Pr} = 0.664 \quad .$$

For a typical HTGR coolant hole mass flow rate of $300 \text{ lb}_m/\text{hr}$ with a center line coolant temperature of 1200°F (1660°R) and of 0.625 in. (0.0521 ft) diameter, the Reynold's number is then

$$N_{\text{Re}} = 71800 ,$$

which is clearly fully turbulent.

The convective heat transfer coefficient for a circular hole is then

$$h = 478 \text{ Btu/hr-ft}^2\text{-}^\circ\text{F} .$$

This value is modified by a wetted perimeter factor for a circular hole when modeled by a equal sided polygon as discussed in Section B.5.

For simplicity, the graphite conductivity, K_g , was taken as a constant. The value of $16.0 \text{ Btu/hr-ft-}^\circ\text{F}$ that was used was typically employed in prior HTGR fuel element thermal analyses for zero to one year old graphite (Ref. B-1).

B.4 FUEL HOLE SURFACE HEAT FLUX

The magnitude of the fuel hole surface heat flux, q''_{FH} , was set, in conjunction with the other heat transfer parameters, to be representative of that in HTGR fuel elements. The value used was $48800 \text{ Btu/hr-ft}^2$. For the purposes of this numerical accuracy study, its value was arbitrarily chosen such that the overall element temperature difference be representative of that found in HTGR fuel elements.

B.5 WETTED PERIMETER FACTORS

Both the center coolant hole heat transfer coefficient, h , and the fuel hole surface heat flux, q''_{FH} , were modified to account for the increase in perimeter resulting from modeling circular holes by regular polygons. Since the hole area, A , is preserved during the refinement process,

$$A = \frac{\pi d^2}{4} = \frac{na^2}{4 \tan \alpha} ,$$

where d = hole diameter ,
 n = number of sides of regular polygon ,
 a = length of side of polygon, and
 α = one half of the central angle subtended by a side
of length a
 $= 360^\circ/2n$.

Solving for a ,

$$a = d \left(\frac{\pi \tan \alpha}{n} \right)^{1/2} .$$

The polygon perimeter, P , is na . The wetted perimeter factor F_{wp} , is then

$$F_{wp} = \frac{C}{p} = \frac{\pi d}{na} = \left(\frac{\pi}{n \tan \alpha} \right)^{1/2} ,$$

which approaches unity as n goes to infinity.

The following table gives the wetted perimeter factors for the seven meshes used for the one-twelfth sector thermal analysis.

Mesh	n		Fwp	
	Fuel Hole	Coolant Hole	Fuel Hole	Coolant Hole
B1	6	12	.9523	.9885
C1	12	12	.9885	.9885
B2	12	24	.9885	.9971
C2	24	24	.9971	.9971
B3	24	48	.9971	.9993
C3	48	48	.9993	.9993
B4	48	96	.9993	.9998

B.6 TEPC SAMPLE PROBLEM

Table B-1 lists the input data for the one-twelfth sector mesh B1. The TEPC output is shown in Table B-2 for this problem. Other cases were all similar.

TABLE B.1
TEPC SAMPLE PROBLEM INPUT DATA

```

QED RMS*THERMALDATA.TWSB1
READ-ONLY MODE
CASE UPPER ASSUMED
ED 15R2 6A-B -TUE-01/08/80-14:47:26-(0,)
EDIT
0:>LNPI
1:      ***   SEVEN HOLE BLOCK   - ONE TWELFTH SECTION (MESH B1)   ***
2:
3: PLANE      THERMA
4: GEOMET
5:      10      12      0      10      12
6:      1      1      2      4      1      1.0
7:      2      2      3      4      1      1.0
8:      3      3      4      5      1      1.0
9:      4      4      5      6      1      1.0
10:     5      5      6      8      1      1.0
11:     6      5      7      8      1      1.0
12:     7      7      8      10     1      1.0
13:     8      7      10     11     1      1.0
14:     9      7      9      11     1      1.0
15:    10     9      11     12     1      1.0
16:     1      .3198      0.
17:     2      .2770      .1599
18:     3      .4028      .2326
19:     4      .4400      0.
20:     5      .6409      .0951
21:     6      .6409      0.
22:     7      .8790      .2326
23:     8      .8500      0.
24:     9      .8790      .5075
25:    10      1.14315      0.
26:    11      1.14315      .330
27:    12      1.14315      .660
28: THERMA
29:     1      COOLANT HOLE
30:     1      2      0      0
31:     1      2
32: 1200. 1200.
33: 300.  .664  .625  .9885
34: 48800. .9523
35:     0      NO GAPS
36:     0      NO FIXED NODAL TEMPERATURES
37:     1      ONE HEAT FLUX BOUNDARY FOR FUEL ROD
38:     1      4
39:     3      5      7      9
40:     1      0
41:     1      12      1200.
42:     1      2      .01
43:      1.0      1      1      1      0      0

      Finite
      Element
      Data

      Node
      Data

EOF:43

```

TABLE B.2
TEPC OUTPUT MODEL B1

***		SEVEN HOLE BLOCK		- ONE TWELFTH SECTOR (MODEL B1)		***
PLANE		THERMA				
GEOMET				2		
NUMBER OF ELEMENT		=		10		
NUMBER OF NODES		=		12		
NUMBER OF BLOCKS OF MESH GENERATION		=		0		
NUMBER OF ELEMENTS TO BE READ FROM CARDS		=		10		
NUMBER OF NODES TO BE READ FROM CARDS		=		12		

ELEMENT	I	J	K	MATERIAL	VOLUME
1	1	4	2	1	9.6100-03
2	2	4	3	1	1.5983-02
3	3	4	5	1	2.5134-02
4	4	6	5	1	9.5528-03
5	5	6	8	1	9.9427-03
6	5	8	7	1	2.5697-02
7	7	8	10	1	3.4093-02
8	7	10	11	1	4.3585-02
9	7	11	9	1	3.6307-02
10	9	11	12	1	4.3585-02

NODE	X-ORD	Y-ORD	NODE	X-ORD	Y-ORD
1	.319800	.000000	4	.440000	.000000
2	.277000	.159900	5	.640900	.095100
3	.402800	.232600	6	.640900	.000000
7	.879000	.232600	10	1.143150	.000000
8	.850000	.000000	11	1.143150	.330000
9	.879000	.507500	12	1.143150	.660000

THERMA

* * * 1 COOLANT HOLE

BLOCK NO.= 1 NODES= 2 IFT= 0 IH= 0

LIST OF NODES IN THIS BLOCK

1 2

TABLE B2 (Concluded)

TEPC OUTPUT MODEL B1

INITIAL FLUID TEMPERATURE
1200.01200.0

MASS FLOW = 300.0 LBM/HR
PRANDTL NUMBER = .564
COOLANT HOLE DIA. = .625 IN.
COOLANT HOLE PERIMETER FACTOR = .988

FUEL ROD HEAT FLUX = 48800. BTU/HR/FT-SQ
FUEL HOLE PERIMETER FACTOR = .952

* * * 0 NO GAPS

* * * 0 NO FIXED NODAL TEMPERATURES

* * * 1 ONE HEAT FLUX BOUNDARY FOR FUEL ROD
2 5 7 9

NDCR NUGAP NDFIX NDFLUX
2 0 C 4

* * * * 1 GROUPS C NODES
1200.0 1200.0 1200.0 1200.0 1200.0 1200.0
1200.0 1200.0 1200.0 1200.0 1200.0 1200.0

NO. OF PERIOD = 1 NO. OF ITERATIONS = 2 TOLERANCE = .0100

TIME INCREMENT = 1.00000

NO. OF STEPS = 1

NO. OF PRINT FREQUENCY = 1

STEADY STATE, 1

VARIABLE CONDUCTIVITY, C

RADIATION, C

TOTAL HEAT GENERATED IS .0000 BTU/HR

TIME REQUIRED TO ASSEMBLE THERMAL CONDUCTANCE MATRIX = .0316 SECONDS

PERCENTAGE ERROR = .46847384

PERCENTAGE ERROR = .00000000

NODAL TEMPERATURES FOR TIME = 1.00000

NODE	TEMP.	NODE	TEMP.	NODE	TEMP.
1	1699.77	3	1801.49	5	2037.92
2	1681.35	4	1829.50	6	2029.12
7	2216.03	9	2257.65	11	2228.00
8	2153.47	10	2194.96	12	2245.15

B.7 REFERENCES

1. Saeger, J., "HEXT, A special Purpose Heat Conduction Code for the HTGR Core," GAMD-10534, March 3, 1971.
2. Shenoy, A.S., and D. W. McEachern, "HTGR Core Thermal Design Methods and Analysis," GA-A12985, December 31, 1974.

APPENDIX C
STRESS ANALYSIS OF ONE-TWELFTH AND
ONE-HALF SECTORS

The two dimensional linear finite element code, SAFIRE, was used for the twelfth sector thermal stress and half sector mechanical load analyses. Nodal temperatures from the TEPC code were used in the generalized plane strain analyses of the one-twelfth sector. Due to the geometrical and structural symmetry of this sector, the axial strain is constant across the cross section (zero beam curvatures). To allow for the stress free thermal expansion of the sector, roller boundary conditions are employed on the two lines of symmetry of the sector as shown in Fig. 9. These conditions allow free movement of the sector radially outward along the symmetry lines but yield zero net force across these lines. Since these lines have zero rotation, an in-plane bending moment results. The axial strain condition also leads to a self equilibrated axial bending moment. The input data listing for the one-twelfth sector model B1 is shown in Table C1. The SAFIRE output is given in Table C2. Other twelfth sector cases were similar.

The one-half sector problem has only one line of loading symmetry and roller conditions were also utilized on this line as shown in Fig. 30. A uniform pressure of 100 psi was applied on one face and roller conditions were also employed on the opposite face to simulate a rigid frictionless surface that supplies the reaction force. The input data listing for the half element model HB1 is shown in Table C3. The SAFIRE output for this case is given in Table C4. Other half sector cases are similar.

The material properties used for all cases were from the built-in H-451 graphite module. The element thickness was taken as unity with a hex flat (log radius) dimension of 1.32 in. (the radius of the seven hole element model). The complete set of material properties (assuming a transversely isotropic log) are listed in Table C2 as part of the SAFIRE code output.

TABLE C.1
SAFIRE SAMPLE PROBLEM INPUT DATA

@ED RMS*SAFIREDATA.TW581

READ-ONLY MODE

CASE UPPER ASSUMED

ED 15R2 GA-B -TUE-01/08/80-14:52:47-(0,)

EDIT

0:>LNPI

1:	***	ONE TWELFTH SECTOR (SEVEN HOLE BLOCK) MODEL B1										***	
2:	2	1	1	1	0	1	1	0	70	0	-1	2	CD 2
3:	10	12	1	1	1	0	-1	0	0	-1	0	-1	CD 3
4:	1	5	1	-1	-1	0	0	0	0	0	0	0	CD 3A
5:		0.											CD 3B
6:	0												CD 3C
7:	1												CD 3D
8:	451	0	1										M.O.1
9:	1	1	2	4									CD 4
10:	2	2	3	4									
11:	3	3	4	5									
12:	4	4	5	6									
13:	5	5	6	8									
14:	6	5	7	8									
15:	7	7	8	10									
16:	8	7	10	11									
17:	9	7	9	11									
18:	10	9	11	12									
19:	1	.3198		0.									CD 5
20:	2	.2770		.1599									
21:	3	.4028		.2326									
22:	4	.4400		0.									
23:	5	.6409		.0951									
24:	6	.6409		0.									
25:	7	.8790		.2326									
26:	8	.8500		0.									
27:	9	.8790		.5075									
28:	10	1.14315		0.									
29:	11	1.14315		.330									
30:	12	1.14315		.660									
31:		1.0		1.32		0.		0.		0.			CD 6
32:	1	1699.8	2	1681.4	3	1801.5	4	1829.5	5	2037.9	6	2029.1	CD 10
33:	7	2215.9	8	2153.4	9	2257.5	10	2194.8	11	2227.9	12	2245.0	
34:		0.											CD 11
35:		0.											CD 21
36:	-1.												CD 25
37:	0	1		0.		0.		0.	5				CD 31
38:	1	4	6	8	10								CD 32
39:	0	1		30.		0.		0.	4				CD 31
40:	2	3	9	12									CD 32
41:													CD 32A
42:	0	1	1		0.		0.		0.				CD 36

EOF:42

SAFIRE OUTPUT FOR ONE-TWELFTH
SECTOR SAMPLE PROBLEM THERMAL STRESS ANALYSIS

PPPPPPPP	RRRRRRRR	000000	GGGGGG	RRRRRRRR	AAAAAA	M	M
P P	R R	0 0	G G	R R	A A	MM	MM
P P	R R	0 0	G G	R R	A A	MM	MM
P P	R R	0 0	G	R R	A A	M M	M M
PPPPPPPP	RRRRRRRR	0 0	G	RRRRRRRR	A A	M M	M M
P P	R R	0 0	G GGG	R R	AAAAAAAA	M M	M M
P P	R R	0 0	G G	R R	A A	M	M
P P	R R	0 0	G G	R R	A A	M	M
P P	R R	0 0	G G	R R	A A	M	M
P	R R	000000	GGGGGG	R R	A A	M	M

SSSSSSSS	AAAAAA	FFFFFFFF	IIIIIIII	RRRRRRRR	EEEEEEEE
S S	A A	F	I	R R	E
S S	A A	F	I	R R	E
S	A A	F	I	R R	E
SSSSS	AAAAAA	FFFFF	I	RRRRRRRR	EEEEEE
S	A A	F	I	R R	E
S S	A A	F	I	R R	E
S S	A A	F	I	R R	E
SSSSSSSS	A A	F	IIIIIIII	R R	EEEEEEEE

DATE - 12 JUL 79

TIME - 12:00:49

JADD,P RMS*SAFIREDATA.TWSB1

UN

MSG,A POTANG*SAFIRE4F.

