MLM-2208 (LD)

MLM-2208 (LD)

[redacted]

Navy Heat Source Safety Tests

C. G. Anderson and W. B. Cartmill

June 18, 1975

This document is
PUBLICLY RELEASABLE
Authorizing Official
Date: 6-25-09

[redacted]

MOUND LABORATORY
Miamisburg, Ohio
operated by

Monsanto

MONSANTO RESEARCH CORPORATION
a subsidiary of Monsanto Company
for the
UNITED STATES ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
U. S. Government Contract No. AT-33-1-GEN-53

Navy Heat Source Safety Tests

Issued: June 18, 1975

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or 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.

MONSANTO RESEARCH CORPORATION

A Subsidiary of Monsanto Company

MOUND LABORATORY

Miamisburg, Ohio 45342

operated for

UNITED STATES ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

U.S. Government Contract No. AT-33-1-GEN-53

DISTRIBUTION

EXTERNAL

B. K. Blake, DAO, ERDA
D. K. Nowlin, ALO, ERDA
Lt. Comm. J. L. Renzetti, NNPU-USN
N. R. Thielhe, SNS/ERDA
E. A. Walker, DAO, ERDA

INTERNAL

W. R. Amos
C. G. Anderson
C. O. Brewer
L. Bretland
C. E. Burgan
W. B. Cartmill
D. L. Coffey
J. W. Doty
T. C. Elswick
D. E. Friedline
K. V. Gilbert
R. S. Grimm
R. R. Jaeger
E. W. Johnson
L. V. Jones
D. P. Kelly
B. R. Kokenge
D. F. Luthy
D. L. Prosser
B. D. Scearce
A. F. Schmidt
P. E. Teaney
J. G. Villars (2)
W. C. Wyder
Library (15)
Publications (6)

TABLE OF CONTENTS

	Page
INTRODUCTION	4
PURPOSE	5
METHODS AND PROCEDURE	
Pretest Considerations	5
Test Procedures	5
Test Organization	5
Calculations for Required Pressure Test Pressures	6
Test Results	6
ATTACHMENT A - PHOTOGRAPHS OF CAPSULES AND EQUIPMENT	7
ATTACHMENT B - TEST PROCEDURE	13
ATTACHMENT C - TEST DATA	19
ATTACHMENT D - FIRE TEST DATA	22
ATTACHMENT E - CALCULATIONS: PRESSURE TEST PRESSURES	28
ATTACHMENT F - POST-MORTEM REPORT	31

INTRODUCTION

Four simulant-fueled Navy Heat Sources underwent impact, percussion, 800°C thermal shock, immersion, and pressure tests and satisfactorily passed a 10^{-4} cm^3/sec helium leak test after each of the above tests.

Some collapsing of the capsules did occur during the 14,700 psig external pressure test, which was most probably due to the dents incurred during the percussion tests. The collapsed condition did not alter the integrity of the capsules and all four passed the 10^{-4} (STP) cm^3/sec helium leak test (See Attachment A, Figure 1).

Five strength member capsules (Attachment A, Figure 2) underwent and satisfactorily passed a simulated 800°C fire test for a time period in excess of one-half hour.

PURPOSE

The purpose of these tests was to validate the integrity of the Navy Heat Source after imposing conditions which might, in the extreme, be encountered singly or serially so that safety would be assured.

METHODS AND PROCEDURE

Pretest Considerations

- The percussion and external pressure test fixtures (Attachment A, Figures 3 and 4 respectively) were designed and built to upgrade previous equipment and methods. The lead plate used for the percussion test was carefully selected from hardness tests.
- A scaffold (Attachment A, Figure 5) was built for the impact test to ensure operator safety and to include space for the heater required for the 400°C portion of the test.
- Gauges and transducers needed for test readings were calibrated in the Standards Laboratory.
- Thermocouple output was checked with a digital voltmeter for use on the fire test recorders (Attachment A, Figure 6).

Test Procedures

The test plan used is outlined in Attachment B. The actual tests (See Attachments C and D for test data) made were as agreed upon by the Navy, the Energy Research and Development Administration and Monsanto Research Corporation.

Test Organization

The test organization consisted of:

Test Supervisor - C. O. Brewer, MRC
Test Operations - C. G. Anderson, MRC
- C. P. Johnston, MRC
- R. C. McWilliams, MRC
Observer - F. E. Rosell, Jr., Navy

Calculations for Required Pressure Test Pressures

The required pressures were as calculated in Attachment E.

Test Results

No test failures were encountered and the results of the tests verify that the Navy Heat Source is acceptable for its intended use. The post-mortem report with photographs is given in Attachment F.

ATTACHMENT A

PHOTOGRAPHS OF CAPSULES AND EQUIPMENT

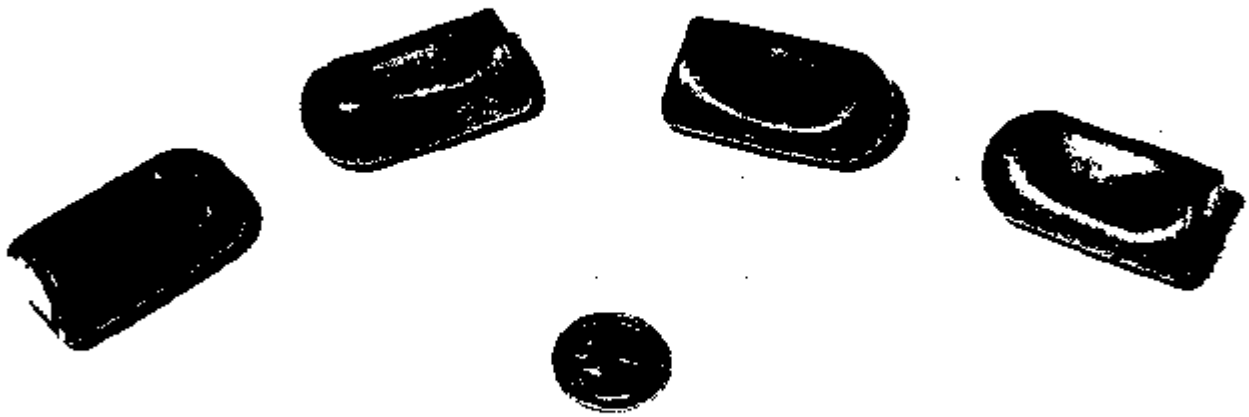

FIGURE 1 - Capsules after helium leak testing.

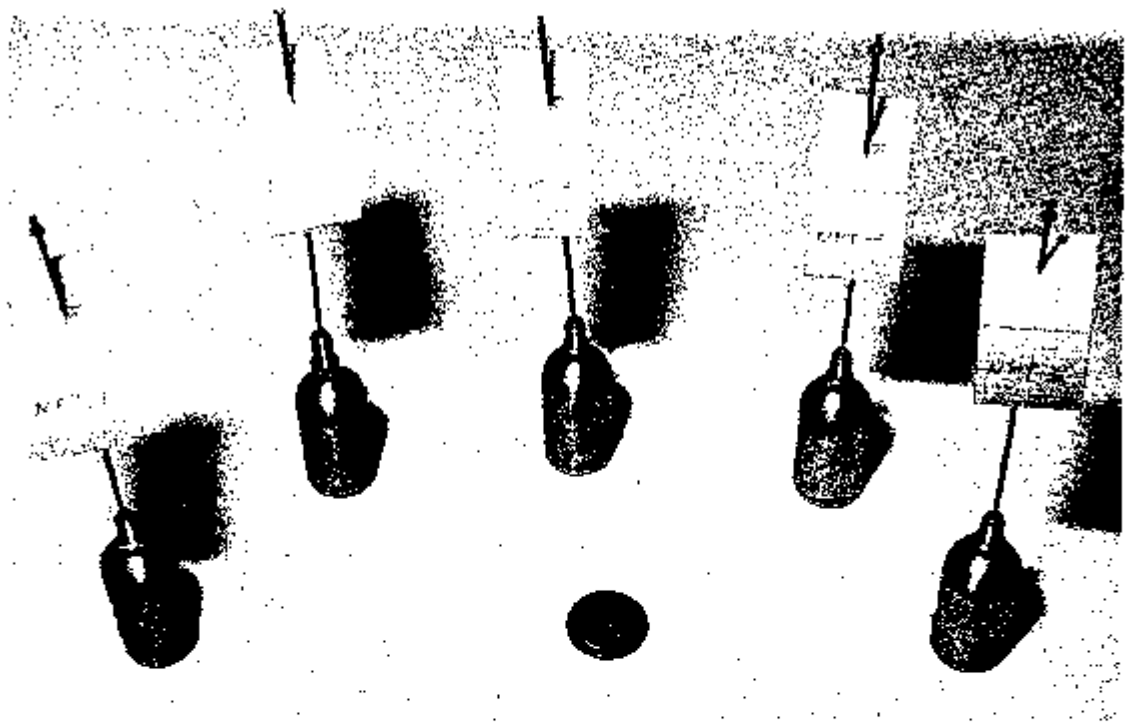

FIGURE 2 - Capsules after fire test.

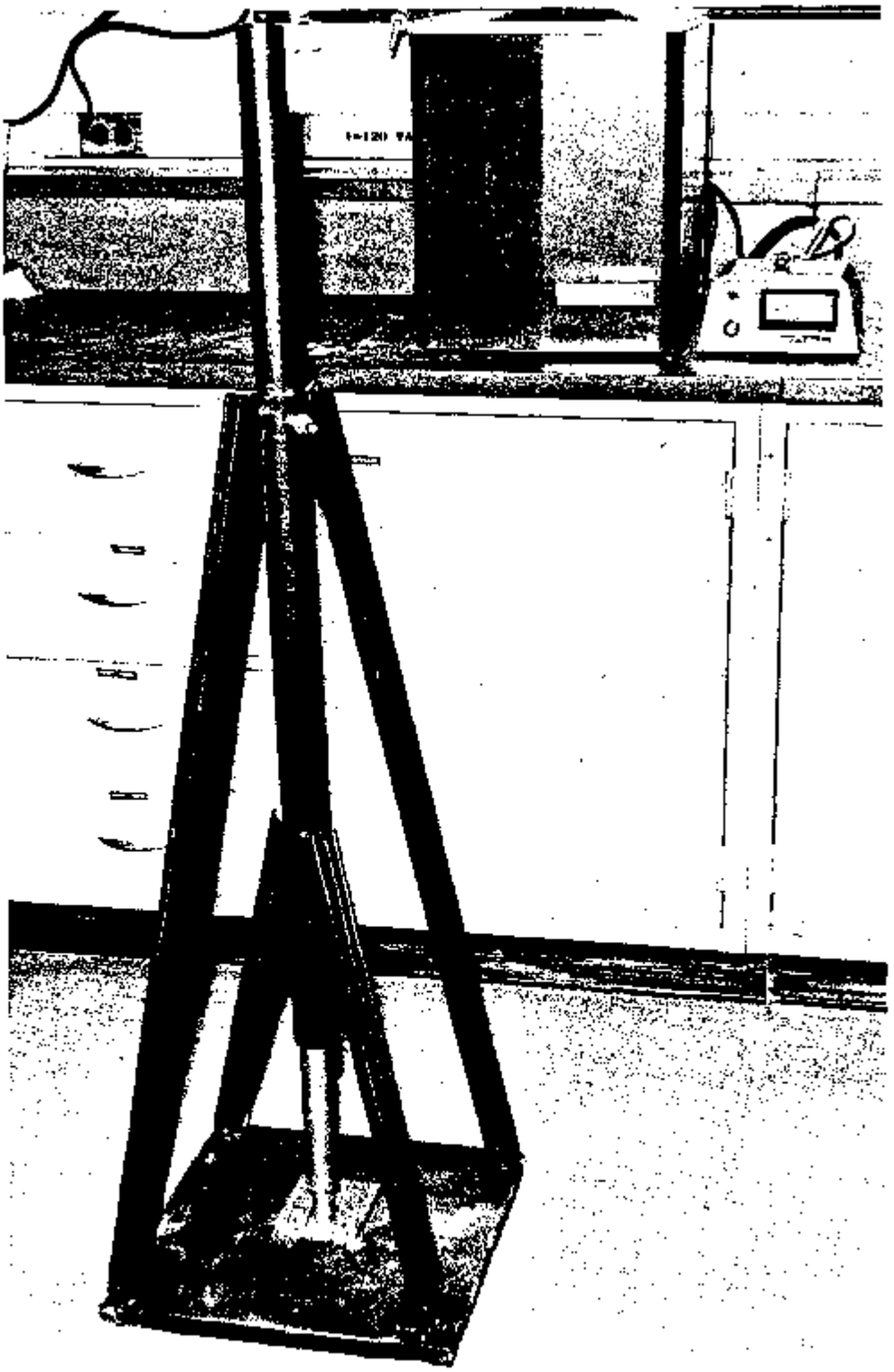

FIGURE 3 - Percussion test apparatus.

