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Air Blast Destructive Testing of NUKON® Insulation Simulation of a Pipe Break LOCA

Tests 1,2,3,4,7 and 8
Final Report

October 22, 1993

Testing Performed for

Performance Contracting, Inc.
Engineered Systems Division
4025 Bonner Industrial Drive
Shawnee, Kansas 66226

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This report summarizes air blast destructive testing on the NUKON Thermal Insulation Syst
The specific test results depend on the mechanical properties of the individual NUKON components, the specific NUKON design, and the processes used in the NUKON component fabrication. Other insulation systems may look similar, but have significantly different mechanical properties and hence may give very different results when subjected to blast destructive tests. For performance data on the behavior of other insulation systems, these systems should also be subjected to these tests. Therefore, these NUKON test results are product specific and not generic.

TABLE OF CONTENTS

ABSTRACT

A pipe break loss of coolant accident (LOCA) in a nuclear power plant will be accompanied by a high pressure steam jet. It is possible that insulation covering pipes and equipment in the containment building could be dislodged and fragmented by the jet of steam. Insulation debris, if carried by the flow for the emergency core cooling system (ECCS), could collect on the screens or strainers surrounding the pump suction, creating head loss. Excessive head loss could possibly lead to insufficient available suction head, pump cavitation and inadequatet emergency core cooling. Testing and analysis have been performed (by others) to determine the head loss resulting from debris collected on the pump suction screens or strainers.

The purpose of this test program was to characterize the extent of NUKON insulation destruction and nature of the debris that would result from a pipe break LOCA. This was accomplished by simulating a pipe break by means of a rupture disc mounted to a pressure vessel (called a burst tank) containing compressed air. NUKON insulation materials were mounted to a pipe such that they were impacted by the air blast that accompanied the failure of the rupture disc. The insulation materials and burst tank were installed within a pressure vessel large enough to contain and allow for the collection of all insulation debris.

This test program involved six tests. The results of each test consisted of:

- a map and photographs of the location of pieces of debris
- data of the weight distribution of the debris
- actual debris samples to be used for head loss testing

The results are compared to the insulation debris model published by the USNRC in NUREG/CR-0897. This report defines a zone of destruction formed by a 90° cone extending seven nozzle diameters (7D) from the exhaust nozzle.

The following conclusions are reached:

1. Less than 30% (by weight) of the NUKON base wool located within the zone of destruction is fragmented into small pieces that are considered capable of being transported to a suction strainer in a BWR suppression pool, as described in the NUREG report.
2. The pipe on which the NUKON insulation is mounted can provide some protection from fragmentation because it blocks the direct impact of the jet. This phenomenon is called "shadowing", it was observed within the zone of destruction.
3. NUKON metal jacketing can provide significant protection from fragmentation as close as 2.2 nozzle diameters from the exhaust.
4. The test results indicate that the NUREG model is in some cases correct and in other cases conservative.

Introduction

This report describes six tests of NUKON pipe insulation blankets and metal jacketing. The general objective was to determine the effect of an impacting high pressure air jet. The specific objective was to classify by weight the distribution of debris resulting from the impact of the high pressure jet. The jet is intended to simulate the flow resulting from a pipe break loss of coolant accident (LOCA).

Test Facility

The test facility consists of three basic components:

1. A pressure vessel of approximately 2400 cubic feet in volume called the "test chamber". All inside surfaces are smoothly finished and painted white. Two flanged ports with inside diameters of 30 inches provide access to the interior. The interior is divided into three sections of approximately equal volumes for descriptive purposes. They are identified as "north", "south" and "center".
2. A pressure vessel of approximately 6500 cubic inches in volume called the "burst tank". It is made up of 12" (nominal) schedule 80 pipe with a 6" (nominal) flange mounted to one end and a cap on the other end. A rupture disc assembly (manufactured by Continental Disc Corporation) is mounted to the flange.
3. A mounting pipe (installed vertically in the test chamber) holds the insulation blankets in position in front of the jet formed by the air flowing through a nozzle from the burst tank. This pipe has an outside diameter of 12.75 inches.

The burst tank is mounted within the test chamber as shown in Figure 1. Appropriate structural components support the burst tank and mounting pipe. The 35" dimension shown in the figure is measured from the rupture disc flange to the mounting pipe surface.A 4" diameter nozzle was mounted downstream of the rupture disc for all but one of the tests. The position of both burst tank and mounting pipe can be slightly adjusted. A small bore pressure line connects the burst tank to a source of high pressure air.

The following figures show the test facility. Figure 2 is the exterior view showing the access port. Figure 3 is an interior view looking South. Figure 4 is an interior view looking North, a 4" diameter exhaust pipe and the rupture disc are visible. Figures 3 and 4 both show that the burst tank is mounted with U-bolts to enable adjusting the tank position.

The testing described in this report involves a much smaller volume of fluid than would be involved in a LOCA. This difference is not considered to be significant for the following reason: A jet flow with supersonic conditions accompanying the initiation of a LOCA will completely dislodge the adjacent insulation. Jet flow present as the LOCA progresses will not produce additional debris because the insulation is no longer in the immediate vicinity. It is concluded that the present testing effectively simulates the initiation of a LOCA, the most important part of the process.

Test Articles

The NUKON Insulation System for piping consists of removable/reusable insulation blankets and removable/reusable metal jacketing. The system is pre-engineered and pre-fabricated by Performance Contracting, Inc.. The NUKON blankets are of five raw materials:

1. NUKON Base Wool: a custom made, low density, flexible, resilient fibrous glass wool
2. Woven fiberglass scrim: a reinforcing scrim for the NUKON Base Wool
3. Woven fiberglass fabric: a heavy, high strength fabric with a custom chemical finish
4. Velcro type fastener: a high strength hook and loop fastener material
5. Fiberglass sewing thread: a high strength fiberglass thread

The NUKON metal jacketing is 22 gauge 300 series stainless steel that wraps completely around the NUKON blankets. Jackets have rolled edges, "shiplap" type lap joints, and a high strength latch and strike combination riveted in place at least every twelve inches. One jacket section is designed to overlap the adjacent section by approximately three inches, thus a 36 inch section will cover a 33 inch length of insulated pipe. Typically, the NUKON blankets have a finished thickness that is approximately ¼" greater than nominal; installation of the metal jacket will compress the blanket resulting in an installation of nominal thickness.

Each NUKON blanket used in the testing was designed to cover 24 inches (in the axial direction) of a piece of pipe with outside diameter of 12.75 inches. The nominal blanket thickness was 3 inches resulting in an overall outside diameter of 18.75 inches. The specific blankets used in the tests were identified as 1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B and 3C from lot BS-5-93 and 5A, 5B and 5C from lot BS-7-93.

Test blankets were received from the Owens Corning Science and Technology Center. At Owens Corning the blankets were exposed to a 550 °F surface for a period of at least 24 hours. All the blankets exhibited a dark coloration on the inner surface that would indicate the application of heat. Typical blankets are shown in Figure 5. Copies of certification forms from Owens Corning are contained in Appendix A.

Tests 3 and 4 involved covering the insulating blankets with standard 36 inch wide NUKON metal protective jacketing. The specific pieces used in the tests were identified as 1, 2, 3 and 4 on attached metal tags.

Test Procedure

The following general procedure was applied. Relevant details are given for each test.

1. Mount the rupture disc and associated pipe.
2. Weigh each NUKON blanket that will be installed.
3. Mount the NUKON blankets.
4. Clean all inner surfaces of the test chamber with vacuum cleaner and damp rag.
5. Seal the test chamber.
6. Pressurize the burst tank until the rupture disc fails.

7. Vent the test chamber such that any entrained NUKON debris is collected.
8. Collect all NUKON debris within the test chamber. Photos are taken throughout the collection procedure using both 35mm and Polaroid film formats.
9. Classify and weigh all NUKON debris. The weight of any bags used to contain debris or blankets (prior to testing) must be accounted for.

Equipment Used

A model KA32S scale (manufactured by Mettler/Toledo, Inc.) was used to determine all weights. This scale was brand new and therefore had never been calibrated at CEESI. A set of calibrated class F weights (manufactured by Rice Lake Weighing Systems) was used to calibrate the scale during the tests.

The following conditions were monitored during the test:

1. Pressure in the burst tank. This value was recorded.
2. Pressure in the test chamber. This pressure was used to detect any leakage from the high pressure components.
3. Temperature in the test chamber. This was observed for the first two tests only.

The instruments were calibrated in accordance with the requirements of the CEESI quality system. The data from all three instruments were recorded by an HP 3497 data acquisition system (manufactured by Hewlett Packard).

The debris after a test was collected by hand and with the aid of a vacuum cleaner (Shop Vac model number 8030) with a 2" diameter inlet hose. The vacuum cleaner collection chamber and fabric filter element were cleaned prior to use. The filter element fabric was weighed before and after each test.

NUKON Debris Classification

The debris from tests 4, 7 and 8 was classified according to weight based on the categories tabulated below. The objective is to provide quantitative data to compare the results of different tests.

Classification	Debris Description	Debris Weight Range
Size 0	sand and metal fragments	n/a
Size 1	base wool	0 - 0.002 lb
Size 2	base wool	0.002 - 0.01 lb
Size 3	base wool	0.01 - 0.05 lb
Size 4	base wool	> 0.05 lb
Size 5	fabric	n/a

Typical examples of Sizes 1-4 debris are shown in Figures 6 - 9, these are debris that were collected after Test 7. Debris classified as Sizes 2, 3 and 4 still retain the layered structure present in the original blanket. Size 1 debris is typically composed of clumps of fibers with a few pieces of textile fibers, scrim and individual fibers, this can be seen in Figure 6. The density of debris in Sizes 2, 3 and 4 is typically greater than that of Size 1 debris. It is believed that Size 1 debris results from direct impact by the jet; Sizes 2, 3 and 4 result from indirect impact.

It is believed that Size 1 debris is most likely to affect the emergency core cooling system (see the report NUREG-0897, *Containment Emergency Sump Performance*, October 1985).

Summary of Test Conditions:

Basic characteristics of the six tests are tabulated below. The "Exhaust to Blanket Distance" is the distance from the jet exhaust to the closest surface of the blanket (L) expressed as a number of (exhaust) pipe diameters (D). The tests identified as 5 and 6 were not part of this test program.

Test	Exhaust to Blanket Distance [L/D]	NUKON Metal Jacket	Burst Pressure [psig]
1	2.2	no	1553
2	4.0	no	1534
3	2.2	yes	1629
4	2.2	yes	1676
7	2.2	no	1550
8	6.2	no	1660

Test 1 (4" nozzle, L/D = 2.2, unjacketed NUKON blankets)

Setup:

The NUKON blankets used in this test were identified as 1A, 1B and 1C. The jet flow exhausted through a 4.03 inch ID pipe, the burst pressure was 1553 psia. The distance from the pipe exit (jet exhaust) to the mounting pipe surface was 11.75 inches. The nearest insulation surface was therefore located 2.2 exhaust pipe diameters from the exhaust. The three blankets were mounted with 1C on top, 1B in the center and 1A at the bottom of the mounting pipe. The velcro fasteners for all three blankets faced away from the rupture disc. The blankets were mounted such that blanket 1B was positioned slightly below the centerline of the jet.

Results:

The "after test" conditions are shown in Figures 10 - 12. Blanket 1B was destroyed, most of the larger pieces were located in the south end of the test chamber. Both of the other blankets were dislodged from the pipe but were not damaged. One blanket was located immediately to the left of the mounting pipe. The other blanket was located in the north end of the chamber. It was not noted as to which blanket (1A or 1C) was found in which location.

The following procedure was applied to collect the NUKON debris:

1. Place the undamaged blanket found at the north end of the chamber into the (1C or 1A) bag.
2. Vacuum up the small debris at the north end.
3. Place "larger pieces" found in the center section into the 1B-1 bag. A "larger piece" was anything that was judged to be too large for the vacuum cleaner.
4. Vacuum up the remaining small debris in the center section of the chamber.
5. Place the undamaged blanket found at the south end of the chamber into the (1C or 1A) bag.
6. Place "larger pieces" found in south section into the 1B-1 bag. A "larger piece" was anything that was judged to be too large for the vacuum cleaner. In the south section many pieces were found with attached scrim and/or backing.
7. Vacuum up the remaining small debris in the south section of the chamber.
8. Empty vacuum cleaner into bag 1B-2.

