LA-UR-81-685

MASTER

CONF-810314--42

TITLE: DESIGN AND OPERATION WATER-COOLED PYROLYTIC GRAPHITE TARGETS AT LAMPF

AUTHOR(S): R. D. Brown and D. L. Grisham

SUBMITTED TO: Particle Accelerator Conference, Washington, DC, March 11-13, 1981

University of California

LOS ALAMOS SCIENTIFIC LABORATORY
Post Office Box 1663 Los Alamos, New Mexico 87545
An Affirmative Action/Equal Opportunity Employer

Form No. 836 R3
St. No. 2629
12/78

UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

DESIGN AND OPERATION
WATER-COOLED PYROLYTIC GRAPHITE TARGETS AT LAMPF*

R. D. Brown and D. L. Grisham
Los Alamos National Laboratory
Los Alamos, NM 87545

Summary

Design considerations and actual operating experience are reported for water-cooled pyrolytic graphite targets at the Clinton P. Anderson Meson Physics Facility (LAMPF). Emphasis is placed on the use of finite element computer calculations to determine target temperatures and stresses, which can then be evaluated to judge the usefulness of a particular design. Consideration is also given to the swelling of the target following irradiation, and to the measures taken to prolong target lifetime.

Introduction

An important application of LAMPF is the generation of negative pions for use in an experimental cancer therapy program conducted jointly by the University of New Mexico Medical School and the Los Alamos National Laboratory. Consideration of the relative π^- flux produced by various target materials, electron contamination of the pion beam, and thermal properties led to the choice of a carbon target.

There are two important boundary conditions on the biomedical target--the first a limit on target thickness imposed by the inside diameter of the target-insertion vacuum tube and pion channel acceptance, the second the need to maximize the π^- flux to make possible rapid patient treatment. These conditions led to the choice of pyrolytic graphite, which (at 2.2 g/cm^3) is 25% denser than a typical polycrystalline graphite, providing a higher pion flux per unit thickness. The high thermal conductivity of pyrolytic graphite (890 W/m·K at room temperature) makes it possible to remove much of the heat generated by direct water cooling, lessening the heat load received by the vacuum box through radiation.

Figure 1 shows the original biomedical target design. Vertical target motion allows either the full target thickness to be placed in the beam or a 10% thickness target to be used. The latter consists of the thin fins extending down from the full thickness plates.

Target Fabrication

Basic fabrication methods for these targets have been discussed in an earlier paper.[1] Examination of the braze joints between the pyrolytic graphite and the copper cooling tubes has shown that the braze material remains intact while circumferential cracks develop in the pyrographite, reducing the efficiency of heat transfer to the cooling tubes. To improve the heat transfer capability of these joints, we are now experimenting with a two-stage joining procedure in which a thin layer of titanium/copper/silver alloy is first brazed onto the graphite. The second stage consists of soldering a copper manifold to the braze layer at low temperature. The much smaller temperature change on cooling should reduce the thermal stresses substantially.

Target Heating and Temperature Calculations

The target is heated through ionization energy losses from the proton beam and secondary particles generated from interaction between the protons and the target nuclei. Calculations of the heat produced in a 6.5-cm-long pyrolytic graphite target give a value of 48 kW/mA, which is within 10% of the measured value.[2]

A finite element calculation of target temperatures was run using the AYER code,[3] which solves the two-dimensional heat equation implicitly for plane or axisymmetric geometries. The proton beam was assumed to have a Gaussian distribution, with FWHM = 4.9 mm. The boundary condition at the cooled end of the target was specified by assuming a bulk water temperature and a heat transfer coefficient based on the flow through the tubes. In addition, a joint efficiency between 0 and 1 multiplies the heat transfer area, taking into account the known cracking of the graphite near the tubes and the greater efficiency of the segments of the tube surface nearest the heat source. Joint efficiencies of 0.5 gave results in good agreement with thermocouples located near the cooling tubes.

All the calculations assume the temperature in the direction of the proton beam to be constant. By using the maximum power supplied to the target at the exit face, conservative temperature and stress values

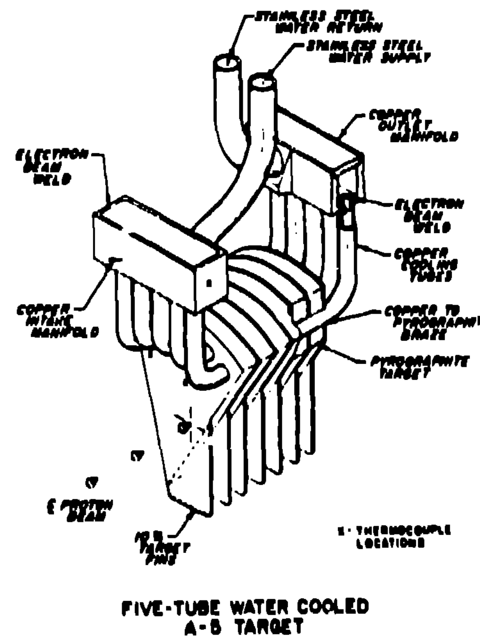

Fig. 1. The original six-plate, water-cooled biomedical target. The target places 6.5 cm of pyrolytic graphite in the proton beam.