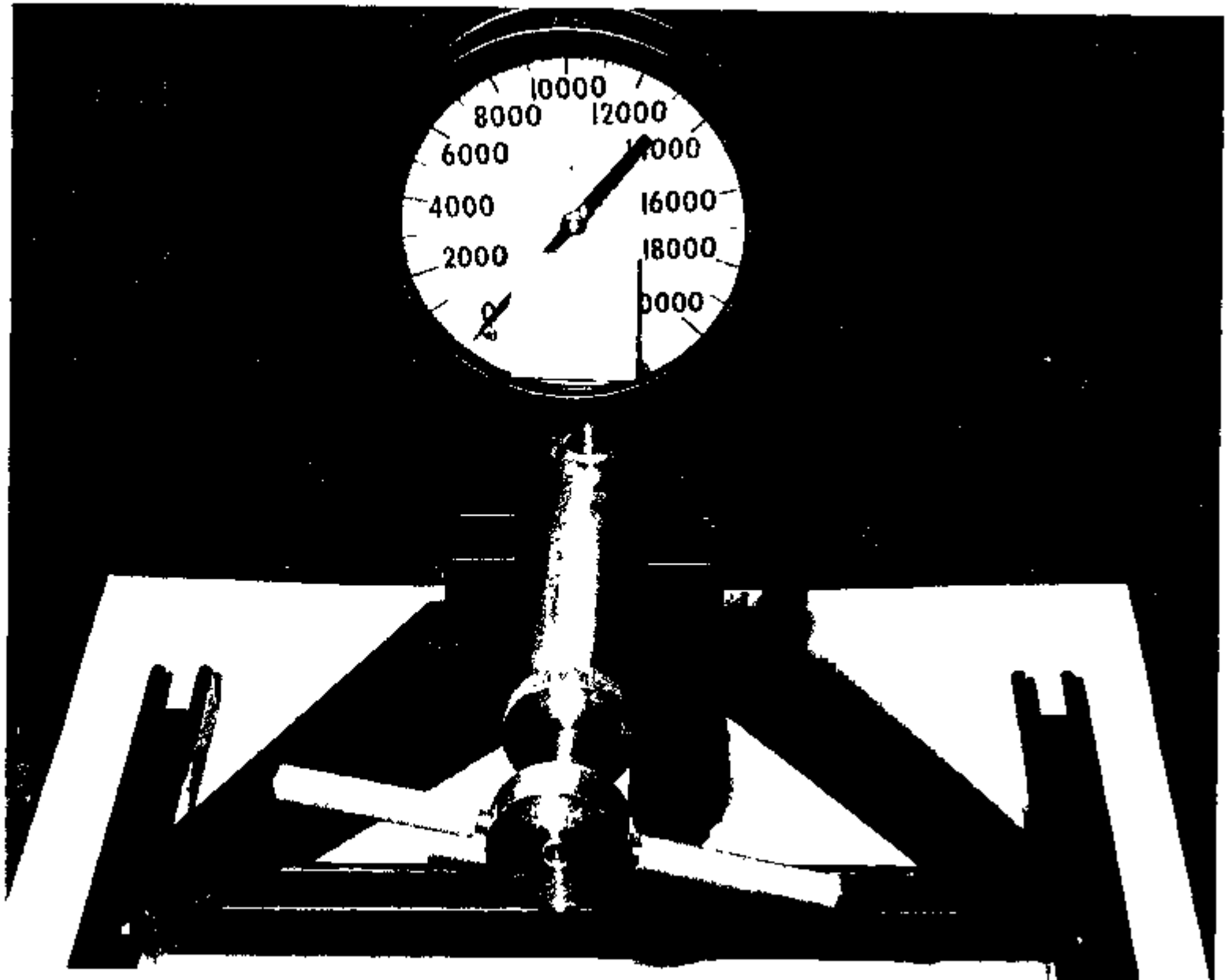

FIGURE 4 - Pressure test apparatus.

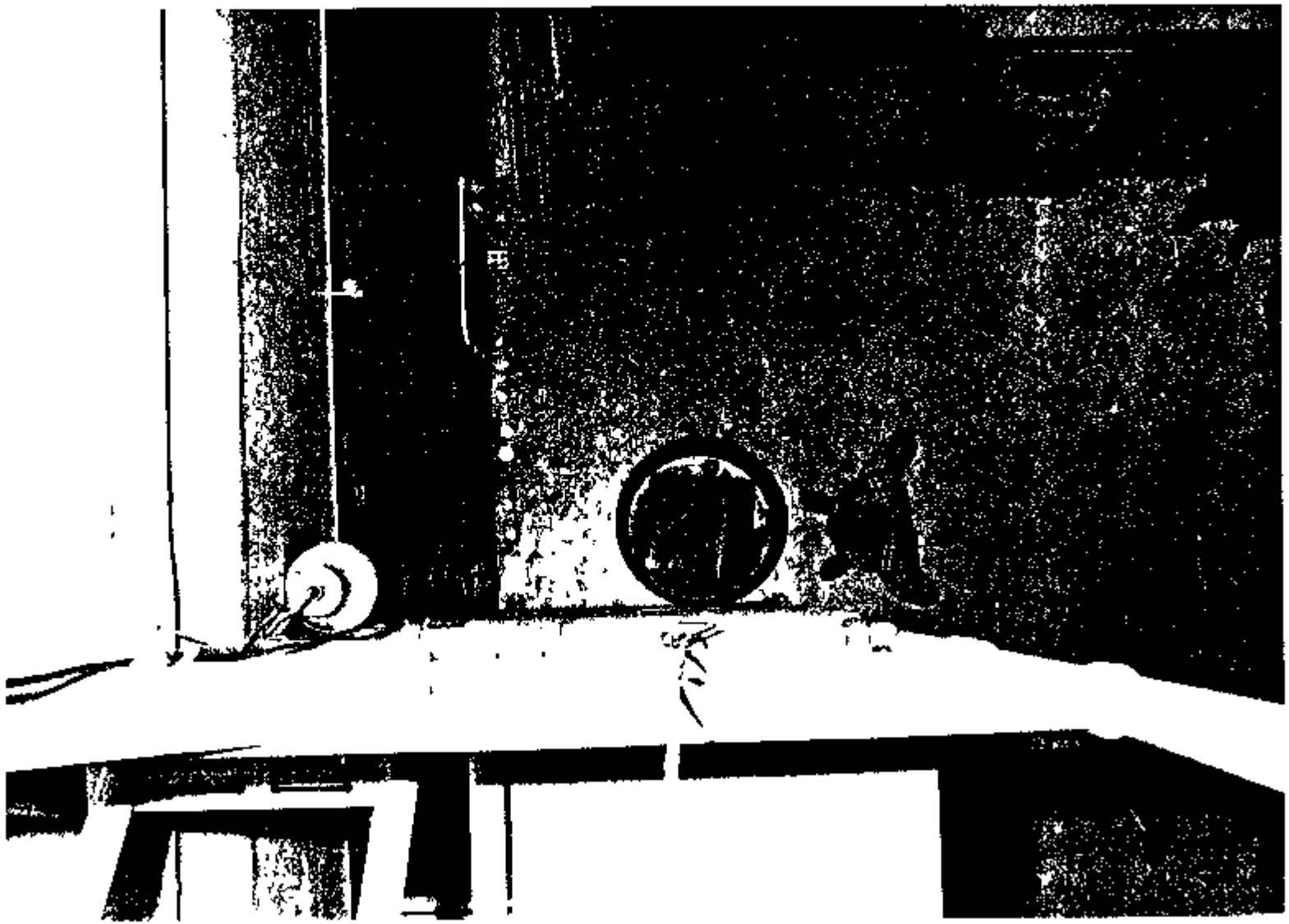

FIGURE 5 - Scaffold for impact test (view looking down).

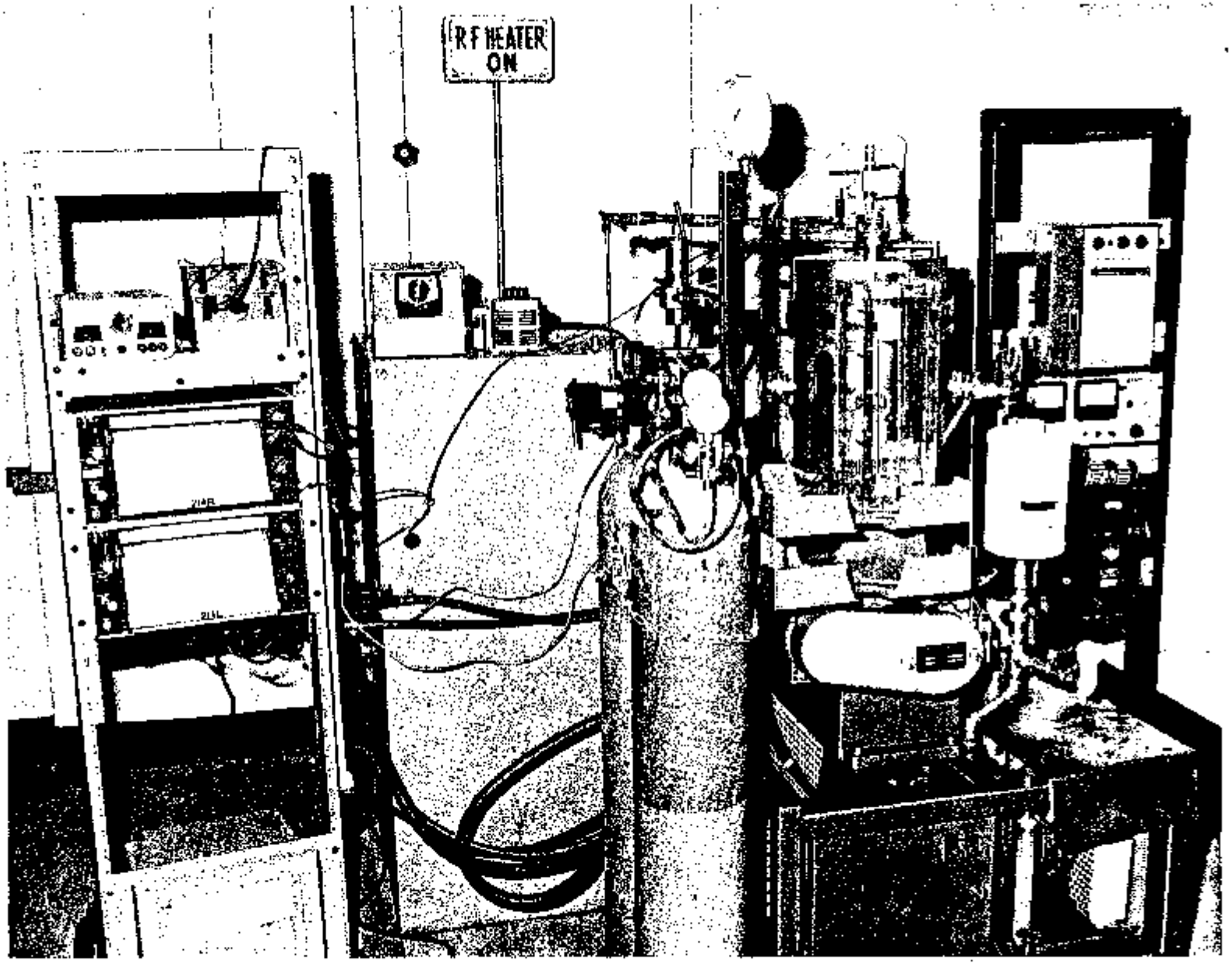

FIGURE 6 - Fire test apparatus.