RT,TL POTANG*SAFIRE4F.

IRPUR 27R3 GA-A E33 SL73R1 07/12/79 12:00:42

POTANG*SAFIRE4F(1) ELEMENT TABLE

NAME	VERSION	TYPE	DATE	TIME	SEQ #	SIZE-PRE,TEXT	(CYCLE WORD)	PSRMODE	LOCATION
REDIV	S	FELOCATABLE	29 SEP 75	11:43:18	1	1	5		1792
COMMON		FOR PROC	28 DEC 76	17:51:10	2		51	1 0 1	1798
ASF2		FOR SYMB	28 DEC 76	17:51:21	3		10	5 0 1	1849
ASF2		RELOCATABLE	28 DEC 76	17:51:22	4	2	8		1859
ASRD		FOR SYMB	28 DEC 76	17:51:33	5		10	5 0 1	1869
ASGD		FELOCATABLE	28 DEC 76	17:51:34	6	2	8		1879
ASSEM		FOR SYMB	28 DEC 76	17:51:48	7		36	5 0 1	1889
ASSEM		FELOCATABLE	28 DEC 76	17:51:53	8	3	28		1925
BCELEM		FOR SYMB	28 DEC 76	17:52:02	9		16	5 0 1	1956
BCELEM		FELOCATABLE	28 DEC 76	17:52:06	10	2	15		1972
REAMDF		FOR SYMB	28 DEC 76	17:52:26	11		18	5 0 1	1989
REAMDF		RELOCATABLE	28 DEC 76	17:52:28	12	2	10		2007
BODY		FOR SYMB	28 DEC 76	17:52:43	13		6	5 0 1	2019
BODY		FELOCATABLE	28 DEC 76	17:52:45	14	2	5		2025
BODYIN		FOR SYMB	28 DEC 76	17:52:47	15		10	5 0 1	2032
BODYIN		FELOCATABLE	28 DEC 76	17:52:49	16	2	8		2042
BOUNDC		FOR SYMB	28 DEC 76	17:52:53	17		57	5 0 1	2052
BOUNDC		RELOCATABLE	28 DEC 76	17:53:00	18	3	60		2109
CLEAR		FOR SYMB	28 DEC 76	17:53:11	19		3	5 0 1	2172
CLEAR		FELOCATABLE	28 DEC 76	17:53:12	20	1	2		2175
CLESUM		FOR SYMB	28 DEC 76	17:53:24	21		3	5 0 1	2178
CLESUM		RELOCATABLE	28 DEC 76	17:53:26	22	1	2		2181
CONCHK		FOR SYMB	28 DEC 76	17:53:38	23		13	5 0 1	2184
CONCHK		RELOCATABLE	28 DEC 76	17:53:41	24	3	9		2197
CONTR		FOR SYMB	28 DEC 76	17:53:45	25		12	5 0 1	2209
CONTR		FELOCATABLE	28 DEC 76	17:53:47	26	1	5		2221
CREEP		FOR SYMB	28 DEC 76	17:53:50	27		42	5 0 1	2227
CREEP		FELOCATABLE	28 DEC 76	17:53:56	28	3	43		2269
CRKIND		FOR SYMB	28 DEC 76	17:54:24	29		8	5 0 1	2315
CRKIND		RELOCATABLE	28 DEC 76	17:54:26	30	1	5		2323
DEBTEM		FOR SYMB	28 DEC 76	17:54:27	31		2	5 0 1	2329
DEBTEM		FELOCATABLE	28 DEC 76	17:54:29	32	1	2		2331
DEBUGG		FOR SYMB	28 DEC 76	17:54:43	33		3	5 0 1	2334
DEBUGG		RELOCATABLE	28 DEC 76	17:54:44	34	1	2		2337
DISPRT		FOR SYMB	28 DEC 76	17:54:49	35		19	5 0 1	2340
DISPRT		RELOCATABLE	28 DEC 76	17:54:52	36	2	15		2359
DUBLIN		FOR SYMB	28 DEC 76	17:55:03	37		22	5 0 1	2376
DUBLIN		FELOCATABLE	28 DEC 76	17:55:05	38	2	14		2398
ELADD		FOR SYMB	28 DEC 76	17:55:16	39		14	5 0 1	2414
ELADD		FELOCATABLE	28 DEC 76	17:55:19	40	2	8		2428
ELINIT		FOR SYMB	28 DEC 76	17:56:30	41		32	5 0 1	2438
ELINIT		FELOCATABLE	28 DEC 76	17:56:35	42	3	24		2470
ELPRT1		FOR SYMB	28 DEC 76	17:56:37	43		29	5 0 1	2497
ELPRT1		FELOCATABLE	28 DEC 76	17:56:41	44	2	34		2526
ELPRT2		FOR SYMB	28 DEC 76	17:56:43	45		12	5 0 1	2562
ELPRT2		FELOCATABLE	28 DEC 76	17:56:45	46	2	12		2574
ELPRT3		FOR SYMB	28 DEC 76	17:56:46	47		5	5 0 1	2588

C-4

FLPRT3	PELOCATABLE	28 DEC 76	17:56:47	48	2	4					2593
FACT	FOR SYMB	28 DEC 76	17:56:49	49		71	5	0	1		2599
FACT	RELOCATABLE	28 DEC 76	17:56:54	50	2	34					2670
FORCE	FOR SYMB	28 DEC 76	17:56:56	51		44	5	0	1		2706
FORCE	RELOCATABLE	28 DEC 76	17:57:00	52	3	29					2750
GEOM	FOR SYMB	28 DEC 76	17:57:02	53		26	5	0	1		2782
GEOM	PELOCATABLE	28 DEC 76	17:57:05	54	3	20					2808
GLOBC	FOR SYMB	28 DEC 76	17:57:07	55		18	5	0	1		2831
GLOBC	RELOCATABLE	28 DEC 76	17:57:09	56	2	17					2849
GWEBT	FOR SYMB	28 DEC 76	17:57:10	57		27	5	0	1		2868
GWEBT	RELOCATABLE	28 DEC 76	17:57:12	58	1	22					2895
H327	FOR SYMB	28 DEC 76	17:57:19	59		60	5	0	1		2918
H327	RELOCATABLE	28 DEC 76	17:57:22	60	1	29					2978
H451	FOR SYMB	28 DEC 76	17:57:24	61		61	5	0	1		3008
H451	RELOCATABLE	28 DEC 76	17:57:26	62	1	29					3069
INITL	FOR SYMB	28 DEC 76	17:57:29	63		77	5	0	1		3099
INITL	RELOCATABLE	28 DEC 76	17:57:40	64	3	69					3176
INITLC	FOR SYMB	28 DEC 76	17:57:43	65		40	5	0	1		3248
INITLC	RELOCATABLE	28 DEC 76	17:57:47	66	4	35					3288
IRRADN	FOR SYMB	28 DEC 76	17:58:03	67		7	5	0	1		3327
IRRADN	RELOCATABLE	28 DEC 76	17:58:05	68	2	5					3334
LCHKR	FOR SYMB	28 DEC 76	17:58:06	69		10	5	0	1		3341
LCHKR	RELOCATABLE	28 DEC 76	17:58:07	70	1	9					3351
LOGPOS	FOR SYMB	28 DEC 76	17:58:08	71		5	5	0	1		3361
LOGPOS	RELOCATABLE	28 DEC 76	17:58:09	72	1	3					3366
LOOKUP	FOR SYMB	28 DEC 76	17:58:10	73		8	5	0	1		3370
LOOKUP	PELOCATABLE	28 DEC 76	17:58:11	74	1	8					3378
MAIN	FOR SYMB	28 DEC 76	17:58:14	75		25	5	0	1		3387
MAIN	RELOCATABLE	28 DEC 76	17:58:17	76	3	11					3412
MATIN	FOR SYMB	28 DEC 76	17:58:32	77		118	5	0	1		3426
MATIN	RELOCATABLE	28 DEC 76	17:58:42	78	2	116					3544
MATPRO	FOR SYMB	28 DEC 76	17:58:44	79		34	5	0	1		3662
MATPRO	PELOCATABLE	28 DEC 76	17:58:48	80	3	22					3696
MESH	FOR SYMB	28 DEC 76	17:58:50	81		28	5	0	1		3721
MESH	RELOCATABLE	28 DEC 76	17:58:54	82	3	22					3749
MOVE	FOR SYMB	28 DEC 76	17:58:55	83		3	5	0	1		3774
MOVE	RELOCATABLE	28 DEC 76	17:58:55	84	1	2					3777
MODERC	FOR SYMB	28 DEC 76	17:58:58	85		53	5	0	1		3780
MODERC	PELOCATABLE	28 DEC 76	17:59:06	86	3	39					3833
NOPMF	FOR SYMB	28 DEC 76	17:59:07	87		10	5	0	1		3875
NOPMF	PELOCATABLE	28 DEC 76	17:59:09	88	1	7					3885
PERMAN	FOR SYMB	28 DEC 76	17:59:22	89		6	5	0	1		3893
PERMAN	RELOCATABLE	28 DEC 76	17:59:24	90	2	5					3899
PRESBC	FOR SYMB	28 DEC 76	17:59:27	91		43	5	0	1		3906
PRESBC	RELOCATABLE	28 DEC 76	17:59:34	92	3	32					3949
PRINT	FOR SYMB	28 DEC 76	17:59:36	93		17	5	0	1		3984
PRINT	PELOCATABLE	28 DEC 76	17:59:39	94	1	21					4001
SGINIT	FOR SYMB	28 DEC 76	17:59:44	95		29	5	0	1		4023
SGINIT	PELOCATABLE	28 DEC 76	17:59:48	96	2	16					4052
SMPRT1	FOR SYMB	28 DEC 76	17:59:58	97		24	5	0	1		4070
SMPRT1	PELOCATABLE	28 DEC 76	18:00:02	98	2	23					4094
SMTINT	FOR SYMB	28 DEC 76	18:00:04	99		13	5	0	1		4110
SMTINT	RELOCATABLE	28 DEC 76	18:00:06	100	2	6					4132
SOLVE	FOR SYMB	28 DEC 76	18:00:07	101		42	5	0	1		4140
SOLVE	PELOCATABLE	28 DEC 76	18:00:10	102	2	26					4182
SORT1	FOR SYMB	28 DEC 76	18:00:11	103		16	5	0	1		4210
SORT1	PELOCATABLE	28 DEC 76	18:00:14	104	1	6					4226

