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September 11, 1964

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Subject: **WANL-TME-837, "Final Report Short Graphite Barrel Test," dated August 1964**

Dear Mr. Miller:

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by H. F. C. T.C. 10 SEP 10 1973

Respectfully,

H. F. Faught
amw

H. F. Faught
Program Manager
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August 1964

FINAL REPORT
SHORT GRAPHITE BARREL TEST
(Title Unclassified)

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1.0 SUMMARY

- 1.1 The structural integrity of the graphite barrel, under prolonged compressive stresses to 5000 psi, was verified by testing a H4LM graphite ring. An aluminum ring, having an interference fit with the graphite ring O. D., was heated and allowed to cool on the graphite ring. The assembly was then cooled to -320°F to obtain a compressive stress of 5000 psi on the graphite ring I. D.
- 1.2 An interference of 0.163 in. at room temperature provided a strain of 3900 μ in./in. on the graphite ring I. D. at room temperature and 7500 μ in./in. at -320°F. Since no failure tendency or damage was noted, it may be concluded that the graphite barrel can withstand comparable strains without incurring failure.

2.0 INTRODUCTION AND PURPOSE

- 2.1 Reactor Mechanical Design Analysis Group has calculated combined stresses in the graphite barrel higher than the allowables in the WANL Materials manual. The purpose of this test was to test a H4LM graphite ring up to 5000 psi compressive stress in order to verify the structural integrity of the graphite barrel.

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3.0 OBJECTIVES

3.1 The objectives of this test were to (1) shrink fit an aluminum ring over the graphite ring and obtain strain-temperature curves as the assembly cooled to room temperature, (2) cool the assembly down to -320°F to obtain 5000 psi compressive hoop stress at the graphite ring I. D., and (3) obtain failure load, note instability, etc., should failure occur before 5000 psi stress is obtained.

4.0 CONCLUSIONS

4.1 Since the graphite ring, as tested, withstood 5000 psi compressive stress, it can be concluded that the NRX-A2 graphite barrel can withstand the anticipated compressive stresses without failure.

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5.0 TEST SPECIMENS AND EQUIPMENT

- 5.1 The test specimen consisted of a short hollow H4M graphite cylinder machined out of the end material from a graphite barrel. The ring material was unimpregnated H4M graphite with the radial direction being perpendicular to the grain. The ring was 3 in. in height with a $39.598 \pm .001$ in. O. D. and a 36.11 in. I. D.
- 5.2 The graphite ring was instrumented with five strain gages and five thermocouples. Four thermocouples and five strain gages were mounted on the I. D. with the thermocouples located near the strain gages. The other thermocouple was located on the graphite ring O. D. This was to note the temperature gradient across the ring which was usually in terms of a few degrees only. Three gages were mounted at top, middle and bottom of the ring at 0° and one each at the middle of the ring at 120° and 240° .
- 5.3 An aluminum ring approximately 1 in. thick and 3 in. in height was used to obtain the compressive stresses in the graphite ring. First the aluminum ring was heated, placed over the graphite ring, and allowed to cool to room temperature. Then, since the coefficient of thermal contraction for aluminum (10^{-5} in./in. $^\circ$ F) is greater than that of graphite ($\sim 1.5 \times 10^{-6}$ in./in. $^\circ$ F), the assembled rings were cooled to liquid nitrogen temperature (-320° F). The aluminum ring O. D. was instrumented with strain gages and thermocouples also. A CEC multichannel recorder was used to monitor all thermocouples and strain gages.
- 5.4 Quartz lamps were used to heat the aluminum ring. A foam container with liquid nitrogen was used to slowly cool the assembled rings to -320° F.

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Dimensional measurements were taken of the graphite and aluminum ring I. D.'s and O. D.'s at various phases of the test.