ATTACHMENT B

TEST PROCEDURE

RTG HEAT SOURCE OPERATIONAL SAFETY TEST PLAN

General Heat Source Test Procedure - Testing will be performed on no less than three simulant-fueled capsules. All capsules will be tested to the appropriate portions as per the attached summary sheet. As a minimum, tests 1-7 (Table 2) will be accomplished on at least three capsules of each distinct configuration.

Test 8 must be performed on any capsule strength member having a pressure safety factor of less than three at the end of its mission life or if the mission life exceeds 5 years.

Vibration and High Velocity Impact tests will be performed upon capsules used for outer space missions, consistent with the mission environment.

Such other tests as may be required to satisfy specific design information need will be accomplished.

1.0. Objectives

To evaluate the performance of the heat source under environments equal to or greater than those encountered in actual operation.

a. Evaluate the effect of tests upon clearances.
b. Evaluate the effect of the tests upon material choices.
c. Evaluate the effect of structural changes, if any.

2.0. Scope

The simulant-fueled capsules will be subjected to tests 1-7 listed on the attached test summary sheet (Table 2) and any further tests MRC may determine to be necessary. Test 8 will be performed on five or more strength member assemblies.

3.0. Facilities and Equipment (see Table 1 also)

3.1. Building 36

3.1.1. High Velocity Impact Gun
3.1.2. Percussion Test Equipment
3.1.3. Thermal Test Equipment
3.1.4. Thermal Shock Equipment
3.1.5. Immersion Test Equipment

3.1.6. Pressure Test Equipment
3.1.7. Leak Test Equipment
3.1.8. Fire Simulation Test Equipment

3.2. Alpha Fuels Building

3.2.1. Impact Test Equipment

3.3. Hardware

The following hardware will be used:

Special fixtures - None

Heat source S/N NT-1, NT-2, NT-3 and NT-4

4.0. Overall Instructions

4.1. Handling

4.1.1. No special handling is required for simulant fueled capsules; however, effects of the various tests should not be removed by handling.

4.2. Operating

4.2.1. Insure the safety of employes and the integrity of the test by proper barriers or notices as required.

4.3. Abort Conditions

4.3.1. Should the heat source fail a leakage test, discuss this fact with supervision and the program manager before proceeding.

4.4. Health Physics

4.4.1. Health Physics is not required for simulant fuel.

5.0. Pretest Procedure

5.1. Open Log.

5.2. Record date, time and serial number of parts to be tested. Also record equipment involved in the test.

5.3. Make a general inspection to determine that all facilities and equipment are in working condition and that sufficient standard lab calibrations have been made to validate the tests.

5.4. Zero and/or calibrate the recorders, used for temperature and power if required.

6.0. Test Plan and Sequence

Perform the tests listed on the summary sheet (Table 2) in numerical order; however, a leak test is to be performed after each test except test 8.

Since test 8, the fire test , is performed upon the strength member only, it is performed independently of any other tests.

Any additional tests will be worked into the plan as required by circumstances of such tests.

7.0. Post-Test Procedure

7.1 Remove test item from the test equipment.

7.1.1 Record in the log the results of a complete physical inspection of the test pieces.

7.1.2 Close out the log for the current test.

7.1.3 Go to next test number in sequence, if the current test is the last test, go to Section 8.0. below.

8.0. Post-Test Evaluation

8.1 Check all logs to be sure data is correct.

8.2 Transfer heat source for dye penetrant check and sectioning for final analysis.

8.3. Forward copy of tests to Project Manager.

Table 1

TEST EQUIPMENT LIST

Test Name	Test Location	Test Equipment
Impact (drop)	Bldg. 50	Resistance Furnace (MRC) Capsule Holder/Trigger (MRC) Catch Tank with Steel Plate
Percussion	Bldg. 36	7-Kilogram Steel Bar 2.5 cm o.d. 1/4-Inch Thick Lead Sheet Bar Launch Alignment Pipe ~1-1/8" i.d.
Thermal	Bldg. 36	Furnace, Lindberg HD Crucible
Thermal Shock	Bldg. 36	Furnace, Lindberg HD Crucible Ice Water in Stainless Beaker
Immersion	Bldg. 36	Continuation of above test at room temperature
Pressure	Bldg. 36	Pressure Chamber (MRC)
Leakage	Bldg. 36	Veeco MS-9 Leak Detector (or equal) Standard Leak
Creep Rupture	Bldg. 36	High Pressure Gauges and Tubing Varian Vacuum System Resistance Furnace (MRC)
Impact (high velocity)	Bldg. 36	Impact Gun - Machine Dynamics Inc. Induction Heater - Cycle Dyne

Table 2

CAPSULE SAFETY TESTS

Item	Test	Test Description	Test Requirement Source
1	Impact Test*	A 9-meter (29.53 ft) drop of the capsule at room temperature then operating temperature on an unyielding surface.	IAEA/ENEA Safety Series 33 Appendix I, 2.1
2	Percussion Test*	A 7-kilogram (15.44 lb) drop of a steel bar 2.5 centimeters (0.98 in.) diameter from a height of 1 meter (39.4 in.) with its flat end hitting the capsule at room temperature then operating temperature, while the capsule is resting on lead sheet on an unyielding surface.	IAEA Safety Series 33 Appendix I, 2.2
3	Thermal Test	A hot soak of capsule at 800°C for 30 minutes.	IAEA Safety Series 33 Appendix I, 2.3
4	Thermal Shock	Heat capsule to operating temperature and plunge it into 0°C water and cool for 10 minutes.	IAEA Safety Series 33 Appendix I, 2.4
5	Immersion Test	Immerse capsule in water at 15 meters (21.3 psig) pressure for 24 hours.	IAEA Safety Series 6 Section VII, 721 & 10CFR71
6	Pressure Test	Apply external pressure of 1000 bars (14,700 psig) to the capsule.	IAEA Safety Series 33 Appendix I, 2.5
7	Leakage Test	A helium leakage test shall show no more than 10^{-4} (STP) cm^3/sec after the testing equipment has been calibrated with a 10^{-8} range standard leak. This test will be made after each of the above tests.	IAEA Safety Series 33 Appendix I, 2.6 Reg. Guide 6.3, Section C
8	Fire Simulation Creep Rupture Test	A minimum of 5 strength members will be internally pressurized to the 20-year life capsule pressure at an operating temperature of 300°C and given a simulated fire test at 800°C for one-half hour.	IAEA Safety Series 33, 2.7 Design Conformation

*Note: Room temperature for these tests is defined as 18°C to 29°C, and operating temperature as 400°C.

ATTACHMENT C

TEST DATA

NAVY CAPSULE SAFETY TESTS

Monday, 12-16-74

0900 - Made room-temperature, 9-meter drop test on the four (NT-1, 2, 3 & 4) simulant fueled units. Leak checked - OK.

1300 - Above tests repeated with capsules at 400°C. Leak checked - OK.

1500 - Performed 7 kilogram steel bar drop from 1 meter onto each capsule at room temperature. Leak checked - OK. Repeated above test with capsules at 400°C. Leak checked - OK. After each test, dents were observed in the capsules, approximately 1/16 in. deep, at points of impact.

Tuesday, 12-17-74

0900 - Made 800°C soak test for 30 minutes on the four capsules. Leak checked - OK.

1300 - Hot soaked the four capsules at 400°C for 30 minutes and plunged each into 0°C water. Leak checked - OK.

1500 - Pressurized the four capsules in water to 21.3 psig for 24 hours.

Wednesday, 12-18-74

1300 - Water soak at 21.3 psig for 24 hours complete. Leak checked - OK.

1700 - Set-up for 14,700 psig external pressure test.

Thursday, 12-19-74

0800 - Began 14,700 psig external pressure tests

1000 - All four units tested at 14,700 psig. All units collapsed under pressure. All units started to yield between 9000-12000 psig. The depressed areas occur where the percussion test made an indentation. All units appear to have survived the test without cracking.

1230 - Heat source units are awaiting helium leak test. All leak checked 4×10^{-8} cm^3/sec.

1330 - Start test for fire simulation on NPT-1 strength member.

1530 - Test terminated OK. Bubble test after first test disclosed slight bubble in acetone at 1/16" compression fitting. Will increase torque on nut from 50 to 60 inch-lb for balance of units.

Friday, 12-20-74

1040 - Start ramp for NPT-2 from 300°C to 800°C. 11:28 test completed - OK.

1435 - Start NPT-3 ramp from 300°C to 800°C. Test completed at 15:25.

Monday, 12-23-74

1030 - NPT-4 ramp from 300°C to 800°C started. Test completed at 10:55.

1449 - NPT-5 ramp from 300°C to 800°C started. Test completed at 16:20 p.m.

Tuesday & Wednesday - Christmas Holidays

Thursday, 12-26-74 - Remove NPT-5 from rig.

