SEP 2 1958

MASTER

88

OAK RIDGE NATIONAL LABORATORY

operated by

UNION CARBIDE CORPORATION

NUCLEAR DIVISION

for the

U.S. ATOMIC ENERGY COMMISSION

ORNL - TM - 1574

ADDENDUM - INFLUENCE OF CROSS-SECTIONAL SHAPE ON IRRADIATION-
INDUCED STRESSES IN GRAPHITE COLUMNS

F. J. Witt   B. L. Greenstreet

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

NOTICE This document contains information of a preliminary nature and was prepared primarily for internal use at the Oak Ridge National Laboratory. It is subject to revision or correction and therefore does not represent a final report.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

H.C. \$ 1.00; MN 1.50

ORNL-TM-1574

Contract No. W-7405-eng-26

Reactor Division

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, expressed or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission, or employee of such contractor, to the extent that such employee or contractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

ADDENDUM — INFLUENCE OF CROSS-SECTIONAL SHAPE ON IRRADIATION-INDUCED STRESSES IN GRAPHITE COLUMNS

F. J. Witt   B. L. Greenstreet

RELEASED FOR ANNOUNCEMENT
IN NUCLEAR SCIENCE ABSTRACTS

AUGUST 1966

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

ADDENDUM - INFLUENCE OF CROSS-SECTIONAL SHAPE ON IRRADIATION-
INDUCED STRESSES IN GRAPHITE COLUMNS

F. J. Witt   B. L. Greenstreet

Abstract

This report supplements a paper published in Nuclear Science and Engineering entitled "Influence of Cross-Sectional Shape on Irradiation-Induced Stresses in Graphite Columns." In particular the results from the study of non-circular geometrical shapes are discussed with reference to the complete stress plots for the various configurations. These plots were not presented in full in the original paper.

Introduction

A paper was published by the authors in Nuclear Science and Engineering that treats the subject of geometrical shape with reference to irradiation-induced stresses in graphite columns.¹ In Part IV of the paper, ten configurations representing various cross sections of a typical moderator column of the Experimental Gas-Cooled Reactor were discussed. Because of space limitations and for general interest, isobars of principal stresses for only one configuration were presented in the paper. This report supplements the paper by presenting the isobars of the principal stresses for all the configurations. For continuity of presentation some of the figures presented in the paper are included in this report.

Graphite moderator columns of nuclear reactors undergo dimensional changes when subjected to fast neutrons during the operation of the reactor. These changes, which are a function of temperature as well as exposure, give rise to stresses and strains analogous to thermal stresses and strains. Good design in many cases calls for minimizing these stresses and strains without compromising the other desirable features of the reactor.

The configurations considered in this report are prisms with one or more cylindrical holes and various sectors of these prisms. All the

configurations were analyzed with the NBC computer program.² This program assumes a plane-strain linear-elastic transversely isotropic model.

Analyses of the Configurations

The ten configurations shown in Fig. 1 are based on the typical moderator column for the Experimental Gas-Cooled Reactor (EGCR);³ that is, a 16-in.-square cross section with four 5.25-in.-diam channels (labeled a in Fig. 1). Various schemes for subdividing the column are labeled b, c, f, and h. Three configurations, d, e, and g, in Fig. 1 are alternate configurations. The first, d, is an 8-in.-wide infinite slab with fuel channels on 8-in. centers; the second, e, is infinite in all directions with fuel channels located on an 8-in.-square pitch; and the third, g, is similar to the first except that it is 16 in. wide and has two rows of holes. The arrows indicate directions of infinite extension. It was assumed that there would be no external restraint against axial strain or bowing. However, bowing will occur in only two cases, the left-hand portions of sketches b and h in Fig. 1.