STALOC	FOR SYMB	28 DEC 76	18:00:18	105		114	5	0	1	4233
STALOC	PELOCATABLE	28 DEC 76	18:00:34	106	3	87				4347
STFAXI	FOR SYMB	28 DEC 76	18:00:44	107		1	5	0	1	4437
STFAXI	PELOCATABLE	28 DEC 76	18:00:44	108	1	1				4438
STFGPS	FOR SYMB	28 DEC 76	18:00:50	109		17	5	0	1	4440
STFGPS	PELOCATABLE	28 DEC 76	18:00:52	110	2	10				4457
STFPST	FOR SYMB	28 DEC 76	18:00:55	111		19	5	0	1	4469
STFPST	PELOCATABLE	28 DEC 76	18:00:59	112	2	19				4488
STIFF	FOR SYMB	28 DEC 76	18:01:11	113		33	5	0	1	4509
STIFF	PELOCATABLE	28 DEC 76	18:01:15	114	3	28				4542
TFTAPE	FOR SYMB	28 DEC 76	18:01:36	115		8	5	0	1	4573
TFTAPE	PELOCATABLE	28 DEC 76	18:01:38	116	2	4				4581
THERML	FOR SYMB	28 DEC 76	18:01:54	117		11	5	0	1	4587
THERML	PELOCATABLE	28 DEC 76	18:01:56	118	2	8				4598
TIMIN	FOR SYMB	28 DEC 76	18:02:03	119		92	5	0	1	4608
TIMIN	PELOCATABLE	28 DEC 76	18:02:17	120	3	90				4700
CREEPC	PELOCATABLE	29 DEC 76	09:12:36	121	4	39				4793
ELEMC	FOR SYMB	05 JAN 77	10:04:41	122		201	5	0	1	4836
ELEMC	PELOCATABLE	05 JAN 77	10:04:54	123	4	198				5037
BCOUT	FOR SYMB	09 FEB 77	17:05:30	124		56	5	0	1	5239
BCOUT	PELOCATABLE	09 FEB 77	17:05:47	125	3	43				5295
ELECAL	FOR SYMB	09 FEB 77	17:05:58	126		108	5	0	1	5341
ELECAL	PELOCATABLE	09 FEB 77	17:06:12	127	4	71				5449
HH	FOR SYMB	09 FEB 77	17:06:23	128		39	5	0	1	5524
HH	PELOCATABLE	09 FEB 77	17:06:29	129	3	27				5563
STRESS	FOR SYMB	09 FEB 77	17:06:39	130		74	5	0	1	5593
STRESS	PELOCATABLE	09 FEB 77	17:06:46	131	3	55				5667
OPTION	FOR SYMB	27 APR 77	16:54:07	132		153	5	0	1	5725
OPTION	PELOCATABLE	27 APR 77	16:54:13	133	2	129				5878
CREEPC	FOR SYMB	09 MAY 77	10:19:16	134		50	5	0	1	6009
SHUTDC	FOR SYMB	09 MAY 77	10:20:10	135		38	5	0	1	6059
SHUTDC	PELOCATABLE	09 MAY 77	10:20:17	136	4	28				6097
TRITE	FOR SYMB	26 JUL 77	13:35:07	137		34	5	0	1	6129
TRITE	PELOCATABLE	26 JUL 77	13:35:11	138	2	26				6163
DRITE	FOR SYMB	16 MAY 79	13:53:06	139		32	5	0	1	6191
DRITE	PELOCATABLE	16 MAY 79	13:53:32	140	4	27				6223
MAPS	FOR SYMB	07 JUN 79	13:13:12	141		70	5	0	1	6254
MAPS	PELOCATABLE	07 JUN 79	13:14:43	142	3	66				6324
CHGS4C	ELT SYMB	11 JUN 79	11:28:18	143		6	5	0	1	6393
ROTATE	FOR SYMB	11 JUN 79	11:10:18	144		7	5	0	1	6399
ROTATE	PELOCATABLE	11 JUN 79	11:10:27	145	1	4				6406
CHG4F	ELT SYMB	02 JUL 79	11:21:05	146		2	5	0	1	6411
ELASTC	FOR SYMB	02 JUL 79	11:23:16	147		63	5	0	1	6413
ELASTC	PELOCATABLE	02 JUL 79	11:24:19	148	4	46				6476
SAFIRE	MAP SYMB	02 JUL 79	11:24:20	149		9	5	0	1	6526
SAFIRE	ABSOLUTE	02 JUL 79	11:24:20	150		1863				6535
NEXT AVAILABLE LOCATION-										8398

ASSEMBLER PROCEDURE TABLE EMPTY

COBOL PROCEDURE TABLE EMPTY

FORTRAN PROCEDURE TABLE

NAME	LOCATION	SEQ #	D NAME	LOCATION	SEQ #	D NAME	LOCATION	SEQ #
CENTR	51741	2	CONTL	50802	2	CREPP	51527	2
DATA	50861	2	DEBUG	51758	2	ELLOC	51427	2

GECME	51686	2	GLODF	51559	2	GPROPS	50346	2
INOUT	50624	2	LOCCM	51087	2	LOGPO	51543	2
OPTIN	50711	2	SEG	51658	2	SIZE	50990	2
STFOR	51725	2	TIME	51598	2			

ENTRY POINT TABLE EMPTY

JELT,D RMS*SAFIREDATA.TWSB1
ELT 8R1 S74Q1C 07/12/79 12:00:45 (0)

END ELT. ERRORS: NONE. TIME: 0.104 SEC. IMAGE COUNT: 42

QASG,A RMS*SAFTWSB1.

QUSE 9,RMS*SAFTWSB1

QXQT POTANG*SAFIRE4F.SAFIRE

ONE TWELFTH SECTOR (SEVEN HOLE BLOCK) MODEL B1

CARD 2 - OPTIONS

INDELT	ITYPE	IFTYPE	NTMP	NDOSE	NTMUN	NTIMUN	NSTEP	NCMAX	NORM	NRSTAR	ITAPE
2	1	1	1	0	1	1	0	70	0	-1	2

THIS IS A GENERALIZED PLANE STRAIN ANALYSIS

TEMPS INPUT ON NODAL POINT BASIS

DOSES INPUT ON NODAL POINT BASIS

TEMPERATURES VARY SPATIALLY, CONSTANT WITH TIME

FAST FLUX IS UNIFORM AND CONSTANT

TEMPERATURES ARE INPUT AND OUTPUT IN DEG F

TIMES ARE INPUT AND OUTPUT IN DAYS

TIME STEP IS CONSTANT FOR ALL STEPS

CORE SIZE FOR THIS RUN IS 70 K WORDS

INFINITY NORM (MAXIMUM ABSOLUTE VALUE)

NO RESTART TAPES TO BE MOUNTED. ALL INPUT ON CARDS

DISPLACEMENTS AS WELL AS STRESSES, STRAINS, AND STRESS RATIOS WILL BE SAVED ON TAPE

CARD 3 - PROBLEM INDICES

NUMELT	NUMNOD	NTIME	NSTART	NSTOP	NSHUT	NOCREP	ISKIPK	NBC	NPRES	NGLO	NOBF
10	12	1	1	1	0	-1	0	0	-1	0	-1

NUMELT = 10 NUMBER OF FINITE ELEMENTS IN MESH

NUMNOD = 12 NUMBER OF NODES IN MESH

NTIME = 1 NUMBER OF TIME POINTS IN HISTORY

NSTART = 1 START TIME FOR CALCS IN THIS RUN

NSTOP = 1 STOP TIME FOR CALCS IN THIS RUN

NSHUT = 0 NUMBER OF INPUT SHUTDOWN TEMPERATURES

NO CREEP CALCULATION. ONE SHOT ELASTIC ANALYSIS

START-OF-STEP ELASTIC STIFFNESS IS UPDATED FOR EACH TIME STEP

IN-PLANE BOUNDARY CONDITIONS ARE CONSTANT

NO PRESSURE LOADS

OUT-OF-PLANE BOUNDARY CONDITIONS ARE CONSTANT

NO BODY FORCE BEING CONSIDERED

CARD 3A - PRINTOUT OPTIONS

IFAIL	NPTSUM	NSORT	(NPPINT(I), I=1,4)				(IPPINT(I), I=1,4)				NCRAK
1	5	1	-1	-1	0	0	0	0	0	0	

FAILURE CRITERION PASES ON MAXIMUM TENSILE OR COMPRESSIVE STRESS

NPTSUM = 5 NUMBER OF SPATIAL POINTS PRINTED IN STRESS/STRAIN SUMMARY

SUMMARY PRINT SORTED BY MAXIMUM NORMAL STRESS/STRENGTH RATIO

TIME STEP PRINTOUT OPTIONS FOR FOUR BLOCKS GIVEN BELOW

6-1
NPRINT(I)<0 PRINT ALL TIME STEPS
NPRINT(I)=0 NO PRINTOUT FOR THIS BLOCK
NPRINT(I)>0 PRINT NPRINT TIME STEPS

NPRINT(1) = -1 OPTION FOR OPERATING STRESS SUMMARY

NPRINT(2) = -1 OPTION FOR OPERATING STRESS DETAILS

NPRINT(3) = 0 OPTION FOR SHUTDOWN STRESS SUMMARY

NPRINT(4) = 0 OPTION FOR SHUTDOWN STRESS DETAILS

PRINTOUT CONTENT OPTIONS FOR FOUR BLOCKS GIVEN BFLOW

IPRINT(I)<0 PRINT FULL INFORMATION
IPRINT(I)=0 PRINT MAIN RESULT IN ONE TABLE
IPRINT(I)>0 PRINT MAIN AND SECONDARY RESULTS IN TWO TABLES

IPRINT(1) = 0 OPTION FOR OPERATING STRESS SUMMARY

IPRINT(2) = 0 OPTION FOR OPERATING STRESS DETAILS

IPRINT(3) = 0 OPTION FOR SHUTDOWN STRESS SUMMARY

IPRINT(4) = 0 OPTION FOR SHUTDOWN STRESS DETAILS

NO CRACKING ALLOWED

CARD 3P - RELAXATION PARAMETER

RELAXP = 1.000000

CARD 3C - SUBSTEP OPTIONS

NSUBS = 0 NO SUBDIVISION (= 1 SUBSTEP)

CARD 3D - OPTIONS FOR STRESS RATIO IN SORTING PRINTOUT

IRATIO = 1 STRESS RATIO IS CONSTANT FOR ALL TIME STEPS

MATERIAL PROPERTY INPUT OPTIONS

MATERL = 451

MCHG = 0

MPRINT = 1

BUILT-IN DATA FOR H451 HAS BEEN INITIALIZED

BUILT-IN DATA FOR MATERIAL 451 SET 1

ULTIMATE TENSILE STRENGTH (AXIAL) VS. POSITION IN THE LOG

END CENTER	END EDGE	MID-L CENT	MID-L EDGE
.225000+04	.272800+04	.176400+04	.333700+04

ULTIMATE TENSILE STRENGTH (RADIAL) VS. POSITION IN THE LOG

END CENTER	END EDGE	MID-L CENT	MID-L EDGE
.219500+04	.234200+04	.142500+04	.236500+04

BUILT-IN DATA FOR MATERIAL 451 SET 2

AXIAL YOUNG'S MODULUS VS. POSITION IN THE LOG

END CENTER	END EDGE	MID-L CENT	MID-L EDGE
.118000+07	.129000+07	.111000+07	.138000+07

RADIAL YOUNG'S MODULUS VS. POSITION IN THE LOG

END CENTER	END EDGE	MID-L CENT	MID-L EDGE
.110000+07	.107000+07	.980000+06	.112000+07

BUILT-IN DATA FOR MATERIAL 451 SET 3

STRENGTH VS. MODULUS EXPONENTS

AXIAL - (SZ/SZ0) = (EZ/EZ0)**.500

RADIAL - (SR/SP0) = (ER/ER0)**.500

TEMPERATURE DEPENDENCE OF UNIRRADIATED YOUNG'S MODULUS

$E = E0 * (1.0 + .150000-03 * T + .000000 * (T**2))$

BUILT-IN DATA FOR MATERIAL 451 SET 4

YOUNG'S MODULUS CHANGE (PCT) VS. DOSE (10**21 NVT) AT 4 TEMPERATURES (C)

MODULUS CHANGE (PCT) TABLE FOR 400.0 DEG C

TABULATED FUNCTION Y(X) WITH X=DOSE AND Y=EYMC

C-11

FIRST DOSE IN TABLE = .000000
 INCREMENTAL DOSE IN TABLE = .250000*00
 NUMBER OF (X,Y) PAIRS IN TABLE = 33 WITH 8 PER LINE

(.00, .00)	(.25, 83.00)	(.50, 90.50)	(.75, 95.00)	(1.00, 98.10)	(1.25, 100.80)	(1.50, 102.80)	(1.75, 104.80)
(2.00, 106.50)	(2.25, 108.00)	(2.50, 109.80)	(2.75, 111.30)	(3.00, 113.00)	(3.25, 114.50)	(3.50, 116.30)	(3.75, 117.40)
(4.00, 119.30)	(4.25, 121.00)	(4.50, 122.80)	(4.75, 124.30)	(5.00, 126.00)	(5.25, 127.40)	(5.50, 129.00)	(5.75, 130.60)
(6.00, 132.20)	(6.25, 133.80)	(6.50, 135.40)	(6.75, 137.00)	(7.00, 138.60)	(7.25, 140.20)	(7.50, 141.80)	(7.75, 143.40)
(8.00, 145.20)	(						

MODULUS CHANGE (PCT) TABLE FOR 600.0 DEG C

TABULATED FUNCTION Y(X) WITH X =DOSE AND Y =YMC
 FIRST DOSE IN TABLE = .000000
 INCREMENTAL DOSE IN TABLE = .250000*00
 NUMBER OF (X,Y) PAIRS IN TABLE = 33 WITH 8 PER LINE

(.00, .00)	(.25, 68.00)	(.50, 76.80)	(.75, 81.60)	(1.00, 85.30)	(1.25, 88.00)	(1.50, 90.40)	(1.75, 92.00)
(2.00, 93.50)	(2.25, 94.80)	(2.50, 95.50)	(2.75, 96.50)	(3.00, 97.50)	(3.25, 98.40)	(3.50, 99.00)	(3.75, 100.00)
(4.00, 100.80)	(4.25, 101.20)	(4.50, 102.00)	(4.75, 102.80)	(5.00, 103.40)	(5.25, 104.00)	(5.50, 104.70)	(5.75, 105.30)
(6.00, 105.90)	(6.25, 106.50)	(6.50, 107.10)	(6.75, 107.80)	(7.00, 108.40)	(7.25, 109.00)	(7.50, 109.60)	(7.75, 110.20)
(8.00, 110.60)	(						