ATTACHMENT D

FIRE TEST DATA

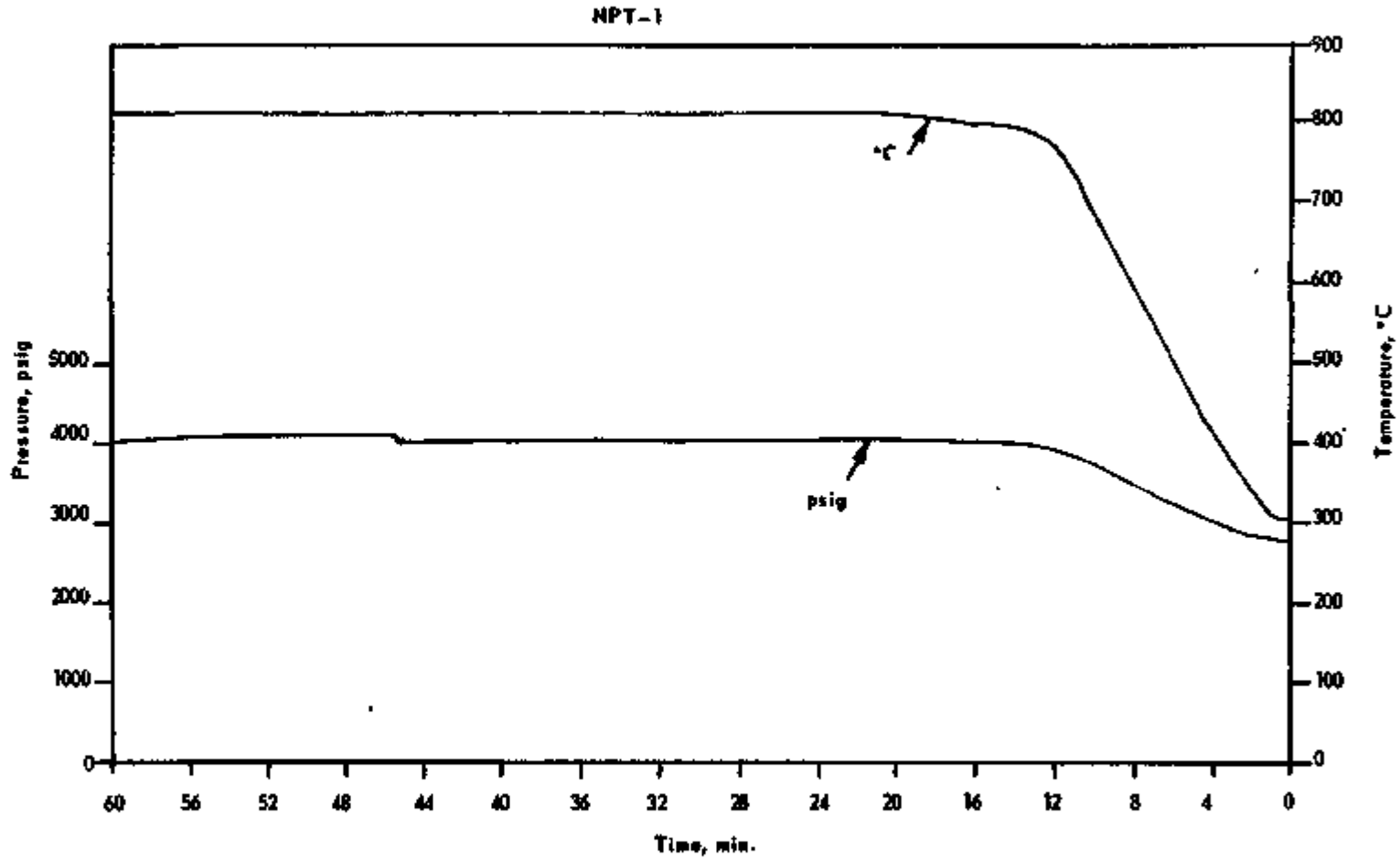

FIGURE 7 - Fire test data for NPT-1.

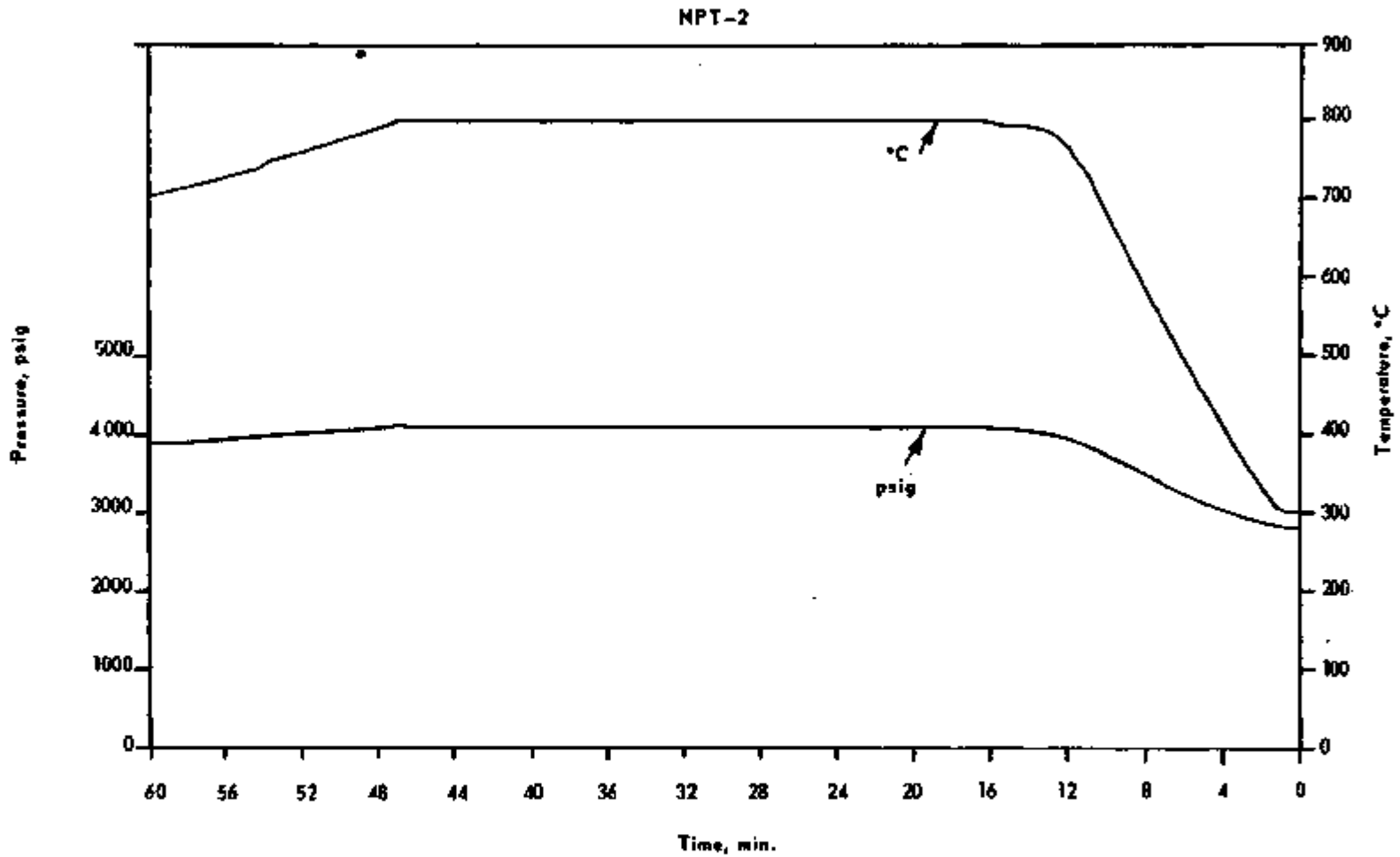

FIGURE 8 - Fire test data for NPT-2.

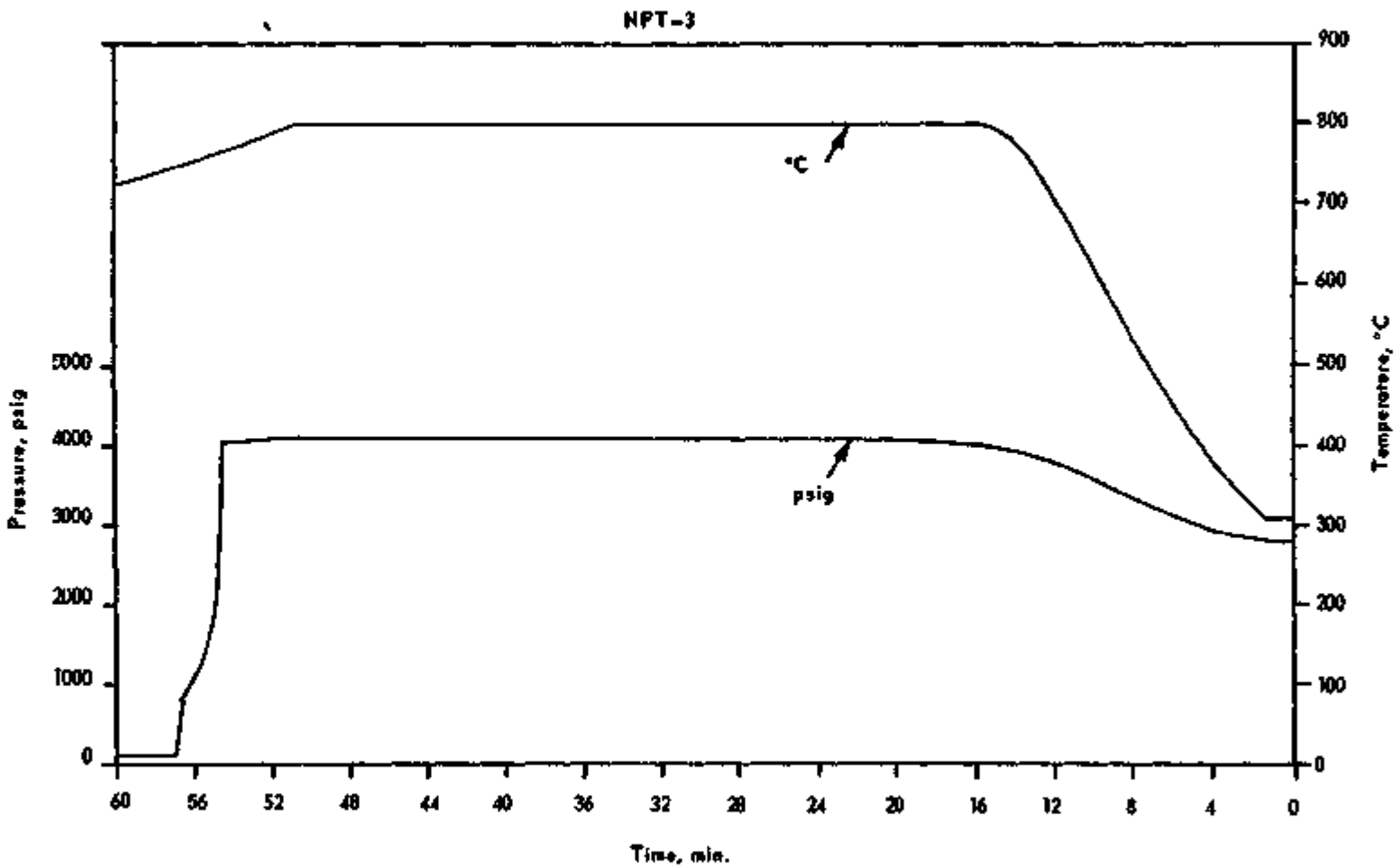

FIGURE 9 - Fire test data for NPT-3.