The results of weighing the Test 1 debris are tabulated below (blankets 1A and 1C were undamaged):

NUKON Blankets	Gross Weight [lb]	Bag Weight [lb]	Net Weight [lb]
1A initial	10.417	0.244	10.173
1B initial	10.5058	0.244	10.2618
1C initial	10.4978	0.244	10.2538
Total			30.6886
1A final	10.4688	0.244	10.2248
1C final	10.4982	0.244	10.2542
1B-1 final	8.4438	0.244	8.1998
1B-2 final	2.2478	0.244	2.0038
Total			30.6826

The contents of bag 1B-2, which consisted of the small NUKON debris, were shipped to Alden Research Laboratory (Holden, MA) for head loss testing.

Test 2 (6" nozzle, L/D = 4.0, unjacketed NUKON blankets)

Setup:

The NUKON blankets used in this test were identified as 2A, 2B and 2C. The jet flow exhausted directly from the rupture disc, (nominal flow diameter = 6") the burst pressure was 1534 psia. The distance from the pipe exit (jet exhaust) to pipe surface was 26.75 inches. The nearest insulation surface was therefore located 4.0 pipe diameters from the exhaust. The three blankets were mounted with 2C at the top, 2B in the center and 2A at the bottom of the mounting pipe. The velcro fastener for 2C faced into the burst plate, the velcro fasteners for 2A and 2B faced away from the rupture disc. The blankets mounted such that blanket 2B was centered about the jet in the vertical direction.

Results:

The "after test" conditions are shown in Figures 13 - 15. Blanket 2B was destroyed; the largest piece was located below the burst tank, most of the rest were located in the south end of the test chamber. Most of the woven fabric was found wrapped around the base of the mounting pipe. The other two blankets were dislodged from the pipe but were not damaged. Blanket 2A was located immediately to the left of the mounting pipe. Blanket 2C was found wedged between the mounting pipe and the "I-beam" located immediately behind the mounting pipe.

The debris collection procedure is listed below. A "large piece" consists of scrim and/or woven fabric and/or insulation. A "medium sized piece" consists of an unbroken piece of NUKON base wool measuring at least two inches in two of the three dimensions. A "medium sized piece" contains little or no scrim or woven fabric. Everything else is considered a "small piece". The procedure was to:

1. Collect medium sized pieces by hand from the north end of the chamber into the 2B-2 bag.
2. Vacuum small pieces from north end.
3. Collect medium sized pieces by hand from the center part of the chamber into the 2B-2 bag.
4. Place single large piece of the 2B blanket into the 2B-1 bag.
5. Vacuum small pieces from center part of the chamber.
6. Place 2A blanket into the 2A bag.
7. Place 2C blanket into the 2C bag.
8. Place several large pieces of the 2B blanket from the south end into the 2B-1 bag.
9. Place several medium sized pieces of the 2B blanket from the south end into the 2B-2 bag.
10. Vacuum small pieces from south end.
11. Empty vacuum cleaner into bag 2B-3

The results of weighing the Test 2 debris are tabulated below (blankets 2A and 2C were undamaged):

NUKON Blanket	Gross Weight [lb]	Bag Weight [lb]	Net Weight [lb]
2A initial	10.3926	0.244	10.1486
2B initial	10.4574	0.244	10.2134
2C initial	10.4496	0.244	10.2056
Total			30.5676
2A final	10.4586	0.244	10.2146
2C final	10.3676	0.244	10.1236
2B-1 final	8.802	0.244	8.558
2B-2 final	1.1052	0.244	0.8612
2B-3 final	1.2006	0.244	0.9566
Total			30.714

The second weighing was greater by 0.1464 lb_m. The reason for this increase might be that pieces of the rupture disc were vacuumed up. The contents of bags 2B-2 (labelled "hand picked") and 2B-3 (labelled "vacuumed up") were shipped to Alden Research Laboratory for head loss testing. Bag 2B-3 contained the smallest pieces of debris.

Test 3 (4" nozzle, L/D = 2.2, metal jacketed NUKON blankets, latches away from jet)

Setup:

This test used NUKON blankets covered with NUKON metal jacketing. The NUKON blankets were identified as 1C, 2A and 2C. Blanket 1C was also used in Test 1 but was undamaged. The jet flow exhausted through a 4.03 inch ID pipe, the burst pressure was 1629 psia. The distance from the pipe exit (jet exhaust) to the mounting pipe surface was 11.75 inches. The nearest insulation surface was therefore located 2.2 pipe diameters from the exhaust. The three blankets were mounted with 2A on top, 2C in the center and 1C at the bottom of the mounting pipe. The velcro fasteners for all three blankets faced away from the rupture disc. The blankets were mounted such that blanket 2C was positioned at the centerline of the jet.

The NUKON metal jacketing was mounted with section 2 on top and section 1 on the bottom. The bottom of section 2 overlaped the top of section 1 by 2.75 inches. The latches holding the jacketing in place were located on the back side of the pipe (away from the rupture disc). The assembly of blanket and metal jacket was positioned such that the lap joint between the metal jackets was located at the centerline of the jet.

Results:

No fibrous debris was found as a result of this test. Blanket 2A and metal section 2 were completely dislodged from the mounting pipe by the air jet. Both were located towards the north end after the test as shown in Figure 16. Blanket 1C and metal section 1 were still mounted on the pipe after the conclusion of the test, all three sets of metal jacket latches and strikes were still fastened. The velcro fasteners of blanket 2C, the middle blanket, were pulled open but the blanket was still held in approximately the original position by metal jacket section 1.

Blankets 2A and 1C sustained no damage. Three observations were made regarding the middle blanket, 2C, they are listed below and shown in Figures 17 and 18:

1. A four inch diameter hole was located at the point of jet impact. This blanket sustained some damage but was not destroyed as was the case in the first two tests. No debris resulted.
2. The woven fabric exhibited some weave and seam failures.
3. The insulation thickness was reduced over a 14 inch wide area at the center of the blanket. The insulation thickness was increased over an area above and to the left of the center.

Both metal jackets are shown in Figure 19. Figure 20a shows the front view of the jacket 2 surface. Some curling of the corners and edge damage was sustained. A deep dent was located in the area immediately in front of the jet. Smaller and deeper dents were observed to be concentrated within a radius of 4 inches from the jet impact point. These dents were assumed to be caused by pices of the rupture disc. Figure 20b shows the top view of metal jacket 2 "flatter" area (of 27 inch width) corresponds to the large dent shown in Figure 20a. A large was also observed in jacket 1, the geometry was similar to that indicated in Figure 20a. The side view of metal jacket 1 is shown in Figure 20c.

Test 4 (4" nozzle, L/D = 2.2, metal jacketed NUKON blankets, latches facing jet)

Setup:

This test used NUKON blankets covered with NUKON metal jacketing. The NUKON blankets were identified as 3A, 3B and 3C. The jet flow exhausted through a 4.03 inch ID pipe, the burst pressure was 1676 psia. The distance from the pipe exit (jet exhaust) to the mounting pipe surface was 11.75 inches. The nearest insulation surface was therefore located 2.2 pipe diameters from the exhaust. The three blankets were mounted with 3C on top, 3B in the center and 3A at the bottom of the mounting pipe. The velcro fasteners for all three blankets faced away from the rupture disc. The blankets were mounted such that blanket 3B was positioned at the centerline of the jet.

The metal jacketing was mounted with section 3 on top and section 4 on the bottom. The bottom of section 3 overlaped the top of section 4 by approximately 2 inches. The latches and strikes holding the jacketing in place were located on the front side of the pipe (towards the rupture disc). The assembly of blanket and metal jacket was positioned such that the lap joint between the metal jackets was located at the centerline of the jet.

Results:

Both sections of metal jacketing and insulation blanket 3B were dislodged and heavily damaged by the air blast; the locations are shown in Figures 21, 22 and 23. Figures 24 and 25 record the condition of the two metal jacket sections. Each figure contains an outside surface view that can be interpreted as a map of the surface condition. The top view in each figure is an attempt to document the distortion from the original circular shape. Each jacket section had been held in position by latches and strikes; the air blast removed some of this hardware. In all cases the rivets had torn through the metal jackets. The condition of the hardware is noted in the figures.

Insulation blankets 3A and 3C were dislodged but not at all damaged by the air blast. Blanket 3B was blown apart by the air blast, most of the larger pieces were located in the south end of the test chamber.

Tabulated below are weighing data of blanket 3B. Debris in the smallest size category (Size 1) accounts for 28.0% of the total weight of base wool.

NUKON Debris Classification	Total Weight [lb]	Bag Weight [lb]	Net Weight [lb]	Percent of Base Wool Total
Size 0	0.0864	0.0502	0.0362	0.5
Size 1	2.0368	0.2452	1.7916	28.0
Size 2	0.4730	0.0368	0.4362	6.8
Size 3	0.6465	0.0368	0.6088	9.5
Size 4	3.7820	0.2452	3.5368	55.2
Total (Base Wool)			6.4096	
Size 5 (Fabric)	4.1828	0.5376	3.6452	
Total			10.0548	

Test 7 (repeat of Test 1 conditions)

Setup:

The NUKON blankets used for this test were identified as 5A, 5B and 5C. The jet flow exhausted through a 4.03 inch ID pipe, the burst pressure was 1550 psia. The distance from the pipe exit (jet exhaust) to the mounting pipe surface was 11.75 inches. The nearest blanket surface was therefore located 2.2 pipe diameters from the exhaust. The three blankets were mounted with 5A on top, 5B in the center and 5D at the bottom of the mounting pipe. The velcro fasteners for all three blankets faced away from the rupture disc. The blankets were mounted such that blanket 5B was positioned at the centerline of the jet.

Results:

S. wn in Figures 26 - 28 are the "post test" conditions; blanket 5B, the middle blanket, was destroyed as in Test 1. Some of the larger pieces from 5B ended up in the South end. Blankets 5A and 5C were undamaged, they both ended up lodged below the burst tank.

Tabulated below are weighing data of blanket 5B. Debris in the smallest size (Size 1) category accounts for 22.4% of the total weight of base wool.

NUKON Debris Classification	Total weight [lb]	Bag weight [lb]	Net weight [lb]	Percent of Base Wool Total
Size 0	0.167	0.05	0.117	1.8
Size 1	1.695	0.2454	1.4496	22.4
Size 2	0.2566	0.0368	0.2198	3.4
Size 3	0.355	0.0368	0.3182	4.9
Size 4	5.2224	0.8418	4.3806	67.5
Total (Base Wool)			6.4852	
Size 5 (Fabric)	3.0806	0.0368	3.0438	
Total			9.529	

Test 8 (4" nozzle, L/D = 6.2, unjacketed NUKON blankets)

Setup:

The NUKON blankets used for this test were identified as 5A, 5C and 2A. Blanket 2A had a slight seam failure from Test 2, it is felt that this did not affect the final test results. The jet flow exhausted through a 4.03 inch ID pipe, the burst pressure was 1660 psia. The distance from the pipe exit (jet exhaust) to the mounting pipe surface was 28 inches. The nearest insulation surface was therefore located 6.2 pipe diameters from the exhaust. The three blankets were mounted with 5A on top, 2A in the center and 5C at the bottom of the mounting pipe. The velcro fasteners for all three blankets faced away from the rupture disc. The blankets were mounted such that blanket 2A was positioned at the centerline of the jet.

Results:

Shown in Figures 29 - 30 are the "post test" conditions. Blanket 2A was destroyed as in the previous tests but there was visibly less debris generated. The larger piece of blanket 2A ended up at the base of the mounting pipe. The other two blankets wer undamaged. Blanket 5A ended up in the North end. Blanket 5C ended up lodged below the burst tank.

Tabulated below are weighing data of blanket 2A. Debris in the smallest size (Size 1) category accounts for 11.9% of the total weight of base wool.

