**Westinghouse
Astronuclear
Laboratory**

**WANL-TME-2693
APRIL 1970**

**DATA ITEM T-119
CRYOGENIC
THERMAL SHOCK OF SHIELD MODULE
FINAL TEST REPORT**

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Westinghouse Astronuclear Laboratory

Subcontract NP-1

CODE IDENT NO. 14683

WANL-TME-2693
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THERMAL SHOCK OF SHIELD MODULE

FINAL TEST REPORT

NOTICE

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APPROVED BY:

J. G. Gallagher, Manager
NERVA Design Engineering

INFORMATION CATEGORY

J. M. Houghton
AUTHORIZED CLASSIFIER

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ABSTRACT

A hexagonal shield module of BATH material is thermally shocked at $-27^{\circ}\text{F}/\text{second}$ on its periphery by flowing chilled helium (-320°F) through the module ID at a mass flow rate of 1.1 pounds/second. A ramp rate of $-24^{\circ}\text{F}/\text{second}$ is the calculated shield module temperature ramp associated with propellant flow and temperature requirements to simulate a mid-map startup nozzle chamber temperature ramp of $150^{\circ}\text{F}/\text{second}$. The resultant strains are converted to stresses and compared with calculated stresses. The maximum calculated tensile stress is 6300 psi and the corresponding minimum ultimate strength is 15,200 psi. The post-test calculated stresses and the test results are in reasonable agreement.

There is no observable damage to the BATH shield module.

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1.0 INTRODUCTION

A hexagonal shield module of BATH composite material was subjected to a cryogenic thermal shock of $-27^{\circ}\text{F}/\text{second}$ on its periphery by passing a chilled helium (-320°F) through the module ID at 1.1 pound/second. Thermal shock induced strains were recorded, converted to stresses, and compared to calculated stresses obtained from the FEATS computer code.

1.1 TYPE OF REPORT

This report is a final report.

1.1.2 Scope of Test Document

The scope of test document is TS: 62-DE-189-1.

1.1.3 Functional Category of Test

The test is a cryogenic thermal shock test of a candidate reactor material.

1.1.4 Contractor

Westinghouse Astronuclear Laboratory (WANL/14683), under Subcontract NP-1, CY 1970.

1.1.5 Test Facility

Engineering Mechanics Laboratory (EML) Building 8, Test Date, 23 October 1969.

1.2 PURPOSE OF TESTS AND ANALYSIS

1.2.1 To determine the thermal shock properties of a proposed R-1 shield module when exposed to a simulated start-up transient.

2.0 REFERENCES AND ASSUMPTIONS

2.1 SPECIFICATION

CEI No. CP-677562

2.2 DATA REQUIREMENT SHEET

WANL Data Requirement Sheet T-119.

2.3 SCOPE OF TEST DOCUMENT

TS: 62-DE-189-1.

2.4 ASSUMPTIONS

2.4.1 That temperature and strain measurements, taken on the shield module during a flow rate associated with the nozzle chamber ramp of $150^{\circ}\text{F}/\text{second}$, can be useful for comparison with calculated results.

2.4.2 That a finite element structural module can be used for calculating the transient stresses in the BATH shield test module using the plane strain option of the FEATS computer code.

3.0 DESCRIPTION OF TEST ARTICLE

The BATH Shield Module is shown in Figures 3-1 and 3-2. It is a composite of the following materials:

<u>Bar</u>	<u>Description</u>	<u>% Volume</u>	<u>Supplier</u>	<u>P. O.</u>	<u>PDS</u>
No. 9	Aluminum powder	67.95	Alcoa	94412	30006-B
	Titanium Hydride ($\text{TiH}_{1.96}$)	25.4	Ventron	96064	Grade E
	Boron Carbide	6.65	Carborundum	94409 (-325 mesh)	Nuclear Grade

The shield module (Dwg. 388D527 HO1) is an Alcoa extrusion (P. O. 97265) of the Sylvania Iso-Press pressing (P. O. 99418). This module was authorized by ECO No. 16573 and fabricated on W. O. 00257. The BATH material characterization and complete description has been reported in TME-1947.