MODULUS CHANGE (PCT) TABLE FOR 900.0 DEG C

TABULATED FUNCTION Y(X) WITH X =DOSE AND Y =YMC
 FIRST DOSE IN TABLE = .000000
 INCREMENTAL DOSE IN TABLE = .250000*00
 NUMBER OF (X,Y) PAIRS IN TABLE = 33 WITH 8 PER LINE

(.00, .00)	(.25, 54.00)	(.50, 63.80)	(.75, 68.60)	(1.00, 71.40)	(1.25, 73.20)	(1.50, 75.00)	(1.75, 75.70)
(2.00, 76.70)	(2.25, 77.00)	(2.50, 77.30)	(2.75, 78.00)	(3.00, 78.70)	(3.25, 79.30)	(3.50, 80.80)	(3.75, 82.30)
(4.00, 85.20)	(4.25, 90.60)	(4.50, 95.90)	(4.75, 101.00)	(5.00, 106.00)	(5.25, 111.30)	(5.50, 116.80)	(5.75, 122.00)
(6.00, 127.20)	(6.25, 132.40)	(6.50, 137.60)	(6.75, 142.80)	(7.00, 148.00)	(7.25, 153.20)	(7.50, 158.40)	(7.75, 163.60)
(8.00, 169.00)	(						

MODULUS CHANGE (PCT) TABLE FOR 1200.0 DEG C

TABULATED FUNCTION Y(X) WITH X =DOSE AND Y =YMC
 FIRST DOSE IN TABLE = .000000
 INCREMENTAL DOSE IN TABLE = .250000*00
 NUMBER OF (X,Y) PAIRS IN TABLE = 33 WITH 8 PER LINE

(.00, .00)	(.25, 52.00)	(.50, 62.00)	(.75, 66.60)	(1.00, 68.50)	(1.25, 69.00)	(1.50, 69.00)	(1.75, 69.00)
(2.00, 69.00)	(2.25, 69.00)	(2.50, 69.00)	(2.75, 69.00)	(3.00, 69.00)	(3.25, 69.20)	(3.50, 70.00)	(3.75, 70.50)
(4.00, 71.00)	(4.25, 71.50)	(4.50, 72.70)	(4.75, 73.20)	(5.00, 74.30)	(5.25, 75.20)	(5.50, 76.70)	(5.75, 78.10)
(6.00, 79.80)	(6.25, 81.50)	(6.50, 83.40)	(6.75, 85.90)	(7.00, 88.00)	(7.25, 91.20)	(7.50, 94.80)	(7.75, 98.40)
(8.00, 103.00)	(						

BUILT-IN DATA FOR MATERIAL 4F1 SET 5

MULTIAXIAL STRESS/STRAIN PROPERTY RATIOS

ENUXY = .1320 ENUXZ = .1300

PNUXY = .4500 PNUZX = .4500 PCERAT = .8480
 SNUXY = .4500 SNUZX = .4500 SCFRAT = 1.1790

BUILT-IN DATA FOR MATERIAL 451 SET 6

STEADY CREEP MOBILITY (10**-7 IN/IN/(PSI-10**20 NVT)

TABULATED FUNCTION Y(X) WITH X = TEMP AND Y = SCF
 FIRST TEMP IN TABLE = .200000+03
 INCREMENTAL TEMP IN TABLE = .500000+02
 NUMBER OF (X,Y) PAIRS IN TABLE = 25 WITH 8 PER LINE

(200.0, 1.60)	(250.0, 1.67)	(300.0, 1.73)	(350.0, 1.79)	(400.0, 1.86)	(450.0, 1.93)	(500.0, 2.00)	(550.0, 2.08)
(600.0, 2.16)	(650.0, 2.24)	(700.0, 2.33)	(750.0, 2.42)	(800.0, 2.51)	(850.0, 2.60)	(900.0, 2.70)	(950.0, 2.81)
(1000.0, 2.91)	(1050.0, 3.02)	(1100.0, 3.14)	(1150.0, 3.26)	(1200.0, 3.38)	(1250.0, 3.51)	(1300.0, 3.65)	(1350.0, 3.78)
(1400.0, 3.93)							

BUILT-IN DATA FOR MATERIAL 451 SET 7

PRIMARY CREEP SPRING MODULUS (PSI) = PCEZRO * PCE(T)
 PCFZRO = .110000+07
 GRELAX = .200000+00 (PELAXATION DOSE IN 10**20 NVT)

PCE (MULTIPLYING FACTOR) VS. TEMP IN DEG C

TABULATED FUNCTION Y(X) WITH X = TEMP AND Y = PCE
 FIRST TEMP IN TABLE = .000000
 INCREMENTAL TEMP IN TABLE = .500000+02
 NUMBER OF (X,Y) PAIRS IN TABLE = 29 WITH 8 PER LINE

(.0, 2.79)	(50.0, 2.10)	(100.0, 1.93)	(150.0, 1.77)	(200.0, 1.63)	(250.0, 1.49)	(300.0, 1.37)	(350.0, 1.26)
(400.0, 1.15)	(450.0, 1.06)	(500.0, .97)	(550.0, .89)	(600.0, .82)	(650.0, .75)	(700.0, .69)	(750.0, .63)
(800.0, .58)	(850.0, .53)	(900.0, .49)	(950.0, .45)	(1000.0, .41)	(1050.0, .38)	(1100.0, .35)	(1150.0, .32)
(1200.0, .29)	(1250.0, .27)	(1300.0, .24)	(1350.0, .22)	(1400.0, .21)			

BUILT-IN DATA FOR MATERIAL 451 SET 8

THERMAL STRAIN (UNIRADIATED) IN AXIAL (Z) DIRECTION (PCT)

TABULATED FUNCTION Y(X) WITH X = TEMP AND Y = TSZ
 FIRST TEMP IN TABLE = .000000
 INCREMENTAL TEMP IN TABLE = .500000+02
 NUMBER OF (X,Y) PAIRS IN TABLE = 33 WITH 5 PER LINE

(.0, -.800000-02)	(50.0, .800000-02)	(100.0, .260000-01)	(150.0, .420000-01)	(200.0, .600000-01)
(250.0, .800000-01)	(300.0, .100000+00)	(350.0, .120000+00)	(400.0, .142000+00)	(450.0, .165000+00)
(500.0, .188000+00)	(550.0, .212000+00)	(600.0, .235000+00)	(650.0, .260000+00)	(700.0, .283000+00)
(750.0, .310000+00)	(800.0, .335000+00)	(850.0, .358000+00)	(900.0, .384000+00)	(950.0, .410000+00)

(1000.0, .433000+00)	(1050.0, .460000+00)	(1100.0, .489000+00)	(1150.0, .514000+00)	(1200.0, .542000+00)
(1250.0, .570000+00)	(1300.0, .600000+00)	(1350.0, .630000+00)	(1400.0, .660000+00)	(1450.0, .690000+00)
(1500.0, .724000+00)	(1550.0, .755000+00)	(1600.0, .790000+00)	(	

THERMAL STRAIN (UNIRRADIATED) IN RADIAL (X) DIRECTION (PCT)

TABULATED FUNCTION Y(X) WITH X =TEMP AND Y =TSX

FIRST TEMP IN TABLE = .000000

INCREMENTAL TEMP IN TABLE = .500000+02

NUMBER OF (X,Y) PAIRS IN TABLE = 33 WITH 5 PER LINE

(.0, -.800000-02)	(50.0, .110000-01)	(100.0, .320000-01)	(150.0, .520000-01)	(200.0, .740000-01)
(250.0, .950000-01)	(300.0, .120000+00)	(350.0, .143000+00)	(400.0, .168000+00)	(450.0, .193000+00)
(500.0, .219000+00)	(550.0, .246000+00)	(600.0, .275000+00)	(650.0, .303000+00)	(700.0, .332000+00)
(750.0, .358000+00)	(800.0, .388000+00)	(850.0, .416000+00)	(900.0, .441000+00)	(950.0, .473000+00)
(1000.0, .506000+00)	(1050.0, .532000+00)	(1100.0, .562000+00)	(1150.0, .591000+00)	(1200.0, .623000+00)
(1250.0, .653000+00)	(1300.0, .685000+00)	(1350.0, .716000+00)	(1400.0, .750000+00)	(1450.0, .785000+00)
(1500.0, .820000+00)	(1550.0, .852000+00)	(1600.0, .890000+00)	(	

BUILT-IN DATA FOR MATERIAL 451 SET 9

THERMAL STRAIN CHANGE (PCT) VS. DOSE (10**21 NVT) AT 3 TEMPERATURES (C)

7 STRAIN CHG (PCT) AT T = 600.0 DEG C

TABULATED FUNCTION Y(X) WITH X =DOSE AND Y =TSCZ

FIRST DOSE IN TABLE = .000000

INCREMENTAL DOSE IN TABLE = .500000+00

NUMBER OF (X,Y) PAIRS IN TABLE = 17 WITH 8 PER LINE

(.00, .00)	(.50, .60)	(1.00, 1.20)	(1.50, 2.00)	(2.00, 2.60)	(2.50, 3.30)	(3.00, 4.10)	(3.50, 4.70)
(4.00, 5.30)	(4.50, 6.10)	(5.00, 6.80)	(5.50, 7.50)	(6.00, 8.30)	(6.50, 8.80)	(7.00, 9.40)	(7.50, 9.80)
(8.00, 10.30)	(						

2 STRAIN CHG (PCT) AT T = 900.0 DEG C

TABULATED FUNCTION Y(X) WITH X =DOSE AND Y =TSCZ

FIRST DOSE IN TABLE = .000000

INCREMENTAL DOSE IN TABLE = .500000+00

NUMBER OF (X,Y) PAIRS IN TABLE = 17 WITH 8 PER LINE

(.00, .00)	(.50, 1.30)	(1.00, 2.30)	(1.50, 2.80)	(2.00, 3.10)	(2.50, 3.00)	(3.00, 2.70)	(3.50, 2.10)
(4.00, 1.20)	(4.50, .20)	(5.00, -.80)	(5.50, -2.20)	(6.00, -3.40)	(6.50, -4.70)	(7.00, -6.00)	(7.50, -7.40)
(8.00, -8.70)	(						

2 STRAIN CHG (PCT) AT T =1200.0 DEG C

TABULATED FUNCTION Y(X) WITH X =DOSE AND Y =TSCZ

FIRST DOSE IN TABLE = .000000

INCREMENTAL DOSE IN TABLE = .500000+00

NUMBER OF (X,Y) PAIRS IN TABLE = 17 WITH 8 PER LINE

(.00, .00)	(.50, -.30)	(1.00, -.90)	(1.50, -1.80)	(2.00, -3.00)	(2.50, -4.50)	(3.00, -6.10)	(3.50, -8.20)
(4.00, -10.30)	(4.50, -12.60)	(5.00, -15.00)	(5.50, -17.60)	(6.00, -20.10)	(6.50, -22.50)	(7.00, -24.70)	(7.50, -26.90)

(8.00, -29.00) (

X STRAIN CHG (PCT) AT T = 600.0 DEG C

TABULATED FUNCTION Y(X) WITH X =DOSE AND Y =TSCX

FIRST DOSE IN TABLE = .000000

INCREMENTAL DOSE IN TABLE = .500000+00

NUMBER OF (X,Y) PAIRS IN TABLE = 17 WITH 8 PER LINE

(.00, .00) (.50, .60) (1.00, 1.20) (1.50, 2.00) (2.00, 2.60) (2.50, 3.30) (3.00, 4.10) (3.50, 4.70)
(4.00, 5.30) (4.50, 6.10) (5.00, 6.80) (5.50, 7.50) (6.00, 8.30) (6.50, 8.80) (7.00, 9.40) (7.50, 9.80)
(8.00, 10.30) (

X STRAIN CHG (PCT) AT T = 900.0 DEG C

TABULATED FUNCTION Y(X) WITH X =DOSE AND Y =TSCX

FIRST DOSE IN TABLE = .000000

INCREMENTAL DOSE IN TABLE = .500000+00

NUMBER OF (X,Y) PAIRS IN TABLE = 17 WITH 8 PER LINE

(.00, .00) (.50, 1.30) (1.00, 2.30) (1.50, 2.80) (2.00, 3.10) (2.50, 3.00) (3.00, 2.70) (3.50, 2.10)
(4.00, 1.20) (4.50, .20) (5.00, -.80) (5.50, -2.20) (6.00, -3.40) (6.50, -4.70) (7.00, -6.00) (7.50, -7.40)
(8.00, -8.70) (

X STRAIN CHG (PCT) AT T =1200.0 DEG C

TABULATED FUNCTION Y(X) WITH X =DOSE AND Y =TSCX

FIRST DOSE IN TABLE = .000000

INCREMENTAL DOSE IN TABLE = .500000+00

NUMBER OF (X,Y) PAIRS IN TABLE = 17 WITH 8 PER LINE

(.00, .00) (.50, -.30) (1.00, -.90) (1.50, -1.80) (2.00, -3.00) (2.50, -4.50) (3.00, -6.10) (3.50, -8.20)
(4.00, -10.30) (4.50, -12.60) (5.00, -15.00) (5.50, -17.60) (6.00, -20.10) (6.50, -22.50) (7.00, -24.70) (7.50, -26.90)
(8.00, -29.00) (