*Work performed under the auspices of the United States Department of Energy.

are obtained. Effects of thermal radiative cooling from the target edges have been considered, but give temperatures only about 4% lower. About 96% of the heat is removed by the cooling water. Figure 2 shows a typical isothermal map for this target. The temperatures shown for this particular target design are well below the 2250 K level, at which evaporation of graphite begins to limit target lifetime.

Stress Calculations

Computation of stresses in the target can be accomplished by the SAAS[4] program using as inputs the temperature distribution and mechanical constraints on the graphite plates. SAAS is a finite element computer code for solving two-dimensional thermal stress problems. Figure 3 shows a typical map of the maximum principal stresses in the target plates. The maximum tensile and compressive stresses shown in Fig. 3 are about 1250 psi, while the static tensile strength of pyrolytic graphite varies between 5000 and 20 000 psi, and the compressive strength is about 12 000 psi.[5] Thus, the thermal stresses generated should pose no problem. Because the biomedical target is inserted and removed from the proton beam about 100 times a day, the stresses vary cyclically from zero with the target out of the proton beam to the values indicated when in-beam. A study of cyclic stress effects on pyrolytic graphite[6] indicates that the target should survive about 10^6 cycles if the maximum cyclic tensile stress is less than 3000 psi.

Operating Experience and Target Examination

The first water-cooled biomedical target of the present design was run in November 1978. It ran without problems for several months, after which the thermocouple installed in the leading graphite plate abruptly registered temperature increases of several hundred degrees kelvin. The target was subsequently withdrawn and it was found that the plates had swollen heavily along the beam path, producing such large strains in the leading plate as to break it away from the water-cooling tubes.

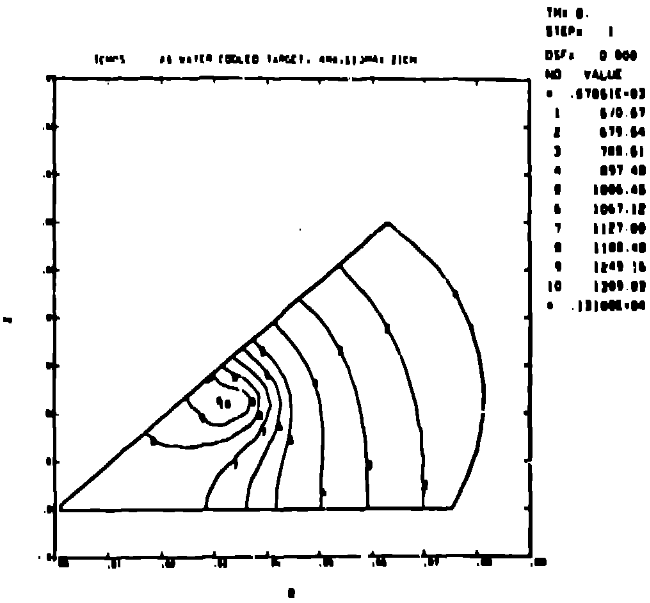

Fig. 2. A map of temperatures calculated for the A-5 target at a beam current of 400 µA. The maximum temperature just exceeds 1300 K near the beam center, while near the cooled surface the temperature drops to 670 K.

A simple model of the plates considered them to be cantilevered beams fixed by the water-cooling tubes and displaced by a fixed amount at the proton beam position. By reducing the thickness of the individual plates by a factor of two (and doubling the number of plates) the strains near the fixed ends would be reduced by two. This would double the time before an end plate would fracture, increasing target lifetime. This solution has been implemented and appears to extend the target lifetime, although no target has yet been pushed to the point where it has fractured.

Previous studies of neutron-irradiated pyrolytic graphite[7] have found swelling in the c-direction. The amount of swelling dropped sharply as the crystallite size L_c increased (Fig. 4). Swelling measurements for