NUKON Debris Classification	Total Weight [lb]	Bag Weight [lb]	Net Weight [lb]	Percent of Base Wool Total
Size 0	0.1702	0.0492	0.121	1.8
Size 1	0.8668	0.05	0.8168	11.9
Size 2	0.1886	0.05	0.1386	2.0
Size 3	0.331	0.05	0.281	4.1
Size 4	6.3686	0.8522	5.5164	80.3
Total (Base Wool)			6.8738	
Size 5 (Fabric)	3.1672	0.05	3.1172	
Total			9.991	

Test Result Observations

The following observations are made based on all six tests:

1. Test 4 showed that the particular metal jacket used for these tests will not prevent destruction of the insulation if the jet impacts the latch side. The likely failure mode of the metal jacket is for the rivets that secure the latches to pull free from the sheet metal.
2. Test 3 showed that the particular metal jacket used for these tests will prevent destruction of the insulation if the jet does not impact the latch side.
3. Test 4 exhibited a 25% increase in the weight of Size 1 debris compared to Test 7. The following explanation is proposed: The air jet strikes the metal jacket and tears it open but does not initially dislodge it. Until the metal is dislodged the insulation is constrained from moving and is subjected to further flow forces from the jet. Unshielded insulation is immediately dislodged from the pipe and not subjected to additional flow forces. It is felt that the exposure of the base wool to the jet after the jacket is ruptured but before it is dislodged is responsible for the increase in Size 1 debris.
4. Test 8 exhibited a 50% decrease in the weight of Size 1 debris compared to Test 7. This is due to the increase in distance between jet exit and insulation surface.

Observations Regarding Jet Geometry

The geometry of the deformed metal jackets from Test 3 can be compared to a theoretical model of the jet pressure distribution. The report:

NUREG/CR-2913 "Two Phase Jet Loads", G. G. Weigand, S. L. Thompson and D. Tomasko, Sandia National Laboratory, January 1983

describes the pressure distribution downstream of a two phase water jet. Figures 32 and 33 contain plots of j[illegible] pressure distributions as well as the undeformed and deformed metal jacket positic[illegible] The jet pressure distribution data were taken from figure 3.23 of the report:

NUREG/CR-0897 "Technical Findings Related to Unresolved Safety Issue A-43", A. W. Serkiz, U.S. Nuclear Regulatory Commission, October 1985

The following initial observations are made:

1. The angle between nozzle and the sharp deformation edge in Figure 33 is approximately 90 degrees. This would indicate that the region of higher destruction follows a 90 degree cone.
2. In Figure 33 the deformation edge corresponds to the 1 bar isobar. In Figure 32 it lies between the 1 bar and 2.5 bar isobars. This difference is attributed to the fact that in Figure 32 the jacket surface is not perpendicular to the flow direction.
3. The 90° cone of destruction is clearly supported by the damage patterns observed on the metal jackets after Test 3. The 90° cone of destruction is not supported by the T[illegible] because there was no damage to blankets 2A and 2C even though they were loc[illegible] within the 90° cone. The 90° cone of destruction is not supported by the Test 8 [illegible] the same reason. At some distance between 2.2D and 4.0D the jet ceases to conti[illegible] expanding at a 90° angle.

Based on thes[illegible] sults a zone of destruction with a different shape is proposed, it is shown in Figure 34.

There is further analysis that can be done based on the present test results:

1. The integrated pressure over the deformed area could be compared to the energy required to produce the sheet metal deformation. These estimates could be compared to the potential energy stored within the burst tank.
2. The pressure data from the NUREG report are based on a wet steam multiphase flow while the test results are based on air. The fluid dynamic similarity between the two has not been established as part of the present investigation.

Conclusions

Six tests were performed where NUKON insulation blankets mounted on a pipe were subjected to an air blast. Two of the six tests also involved NUKON metal jacketing installed over the insulation. The air blast was oriented in the direction perpendicular to the pipe on which the insulation was mounted. The pressure of the air blast ranged from 1534 psig to 1676 psig in the tests. The distance between air blast nozzle and insulation surface was varied from 2.2 to 6.2 nozzle diameters in the tests.

The following conclusions are drawn:

1. The base wool debris produced from damaged NUKON blankets is characterized by clumps of base wool fibers that vary significantly by weight. There is little evidence of individual fibers in the debris.
2. Debris in the smallest size category (base wool clumps lighter than 0.002 lb.) represents less than 30% of the total NUKON base wool by weight (within the fragmented blanket). Debris in this size category is considered to be that which would be most easily transported to a BWR suppression pool following a LOCA. Debris in this size category is believed to have been generated by direct air blast impact.
3. Debris in all but the smallest size category (base wool clumps heavier than 0.002 lb.) represents more than 70% of the total NUKON base wool by weight (within the fragmented blanket). It is not considered likely that debris in these size categories could be easily transported to a BWR suppression pool following a LOCA.
4. Part of a NUKON blanket mounted to the pipe is protected from the air blast by the mounting pipe itself. This phenomenon, called "pipe shadowing" is believed to be partly responsible for the distribution of debris sizes. Only the base wool that is exposed directly to the air blast will result in debris of the smallest size category.
5. The zone of destruction is approximately 90° when the insulation surface is located 2.2 nozzle diameters from the exhaust nozzle. The zone of destruction is significantly less than 90° when the insulation surface is located four or more nozzle diameters from the exhaust nozzle.
6. The use of NUKON metal jacketing can provide 100% protection of the NUKON blanket, even at a nozzle to blanket distance of 2.2 nozzle diameters. The term "100% protection" means that no observable debris is generated. The use of NUKON metal jacketing provides no protection when installed with the lap joint facing the air blast.
7. In general these data support the results in the report: *NUREG/CR-0897 "Technical Findings Related to Unresolved Safety Issue A-43", A. W. Serkiz, U.S. Nuclear Regulatory Commission, October 1985.* Where there are differences, the NUREG report results are found to be conservative.

Future tests are planned to investigate the effects of:

- staturated steam instead of air
- different mounting configuration of NUKON insulation