BUILT-IN DATA FOR MATERIAL 451 SET 10

IRRADIATION STRAIN POLYNOMIAL COEFFICIENTS

Z DIRECTION

1/ .876020+00	2/ -.672670-02	3/ .148110-04	4/ -.123980-07	5/ .327750-11
6/ -.170400+00	7/ .106530-02	8/ -.215420-05	9/ .153100-08	10/ -.323670-12
11/ .237350-02	12/ -.920580-05	13/ .000000	14/ .277540-10	15/ -.169300-13

X DIRECTION

1/ .100882+01	2/ -.715160-02	3/ .150420-04	4/ -.119720-07	5/ .301220-11
6/ -.146140+00	7/ .937810-03	8/ -.192620-05	9/ .137310-08	10/ -.277410-12
11/ .276930-02	12/ -.142850-04	13/ .162470-07	14/ .108030-10	15/ -.122870-13

BUILT-IN DATA FOR MATERIAL 451 SET 11

THERMAL CONDUCTIVITY SCALAR CONSTANTS

KUNIT = .241900+03 (PROGRAM K UNITS)/(CAL/CM-SEC-DEG C)
 TROOM = .270000+02 DEG C
 TBARF = .800000+00 FRACTIONAL DISTANCE (<1.0)
 KALPH = .570700+01 (ALPHA)
 KB = .616500+01 1/LA IN (10**4 CM-1)

ATAU = -.305900+00 TAU = ATAU + BTAU*TJ (DEG C)
 BTAU = .958000-03
 ABTMIN = .600000+03 LOWER LIMIT OF TJ IN TAU EQN.
 CKSAT = -.343000+01 KSAT = EXP(CKSAT + DKSAT*TJ)
 DKSAT = .122200-02

BUILT-IN DATA FOR MATERIAL 451 SET 12

KUT FUNCTION

TABULATED FUNCTION Y(X) WITH X =TEMP AND Y =KUT

FIRST TEMP IN TABLE = -.173000+03

INCREMENTAL TEMP IN TABLE = .500000+02

NUMBER OF (X,Y) PAIRS IN TABLE = 35 WITH 6 PER LINE

(-173.0, 93.50) (-123.0, 48.80) (-73.0, 12.80) (-23.0, 6.38) (27.0, 4.79) (77.0, 3.56)
 (127.0, 2.90) (177.0, 2.56) (227.0, 2.22) (277.0, 2.06) (327.0, 1.91) (377.0, 1.78)
 (427.0, 1.64) (477.0, 1.56) (527.0, 1.48) (577.0, 1.41) (627.0, 1.34) (677.0, 1.28)
 (727.0, 1.23) (777.0, 1.17) (827.0, 1.10) (877.0, 1.06) (927.0, 1.01) (977.0, .98)
 (1027.0, .94) (1077.0, .91) (1127.0, .88) (1177.0, .86) (1227.0, .84) (1277.0, .82)
 (1327.0, .80) (1377.0, .78) (1427.0, .77) (1477.0, .75) (1527.0, .74) (

KBT FUNCTION

TABULATED FUNCTION Y(X) WITH X =TEMP AND Y =KBT

FIRST TEMP IN TABLE = -.173000+03

INCREMENTAL TEMP IN TABLE = .500000+02

NUMBER OF (X,Y) PAIRS IN TABLE = 35 WITH 6 PER LINE

(-173.0, 2.88) (-123.0, 5.95) (-73.0, 9.60) (-23.0, 13.25) (27.0, 16.65) (77.0, 19.58)
 (127.0, 22.50) (177.0, 24.75) (227.0, 27.00) (277.0, 28.65) (327.0, 30.30) (377.0, 31.50)
 (427.0, 32.70) (477.0, 33.70) (527.0, 34.70) (577.0, 35.10) (627.0, 35.50) (677.0, 35.75)
 (727.0, 36.00) (777.0, 36.00) (827.0, 36.00) (877.0, 36.00) (927.0, 36.00) (977.0, 36.00)
 (1027.0, 36.00) (1077.0, 36.00) (1127.0, 36.00) (1177.0, 36.00) (1227.0, 36.00) (1277.0, 36.00)
 (1327.0, 36.00) (1377.0, 36.00) (1427.0, 36.00) (1477.0, 36.00) (1527.0, 36.00) (

KDT FUNCTION

TABULATED FUNCTION Y(X) WITH X =TEMP AND Y =KDT

FIRST TEMP IN TABLE = -.173000+03

INCREMENTAL TEMP IN TABLE = .500000+02

NUMBER OF (X,Y) PAIRS IN TABLE = 35 WITH 8 PER LINE

(-173.0, 4.46) (-123.0, 3.84) (-73.0, 3.21) (-23.0, 3.12) (27.0, 3.02) (77.0, 3.13) (127.0, 3.24) (177.0, 3.37)
 (227.0, 3.51) (277.0, 3.59) (327.0, 3.66) (377.0, 3.72) (427.0, 3.78) (477.0, 3.83) (527.0, 3.88) (577.0, 3.90)
 (627.0, 3.91) (677.0, 3.93) (727.0, 3.94) (777.0, 3.94) (827.0, 3.94) (877.0, 3.94) (927.0, 3.94) (977.0, 3.94)

(1027.0, 3.94)	(1077.0, 3.94)	(1127.0, 3.94)	(1177.0, 3.94)	(1227.0, 3.94)	(1277.0, 3.94)	(1327.0, 3.94)	(1377.0, 3.94)
(1427.0, 3.94)	(1477.0, 3.94)	(1527.0, 3.94)	(				

END OF PROPERTY PRINTOUT

ASG,T 13,D/1/TRK/100000

ASG,T LUSEGC,D/P1/TRK/100000

ASG,T LULOAD,D/78/TRK/100000

ASG,T LUTIME,D/34/TRK/100000

ASG,T LUIBC-,D/24/TRK/100000

ASG,T LUELEM,F2/1/P05/27

C-17 FINITE ELEMENT MESH - ELEMENT DESCRIPTIONS

* ELT	I	J	K	* ELT	I	J	K	* ELT	I	J	K	* ELT	I	J	K
* 1	1	2	4	* 2	2	3	4	* 3	3	4	5	* 4	4	5	6
* 6	5	7	8	* 7	7	8	10	* 8	7	10	11	* 9	7	9	11

FINITE ELEMENT MESH - NODE COORDINATES

* NODE	X COORD.	Y COORD.	* NODE	X COORD.	Y COORD.	* NODE	X COORD.	Y COORD.	* NODE	X COORD.	Y COORD.
* 1	.31980+00	.00000	* 2	.27700+00	.15990+00	* 3	.40280+00	.23260+00	* 4	.44000+00	.00000
* 5	.64090+00	.95100-01	* 6	.64090+00	.00000	* 7	.87900+00	.23260+00	* 8	.85000+00	.00000
* 9	.87900+00	.50750+00	* 10	.11432+01	.00000	* 11	.11432+01	.33000+00	* 12	.11432+01	.66000+00

THICK =	.10000000+01	THICKNESS OF ELEMENT
FLAT =	.13200000+01	HEX FLAT (RADIUS OF LOG)
XCLOG =	.00000000	X COORD OF LOG CENTER
YCLOG =	.00000000	Y COORD OF LOG CENTER
ZBLOG =	.00000000	Z/C OF CROSS SECTION (0=CTR, 1=END)

GLOBAL EQUATION SEGMENTATION CONTROL INFORMATION

SEGMENT NUMBER	FIRST EQUATION	NUMBER OF EQUATIONS	COUPLED SEGMENT	CONTRIBUTING FIRST	ELFMENT RECORDS LAST	SEGMENT RECORD CONTROL	LENGTHS TOTAL
1	1	27	1	1	10	88	279

MAXIMUM HALF BANDWIDTH ----- 27 EQUATIONS

ROOT MEAN SQUARE BANDWIDTH ----- 10 EQUATIONS

MAXIMUM SEGMENT COUPLING ----- 26 EQUATIONS

JASG,T LUSTIF,F2/1/POS/88

*** TEMPERATURE BLOCK INPUT (DEG F) ***

INFORMATION BELOW IS BY NODE INDICES

TEMP MAP IS SPATIALLY VARYING BUT CONSTANT WITH TIME

1/1699.8	2/1681.4	3/1801.5	4/1829.5	5/2037.9	6/2029.1	7/2215.9	8/2153.4	9/2257.5	10/2194.8
11/2227.9	12/2245.0								

*** FAST FLUX INPUT ***

CONSTANT AND UNIFORM FAST FLUX IS .0000000 N/CM**2-SEC

*** INPUT OF TIME DEPENDENT VARIABLES ***
(EXCLUDING BOUNDARY CONDITIONS)

THE CONSTANT TIME STEP IS .000000 DAYS

THE LIST OF TIME VALUES (DAYS) AT THE END OF EACH TIME STEP IS GIVEN BELOW
THESE ARE INTERNALLY CONVERTED TO SECONDS

1/ .000000

PRINT OF BLOCK 1 IS TO BE DONE AT ALL TIMES

PRINT OF BLOCK 2 IS TO BE DONE AT ALL TIMES

PRINT OF BLOCK 3 OMITTED ENTIRELY

PRINT OF BLOCK 4 OMITTED ENTIRELY

NUMBER OF SUBSTEPS IN EACH TIME STEP

***** 1 TIME STEP *****

*** START TIME = .00000 DAY END TIME = .00000 DAYS ***

***** INPUT OF OPERATING BOUNDARY CONDITIONS FOR THE FIRST TIME STEP *****

THIS INCLUDES : (1) IN PLANE BOUNDARY CONDITIONS (CONCENTRATED FORCES AND/OR DISPLACEMENTS)
(2) IN PLANE NORMAL PRESSURE FORCES (FOR PRESSURE LOADING CASE ONLY)
(3) THREE GLOBAL OUT OF PLANE BOUNDARY CONDITIONS (FOR GPS ELEMENT ONLY)

++ INPUT OF IN PLANE BOUNDARY CONDITIONS ++

THIS IS DONE BY GROUPS. FOR EACH GROUP, THE FOLLOWINGS ARE INPUT:

1. (IBCGP(I), I=1,2) -- BOUNDARY CONDITION CODES (0=FORCE), (1=DISP.).

I=1,2 REFER TO ROTATED X,Y DIRECTIONS

2. BETA -- SKEW BOUNDARY ANGLE IN RADIAN BETWEEN X AND ROTATED X AXIS

3. (BCGP(I), I=1,2) -- SPECIFIED CONCENTRATED FORCES IN LB. (WHEN IBCGP=0) OR NODAL DISPLACEMENTS
IN INCHES (WHEN IBCGP=1). I=1,2 REFER TO ROTATED X,Y DIRECTIONS

4. NODBC -- NUMBER OF BOUNDARY NODES

5. A LIST OF BOUNDARY NODE NUMBERS

GROUP NO	(IBCGP(I), I=1,2)	BETA(DEG)	(BCGP(I), I=1,2)	NODBC	BOUNDARY NODE NUMBERS				
1	0	1	.0000000 .0000000 .0000000	5	1	4	6	8	10
2	0	1	.3000000+02 .0000000 .0000000	4	2	3	9	12	

++ INPUT OF OUT OF PLANE BOUNDARY CONDITIONS ++

FORCE/STRAIN OPTION			FORCE/STRAIN VALUE		
(IGLO(J), J=1,3)			(IGLO(J), J=1,3)		
Z	X-ROT	Y-ROT	Z	X-ROT	Y-ROT
0	1	1	.0000000	.0000000	.0000000

AXIAL Z STRAIN BOUNDARY CONDITION IS A FORCE IN LB.

X ROTATION (Y-Z PLANT) BOUNDARY CONDITION IS A CURVATURE IN RADIAN/IN.

Y ROTATION (X-Z PLANT) BOUNDARY CONDITION IS A CURVATURE IN RADIAN/IN.

*** OPERATING *** *** IN PLANE BOUNDARY DISPLACEMENTS *** *** AND/OR NON-ZERO FORCES ***					
NODE	X - X'	B.C. TYPE		BOUNDARY CONDITIONS (LB. OR IN.)	
NO	ANGLE	X	Y	X	Y
1	.00000	FORCE	DISP.	.00000	.00000
2	.52360	FORCE	DISP.	.00000	.00000
3	.52360	FORCE	DISP.	.00000	.00000
4	.00000	FORCE	DISP.	.00000	.00000
6	.00000	FORCE	DISP.	.00000	.00000
8	.00000	FORCE	DISP.	.00000	.00000
9	.52360	FORCE	DISP.	.00000	.00000
10	.00000	FORCE	DISP.	.00000	.00000
12	.52360	FORCE	DISP.	.00000	.00000

DASG,T LUELEQ,F2/1/POS/35

*** TOTAL AREA OF MESH = .253469+00 X CENTROID = .845358+00 Y CENTROID = .214201+00 ***

AFREE LUELEQ.