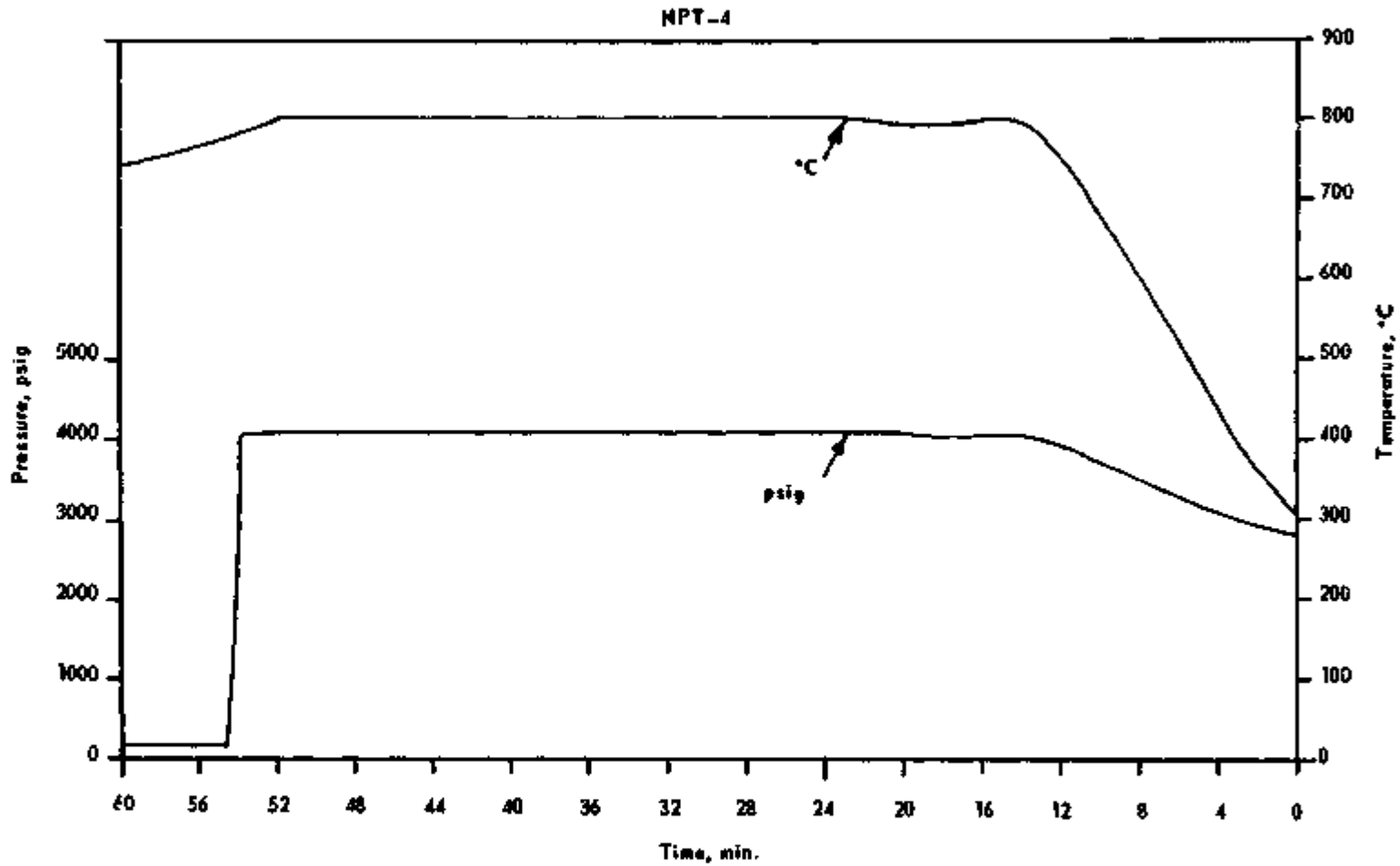

FIGURE 10 - Fire test data for NPT-4.

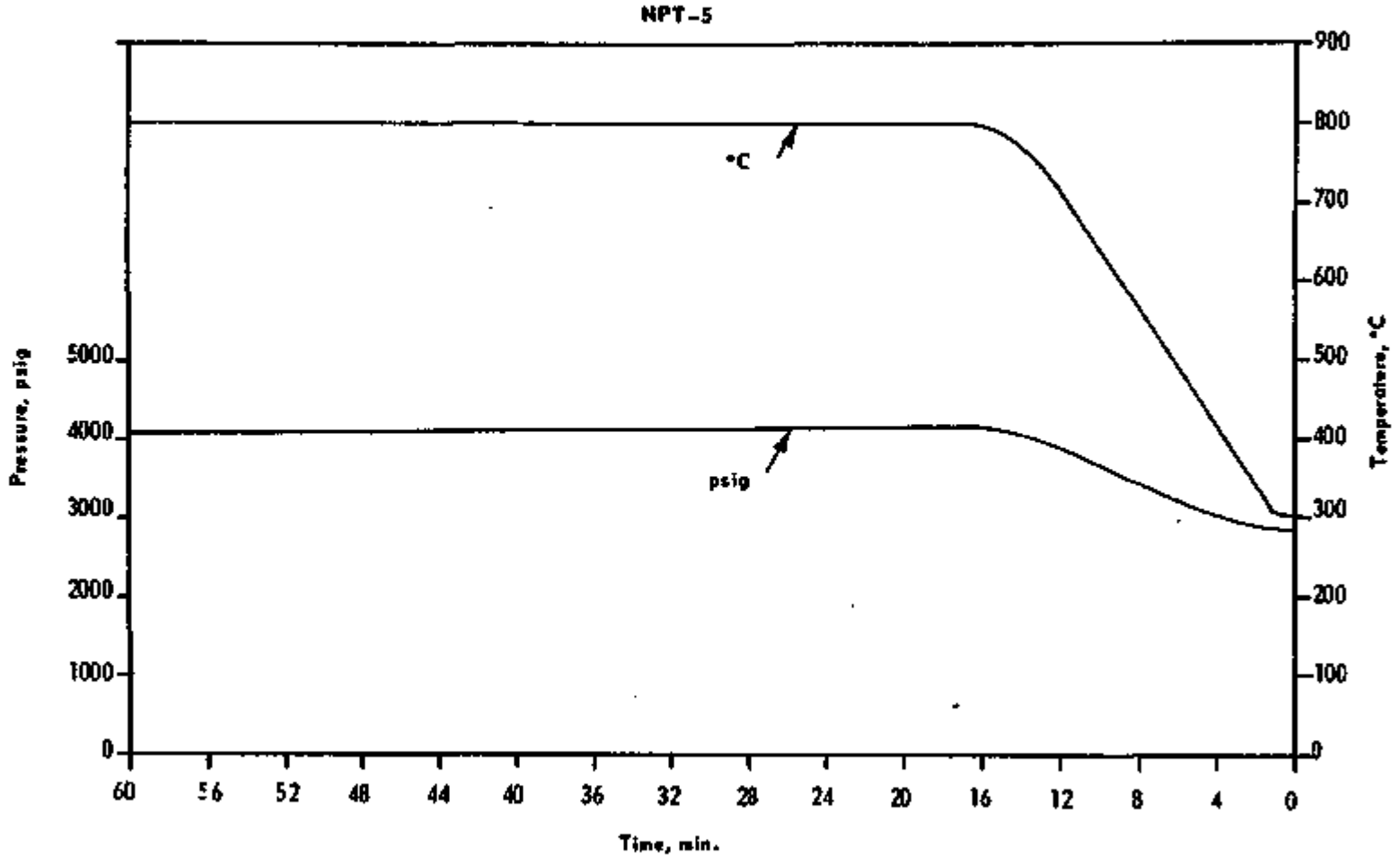

FIGURE 11 - Fire test data for NPT-5.

ATTACHMENT E

CALCULATIONS: PRESSURE TEST PRESSURES

NAVY CAPSULE

Calculation for Pressure Test Strength Member (SM)

(liner assumed ruptured or leaking)

18.5 watts fuel volume (solid, no holes)

$$= \frac{18.5\ W}{70\ W} \times 17.23\ cm^3 = 4.554\ cm^3$$

Liner volume	1.574 cm^3
Volume inside SM	= 6.128 cm^3

Volume inside SM

$$= \text{Hemi} + \text{Cyl}$$

$$= 2/3\ \pi R_i^3 + \pi R_i^2\ l_i$$

$$= 2/3\ \pi\ 0.391^3 + \pi \times 0.391^2 \times 1.319$$

$$= 0.1252 + 0.6335 = 0.7587\ in^3$$

$$= 12.44\ cm^3$$

Void vol in SM = 12.44 cm^3 − 6.13 cm^3 = 6.31 cm^3

Fuel loading 18.5 watts metal (PuO_2)

$$\frac{18.5\ W}{0.576\ W/g} = 32.12\ g\ \text{(metal)}$$

$$\text{Moles metal} = \frac{32.12}{238.} = 0.135 = N_o$$

Moles Helium Produced in 20 Years

$$N = N_o\ (1 - e^{-\lambda t}) \qquad \lambda = 0.693$$

$$N = N_o\ (1 - e^{-0.1587}) \qquad t = \frac{20}{87.4} = 0.229$$

$= N_O\ (1 - 0.8533)$

$= N_O \times 0.1467 = 0.135 \times 0.1467 \qquad \lambda t = 0.1587$

$= 0.0198$ moles in 20 years

Pressure at 20 years

$$P = \frac{NRT}{V_v}$$

$N = 0.0198$
$R = 82$
$T = 1073K$

$$= \frac{0.0198 \times 82 \times 1073K}{6.31}$$

$V_v = 6.31\ cm^3$

$= 276.09$ atm

$= 4059$ psi

$$\frac{P_2V_2}{T_2} = \frac{P_1V_1}{T_1}$$

$T_1 = 300°C$
$= 573K$

$$P_1 = \frac{P_2}{T_2} \times T_1$$

$T_2 = 1073K$

$$P_1 = \frac{4059\ psi}{1073K}$$

$P_2 = 4059$ psi

$$= \frac{4059 \times 573}{1073}$$

$= 2168$ psi

ATTACHMENT F

POST-MORTEM REPORT

MONSANTO RESEARCH CORPORATION — Inter-Office Correspondence

From LOCATION: Navy Heat Source Program

cc: C. G. Anderson
C. O. Brewer

DATE: January 31, 1975

SUBJECT: Evaluation of Navy Test Capsules NT-1, NT-2, NT-3, and NT-4

REFERENCE:

TO : D. F. Luthy

After physical tests were completed on the navy test capsules NT-1, NT-2, NT-3, and NT-4; the thoria fuel simulant was removed by drilling a hole into the bottom of the capsules. The capsules were then cut lengthwise through the center.

Photographs of the inside and outside surfaces of the deformation area of the clad, strength members, and liners were made.

The capsule components were visually examined at 20X and were dye checked for cracks.

Cross-section metallographic samples were taken from each component through the deformation area. Cross-section metallographic samples were taken from each component through the weld at the point of maximum deformation and at 90° of the deformation.

None of the components of the capsules had been breached. Dye indications were found on the inside surface of the liners of NT-1, NT-2, and NT-3. Cracks could be seen, and a photograph of the cracks on NT-1 was made. From cross sections of the cracks, most measured 0.002" deep; however, NT-1 had one that measured 0.003", and NT-3 had one that was 0.004" deep. No cracks were found on NT-4.

Micro hardness of the liner bodies are:

	Inside Edge of Sample	Center of Sample	Outside Edge of Sample
NT-1	310 DPH	271 DPH	308 DPH
NT-2	389 DPH	299 DPH	312 DPH
NT-3	318 DPH	276 DPH	313 DPH
NT-4	316 DPH	288 DPH	307 DPH

There were dye indications on the liner welds at the time of fabrication. Upon investigation of the fabrication of the liners, it was found that the liners were machined after the final heat treatment. Test made on a liner showed chlorine to be present and is believed to be from the cutting fluid used during machining. Various cleaning and off-gassing of liners still had dye indications after welding. A liner was then heat treated at 2600°F for one hour at 10^{-5} torr, and no dye indications were present after welding.

There were some indications on the outside surface of the strength member bodies, which were from smeared metal from the machining during fabrication.

There were dye indications on the inside surface of the clad bodies, which were small pits caused from the as formed etched surface being put into tension by the deformation of the capsule. Cross section of these pits measured 0.001" deep.

There were no cracks found on any of the metallographic samples of the welds. All the weld had full penetration. Photomicrographs were made of each weld at the point of maximum deformation.