6.0 TEST RESULTS

- 6.1 Two preliminary tests were conducted before the aluminum and graphite rings were assembled. The first was a compressive test of H4LM graphite specimens (three 1 in. diameter and three 3/4 in. diameter by 1-1/2 in. long) machined from the same material as was the graphite ring. Failure occurred at strains greater than 2 percent and at stresses of approximately 7500 psi. The nonlinearity of the stress-strain curve is shown in Figure 1.
- 6.2 The other preliminary test conducted was to determine the apparent strain that the strain gages register upon thermal heating and cooling of the rings. Thermal strains at various test temperatures were obtained for all strain gages from repeated heating and cooling of each ring in a free state. These thermal strains are caused by differential expansion of the rings and the strain gages and hence must be known to accurately determine the mechanical stress in the graphite ring at any given time.
- 6.3 The two rings were assembled in two separate tests. In Test I the rings were assembled, as desired by Reactor Mechanical Design, with a diametrical interference of 0.064 in. Upon assembly of the rings, a strain of approximately 1000 μ in./in. was obtained at room temperature. The strain on the graphite ring I. D. then increased to approximately

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4500 μ in./in. when the assembly was cooled to -320°F . This corresponds to about 3750 psi. The strain on the graphite ring I. D. versus temperature of the graphite ring is shown in Figure 2. Corresponding stresses can then be obtained from Figure 1.

6.4 Dimensional measurements of diameters were taken at various phases of the test. Significant diametral measurements are given in Figure 5 in the Appendix. A comparison of dimensions A1 and A2 gives a strain of $\frac{0.040}{36} \approx 1100 \mu\text{in./in.}$ at room temperature which compares approximately to that of the strain gages (see Figure 2). A comparison of dimensions before and after testing indicates that creep of the graphite occurred while under load. O. D. readings (B1 and B2) indicate a 40 mil change from the time the rings were assembled until disassembly about one month later.

6.5 In Test II, Figure 1 was used to calculate the shims needed to obtain a stress of 5000 psi, yet not require an excessive temperature of the aluminum for assembly of the rings. Aluminum shims 0.071 in. thick were used providing a diametral interference of 0.163 in. between the graphite ring O. D. and the aluminum ring I. D. An aluminum ring temperature of over 500°F was required to assemble the rings. Upon cooling the assembled rings, strains (on graphite ring I. D.) of over 3800 μ in./in. and 7500 μ in./in. were obtained at room temperature and -320°F , respectively. From Figure 3, a maximum strain of about 7600 μ in./in. is shown. These strains correspond to 3500 psi at room temperature and 5000 psi at -320°F .

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- 6.6 Dimensional readings of the graphite ring I. D. (A3 and A4) indicate a strain of about 4000 μ in./in. which compares with room temperature strain gage values (see Figure 3). Graphite ring O. D. readings (B2 and B3) indicate that an additional creep set of 14 mils occurred during the two weeks in which the rings were assembled. Creep deformation of graphite under load with time is not a surprising phenomena and need not be discussed here.
- 6.7 Under the sustained loading of Test I and Test II, the ring did not incur any catastrophic failure. No visual damage to the graphite ring can be noticed except for a slight compression and polished effect on the graphite ring O. D. This would be due to the aluminum ring's loading (interface pressure of about 400 psi) and relative shrinkage between the two rings upon cooling to -320°F .
- 6.8 The results are summarized in Figure 4 with the hoop stress on the graphite ring I. D. versus temperature of the assembled rings for both tests. By calculations, a curve of hoop stress versus external pressure can be obtained but certain inaccuracies would be introduced by such calculations.

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7.0 APPENDIX

<u>Figure</u>	<u>Title</u>
1	Stress-Strain Curve for H4LM Graphite Ring Material
2	Strain on the Graphite Ring I. D. Versus Ring Temperature, Test I
3	Strain on the Graphite Ring I. D. Versus Ring Temperature, Test II
4	Stress on the Graphite Ring I. D. Versus Ring Temperature, Tests I and II
5	Dimensional Data

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FIGURE 5

SIGNIFICANT DIMENSIONAL MEASUREMENTS*

A. Graphite Ring I. D.**

1. Ring assembled - Test I = 36.045 in.
2. After Test I - Before Test II = 36.085 in.
3. Assembled Test II = 35.922 in.
4. After Test II = 36.065 in.

B. Graphite Ring O. D.**

1. Before Test I = 39.598 in.
2. After Test I - Before Test II = 39.558 in.
3. After Test II = 39.544 in.

C. Aluminum Ring I. D.**

1. Before Test I = 39.534 in.
2. Before Test II = 39.538 in.

* Taken by Quality Control

** Values given are averages of 4 or more readings about circumference.

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