The assumed fast-neutron exposure distribution corresponded to that for an infinite EGCR type of core for one year. The distribution for such a column is shown in Fig. 2 and was obtained by C. A. Preskitt of ORNL. The average total exposure was about 2100 Mwd/At. [An exposure of 1 Mwd/At in the EGCR is equivalent to a fast-neutron dose of 1.27×10^{17} neutrons/cm² ($E > 0.18$ Mev).] The material properties chosen were

$$E_z \text{ (modulus of elasticity in extrusion direction)} = 1.61 \times 10^6 \text{ psi,}$$

$$E_x \text{ (modulus of elasticity in transverse direction)} = 0.86 \times 10^6 \text{ psi,}$$

$$\alpha_z \text{ (dimensional change coefficient in extrusion direction)}$$

$$= -3.4 \times 10^{-7} \text{ (in./in.)/(Mwd/At),}$$

$$\alpha_x \text{ (dimensional change coefficient in transverse direction)}$$

$$= -1.3 \times 10^{-7} \text{ (in./in.)/(Mwd/At),}$$

$$\mu_{zx} \text{ (strain ratio when stressed in the z direction)} = 0.35.$$

These properties are not exact; however, for comparative purposes the variations from the actual values make no difference.

A summary of the results is given in Ref. 1. Isobars of principal stresses for all ten configurations sketched in Fig. 1 are given in Figs. 3 through 12. The results in Figs. 3 through 8 depict multiply connected bodies and are presented in increasing degrees of geometrical complexity. It is significant that the cross-sectional shape has little effect on the axial stresses. The largest axial stresses occur in Figs. 7 and 8. The stresses in the single-hole configuration (Fig. 3) and the corresponding infinite row of holes (Fig. 6) are very similar near the sides common to the two configurations. Wider discrepancies exist on the symmetry sides. Less similarity exists for the other corresponding configurations (Figs. 4 and 7 and Figs. 5 and 8). Results for the one-, two-, and four-hole configurations (Figs. 3, 4, and 5) are very similar at channel interfaces and common edges. For these six figures (Figs. 3 through 8) the maximum axial stresses only vary by 3%. The smallest maximum in-plane stress is for the single-hole configuration (Fig. 3), and it is 28% less than that for the four-hole configuration (Fig. 5).

Figures 9 through 12 are all simply connected. In particular there are no restraints due to holes. The resulting decrease in in-plane stresses can readily be seen by comparing Figs. 3 and 9. The maximum in-plane stress for the simply connected configuration is only about a third of that in the single-hole body. The reduction in axial stresses is less pronounced although the maximum axial stress for the configuration in Fig. 9 is the smallest of all configurations considered. Figures 10 and 11 exhibit about the same maximum stresses, with the stresses in Fig. 11 being consistently larger. The results in Fig. 12 reflect a severe bending in the cross section, and the maximum in-plane stresses are within 10% of the largest in-plane stresses obtained from this study.

The location and magnitudes of the maximum and minimum stresses are shown in Fig. 13. The maximum principal stresses always occur on the surface of the channel. The minimum stresses always fall along an edge but often interior to the body (in case the edge is a line of symmetry).

In summary, the greatest reduction of stresses occurs in the 4- by 8-in. simply connected configurations. There the maximum in-plane and maximum axial stresses are 22 and 85%, respectively, of those occurring in the EGCR moderator column design (the four-hole configuration depicted

in Fig. 5). Since most extruded graphites have greatest strength in the axial direction, the decrease in in-plane stress is significant. Among the ten configurations considered the general distributions of the axial stresses vary little. This is mainly because the exposure gradient dominates the axial stresses of the models considered in these studies. The in-plane stresses are more sensitive to geometry and vary widely among the results presented.

References

1. F. J. Witt and B. L. Greenstreet, Influence of Cross-Sectional Shape on Irradiation-Induced Stresses in Graphite Columns, Nucl. Sci. Eng., 25(2): 141-151 (June 1966).
2. F. J. Witt, NBC - An IBM 7090 Computer Program for Solving Thermo-elastic Problems, USAEC Report ORNL-3624, Oak Ridge National Laboratory, January 1965.
3. Oak Ridge Operations Office, Experimental Gas-Cooled Reactor Final Hazards Summary Report, Vol. 1. Description and Hazards Evaluation, USAEC Report ORO-586, Oct. 10, 1962.

ORNL-DWG 63-1660A

* ARROWS INDICATE INFINITE SYMMETRY

Fig. 1. Configurations Analyzed for Irradiation-Induced Stresses in an EGCR-Type Column.

ORNL DWG 65 5780

Fig. 2. Average Exposure of an EGCR Column for One Year.