Figure 3-1. Shield Module

Figure 3-2. Transducer Location

4.0 SUMMARY OF TESTS

4.1 NARRATIVE

Helium chilled to -320°F was passed through the ID of the BATH shield module at a mass flow rate of 1.1 pound/second. A preliminary test run with a dummy aluminum shield module established the required mass flow rate necessary to cool the outer surface of the module for the test objective of $-24^{\circ}/\text{second}$. The BATH test fixture assembly seal developed a slight leak allowing helium to find its way to several of the fast response STG surface temperature sensors.

The STG sensor is a very slow mass sensor. It is of the shape and size of a small strain gage and is mounted exactly like a strain gage. Therefore, it reads the exact temperature environment when mounted adjacent to a strain gage. It is possible for this sensor to change faster than the surrounding material when contacted by the fluid cooling agent. Apparently the sensor in this experiment was rapidly chilled without appreciably cooling the BATH material around it. This effect produced erroneous temperature readings at several locations. One temperature sensor (STG 2 at Station 3.5") recorded a temperature ramp of $-27^{\circ}\text{F}/\text{second}$, later verified by thermal analysis calculations. (This approximated the test objective of $-24^{\circ}\text{F}/\text{sec}$). The Structural Analysis Group determined the apparent strain readings using post-test calculated temperatures. Reasonable agreement was obtained between the test results and the calculated stresses (see Section 5).

4.2 TEST CONDITIONS

A schematic of the thermal shock fixture is shown in Figure 4-1 and a photo of the fixture is shown in Figure 4-2. Strain gages compensated for 13 ppm were installed on the shield module along with the temperature sensors, as shown in Figure 3-2. The apparent strain curves are shown in Figure 4-3.

The instrumented shield module was mounted in the test fixture as shown in Figure 4-1. The test fixture pan and the heat exchanger were filled with liquid nitrogen. Valves V4 and V5 were opened 40 degrees, valve V1 was opened and V2 closed. Helium was bled through the set-up loop by opening valve V3. When potentiometer K read -320°F the helium was

Figure 4-1. Thermal Shock Fixture, Schematic

Figure 4-2. Test Fixture

Figure 4-3. Composite Apparent Strain Curves

pressurized to 740 psig and switched from the set-up loop to the shield module loop by energizing timer T1 for ten seconds which simultaneously closed the V1 valve and opened the V2 valve. At the end of ten seconds, valve V2 closed and valve V1 opened and the helium supply system was shut-down. During the test, data were automatically recorded, as shown, in Figure 4-4.

4.3 TEST RESULTS

4.3.1 Recorded Data

Data are recorded in Figure 4-4, and Table 4-1.

4.3.2 Discussion of Data

Compliance with the Test Scope Document TS-62DE-189-1 was achieved. Pretest photos, dye penetrant photos, visual inspection and X-ray photo requirements were met. See representative photos, Figures 4-5 through 4-8. The dye penetrant check included bore inspection. No damage was visible. The pretest and post-test weights were 3.020 pounds.

The objective to confine the cooled helium to the module ID was not completely achieved, in spite of pretest sealing precautions (see Figure 4-9). Consequently, a small amount of helium apparently leaked to the periphery of the shield module. As STG fast response temperature sensors were used (see Face 3 of Figure 4-7) the recorded temperature apparently changed faster than the material temperature due to fluid contact with the temperature sensor.