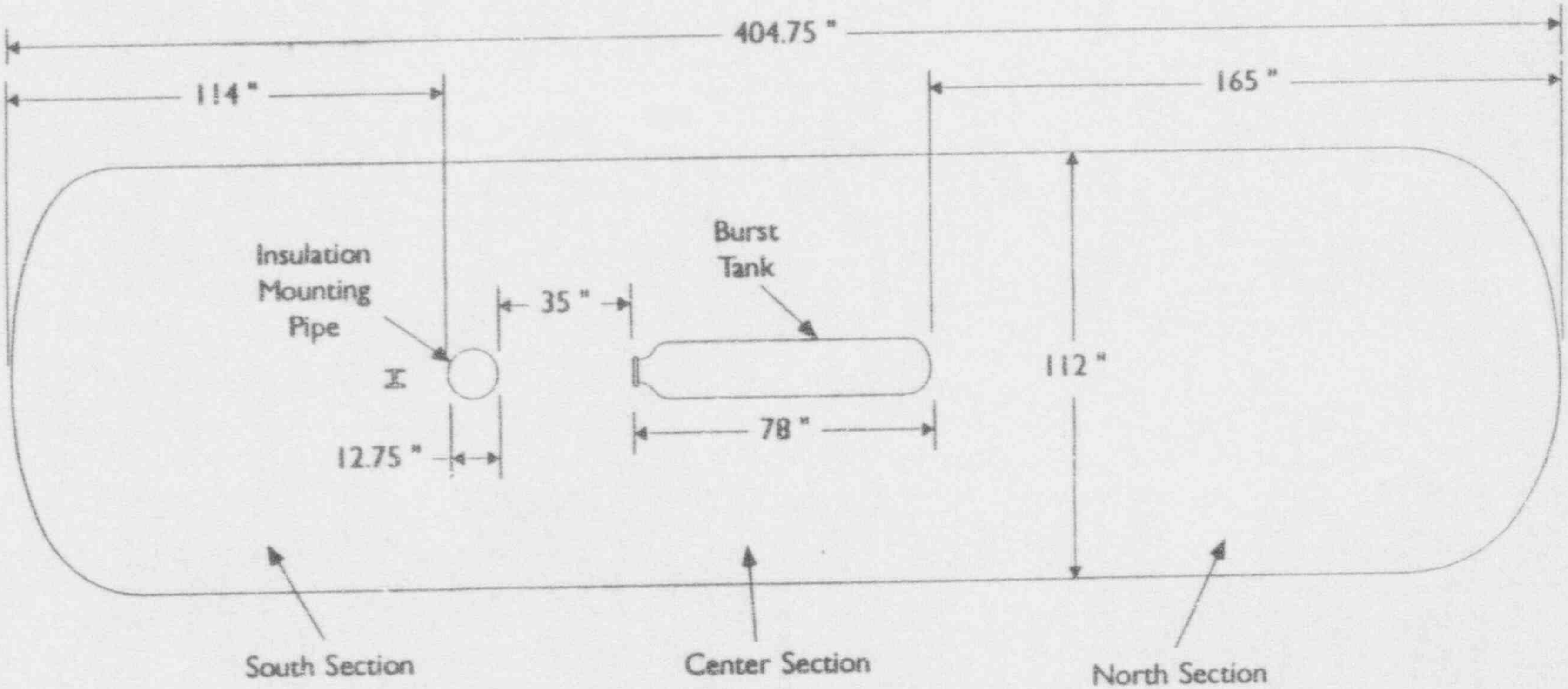


Figure 1: Test Facility Layout

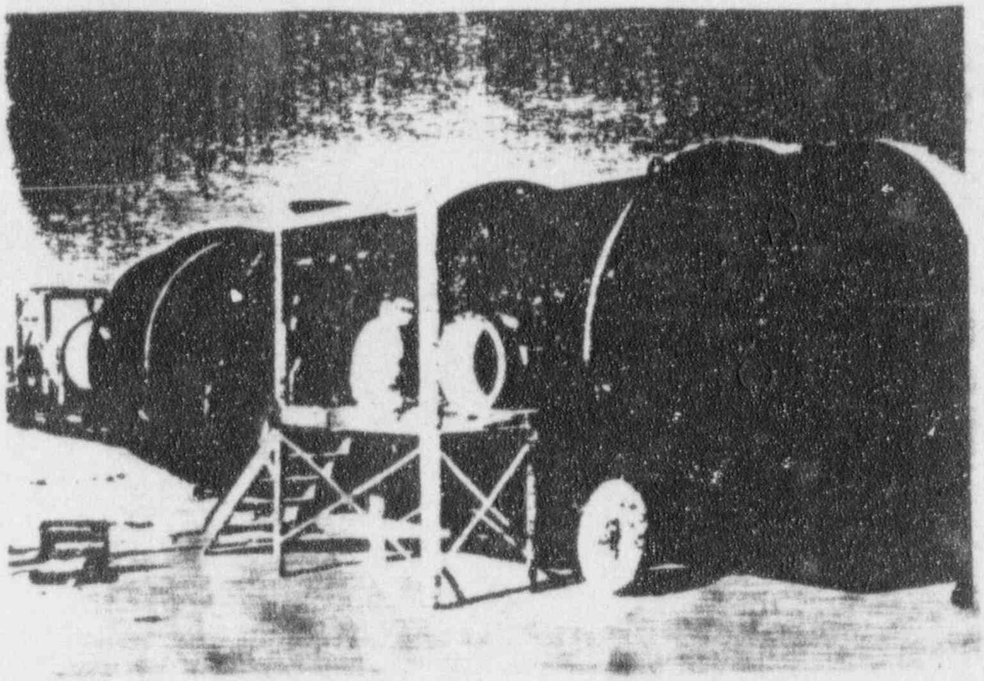


Figure 2: Test Facility - Exterior View

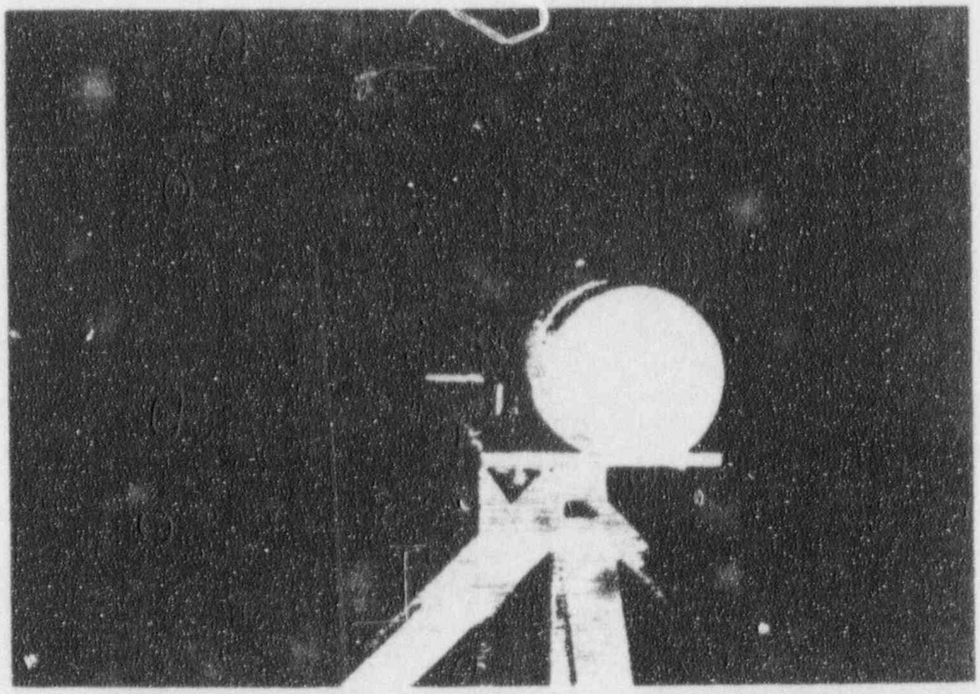


Figure 3: Test Facility - Interior View to to South

Figure 4: Test Facility - Interior View to the North

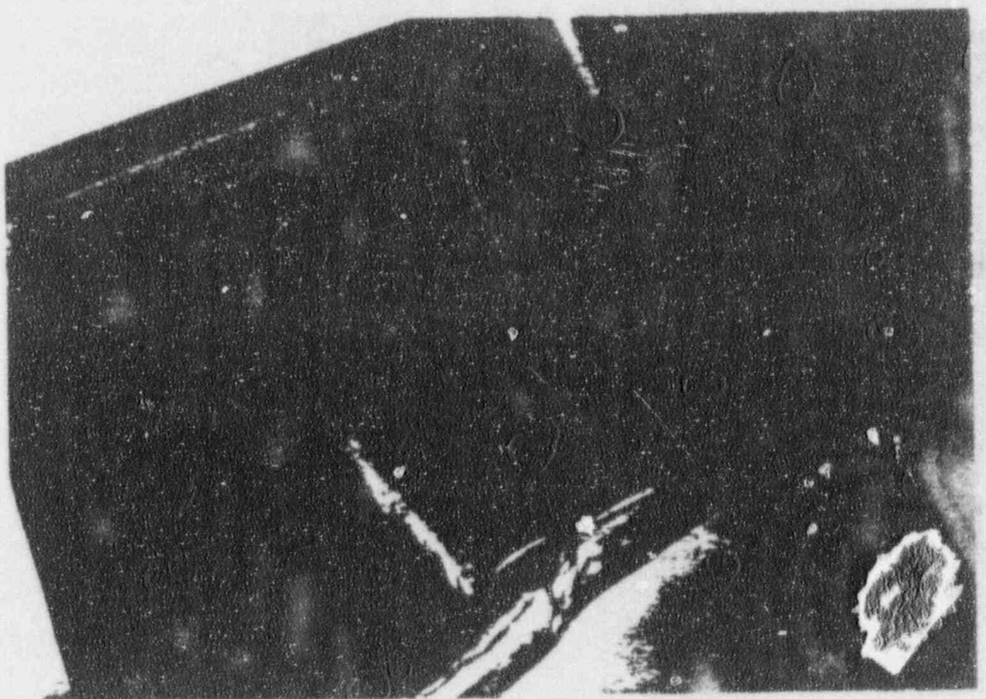


Figure 5: Typical NUKON Blankets

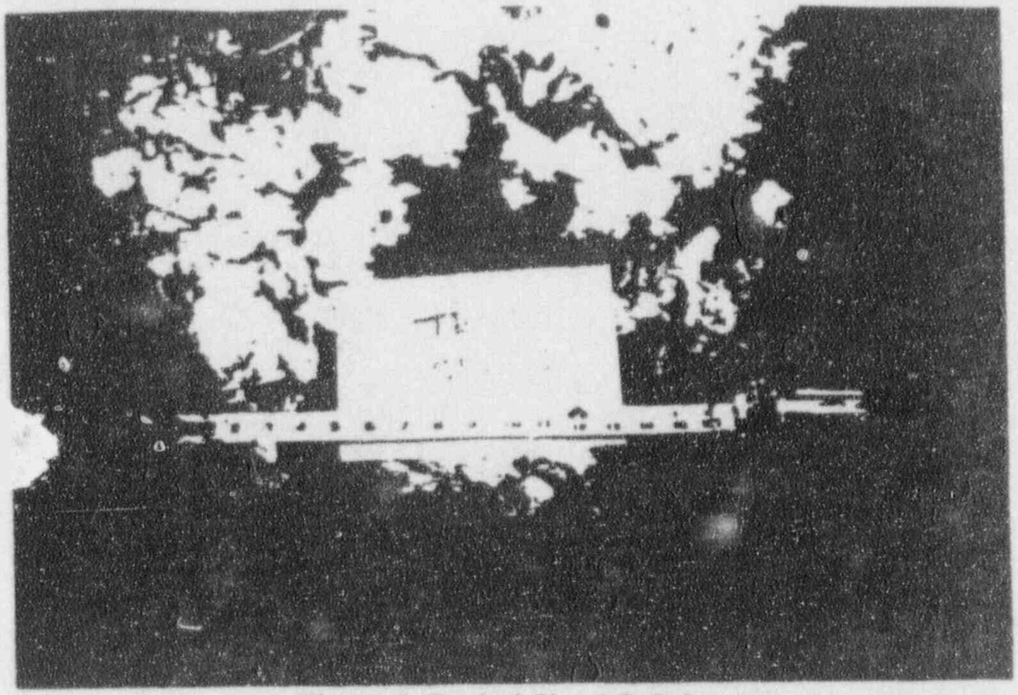


Figure 6: Typical Size 1 Debris

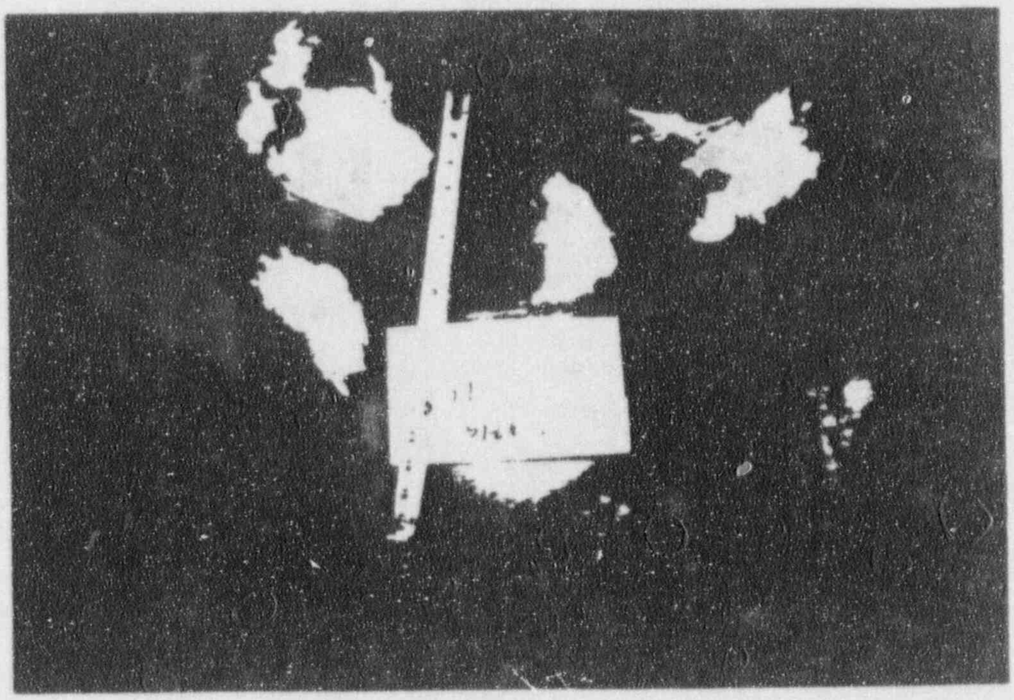


Figure 7: Typical Size 2 Debris

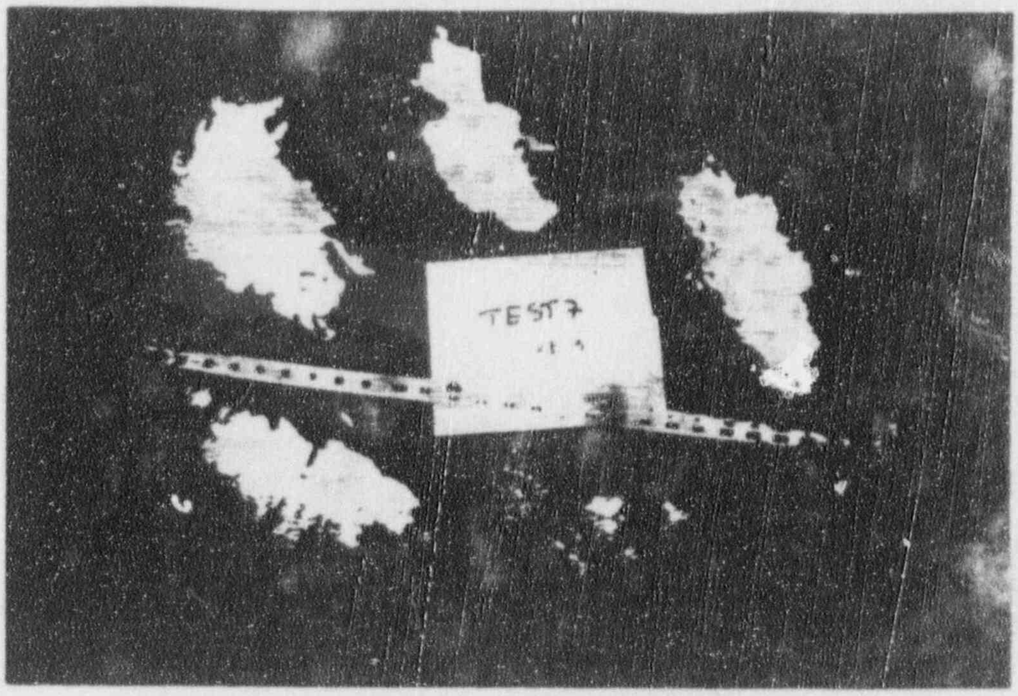