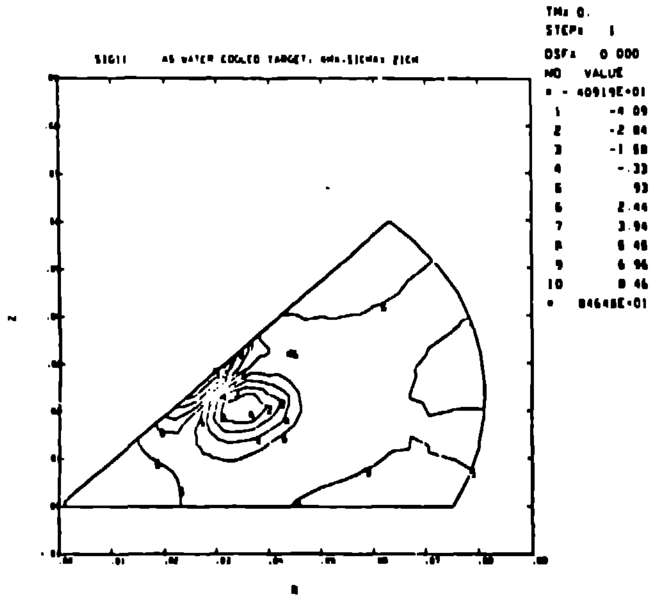

Fig. 3. A stress map for the maximum principal stresses. The maximum tensile stress is about 8.5 MPa (1235 psi), while the greatest compressive stress is -4.1 MPa (-600 psi).

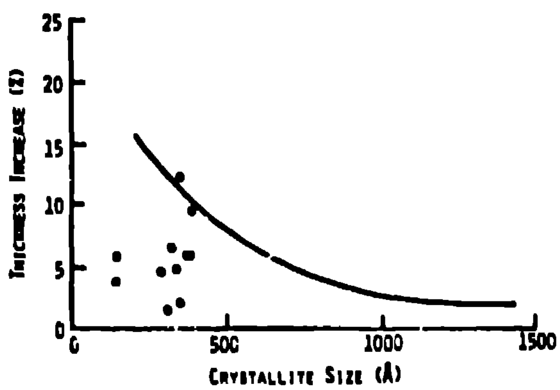

Fig. 4. The curve shows the dependence of neutron-produced swelling on the initial crystallite size for pyrolytic graphite. The points are experimental data from our proton-irradiated pyrolytic graphite.

our proton-irradiated pyrographite were plotted vs crystallite size (Fig. 4). With crystallite sizes ranging between 150 and 400 A in the as-deposited material, there was no indication that samples of larger crystallite size showed lower swelling, as predicted by the neutron results.

In general, the crystallite size of as-deposited pyrolytic graphite can be increased by annealing at temperatures above 3100 K. It is indeed found that when the swelling of as-deposited or annealed pyrolytic graphites is compared with that for single crystals of graphite, the swelling is less in the single crystals.[8] With this in mind, we have annealed some of our as-deposited plates of pyrolytic graphite, some of which have shown increases in the crystallite size. By incorporating these into the target, together with as-deposited plates, we have sought to determine whether it will be possible to reduce the swelling by prior heat treatment of the graphite. These targets will be examined in the near future.

Conclusions

Many of the design problems associated with water-cooled pyrolytic graphite targets have been reviewed. The computational tools used to assure that the target will not see excessive stresses appear adequate, although it may be difficult to decide on the target's lifetime when cyclic stresses approach the fatigue limit. Improvements in the brazing of targets to water-cooling tubes should increase their ability to dissipate greater heat loads. A better understanding of the swelling process may yet lead to its reduction through prior material processing.

Acknowledgments

We would like to thank G. A. Bennett for her work on computer calculation of target temperatures and stresses.

References

1. L. Agnew, T. S. Baldwin, D. L. Grisham, R. C. Holmberg, J. E. Lambert, L. O. Lindquist, R. D. Reiswig, and L. L. Thorn, "Graphite Targets for Use in High Intensity Beams at LAMPF," Particle Accelerator Conference, Accelerator Engineering and Technology, San Francisco, CA (March 1979).

2. J. B. Donahue, "Power Deposition of LAMPF Proton Beam in Various Materials," Los Alamos National Laboratory Group MP-7 technical note MP-7-TN-14 (August 1980).

3. R. G. Lawton, "The AYER Heat Conduction Computer Program," Los Alamos National Laboratory report LA-5613-MS (May 1974).

4. R. V. Browning, D. G. Miller, and C. A. Anderson, "TSAAS: Finite Element Thermal and Stress Analysis of Axisymmetric Solids with Orthotropic Temperature-Dependent Material Properties," Los Alamos National Laboratory report LA-5599-MS (May 1974).

5. W. V. Kotlensky and H. E. Martens, "Tensile Properties of Pyrolytic Graphite to 5000°F," Jet Propulsion Laboratory, California Institute of Technology, JPL Report No. 32-71 (1961).

6. J. J. Cacciotti and V. J. Erdeman, "Fatigue Behavior of a Pyrolytic Graphite," General Electric Company, Aircraft Gas Turbine Division report DM 61-229 (July 1961).

7. R. J. Price, "High-Temperature Neutron Irradiation of Highly Oriented Carbons and Graphites," Carbon 12, 159 (1974).

8. J. C. Bokros, G. L. Guthrie, and D. W. Stevens, "Irradiation-Induced Dimensional Changes in Imperfect Graphite Crystals," Carbon 9, 349 (1971).