MAXIMUM IN-PLANE STRESSES

MINIMUM IN-PLANE STRESSES

ORNL-DWG 65-8269
AXIAL STRESSES

Fig. 3. Isobars of Principal Stresses (in psi) for 8- by 8-in. Column.

MAXIMUM IN-PLANE STRESSES

MINIMUM IN-PLANE STRESSES

ORNL-DWG 65-8271
AXIAL STRESSES

Fig. 4. Isobars of Principal Stresses (in psi) for 8- by 16-in. Column.

Fig. 5. Isobars of Principal Stresses (in psi) for 16- by 16-in. Column.

Fig. 6. Isobars of Principal Stresses (in psi) for Column 8 in. Wide and with Infinite Breadth.

Fig. 7. Isobars of Principal Stresses (in psi) for Column 16 in. Wide and with Infinite Breadth.

MAXIMUM IN-PLANE STRESSES

MINIMUM IN-PLANE STRESSES

ORNL-DWG 65-8273
AXIAL STRESSES

Fig. 8. Isobars of Principal Stresses (in psi) for Column with Infinite Width and Breadth.

MAXIMUM IN-PLANE STRESSES

MINIMUM IN-PLANE STRESSES

ORNL-DWG 65-8274
AXIAL STRESSES

Fig. 9. Isobars of Principal Stresses (in psi) for Simply Connected 4- by 8-in. Column.

MAXIMUM IN-PLANE STRESSES

MINIMUM IN-PLANE STRESSES

ORNL-DWG 65-8277
AXIAL STRESSES

Fig. 10. Isobars of Principal Stresses (in psi) for Simply Connected 4- by 16-in. Column.

Fig. 11. Isobars of Principal Stresses (in psi) for Simply Connected 8- by 8-in. Column.

Fig. 12. Isobars of Principal Stresses (in psi) for Simply Connected 8- by 16-in. Column.

Internal Distribution

1. S. E. Beall	28. S. E. Moore
2. C. E. Center, K-25	29. A. M. Perry
3. J. M. Corum	30. A. W. Savolainen
4. F. L. Culler	31. R. W. Schneider
5. A. P. Fraas	32. M. J. Skinner
6. W. R. Gall	33. J. E. Smith
7-16. B. L. Greenstreet	34. I. Spiewak
17. R. C. Gwaltney	35. D. B. Trauger
18. P. N. Haubenreich	36. R. S. Valachovic
19. P. R. Kasten	37. G. D. Whitman
20. M. I. Lundin	38. R. P. Wichner
21. R. N. Lyon	39-63. F. J. Witt
22. H. G. MacPherson	64. G. T. Yahr
23. R. E. MacPherson	65-66. Central Research Library
24. W. J. McAfee	67-68. Y-12 Document Reference Section
25. H. C. McCurdy	69-71. Laboratory Records Department
26. J. G. Merkle	72. Laboratory Records Department, RC
27. A. J. Miller	

External Distribution

- 73. H. Hessing, Space Nuclear Propulsion Office, Los Alamos Scientific Laboratory
- 74. R. W. Holland, University of Tennessee, Knoxville
- 75. L. E. Hulbert, Battelle Memorial Institute
- 76. J. D. Lubahn, Colorado School of Mines, Golden, Colorado
- 77. L. L. Lyon, Los Alamos Scientific Laboratory
- 78. S. S. Manson, NASA, Lewis Research Center, Cleveland, Ohio
- 79. R. L. Maxwell, University of Tennessee, Knoxville
- 80. J. L. Mershon, AEC, Washington
- 81. J. E. Morrissey, SNPO, AEC, Washington
- 82. R. E. Nightingale, Hanford Atomic Products Operation, Richland, Wash.
- 83. J. C. Rowley, Los Alamos Scientific Laboratory
- 84. W. A. Shaw, Auburn University, Auburn, Alabama
- 85. L. R. Shobe, University of Tennessee, Knoxville
- 86. N. R. Thielke, NASA, Lewis Research Center, Cleveland, Ohio
- 87. George White, Los Alamos Scientific Laboratory
- 88-102. Division of Technical Information Extension (DTIE)
- 103. Research and Development Division, ORO, AEC
- 104-105. Reactor Division, ORO, AEC