Figure 8: Typical Size 3 Debris

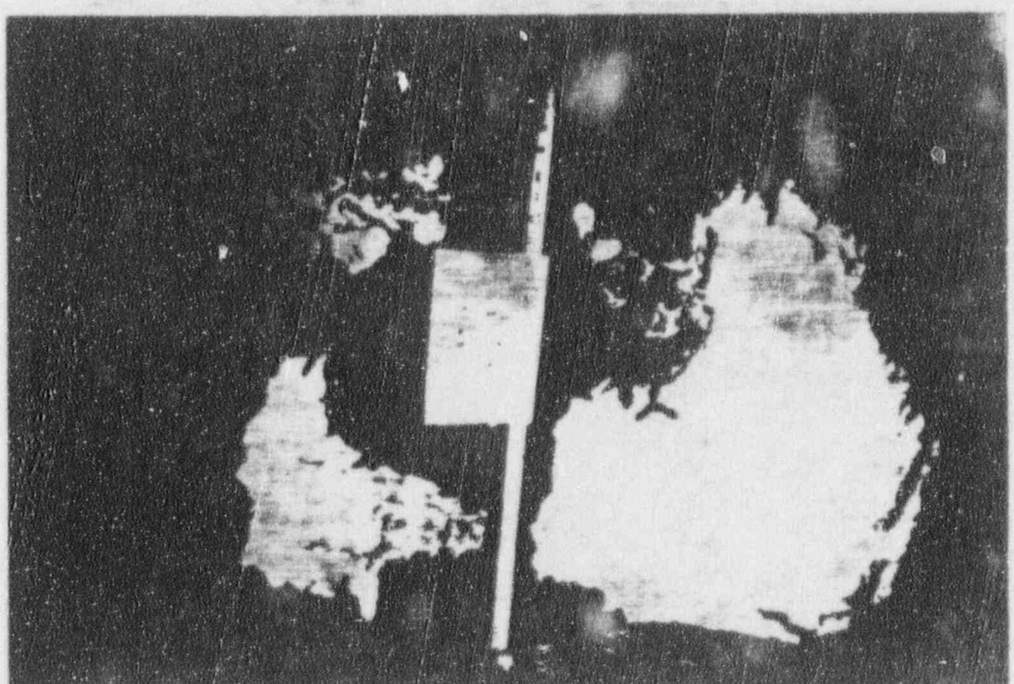


Figure 9: Typical Size 4 Debris

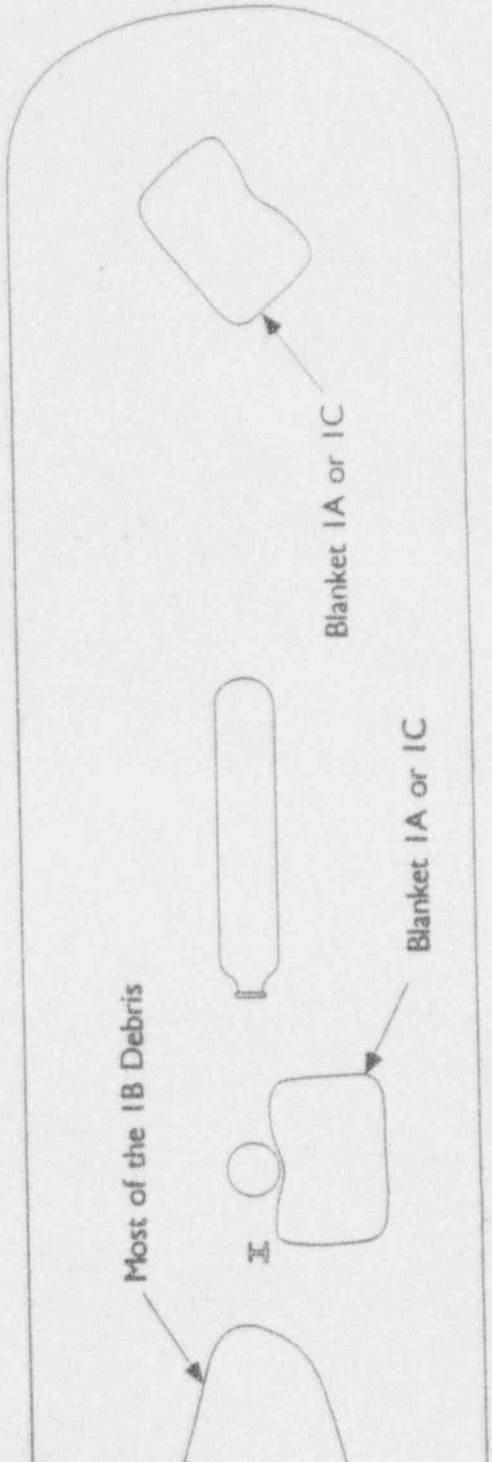


Figure 10: Location of Test 1 Debris

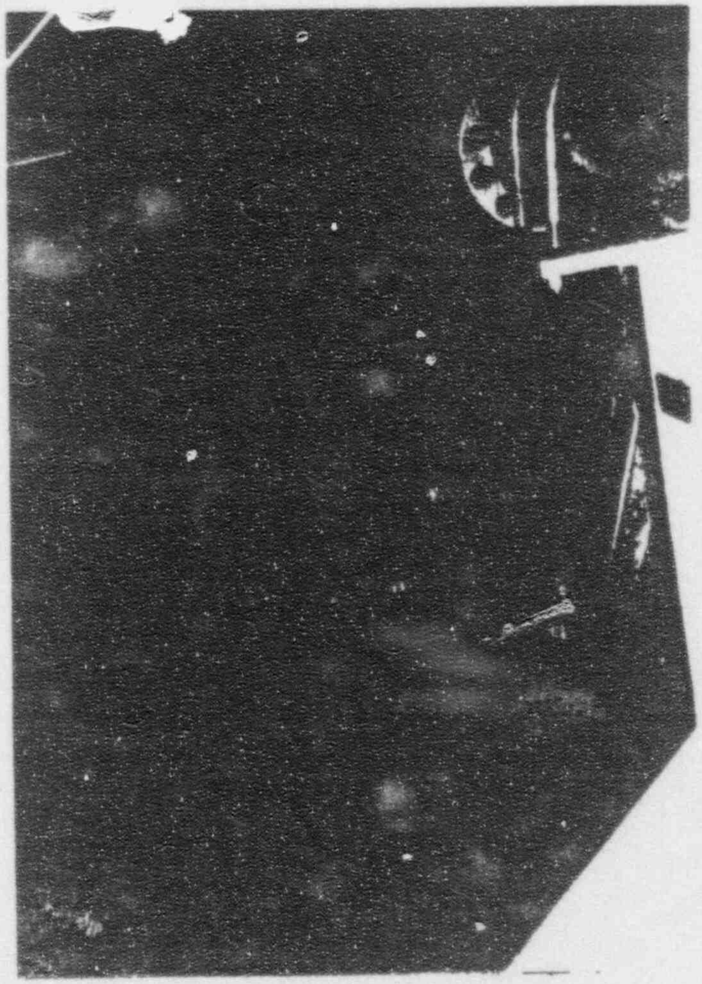


Figure 11: Location of Debris after Test 1

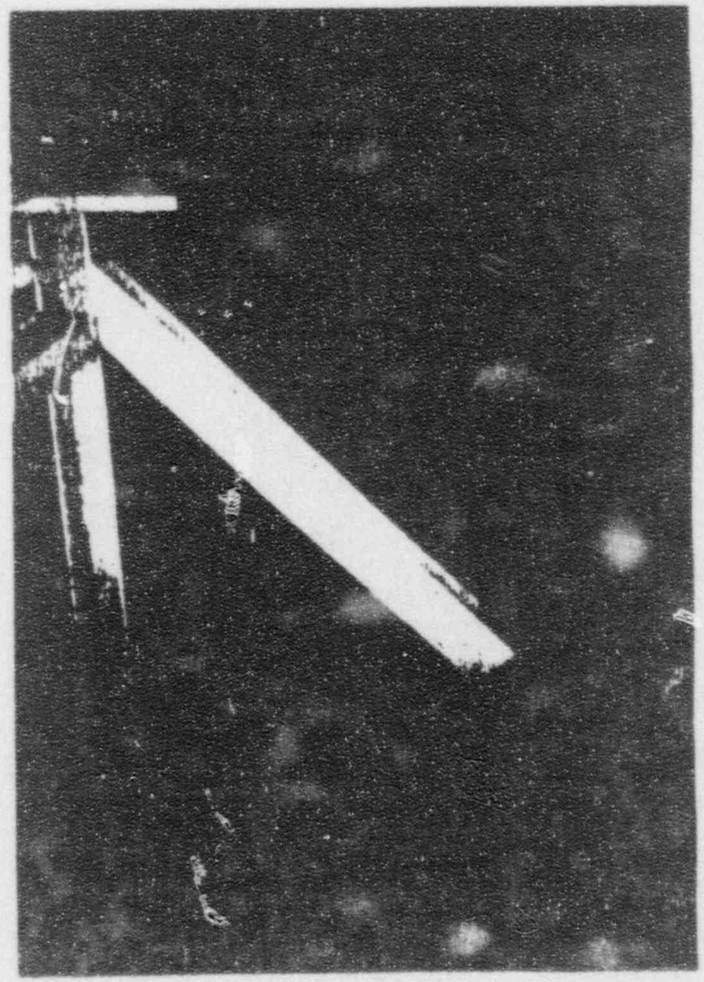


Figure 12: Location of Debris after Test 1

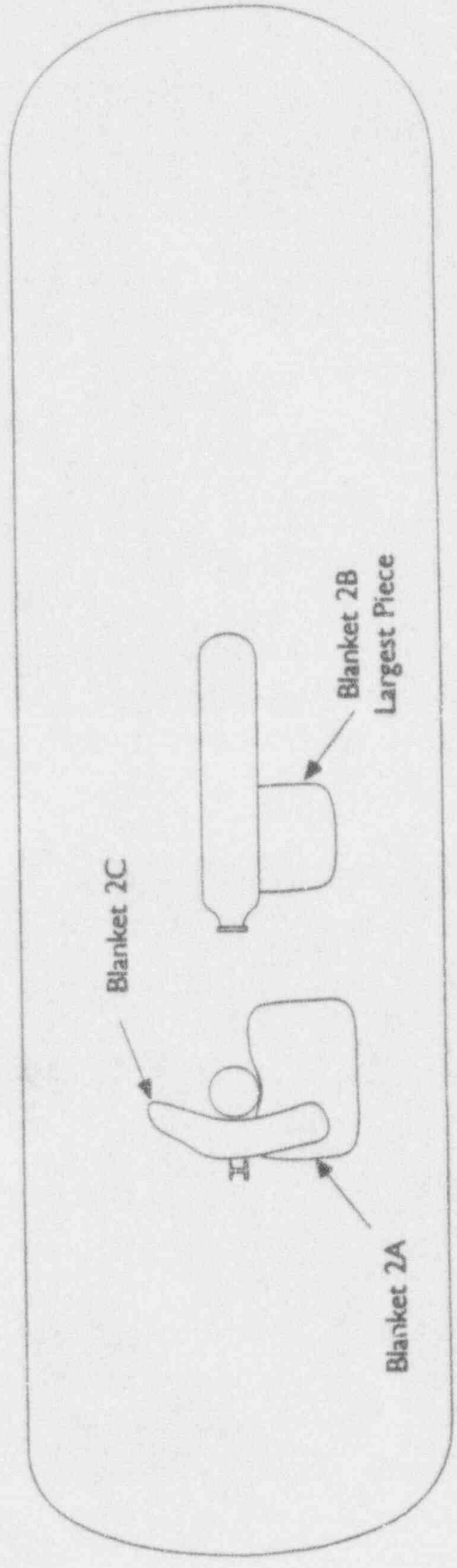


Figure 13: Location of Test 2 Debris

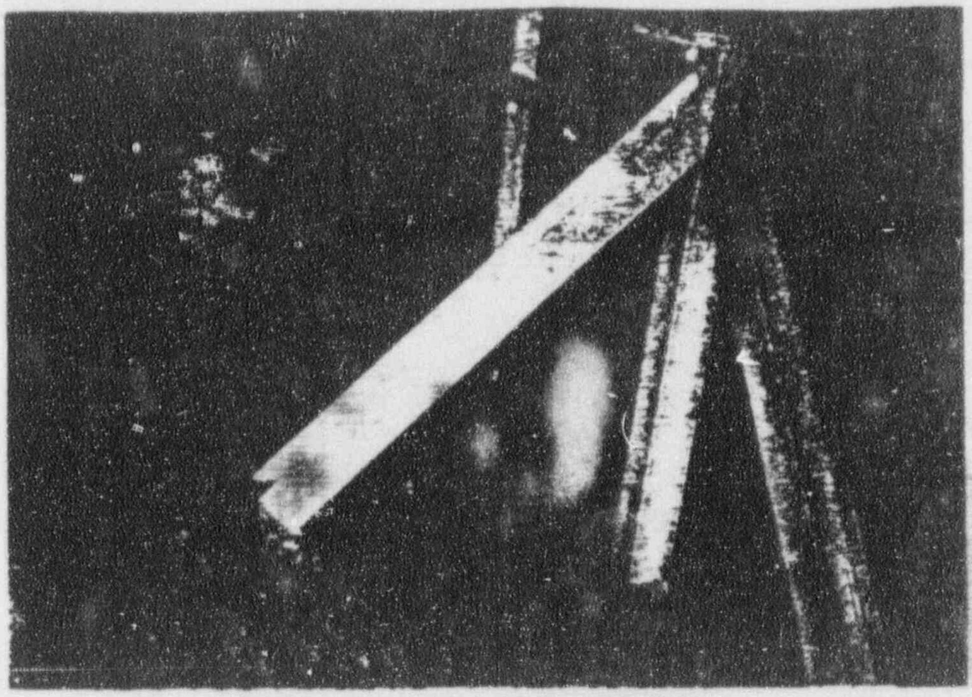


Figure 14: Location of Test 2 Debris

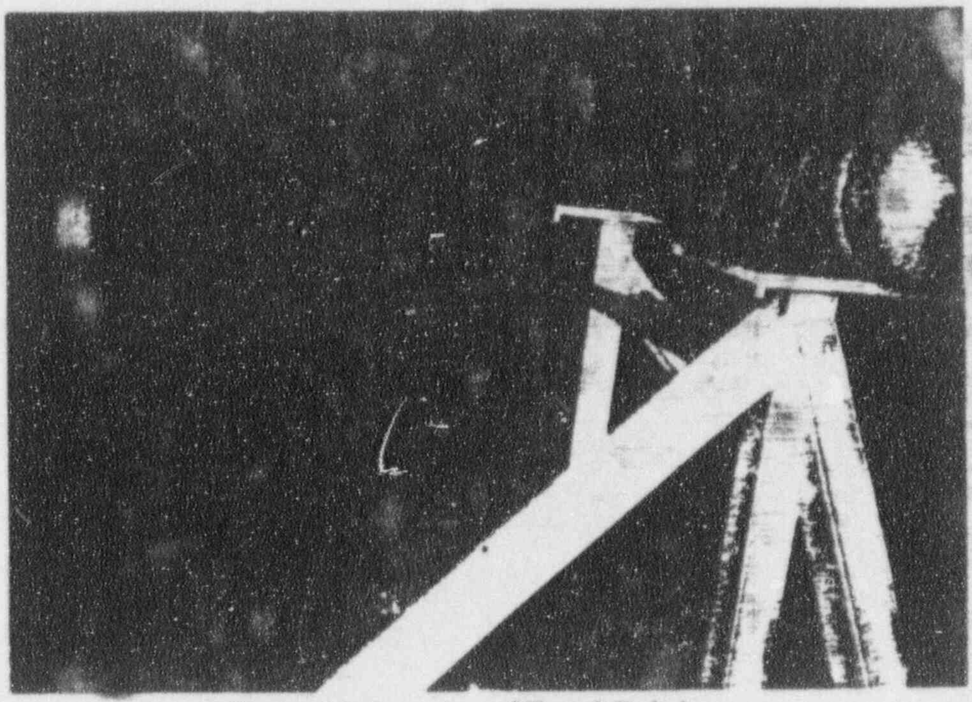