*** OPERATING DISPLACEMENTS AT END OF TIME STEP 1 ***									
NODAL POINT DISPLACEMENTS									
NP	X - DISP.	Y - DISP.	NP	X - DISP.	Y - DISP.	NP	X - DISP.	Y - DISP.	
1	.1802986-02	.0000000	6	.3482335-02	.0000000	11	.6818584-02	.1903086-02	
2	.1743701-02	.0000000	7	.5035778-02	.1390989-02	12	.7990814-02	.0000000	
3	.2428869-02	.0000000	8	.4789495-02	.0000000				
4	.2365759-02	.0000000	9	.6027444-02	.0000000				
5	.3469562-02	.5374313-03	10	.6658028-02	.0000000				

GLOBAL DEGREES OF FREEDOM		
Z STRAIN	=	.5226423-02
X CURVATURE	=	.0000000
Y CURVATURE	=	.0000000

BEAM STRETCHINGS AND DEFLECTIONS (LENGTH OF BEAM = .10000+01 IN.)

		SIMPLY SUPPORTED	CANTILEVER
AXIAL STRETCHING	IN.	.52264-02	.52264-02
MAX Y DEFLECTION (DUE TO X ROTATION)	IN.	.00000	.00000
MAX X DEFLECTION (DUE TO Y ROTATION)	IN.	.00000	.00000
MAX TOTAL LATERAL DEFLECTION	IN.	.00000	.00000
END ROTATION ABOUT X AXIS (Y-Z PLANE)	RAD.	.00000	.00000
END ROTATION ABOUT Y AXIS (X-Z PLANE)	RAD.	.00000	.00000

** MEANING OF CRACK INDICATOR (CRK IND) IN THE ELEMENT STRESS STRAIN RESULTS PRESENTED ON NEXT PAGE **

CRK IND = 0 -- UNCRACKED FOR ALL TIMES

1 -- CRACKED IN PREVIOUS STATE AND STILL CRACKED

-1 -- CRACKED IN THIS STATE

2 -- HEALED IN PREVIOUS STATE AND STILL HEALED

-2 -- HEALED IN THIS STATE

** WE ASSUME THAT THE CRACKED STATE AT END OF STEP IS THE SAME AS THAT CALCULATED AT START OF STEP. I.E., WE ASSUME THAT IN-STEP CREEP MAKES NO CHANGES IN THE START-OF-STEP CRACKED CONFIGURATION

*** OPERATING STRESS STRAIN AT END OF STEP 1 ***
(.00000 DAYS TO .00000 DAYS)

ELT REC	ELT NO	TEMP (DEG F)	*FAST FLUX* (NVT/SEC)	*END DOSE* (1C**21 NVT)	*YOUNGS MODULI(PST)* R Z	*STRESS COMPONENTS* X XY Y Z	IN-PLANE MAX MIN	PRINC STR ANGLE	*STRESS Z	RATIO* R	CRK Z	IND R
1	1	1736.9	.000	.000	.11305*07 .12893*07	294 -288 1063 1647	1160 198	-71.5	.823	.728	0	0
2	2	1770.8	.000	.000	.11364*07 .12986*07	338 -306 603 1489	804 136	-56.7	.731	.498	0	0
3	3	1889.6	.000	.000	.11555*07 .13277*07	586 -21 226 1066	587 225	-3.4	.497	.350	0	0
4	4	1965.5	.000	.000	.11687*07 .13483*07	235 -69 331 735	367 198	-62.4	.331	.213	0	0
5	5	2073.5	.000	.000	.11943*07 .13906*07	537 -70 -95 292	545 -103	-6.3	.122	.297	0	0
6	6	2135.7	.000	.000	.12119*07 .14204*07	486 213 -13 35	564 -92	20.3	.014	.295	0	0
7	7	2188.0	.000	.000	.12435*07 .14781*07	123 145 -308 -291	168 -352	16.9	-.103	.080	0	0
8	8	2212.9	.000	.000	.12671*07 .15220*07	200 167 -697 -458	230 -728	10.2	-.150	.104	0	0
9	9	2233.8	.000	.000	.12608*07 .15085*07	20 240 -647 -569	9P -724	17.9	-.192	.045	0	0
10	10	2243.5	.000	.000	.12902*07 .15646*07	-273 207 -180 -612	-14 -439	51.3	-.188	-.006	0	0

AFREE LULOAD.

AFREE LUSEGC.

AFREE LUTIME.

AFREE LUIBC-.

AFREE LUELEM.

AFREE LUSTIF.

*
* TIME HISTORY OF MIN = ANG = CONDITIONS
* FOR ELEMENTS WITH MAXIMUM R A D I A L A N D A X I A L STRESS RATIOS
*

<----- RADIAL ----->										<----- AXIAL ----->										<---BEAM DEFLECTIONS---> (SIMPLY SUPPORTED)		
TIME INDX	TIME DAYS	ELEM REC	ELEM NO	TEMP DEG F	DOSE 10**21	STRESS (PSI)	STRESS RATIO	NUM CRK	ELEM REC	ELEM NO	TEMP DEG F	DOSE 10**21	STRESS (PSI)	STRESS RATIO	NUM CRK	X BOW	Y BOW	TOTAL BOW				
1	.00	1	1	1736.9	.000	1160.3	.7282	0	1	1	1736.9	.000	1647.9	.823	0	.000	.000	.000				

TABLE C.3
SAFIRE SAMPLE PROBLEM INPUT DATA
ONE HALF ELEMENT ANALYSIS

@ED RMS*SAFIREDATA.HB1P
READ-ONLY MODE

CASE UPPER ASSUMED

ED 15R2 GA-B -TUE-01/08/80-16:55:04-(0,)

EDIT

0:>LNP!

1:	*** ONE HALF SEVEN HOLE ELEMENT (MODEL B1) - PRESSURE LOADING ***											
2:	2	1	1	0	0	1	1	0	70	0	-1	2 CD 2
3:	60	50	1	1	1	0	-1	0	0	0	0	-1 CD 3
4:	1	10	1	0	-1	0	0	0	0	0	0	0 CD 3A
5:		0.										CD 3B
6:	0											CD 3C
7:	1											CD 3D
8:	451	0	1									M.O.1
9:	1	1	2	6								CD 4
10:	2	2	3	8								
11:	3	2	7	6								
12:	4	2	8	7								
13:	5	3	4	8								
14:	6	4	5	9								
15:	7	4	9	8								
16:	8	5	10	9								
17:	9	6	7	12								
18:	10	6	12	11								
19:	11	7	13	12								
20:	12	9	10	14								
21:	13	10	15	14								
22:	14	11	12	16								
23:	15	12	13	17								
24:	16	12	18	16								
25:	17	12	17	19								
26:	18	12	19	18								
27:	19	13	20	17								
28:	20	13	21	20								
29:	21	14	15	22								
30:	22	14	22	21								
31:	23	16	18	24								
32:	24	16	24	23								
33:	25	17	20	19								
34:	26	18	25	24								
35:	27	19	20	26								
36:	28	20	21	27								
37:	29	20	27	26								
38:	30	21	22	27								
39:	31	23	24	28								
40:	32	24	25	29								
41:	33	24	30	28								
42:	34	24	29	31								
43:	35	24	31	30								
44:	36	25	32	29								

TABLE C.3 (Continued)
SAFIRE SAMPLE PROBLEM INPUT DATA
ONE HALF ELEMENT ANALYSIS

45:	37	25	33	32
46:	38	26	27	34
47:	39	26	34	35
48:	40	28	30	37
49:	41	28	37	36
50:	42	29	32	31
51:	43	30	38	37
52:	44	31	32	39
53:	45	32	33	40
54:	46	32	40	39
55:	47	33	35	41
56:	48	33	41	40
57:	49	34	42	35
58:	50	35	42	41
59:	51	37	38	43
60:	52	38	44	43
61:	53	38	45	44
62:	54	39	40	46
63:	55	39	46	47
64:	56	44	45	48
65:	57	45	47	49
66:	58	45	49	48
67:	59	46	50	47
68:	60	47	50	49
69:	1		.319800+00	.000000
70:	2		.440000+00	.000000
71:	3		.640900+00	.000000
72:	4		.850000+00	.000000
73:	5		.114300+01	.000000
74:	6		.277000+00	.159900+00
75:	7		.402900+00	.232500+00
76:	8		.640900+00	.951000-01
77:	9		.879000+00	.232600+00
78:	10		.114300+01	.330000+00
79:	11		.159900+00	.276900+00
80:	12		.220000+00	.381000+00
81:	13		.402800+00	.507500+00
82:	14		.879000+00	.507500+00
83:	15		.114300+01	.660000+00
84:	16		.373100-04	.319800+00
85:	17		.320500+00	.555000+00
86:	18		.832300-04	.465100+00
87:	19		.238100+00	.602500+00
88:	20		.425000+00	.736100+00
89:	21		.640900+00	.644900+00
90:	22		.857400+00	.825000+00
91:	23		-.159800+00	.276900+00
92:	24		-.219900+00	.381000+00
93:	25		-.238100+00	.602500+00
94:	26		.238100+00	.877500+00
95:	27		.571600+00	.990000+00

CD 5

TABLE C.3 (Concluded)
SAFIRE SAMPLE PROBLEM INPUT DATA
ONE HALF ELEMENT ANALYSIS

EOF:132

***** *** ONE HALF SEVEN HOLE ELEMENT (MODEL 91) - PRESSURE LOADING *** *****

CARD 2 - OPTIONS

INDELT	ITYPE	IFTYPE	NTMP	NDOSE	NTEMUN	NTIMUN	NSTEP	NOMAX	NORM	NRSTAR	ITAPE
2	1	1	0	0	1	1	0	70	0	-1	2

THIS IS A GENERALIZED PLANE STRAIN ANALYSIS

TEMPS INPUT ON NODAL POINT BASIS

DOSES INPUT ON NODAL POINT BASIS

TEMPERATURES UNIFORM AND CONSTANT

FAST FLUX IS UNIFORM AND CONSTANT

TEMPERATURES ARE INPUT AND OUTPUT IN DEG F

TIMES ARE INPUT AND OUTPUT IN DAYS

TIME STEP IS CONSTANT FOR ALL STEPS

CORE SIZE FOR THIS RUN IS 70 K WORDS

INFINITY NORM (MAXIMUM ABSOLUTE VALUE)

NO RESTART TAPES TO BE MOUNTED. ALL INPUT ON CARDS

DISPLACEMENTS AS WELL AS STRESSES, STRAINS, AND STRESS RATIOS WILL BE SAVED ON TAPE

CARD 3 - PROBLEM INDICES

NJMELT	NUMNOD	NTIME	NSTART	NSTOP	NSHUT	NDCREP	ISKIPK	NBC	NPRES	NGLO	NOBF
60	50	1	1	1	0	-1	0	0	0	0	-1

NJMELT = 60 NUMBER OF FINITE ELEMENTS IN MESH

NUMNOD = 50 NUMBER OF NODES IN MESH

NTIME = 1 NUMBER OF TIME POINTS IN HISTORY

NSTART = 1 START TIME FOR CALCS IN THIS RUN

NSTOP = 1 STOP TIME FOR CALCS IN THIS RUN

NSHUT = 0 NUMBER OF INPUT SHUTDOWN TEMPERATURES

NO CREEP CALCULATION. ONE SHOT ELASTIC ANALYSIS

START-OF-STEP ELASTIC STIFFNESS IS UPDATED FOR EACH TIME STEP

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SAMPLE PROBLEM MECHANICAL LOAD ANALYSIS

SAFIRE OUTPUT FOR ONE-HALF SECTOR

TABLE C4

IN-PLANE BOUNDARY CONDITIONS ARE CONSTANT
 EDGE NORMAL PRESSURES ARE CONSTANT
 OUT-OF-PLANE BOUNDARY CONDITIONS ARE CONSTANT
 NO BODY FORCE BEING CONSIDERED

 CARD 3A - PRINTOUT OPTIONS

IFAIL,	NPTSUM,	NSORT	(NPRINT(I), I=1,4)				(IPRINT(I), I=1,4)				NCRAK
1	10	1	0	-1	0	0	0	0	0	0	0

 FAILURE CRITERION BASES ON MAXIMUM TENSILE OR COMPRESSIVE STRESS

NPTSUM = 10 NUMBER OF SPATIAL POINTS PRINTED IN STRESS/STRAIN SUMMARY

SUMMARY PRINT SORTED BY MAXIMUM NORMAL STRESS/STRENGTH RATIO

TIME STEP PRINTOUT OPTIONS FOR FOUR BLOCKS GIVEN BELOW

NPRINT(I)<0 PRINT ALL TIME STEPS
 NPRINT(I)=0 NO PRINTOUT FOR THIS BLOCK
 NPRINT(I)>0 PRINT NPRINT TIME STEPS

NPRINT(1) = 0 OPTION FOR OPERATING STRESS SUMMARY

NPRINT(2) = -1 OPTION FOR OPERATING STRESS DETAILS

NPRINT(3) = 0 OPTION FOR SHUTDOWN STRESS SUMMARY

NPRINT(4) = 0 OPTION FOR SHUTDOWN STRESS DETAILS

PRINTOUT CONTENT OPTIONS FOR FOUR BLOCKS GIVEN BELOW

IPRINT(I)<0 PRINT FULL INFORMATION
 IPRINT(I)=0 PRINT MAIN RESULT IN ONE TABLE
 IPRINT(I)>0 PRINT MAIN AND SECONDARY RESULTS IN TWO TABLES