Bill Cartmill

BC:eg

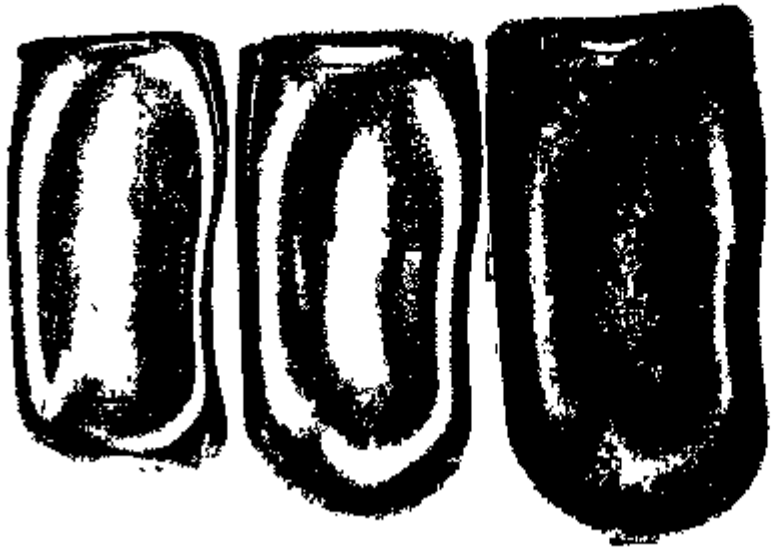

FIGURE 12 - NT-1 outside surface.

FIGURE 13 - NT-1 inside surface.

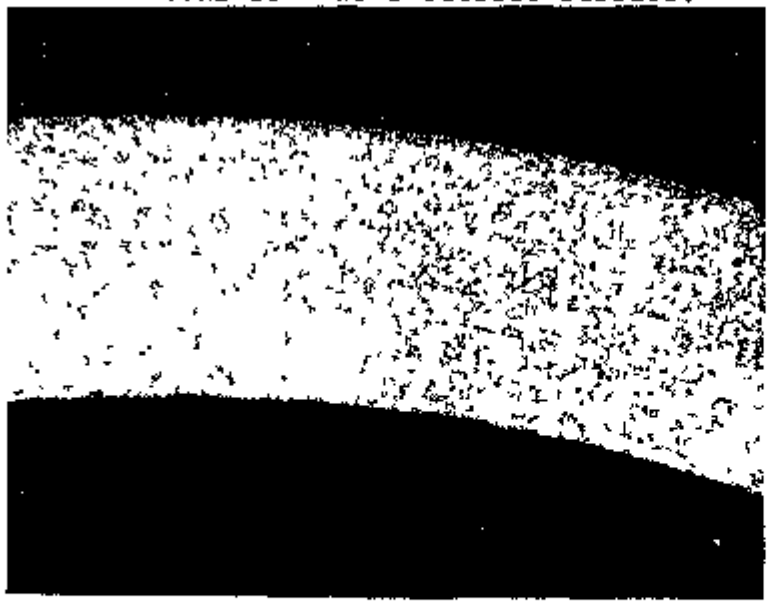

FIGURE 14 - NT-1 strength member (40X).

FIGURE 15 - NT-1 liner (6.5X).

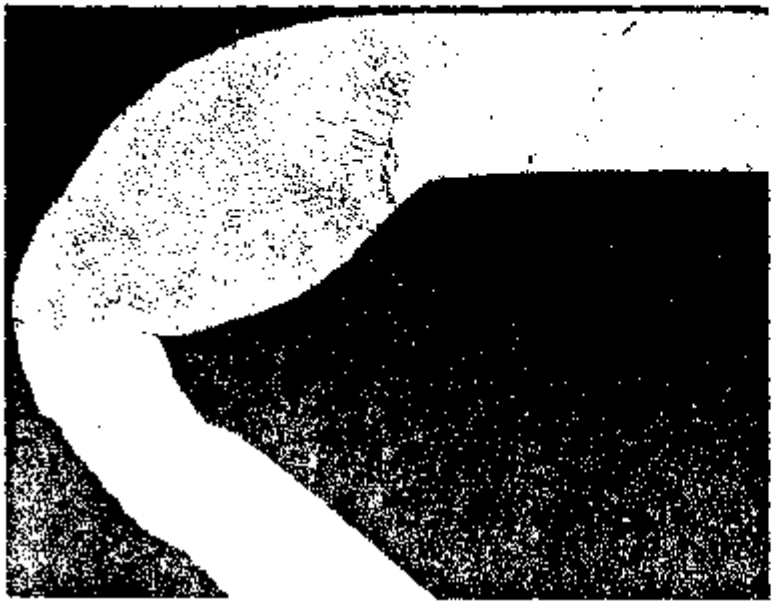

FIGURE 16 - NT-1 liner (40X).

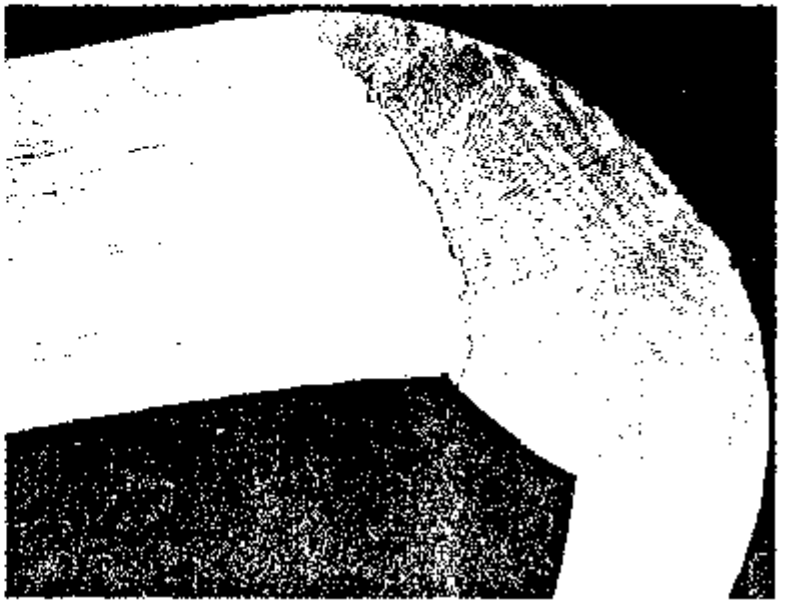

FIGURE 17 - NT-1 strength member (25X).

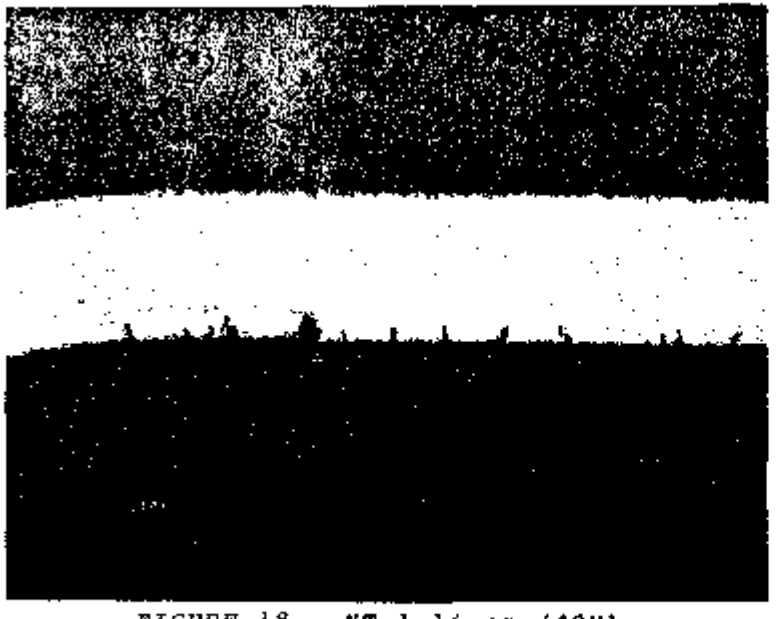

FIGURE 18 - NT-1 liner (40X).

FIGURE 19 - NT-1 clad (25X).

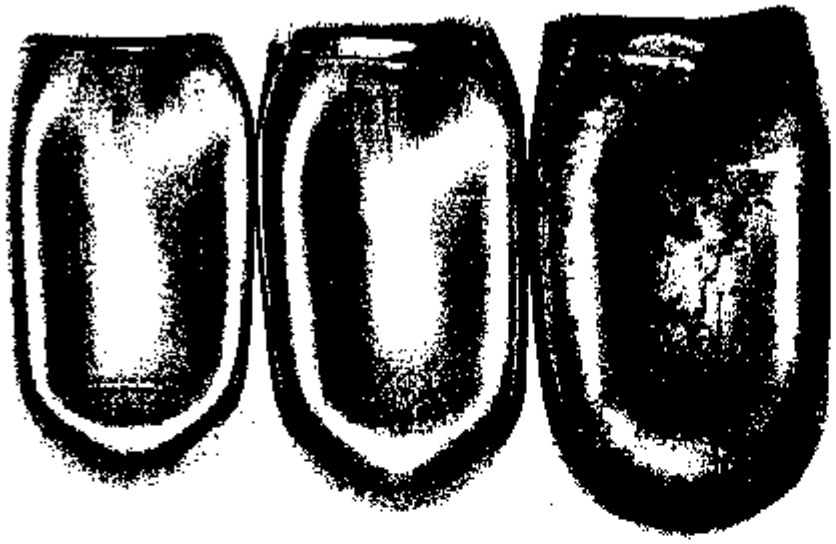

FIGURE 20 - NT-2 outside surface.

FIGURE 21 - NT-2 inside surface.

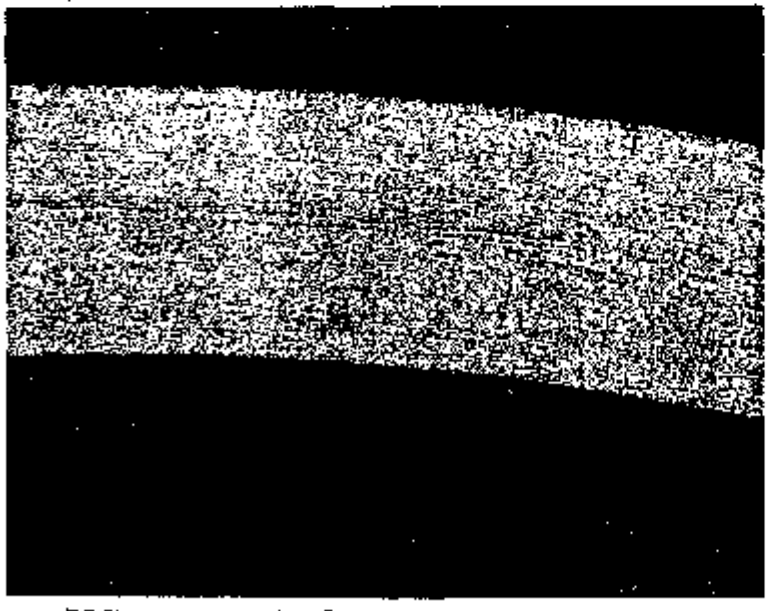

FIGURE 22 - NT-2 strength member (40X).

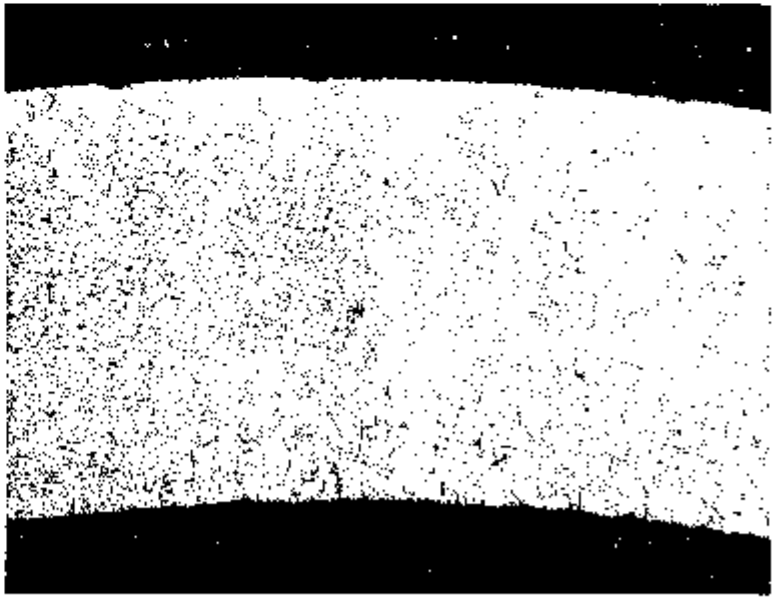

FIGURE 23 - NT-2 clad (40X).