Figure 15: Location of Test 2 Debris

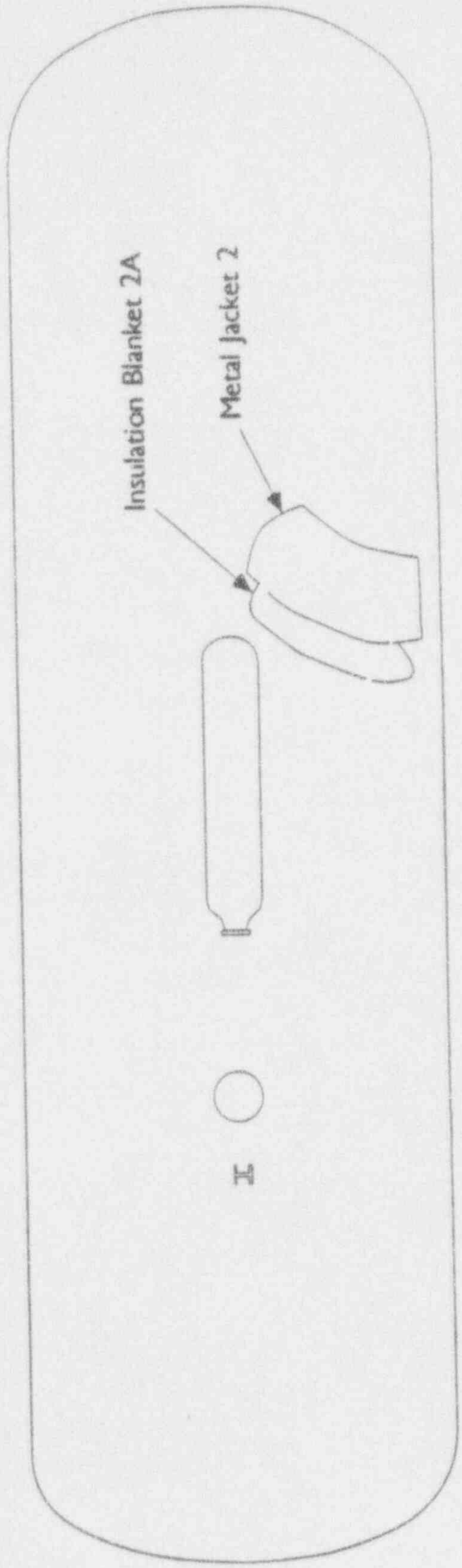


Figure 16: Location of Test 3 Debris

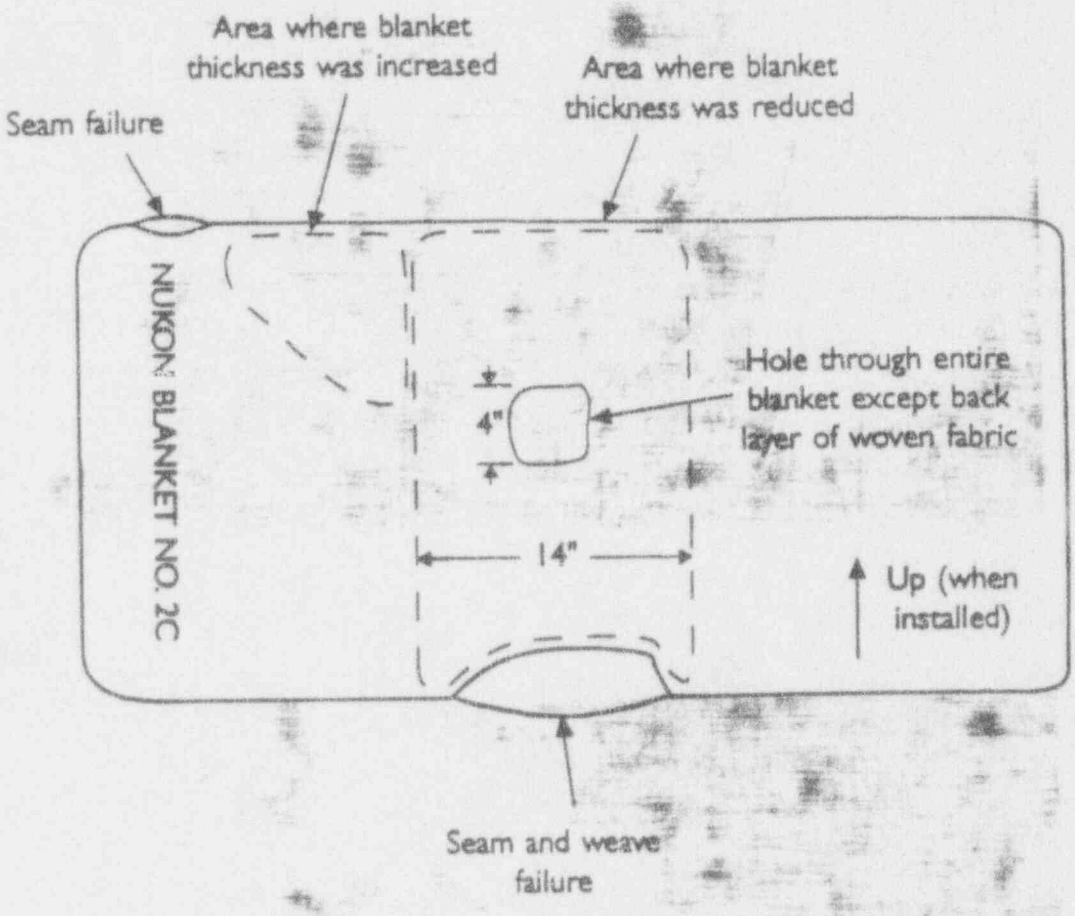


Figure 17: Blanket 2C after Test 3

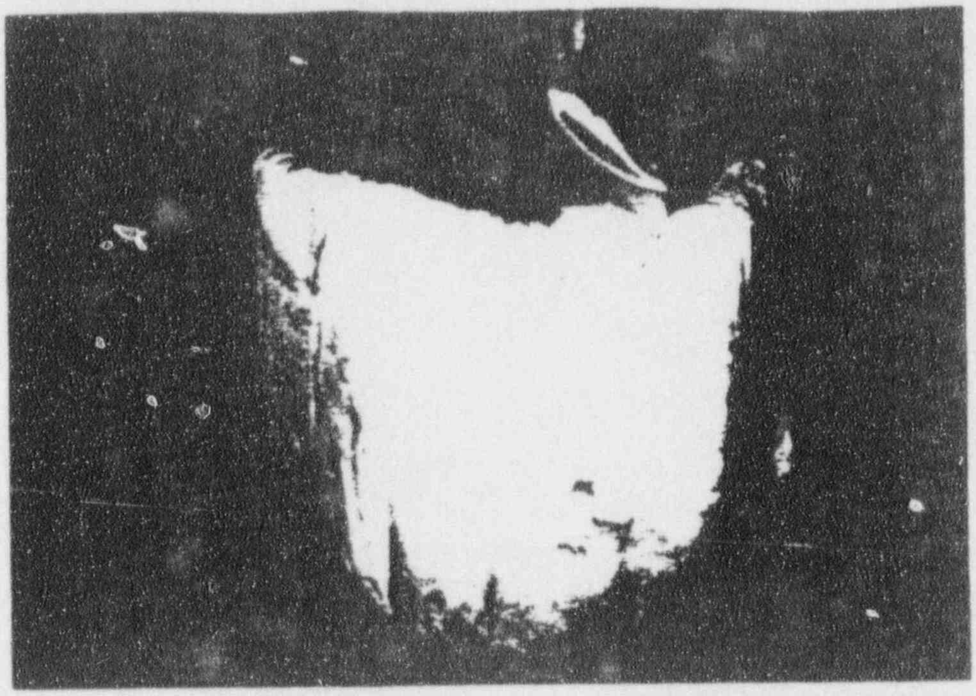


Figure 18: Blanket 2C after Test 3

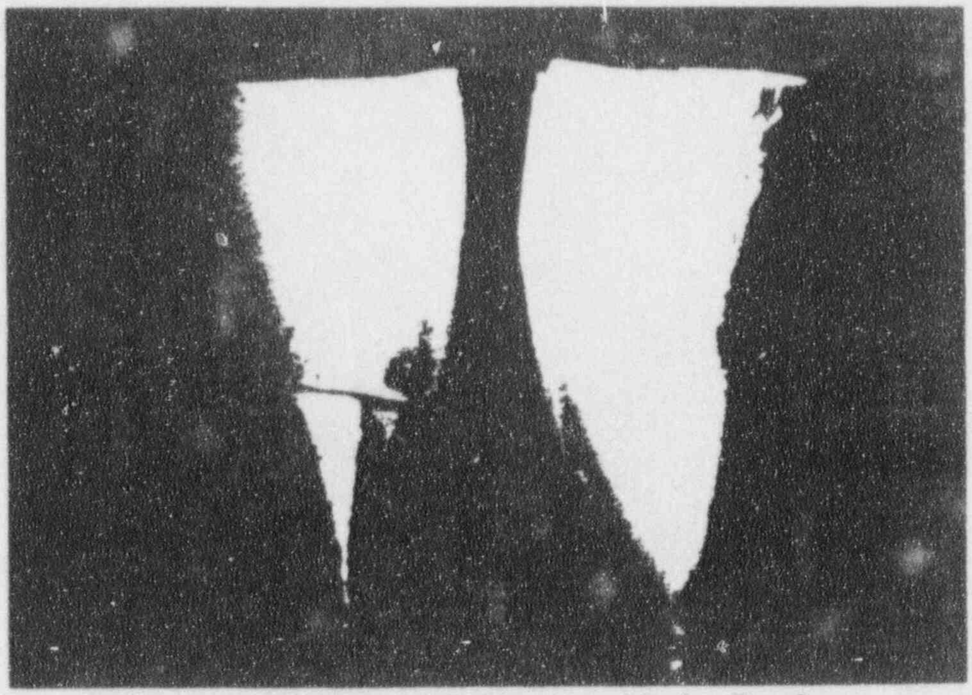


Figure 19: Metal Jacket Sections 1 and 2 after Test 3

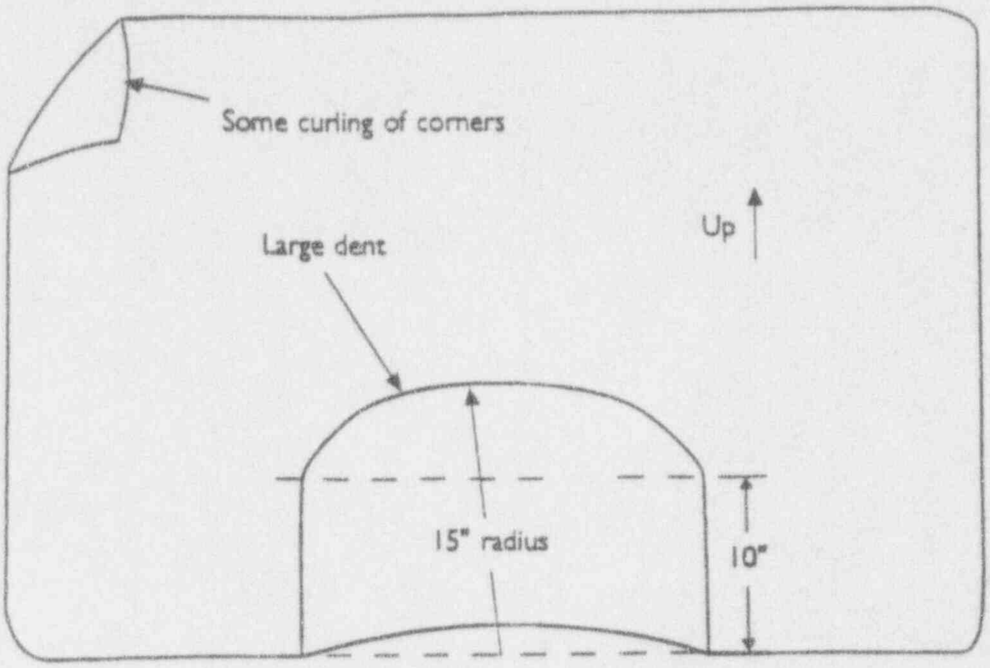


Figure 20a: Surface View of Metal Jacket Section 2 after Test 3

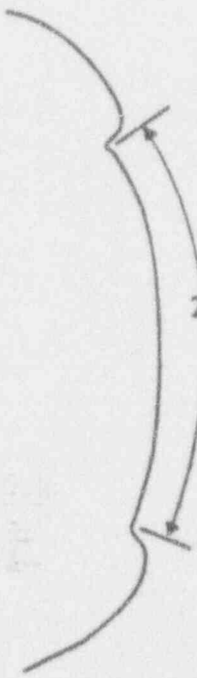