IPRINT(1) = 0 OPTION FOR OPERATING STRESS SUMMARY

IPRINT(2) = 0 OPTION FOR OPERATING STRESS DETAILS

IPRINT(3) = 0 OPTION FOR SHUTDOWN STRESS SUMMARY

IPRINT(4) = 0 OPTION FOR SHUTDOWN STRESS DETAILS

NO CRACKING ALLOWED

 CARD 3B - RELAXATION PARAMETER

RELAXP = 1.000000

CARD 3C - SUBSTEP OPTIONS

NSUBS = 0 NO SURDIVISION (= 1 SUBSTEP)

CARD 3D - OPTIONS FOR STRESS RATIO IN SORTING PRINTOUT

IRATIO = 1 STRESS RATIO IS CONSTANT FOR ALL TIME STEPS

FINITE ELEMENT MESH - ELEMENT DESCRIPTIONS

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* ELT	I	J	K	* ELT	I	J	K	* ELT	I	J	K	* ELT	I	J	K	* ELT	I	J	K
* 1	1	2	6	* 2	2	3	8	* 3	2	7	6	* 4	2	8	7	* 5	3	4	8
* 6	4	5	9	* 7	4	9	8	* 8	5	10	9	* 9	6	7	17	* 10	6	12	11
* 11	7	13	12	* 12	9	10	14	* 13	10	15	14	* 14	11	12	16	* 15	12	13	17
* 16	12	18	16	* 17	12	17	19	* 18	12	19	18	* 19	13	20	17	* 20	13	21	20
* 21	14	15	22	* 22	14	22	21	* 23	16	18	24	* 24	16	24	23	* 25	17	20	19
* 26	18	25	24	* 27	19	20	26	* 28	20	21	27	* 29	20	27	26	* 30	21	22	27
* 31	23	24	28	* 32	24	25	29	* 33	24	30	28	* 34	24	29	31	* 35	24	31	30
* 36	25	32	29	* 37	25	33	32	* 38	26	27	34	* 39	26	34	35	* 40	28	30	37
* 41	28	37	36	* 42	29	32	31	* 43	30	38	37	* 44	31	32	39	* 45	32	33	40
* 46	32	40	39	* 47	33	35	41	* 48	33	41	40	* 49	34	42	35	* 50	35	42	41
* 51	37	38	43	* 52	38	44	43	* 53	38	45	44	* 54	39	40	46	* 55	39	46	47
* 56	44	45	48	* 57	45	47	49	* 58	45	49	48	* 59	46	50	47	* 60	47	50	49

FINITE ELEMENT MESH - NODE COORDINATES

* NODE	X COORD.	Y COORD.	* NODE	X COORD.	Y COORD.	* NODE	X COORD.	Y COORD.	* NODE	X COORD.	Y COORD.
* 1	.31980+00	.00000	* 2	.44000+00	.00000	* 3	.64090+00	.00000	* 4	.85000+00	.00000
* 5	.11430+01	.00000	* 6	.27700+00	.15990+00	* 7	.40290+00	.23250+00	* 8	.64090+00	.95100-01
* 9	.87900+00	.23260+00	* 10	.11430+01	.33000+00	* 11	.15990+00	.27690+00	* 12	.22000+00	.38100+00
* 13	.40280+00	.50750+00	* 14	.87900+00	.50750+00	* 15	.11430+01	.66000+00	* 16	.37310-04	.31980+00
* 17	.32050+00	.55500+00	* 18	.83230-04	.46510+00	* 19	.23810+00	.60250+00	* 20	.42500+00	.73610+00
* 21	.64090+00	.64490+00	* 22	.85740+00	.82500+00	* 23	.15980+00	.27690+00	* 24	.21990+00	.38100+00
* 25	.23810+00	.60250+00	* 26	.23910+00	.87750+00	* 27	.57160+00	.99000+00	* 28	.27690+00	.15990+00
* 29	.32040+00	.55500+00	* 30	.40270+00	.23250+00	* 31	.40280+00	.50740+00	* 32	.42500+00	.73600+00
* 33	.23810+00	.87750+00	* 34	.28580+00	.11550+01	* 35	.17420-06	.10150+01	* 36	.31970+00	.46610-04
* 37	.43990+00	.64130-04	* 38	.64080+00	.95010-01	* 39	.64090+00	.64480+00	* 40	.57160+00	.98990+00
* 41	.28580+00	.11550+01	* 42	.35590-04	.13200+01	* 43	.64080+00	.93430-04	* 44	.84990+00	.12390-03
* 45	.87890+00	.23250+00	* 46	.95740+00	.82490+00	* 47	.87900+00	.50740+00	* 48	.11430+01	.16670-03
* 49	.11430+01	.32980+00	* 50	.11430+01	.65980+00						

THICK =	.10000000+01	THICKNESS OF ELEMENT
FLAT =	.13200000+01	HEX FLAT (RADIUS OF LOG)
XCLG =	.00000000	X COORD OF LOG CENTER
YCLG =	.00000000	Y COORD OF LOG CENTER
ZBLG =	.00000000	Z/R OF CROSS SECTION (0=CTR, 1=END)

GLOBAL EQUATION		SEGMENTATION		CONTROL		INFORMATION	
SEGMENT NUMBER	FIRST EQUATION	NUMBER OF EQUATIONS	COUPLED SEGMENT	CONTRIBUTING FIRST	ELEMENT RECORDS LAST	SEGMENT RECORD CONTROL	LENGTHS TOTAL
1	1	103	1	1	60	316	1857

MAXIMUM HALF BANDWIDTH ----- 103 EQUATIONS

ROOT MEAN SQUARE BANDWIDTH ----- 22 EQUATIONS

MAXIMUM SEGMENT COUPLING ----- 102 EQUATIONS

QASG,T LUSTIF,F2/1/POS/88

*** TEMPERATURE BLOCK INPUT (DEG F) ***

CONSTANT AND UNIFORM TEMPERATURE IS 70.00 DEG F

*** FAST FLUX INPUT ***

CONSTANT AND UNIFORM FAST FLUX IS .00000000 N/CM**2-SEC

*** INPUT OF TIME DEPENDENT VARIABLES ***
(EXCLUDING BOUNDARY CONDITIONS)

THE CONSTANT TIME STEP IS .000000 DAYS

THE LIST OF TIME VALUES (DAYS) AT THE END OF EACH TIME STEP IS GIVEN BELOW
THESE ARE INTERNALLY CONVERTED TO SECONDS

1/ .000000

PRINT OF BLOCK 1 OMITTED ENTIRELY

PRINT OF BLOCK 2 IS TO BE DONE AT ALL TIMES

PRINT OF BLOCK 3 OMITTED ENTIRELY

PRINT OF BLOCK 4 OMITTED ENTIRELY

NUMBER OF SUBSTEPS IN EACH TIME STEP

1/ 1

STRESS RATIO (FOR EACH TIME STEP) BELOW WHICH STRESS PRINTOUT WILL BE SKIPPED

***** 1 TIME STEP *****

*** START TIME = .00000 DAY END TIME = .00000 DAYS ***

***** INPUT OF OPERATING BOUNDARY CONDITIONS FOR THE FIRST TIME STEP *****

THIS INCLUDES : (1) IN PLANE BOUNDARY CONDITIONS (CONCENTRATED FORCES AND/OR DISPLACEMENTS)
 (2) IN PLANE NORMAL PRESSURE FORCES (FOR PRESSURE LOADING CASE ONLY)
 (3) THREE GLOBAL OUT OF PLANE BOUNDARY CONDITIONS (FOR GPS ELEMENT ONLY)

++ INPUT OF IN PLANE BOUNDARY CONDITIONS ++
 THIS IS DONE BY GROUPS. FOR EACH GROUP, THE FOLLOWINGS ARE INPUT:

1. (IBCGP(I), I=1,2) -- BOUNDARY CONDITION CODES (0=FORCE), (1=DISP.).
 I=1,2 REFER TO ROTATED X,Y DIRECTIONS
2. BETA -- SKEW BOUNDARY ANGLE IN RADIANS BETWEEN X AND ROTATED X AXIS
3. (BCGP(I), I=1,2) -- SPECIFIED CONCENTRATED FORCES IN LB. (WHEN IBCGP=0) OR NODAL DISPLACEMENTS
 IN INCHES (WHEN IBCGP=1). I=1,2 REFER TO ROTATED X,Y DIRECTIONS
4. NODBC -- NUMBER OF BOUNDARY NODES
5. A LIST OF BOUNDARY NODE NUMBERS

GROUP	NO	(IBCGP(I), I=1,2)	BETA(DEG)	(BCGP(I), I=1,2)	NODBC	BOUNDARY NODE NUMBERS
1	0	1	.0000000	.0000000	10	1 2 3 4 5 36 37 43 44 48
2	1	0	.0000000	.0000000	3	48 49 50

++ INPUT OF NORMAL PRESSURE LOADS ++
 THERE ARE 1 PRESSURE GROUPS.
 FOR EACH GROUP, THE FOLLOWINGS ARE INPUT:
 PRES = COMMON NORMAL PRESSURE
 NODPR = NUMBER OF NODES ALONG LOADED EDGES IN THIS GROUP
 AND A LIST OF NODE NUMBERS

* GROUP 1 *
 PRES = -.100000+03 (PSI)

NODPR = 3
 PRESSUR NODE NUMBERS ARE GIVEN BELOW
 5 10 15

++ INPUT OF OUT OF PLANE BOUNDARY CONDITIONS ++

FORCE/STRAIN OPTION			FORCE/STRAIN VALUE		
(IGLO(J), J=1,3)			(GLO(J), J=1,3)		
Z	X-ROT	Y-ROT	Z	X-ROT	Y-ROT
0	1	0	.0000000	.0000000	.0000000

AXIAL Z STRAIN BOUNDARY CONDITION IS A FORCE IN LB.
 X ROTATION (Y-Z PLANT) BOUNDARY CONLTION IS A CURVATURE IN RADIEN/IN.
 Y ROTATION (X-Z PLANT) BOUNDARY CONLTION IS A MOMENT IN IN.-LB.

```

      ***
      *** IN PLANE BOUNDARY DISPLACEMENTS ***
      *** AND / OR NON-ZERO FORCES ***
      *** B.C. TYPE BOUNDARY CONDITIONS ***
      (LB. OR IN.)
NO     X - X*      ANGLE      X      Y      X      Y
1      .00000      FORCE DISP.      .00000      .00000
2      .00000      FORCE DISP.      .00000      .00000
3      .00000      FORCE DISP.      .00000      .00000
4      .00000      FORCE DISP.      .00000      .00000
5      .00000      FORCE DISP.      -.16500+02      .00000
13     .00000      FORCE FORCE      -.33000+02      .00000
15     .00000      FORCE FORCE      -.16500+02      .00000
36     .00000      FORCE DISP.      .00000      .00000
37     .00000      FORCE DISP.      .00000      .00000
43     .00000      FORCE DISP.      .00000      .00000
44     .00000      FORCE DISP.      .00000      .00000
48     .00000      DISP. FORCE      .00000      .00000
49     .00000      DISP. FORCE      .00000      .00000
50     .00000      DISP. FORCE      .00000      .00000

```

0ASS,T LUELEQ,F2/1/P0S/35

*** TOTAL AREA OF MESH = .152075+01 X CENTROID = -.117500-04 Y CENTROID = .559454+00 ***

0FREE LUELEQ.

```

*** OPERATING DISPLACEMENTS AT END OF TIME STEP 1 ***
      NODAL POINT DISPLACEMENTS
      NP  X - DISP.  Y - DISP.  NP  X - DISP.  Y - DISP.  NP  X - DISP.  Y - DISP.
      1  -.3351834-03 .0000000  18  -.1898840-03 .6289398-04  35  -.1790996-03 .8868488-04
      2  -.3493447-03 .0000000  19  -.2276798-03 .5507805-04  36  -.7230800-04 .0000000
      3  -.3718274-03 .0000000  20  -.2409876-03 .5818749-04  37  -.6119813-04 .0000000
      4  -.4030663-03 .0000000  21  -.2702306-03 .5374613-04  38  -.4555502-04 -.2959573-05
      5  -.4434436-03 .0000000  22  -.2522756-03 .2147169-04  39  -.8813476-04 .4538804-04
      6  -.2978178-03 .3094704-04  23  -.1411632-03 .4953651-04  40  -.1380507-03 .4638692-04
      7  -.2857190-03 .1097656-04  24  -.1528862-03 .4634902-04  41  -.1727754-03 .6913355-04
      8  -.3697902-03 -.3314406-05  25  -.1409234-03 .4854087-04  42  -.1811482-03 .8583737-04
      9  -.4181111-03 .7257924-05  26  -.2189514-03 .7198366-04  43  -.4532905-04 .0000000
     10  -.4206074-03 -.3096009-04  27  -.2181949-03 .5137556-04  44  -.2374968-04 .0000000
     11  -.2432726-03 .5578624-04  28  -.1005108-03 .2727380-04  45  -.9330546-05 .1626801-05
     12  -.2270397-03 .5312286-04  29  -.1401454-03 .4722003-04  46  -.9368849-04 .1620408-04
     13  -.2303147-03 .4593313-04  30  -.1099246-03 .1221498-04  47  -.1409568-04 .2131806-05
     14  -.3544663-03 .1432130-04  31  -.1396475-03 .4454790-04  48  .0000000 -.4014100-07
     15  -.3283496-03 -.4805909-04  32  -.1197911-03 .5449016-04  49  .0000000 -.6053912-05
     16  -.1902806-03 .6472417-04  33  -.1386635-03 .6685745-04  50  .0000000 -.2048353-04
     17  -.2291677-03 .5136686-04  34  -.1866132-03 .7377448-04

```

GLOBAL DEGREES OF FREEDOM
 C-3 Z STRAIN = -.2083294-05
 X CURVATURE = .0000000
 Y CURVATURE = .7248631-06

BEAM STRETCHINGS AND DEFLECTIONS (LENGTH OF BEAM = .10000+01 IN.)