Figure 4-4. Thermal Shock of Shield Module - Temperature Strain Recording

Figure 4-5. Pretest X-Ray Face 2 of BATH Module

Figure 4-6. Post Test X-Ray Face 2 of BATH Module

Figure 4-7. Pretest Photo Face 3 and 4 of BATH Module

Figure 4-8. Post Test Photo Face 3 and 4 of BATH Module

Figure 4-9. Shield Module Mounted in Test Fixture

TABLE 4-1

STRAIN DATA

Strain Gage	Start		1/2 Sec		1 Sec		2 Sec		3 Sec		4 Sec	
	Strain											
	°F	μ in/in	°F	μ in/in	°F	μ in/in	°F	μ in/in	°F	μ in/in	°F	μ in/in
A1	23	-75	14	-222	-54	-311	-209	-278	-325	-267	-325	-267
A2	12	45	12	-78	-4	-67	-46	-22	-88	0	-116	0
A3	23	0	23	-67	-8	-111	-73	-67	-139	-33	-204	-22
A4	12	22	12	-44	0	-78	-85	-56	-151	0	-209	0
A5	DEFECTIVE											
H1	23	22	14	-115	-54	-222	-209	-189	-325	-145	-325	-111
H2	12	65	12	-66	-4	-178	-46	-156	-88	-110	-116	-78
H3	23	44	23	-78	-8	-178	-73	-49	-139	-66	-204	-22
H4	12	22	12	-88	0	-156	-85	133	-151	-89	-209	-66
H5	DEFECTIVE											
	5 Sec		6 Sec		7 Sec		8 Sec					
	Strain											
	°F	μ in/in	°F	μ in/in	°F	μ in/in	°F	μ in/in				
A1	-325	-267	-325	-300	-325	-311	-325	-345				
A2	-147	-11	-174	-33	-197	-78	-219	-122				
A3	-298	-44	-310	-56	-306	-89	-306	-133				
A4	-267	-22	-317	-67	-317	-111	-317	-145				
A5	DEFECTIVE											
H1	-325	-89	-325	-89	-325	-111	-325	-100				
H2	-147	-56	-174	-44	-197	-55	-219	-66				
H3	-298	11	-310	22	-306	22	-306	+22				
H4	-267	-44	-317	-66	-317	-78	-317	-88				
H5	DEFECTIVE											

5.0 ANALYSIS

5.1 ANALYTICAL MODEL

5.1.1 Thermal

Flow tests were conducted by the EML, subjecting a BATH shield module to cryogenic thermal shock conditions. Previous analyses⁽¹⁾ provided EML with the necessary control parameters and operating conditions for conducting the tests. The purpose of this analysis is to verify measured surface temperatures and to provide Structural Analysis with the detail temperature distributions required for evaluation of the stress within the shield module.

A 30 degree sector of the test module was meshed into a nodal array to obtain the module internal temperature distributions. Figure 5-1 presents a sketch of the test module and the nodal model. The nodal model consisted of 134 internal nodes representing the BATH material matrix, eight surface nodes connected to the wall of the coolant flow channel and a boundary node for the bulk fluid temperature. An adiabatic surface was assumed on the outer surface of the test module.

The chilled length of the test module was 11.5 inches. The conduction model was divided into five axial stations consistent with the location of the five temperature sensors and strain gages at Stations 1.25, 3.5, 5.75, 8.00, and 10.25 inches. This conduction model was then input to the TRACK computer program⁽²⁾.

The hydraulic input to the TRACK computer program consisted of one flow channel with a hydraulic diameter of 1.12 inches, a channel length of 11.5 inches, an inlet pressure of 72 psia, an inlet temperature of 140°R, and a channel flow rate of 1.1 lb/sec. of helium. Material properties for the BATH material were obtained from Thermal Design's Standard Material File⁽³⁾, which serves as a computational data tape developed from Materials Department data input⁽⁴⁾.

The post test analysis resulted in temperature distributions throughout the test specimens, the coolant channel temperature flow, the channel pressure distribution, the heat flux from the surface nodes, and the total power transferred to the fluid as a function of time. The material temperature distributions were used by Structural Analysis calculations reported in Section 5.1.2.

Figure 5-1. Shield Module Test Specimen

Figure 5-2 shows the temperature distributions at Stations 1.25, 3.5, 5.75, 8.0, and 10.25 inch, at time = 2 sec. This figure is characteristic of the calculated temperature distributions input to the Structural Analysis codes. Figure 5-3 presents a comparison of the measured and calculated temperatures from this analysis performed to verify the measured surface temperatures. The results indicate that the best behaved temperature sensor is at 3.5 inches and that the calculation is in good agreement. The predicted temperature histories in Reference 1, illustrated the transient behavior.

5.1.2 Structural

A BATH shield module was subjected to a cryogenic shock to obtain some experimental data on the thermal shock capabilities of the BATH shield material. To obtain some quantitative data, in addition to qualitative results, strain gages were applied to the outer surface of the test specimen and monitored during the ten second thermal shock test. A pre-test stress analysis was performed⁽⁵⁾ to predict stress and strain levels in the BATH test specimen, to set strain gage ranges, and to determine the probability of cracking the test specimen. The purpose of this analysis was to compare the measured strains (which are converted to stresses using Hooke's law) with the post-test calculated stresses.