Figure 20b: Top View of Metal Jacket Section 2 after Test 3

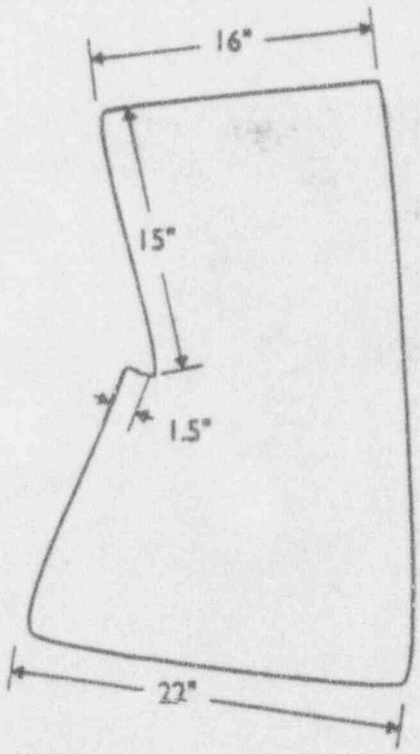


Figure 20c: Side view of Metal Jacket Section 1 after Test 3

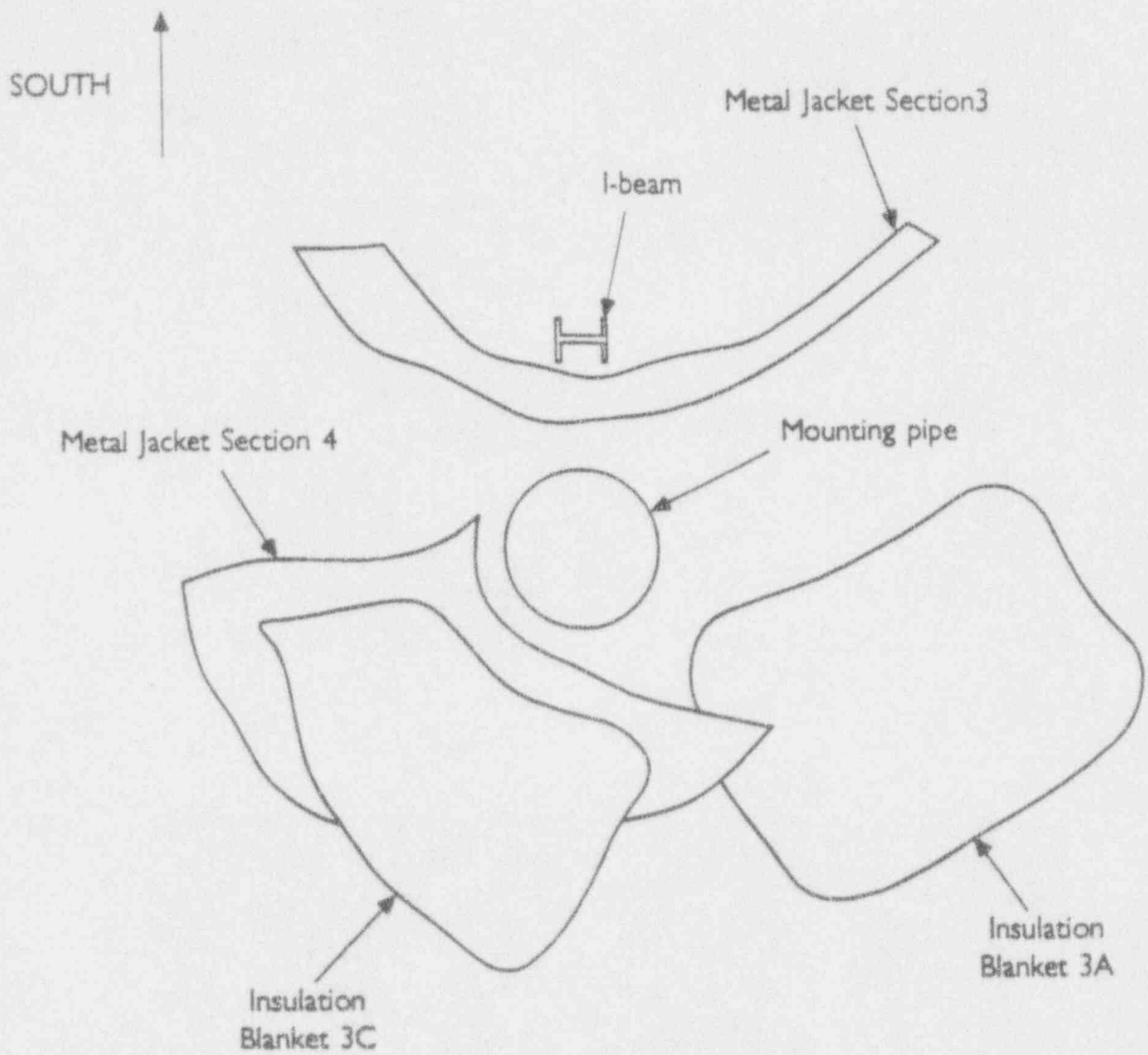


Figure 21: Location of Metal Jackets and Insulation Blankets after Test 4.

Figure 22: Location of Debris after Test 4

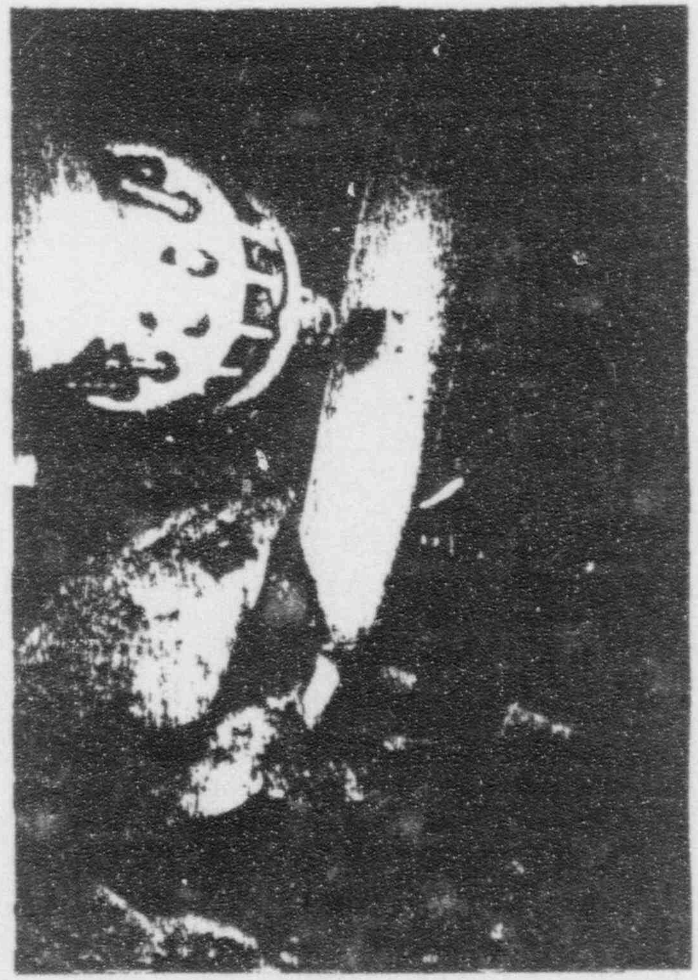
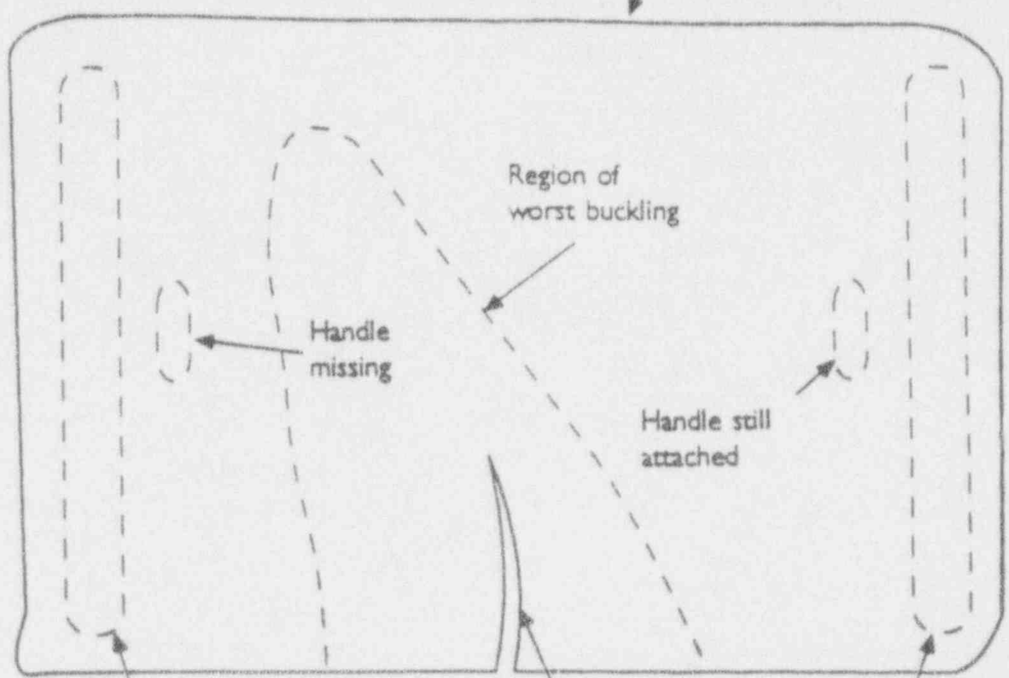


Figure 23: Location of Debris after Test 4



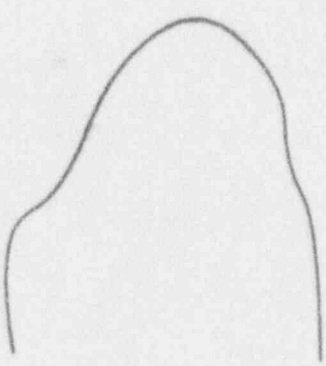


Figure 24: Metal Jacket 3 after Test 4.
Top View (left) and
Outside Surface View (above).