		SIMPLY SUPPORTED	CANTILEVER
AXIAL STRETCHING	IN.	-.20833-05	-.20833-05
MAX Y DEFLECTION (DUE TO X ROTATION)	IN.	.00000	.00000
MAX X DEFLECTION (DUE TO Y ROTATION)	IN.	.90608-07	-.36243-06
MAX TOTAL LATERAL DEFLECTION	IN.	.90608-07	-.36243-06
END ROTATION ABOUT X AXIS (Y-Z PLANE)	RAD.	.00000	.00000
END ROTATION ABOUT Y AXIS (X-Z PLANE)	RAD.	.36243-06	.72486-06

** MEANING OF CRACK INDICATOR (CRK IND) IN THE ELEMENT STRESS STRAIN RESULTS PRESENTED ON NEXT PAGE **

CRK IND = 0 -- UNCRACKED FOR ALL TIMES
 1 -- CRACKED IN PREVIOUS STATE AND STILL CRACKED
 -1 -- CRACKED IN THIS STATE
 2 -- HEALED IN PREVIOUS STATE AND STILL HEALED
 -2 -- HEALED IN THIS STATE

** WE ASSUME THAT THE CRACKED STATE AT END OF STEP IS THE SAME AS THAT CALCULATED AT START OF STEP. I.E., WE ASSUME THAT IN-STEP CRACK MAKES NO CHANGES IN THE START-OF-STEP CRACKED CONFIGURATION

*** OPERATING STRESS STRAIN AT END OF STEP 1 ***
(.00000 DAYS TO .00000 DAYS)

ELT REC	ELT NO	TEMP (DEG F)	*FAST FLUX* (NVT/SEC)	*END DOSE* (10**21 NVT)	*YOUNGS R	MODULI(PSI)* Z	*STRESS X	COMPONENTS* XY	Y	Z	IN-PLANE MAX	PRINC MIN	STR ANGLE	*STRESS Z	RATIO* R	CR4 Z	IND R
1	1	70.0	.000	.000	.99296+06	.11325+07	-90	88	182	24	207	-116	73.5	.013	.140	0	0
2	2	70.0	.000	.000	.10097+07	.11649+07	-121	9	-52	-13	-51	-122	82.2	-.005	-.032	0	0
3	3	70.0	.000	.000	.99571+06	.11378+07	-53	41	13	6	33	-73	64.5	.004	.022	0	0
4	4	70.0	.000	.000	.10038+07	.11534+07	-216	90	11	-14	42	-247	70.8	-.007	.027	0	0
5	5	70.0	.000	.000	.10239+07	.11922+07	-162	9	-59	-15	-58	-163	84.7	-.007	-.034	0	0
6	6	70.0	.000	.000	.10575+07	.12569+07	-144	-22	13	-3	16	-147	-82.2	-.001	.009	0	0
7	7	70.0	.000	.000	.10344+07	.12124+07	-185	-6	2	-10	2	-185	-88.1	-.004	.002	0	0
8	8	70.0	.000	.000	.10757+07	.12920+07	-52	-19	-108	-6	-46	-114	-17.4	-.002	-.023	0	0
9	9	70.0	.000	.000	.99571+06	.11378+07	-70	49	42	8	61	-84	69.5	.004	.041	0	0
10	10	70.0	.000	.000	.99296+06	.11325+07	-191	52	34	-8	45	-203	77.6	-.005	.031	0	0
11	11	70.0	.000	.000	.10038+07	.11534+07	-142	32	109	7	113	-146	82.7	.004	.073	0	0
12	12	70.0	.000	.000	.10687+07	.12787+07	-99	36	14	3	25	-110	73.7	.001	.013	0	0
13	13	70.0	.000	.000	.10929+07	.13253+07	-77	35	-67	-4	-37	-108	49.2	-.001	-.017	0	0
14	14	70.0	.000	.000	.99296+06	.11325+07	-256	108	-31	-25	12	-299	68.1	-.014	.008	0	0
15	15	70.0	.000	.000	.10097+07	.11649+07	-11	-25	23	13	34	-25	-61.4	.007	.022	0	0
16	16	70.0	.000	.000	.99571+06	.11378+07	-174	-20	-37	-15	-34	-177	-81.7	-.008	-.023	0	0
17	17	70.0	.000	.000	.10097+07	.11649+07	-16	-17	10	11	19	-25	-64.0	.006	.012	0	0
18	18	70.0	.000	.000	.10038+07	.11534+07	-168	-12	-11	-11	-10	-160	-85.3	-.006	-.007	0	0
19	19	70.0	.000	.000	.10239+07	.11922+07	-30	-34	55	15	67	-42	-70.7	.007	.040	0	0
20	20	70.0	.000	.000	.10344+07	.12124+07	-150	-13	35	-1	36	-151	-85.8	-.001	.020	0	0
21	21	70.0	.000	.000	.10929+07	.13253+07	-92	36	-5	1	8	-105	69.8	.001	.004	0	0
22	22	70.0	.000	.000	.10687+07	.12787+07	-190	71	-14	-12	11	-215	70.5	-.005	.006	0	0
23	23	70.0	.000	.000	.99571+06	.11378+07	-175	36	-37	-16	-28	-184	76.1	-.008	-.019	0	0
24	24	70.0	.000	.000	.99296+06	.11325+07	-242	-70	-13	-21	6	-262	-74.1	-.012	.004	0	0
25	25	70.0	.000	.000	.10239+07	.11922+07	-35	-26	45	13	53	-43	-73.4	.006	.031	0	0
26	26	70.0	.000	.000	.10038+07	.11534+07	-186	47	-10	-13	1	-199	75.8	-.007	.001	0	0
27	27	70.0	.000	.000	.10344+07	.12124+07	-89	2	52	8	52	-89	89.2	.003	.030	0	0
28	28	70.0	.000	.000	.10575+07	.12569+07	-86	51	-24	0	4	-115	60.6	-.000	.002	0	0
29	29	70.0	.000	.000	.10575+07	.12569+07	-34	20	7	9	16	-43	68.0	.004	.008	0	0
30	30	70.0	.000	.000	.10757+07	.12920+07	-44	9	-39	3	-31	-57	51.7	.001	-.016	0	0
31	31	70.0	.000	.000	.99296+06	.11325+07	-144	-25	30	-3	33	-148	-81.8	-.002	.023	0	0
32	32	70.0	.000	.000	.10097+07	.11649+07	-37	27	7	7	20	-50	64.5	.004	.013	0	0
33	33	70.0	.000	.000	.99571+06	.11378+07	-46	-33	42	11	53	-57	-71.8	.006	.036	0	0
34	34	70.0	.000	.000	.10097+07	.11649+07	-33	33	14	9	31	-50	63.0	.004	.019	0	0
35	35	70.0	.000	.000	.10038+07	.11534+07	-133	-7	101	7	101	-133	-88.2	.004	.065	0	0
36	36	70.0	.000	.000	.10239+07	.11922+07	-51	34	32	9	44	-64	70.5	.004	.026	0	0
37	37	70.0	.000	.000	.10344+07	.12124+07	-103	11	55	6	56	-103	86.0	.003	.032	0	0
38	38	70.0	.000	.000	.10757+07	.12920+07	-39	26	15	10	25	-50	68.0	.004	.013	0	0
39	39	70.0	.000	.000	.10687+07	.12787+07	-96	33	5	1	15	-106	73.2	.001	.008	0	0
40	40	70.0	.000	.000	.99571+06	.11378+07	-37	-28	26	10	37	-48	-69.0	.005	.025	0	0
41	41	70.0	.000	.000	.99296+06	.11325+07	-67	-66	162	23	180	-85	-75.0	.013	.121	0	0
42	42	70.0	.000	.000	.10239+07	.11922+07	-48	40	39	10	55	-63	68.7	.005	.033	0	0
43	43	70.0	.000	.000	.10038+07	.11534+07	-157	-65	25	-5	46	-178	-72.2	-.003	.029	0	0
44	44	70.0	.000	.000	.10344+07	.12124+07	-180	42	22	-8	30	-188	78.7	-.004	.017	0	0
45	45	70.0	.000	.000	.10575+07	.12569+07	-33	-12	0	9	5	-37	-71.5	.003	.003	0	0
46	46	70.0	.000	.000	.10575+07	.12569+07	-102	-37	-20	-3	-5	-117	-68.6	-.001	-.003	0	0
47	47	70.0	.000	.000	.10687+07	.12787+07	-94	-27	10	2	17	-101	-76.0	.001	.009	0	0
48	48	70.0	.000	.000	.10757+07	.12920+07	-46	-29	16	9	27	-58	-68.2	.003	.014	0	0
49	49	70.0	.000	.000	.10929+07	.13253+07	-26	-26	-12	8	7	-44	-52.1	.003	.003	0	0
50	50	70.0	.000	.000	.10929+07	.13253+07	-28	27	-13	8	7	-40	52.9	.003	.003	0	0

51	51	70.0	.000	.000	.10097+07	.11649+07	-86	-6	-43	-5	-42	-87	-81.9	-.003	-.027	0	0
52	52	70.0	.000	.000	.10239+07	.11921+07	-113	-5	-48	-9	-47	-113	-84.5	-.004	-.028	0	0
53	53	70.0	.000	.000	.10344+07	.12123+07	-137	13	-14	-7	-12	-139	83.9	-.003	-.007	0	0
54	54	70.0	.000	.000	.10757+07	.12920+07	-92	-5	-35	-3	-34	-93	-84.9	-.001	-.017	0	0
55	55	70.0	.000	.000	.10687+07	.12786+07	-185	-36	9	-10	16	-191	-79.3	-.004	.008	0	0
56	56	70.0	.000	.000	.10574+07	.12569+07	-86	24	-4	0	2	-93	74.7	.000	.001	0	0
57	57	70.0	.000	.000	.10687+07	.12796+07	-44	5	-3	6	-2	-45	82.0	.002	-.001	0	0
58	58	70.0	.000	.000	.10756+07	.12920+07	-41	10	-24	3	-19	-46	63.7	.001	-.010	0	0
59	59	70.0	.000	.000	.10929+07	.13253+07	-208	-63	11	-12	28	-225	-75.1	-.004	.013	0	0
60	60	70.0	.000	.000	.10929+07	.13252+07	-66	29	-57	-3	-32	-91	49.5	-.001	-.015	0	0

@FREE LUXY--.

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@FREE LUSTIF.

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 *
 * TIME HISTORY OF MIN = ANG = CONDITIONS *
 * FOR ELEMENTS WITH MAXIMUM R A D I A L A N D A X I A L STRESS RATIOS *
 *

TIME INDX	TIME DAYS	<----- RADIAL ----->								<----- AXIAL ----->								<--BEAM DEFLECTIONS--> (SIMPLY SUPPORTED)		
		ELEM REC	ELEM NO	TEMP DEG F	DOSE 10**21	STRESS (PSI)	STRESS RATIO	NUM CR4	ELEM REC	ELEM NO	TEMP DEG F	DOSE 10**21	STRESS (PSI)	STRESS RATIO	NUM CRK	X 30W	Y 30W	TOTAL 30W		
1	.00	1	1	70.0	.000	209.0	.1400	0	1	1	70.0	.000	24.0	.013	0	.000	.000	.000		