A sketch on the shield module test specimen indicating strain gage locations and the structural analytical model are shown in Figure 5-4. The finite element structural model was used to calculate the transient stresses in the BATH test specimen by using the plane strain option of the FEATS code⁽⁶⁾. The stresses were calculated at five axial stations 1.25 in., 3.50 in., 5.75 in., 8.00 in., and 10.25 in. which correspond to the strain gage locations.

The post-test calculated temperature distributions reported in Section 5.1.1 and the measured test specimen internal pressure of 72 psig were input to the structural analytical model. The material properties data for BATH used in the post-test analysis were obtained from References 7 and 8.

To compare the strain gage test data with the post-test calculated stresses, the recorded strains were corrected to eliminate apparent strains using the post-test calculated

Figure 5-2. Material Temperature Distributions at 2 Sec. 30 Degree Sector

Figure 5-3. Comparison of Measured and Calculated Temperatures

Figure 5-4. BATH Shield Module

temperatures; the resultant strains (ϵ (resultant) = ϵ (recorded) - ϵ (apparent)) were converted into corresponding stresses by using the following biaxial stress-strain relations:

$$\sigma_H = \frac{E}{1-\mu} (\epsilon_H + \mu \epsilon_A)$$

$$\sigma_A = \frac{E}{1-\mu} (\epsilon_A + \mu \epsilon_H)$$

where

- σ_H = Hoop or tangential stress
- σ_A = Axial stress
- ϵ_H = Resultant hoop strain obtained from test
- ϵ_A = Resultant axial strain obtained from test
- E = Modulus of elasticity
- μ = Poisson's ratio

The curves plotted in Figure 5-5 represent the classical results of a cylinder cooled at the ID and insulated at the OD⁽⁹⁾. Figure 5-5 shows the variation in OD hoop stress and OD axial stress (normalized to the maximum compressive stress) versus percent length. The length-to-hole diameter ratio and OD-to-ID ratio for the cylinder model shown in Figure 5-5 and the shield test specimen are approximately the same; therefore, the OD stress pattern obtained from the shield test specimen at any given time should be similar to these curves. Note that the cylinder end effects vanish rapidly (10 to 15 percent of the cylinder length), and therefore, the strain gages with the possible exceptions of the end gages (A1, H1, A5, and H5) were in a plane strain condition. Thus, the original assumption of using the plane strain option in the FEATS code is reasonable.

The post-test calculated stresses and the measured stresses (strains) were plotted as a function of time and compared for the five axial stations^(10, 11). Figures 5-6 and 5-7 show the hoop stress histories (compression) of the test specimen outer surface at stations 1.25 inches and 5.75 inches, respectively. On these figures Curve A represents the resultant strains obtained from the test, and Curve B represents the post-test calculated stresses. As can be seen, the calculated stresses are in fair agreement with the test results.

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Figure 5-5. Variation in OD Hoop Stress and Axial Stress Versus Percent Length for a Cylinder Cooled at the ID and Insulated at the OD

Figure 5-6. Hoop Stresses Versus Time, Outer Surface at Station 1.25 In.

Figure 5-7. Hoop Stresses Versus Time, Outer Surface at Station 5.75 In.

Figure 5-8 shows the maximum calculated tensile stresses which occur at the test specimen ID and the corresponding minimum ultimate strengths of BATH. The maximum calculated tensile stress of 6300 psi occurs at approximately one second and the corresponding minimum ultimate strength is 15,200 psi.

Figure 5-8. Maximum Calculated Stresses Versus Time

6.0 CONCLUSIONS

- 6.1 The BATH test specimen did not fracture during the test for a calculated temperature ramp of $-27^{\circ}\text{F}/\text{second}$. The maximum calculated tensile stress is 6,300 psi, and the corresponding minimum ultimate strength is 15,200 psi.
- 6.2 The post-test calculated stresses and the test results are in reasonable agreement.
- 6.3 A visual post-test shield module inspection, following all scheduled tests, showed no visible damage. These results, of no damage, were further substantiated by dye penetrant and radiographic test results.

7.0 REFERENCES

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2. "TRACK, A Computer Program for the Transient and Steady State Coupled Fluid Flow and Heat Conduction Analysis", WANL-TME-1736.
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11. "BATH Shield Module Thermal Shock Post-Test Analysis", WANL-DRM-52434A.

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