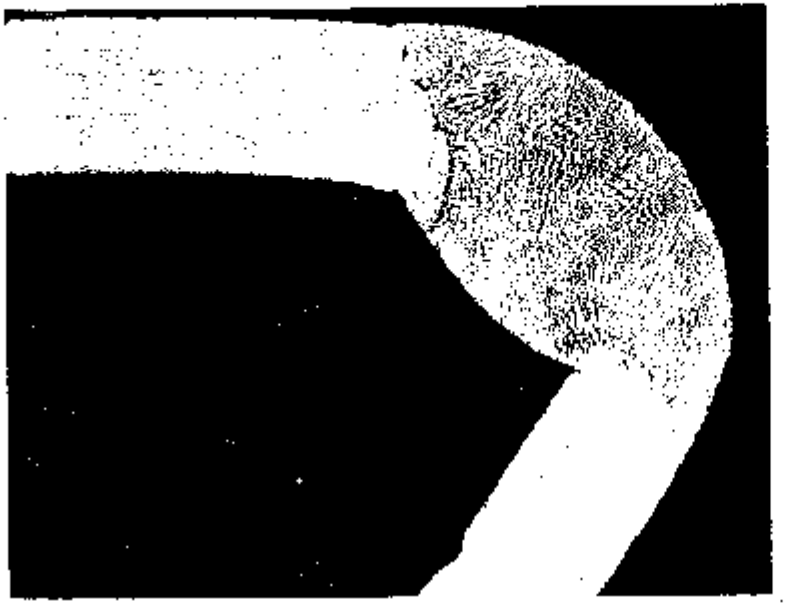

FIGURE 24 - NT-2 liner (40X).

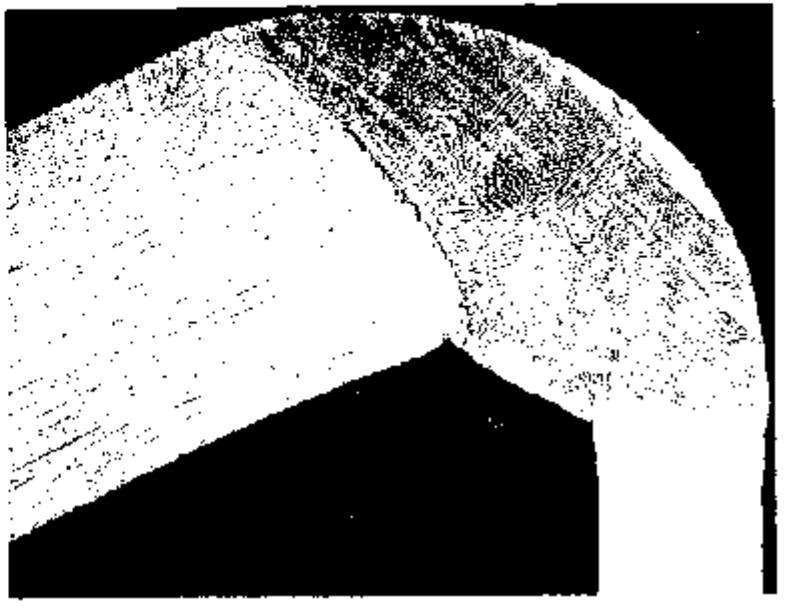

FIGURE 25 - NT-2 strength member (25X).

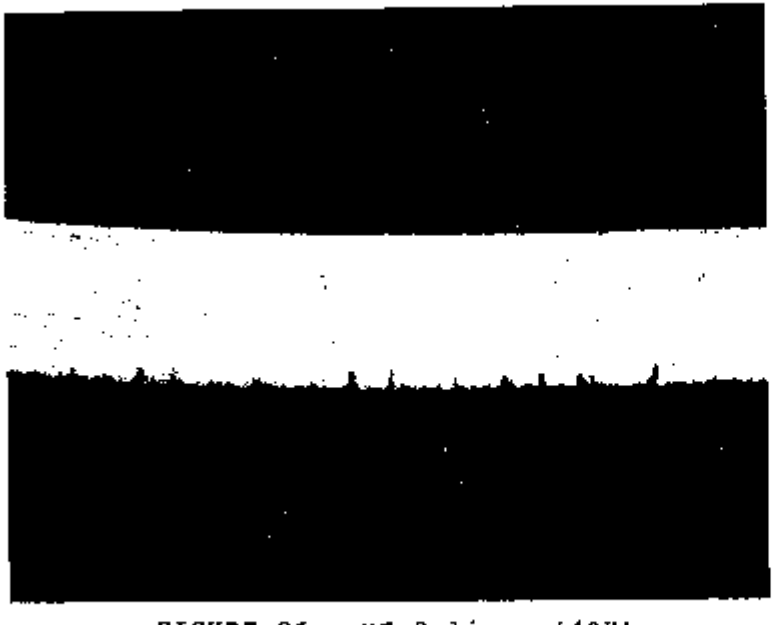

FIGURE 26 - NT-2 liner (40X).

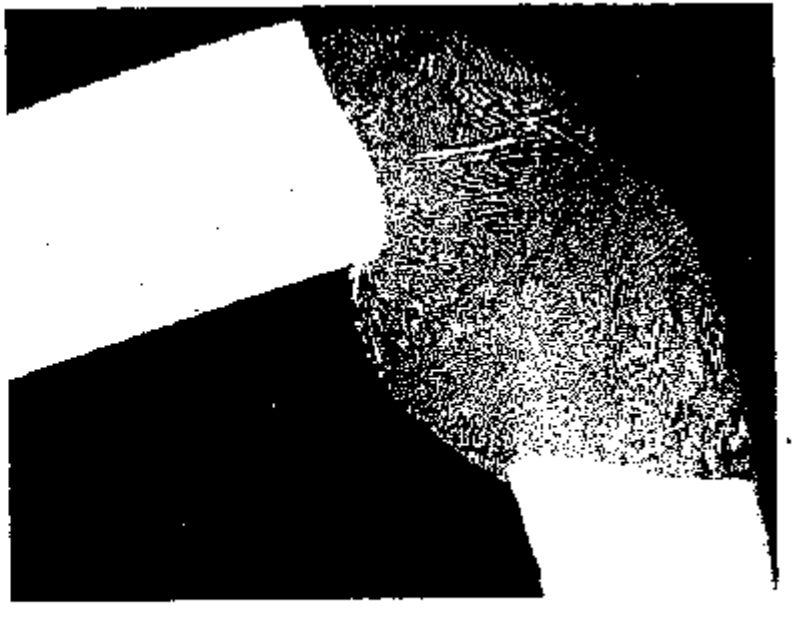

FIGURE 27 - NT-2 clad (25X).

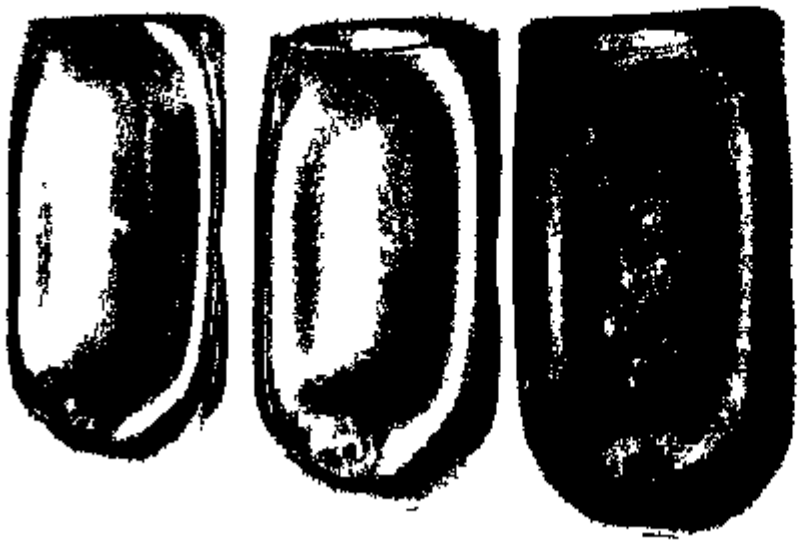

FIGURE 28 - NT-3 outside surface.

FIGURE 29 - NT-3 inside surface.

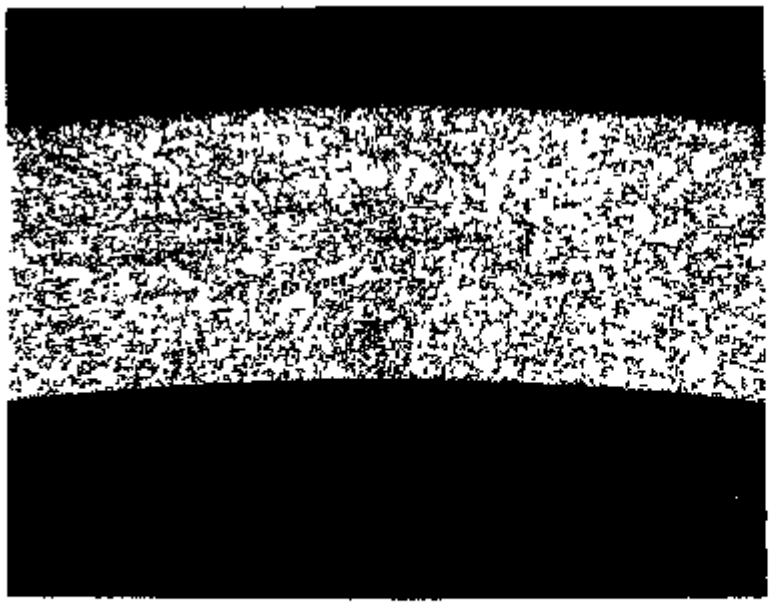

FIGURE 30 - NT-3 strength member (40X).

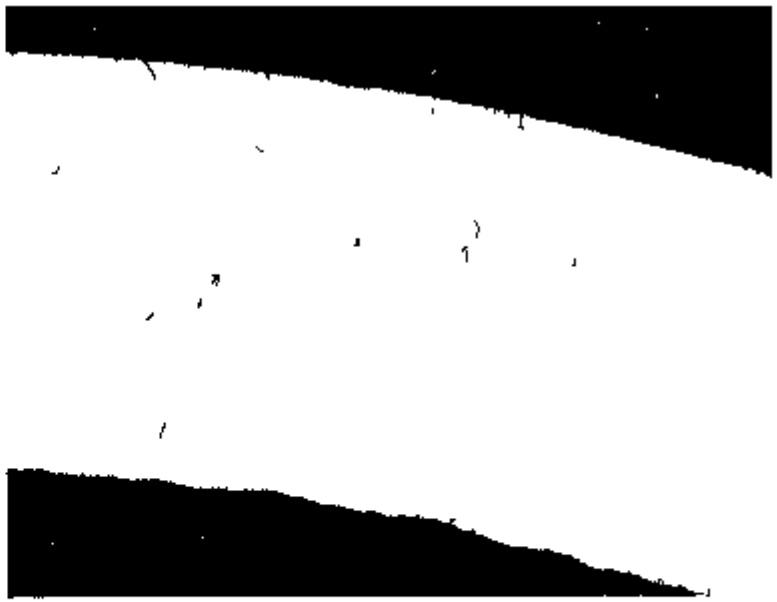

FIGURE 31 - NT-3 clad (40X).

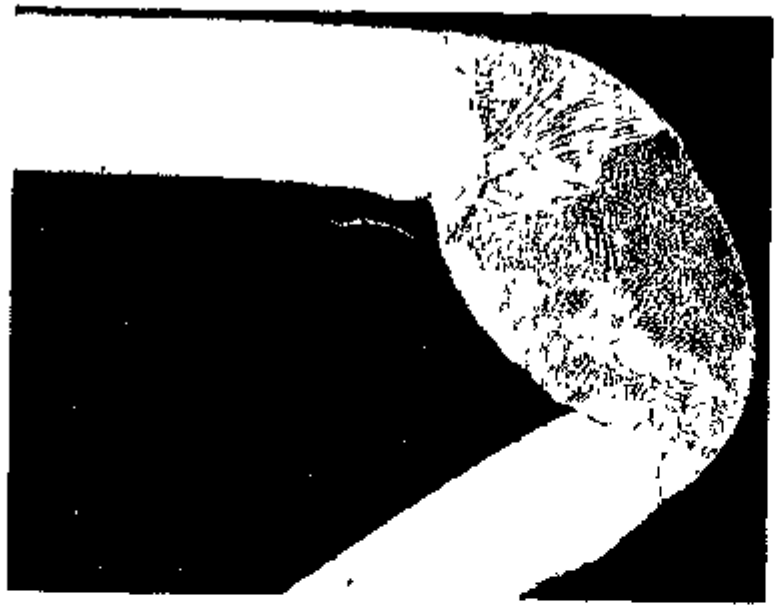

FIGURE 32 - NT-3 liner (40X).

FIGURE 33 - NT-3 strength member (25X).

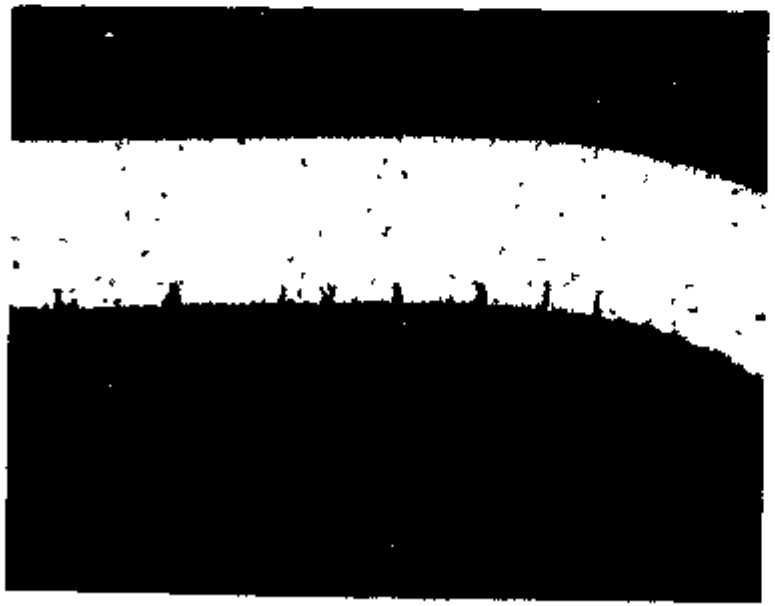

FIGURE 34 - NT-3 liner (40X).

FIGURE 35 - NT-3 clad (25X).

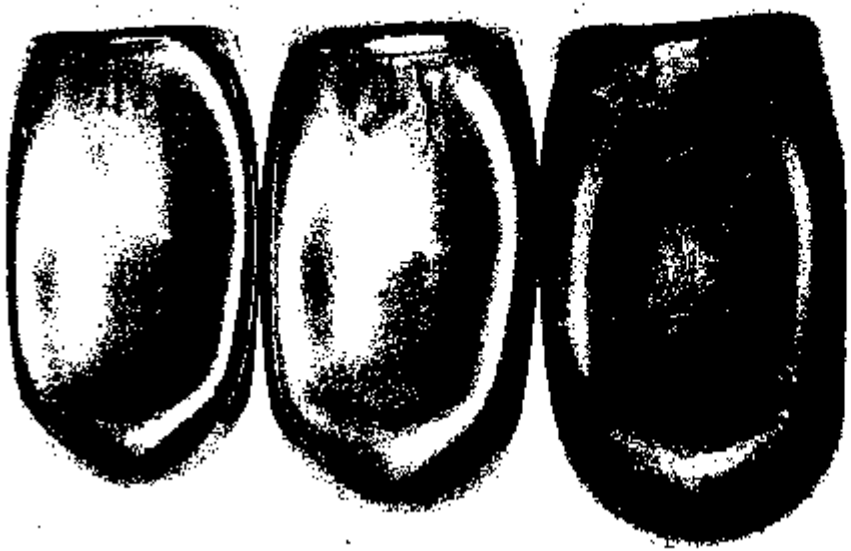

FIGURE 36 - NT-4 outside surface.

FIGURE 37 - NT-4 inside surface.

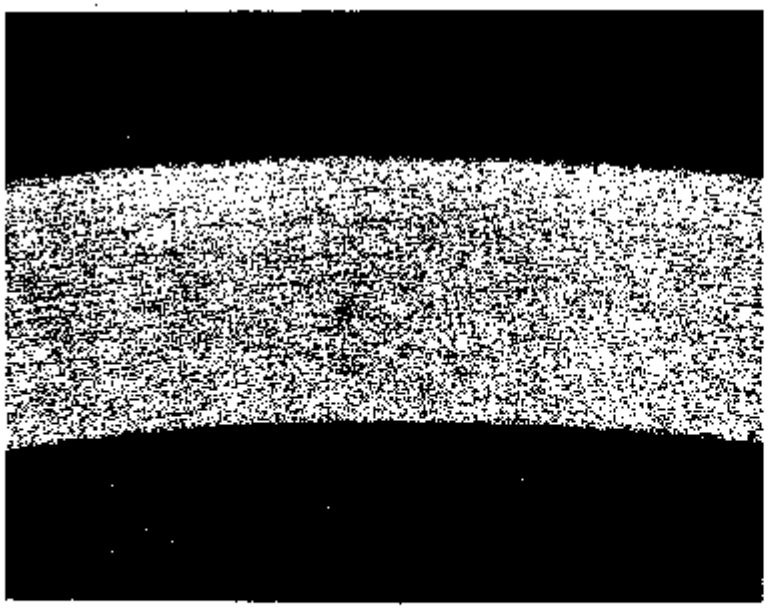

FIGURE 38 - NT-4 strength member (40X).

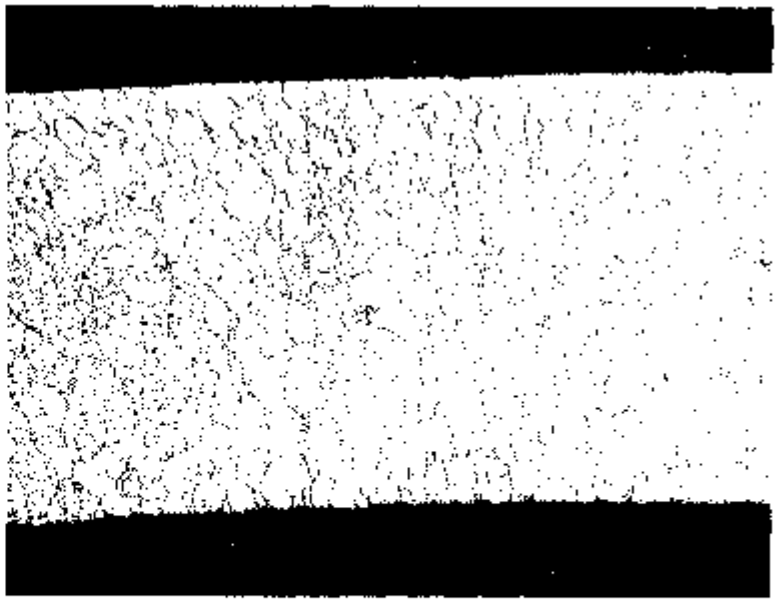

FIGURE 39 - NT-4 clad (40X).

FIGURE 40 - NT-4 liner (40X).

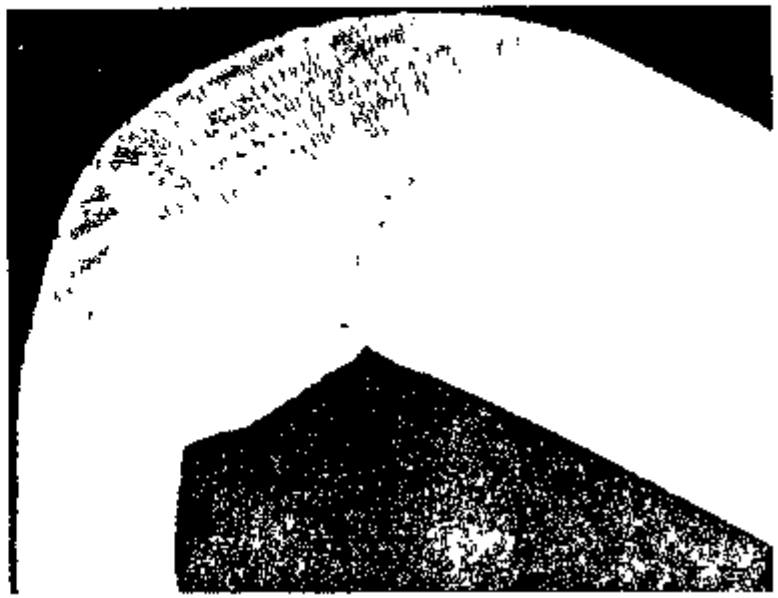

FIGURE 41 - NT-4 strength member (25X).

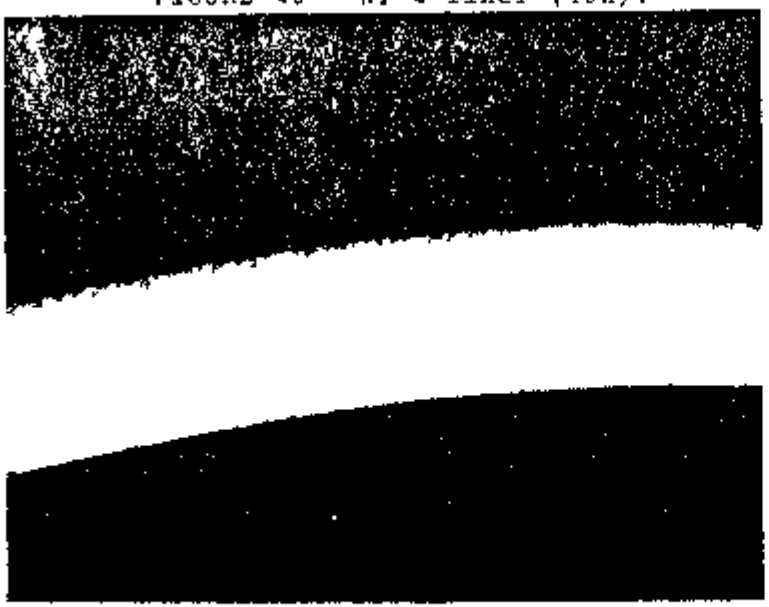

FIGURE 42 - NT-4 liner (40X).

FIGURE 43 - NT-4 clad (25X).