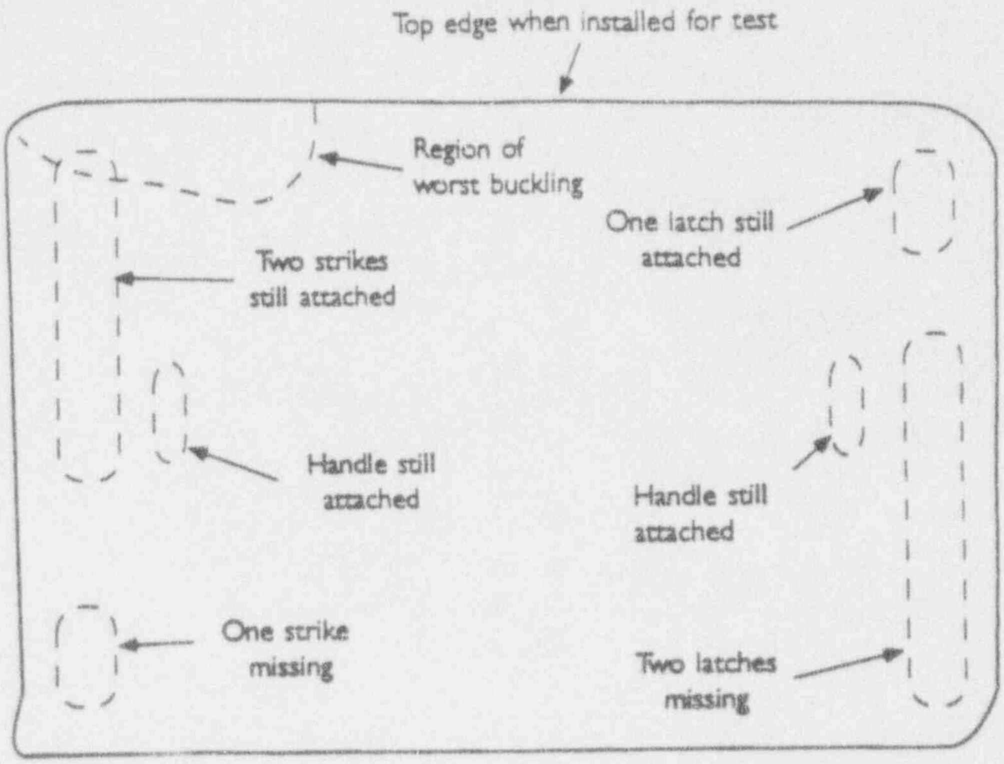


Figure 25: Metal Jacket 4 after Test 4.
Top View (left) and
Outside Surface View (above).

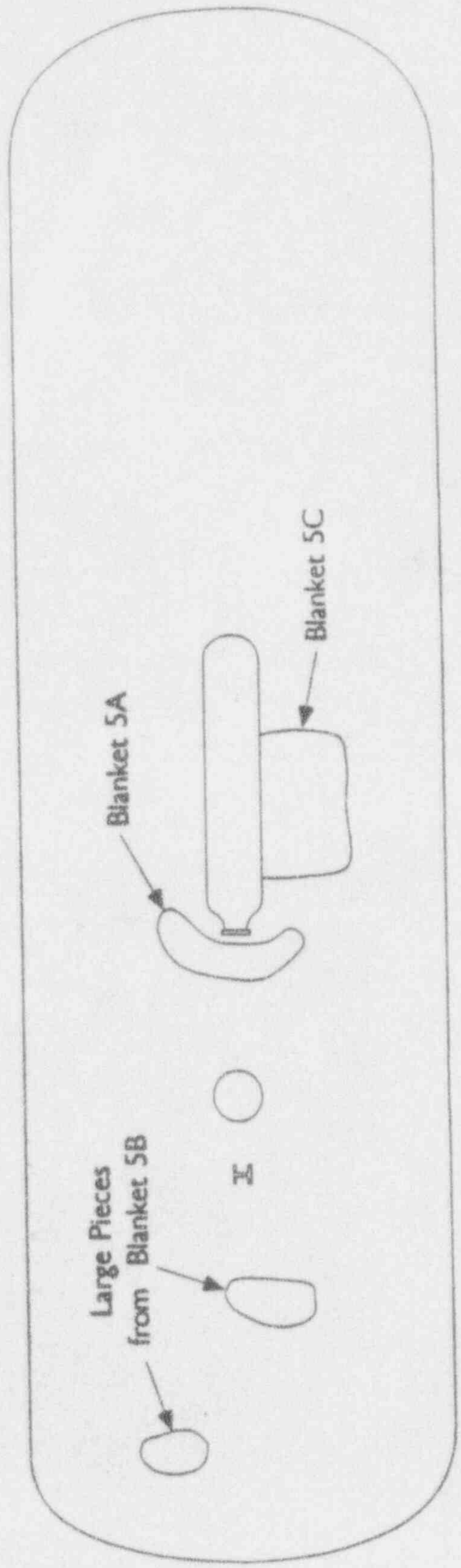


Figure 26: Location of Debris after Test 7

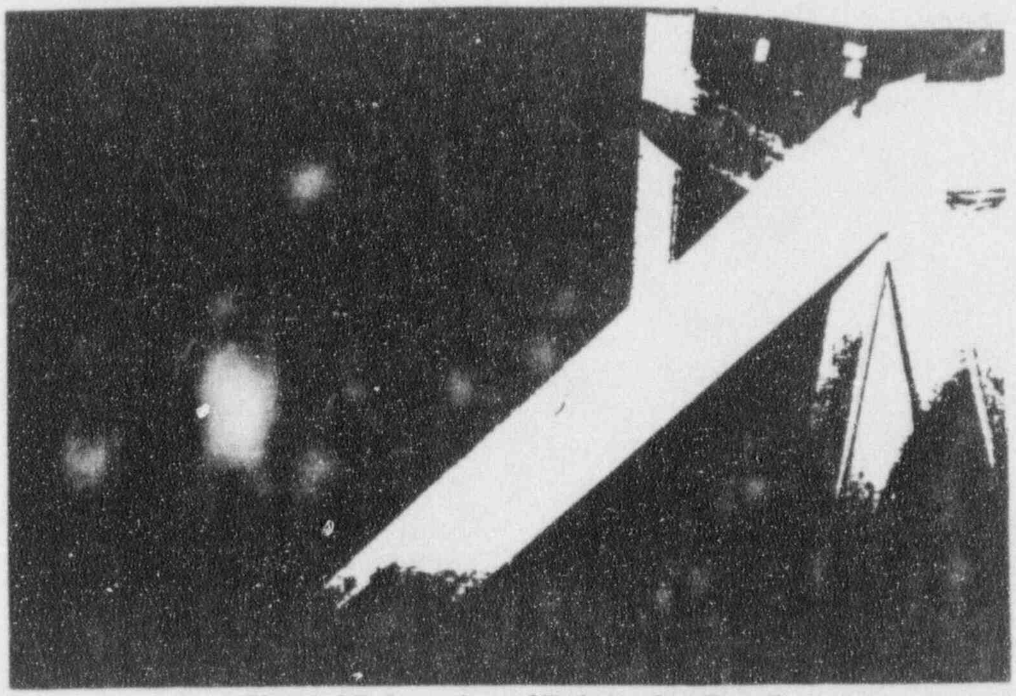


Figure 27: Location of Debris after Test 7

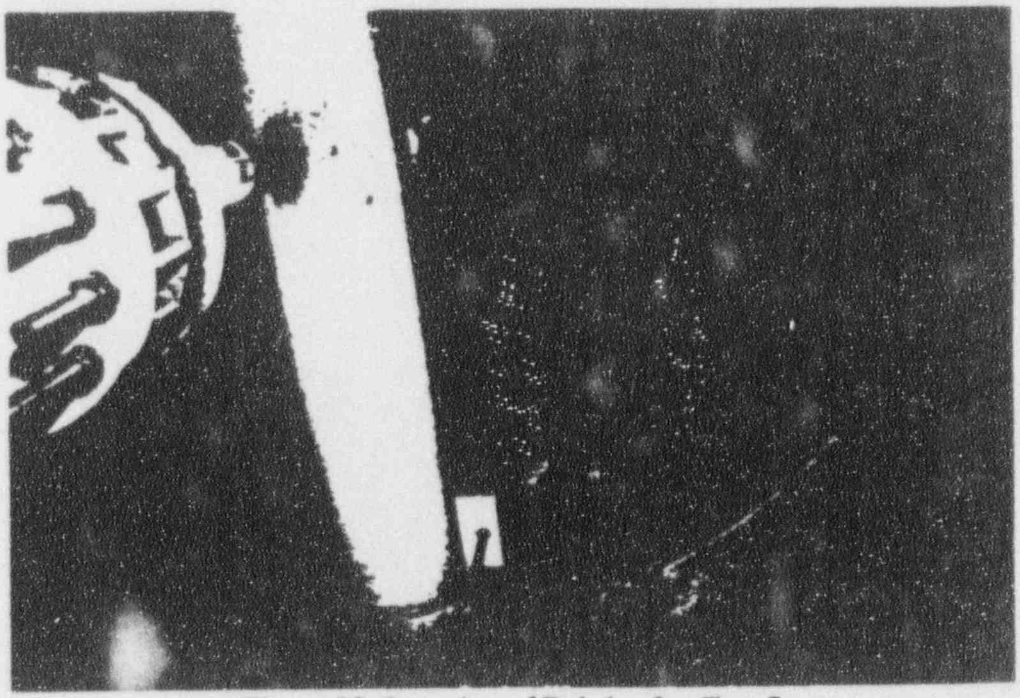


Figure 28: Location of Debris after Test 7

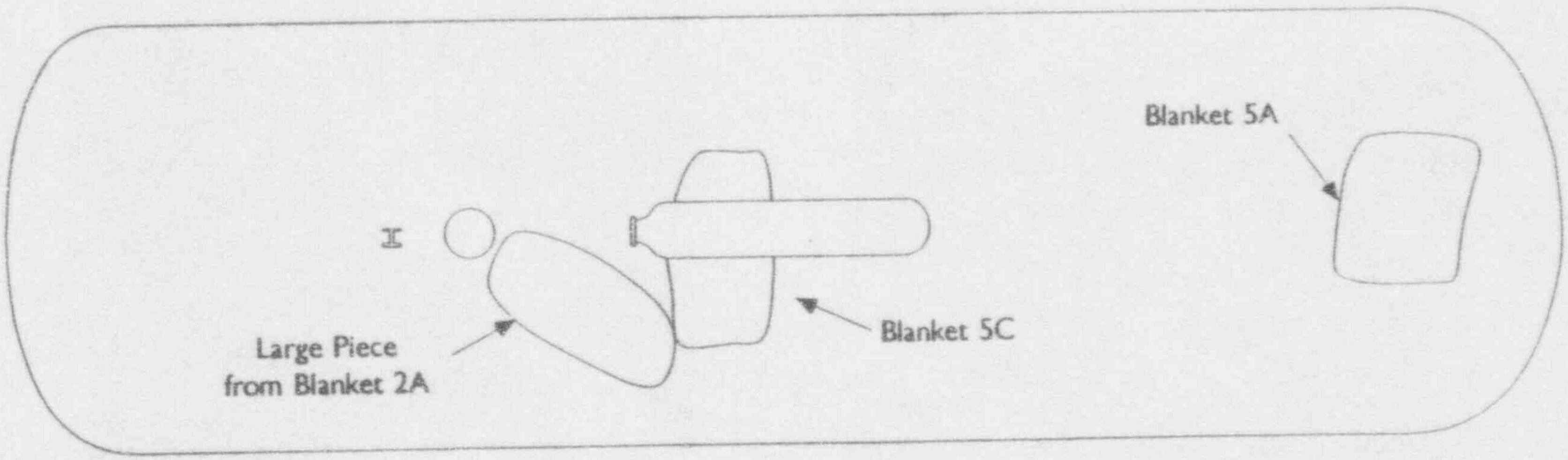


Figure 29: Location of Debris after Test 8

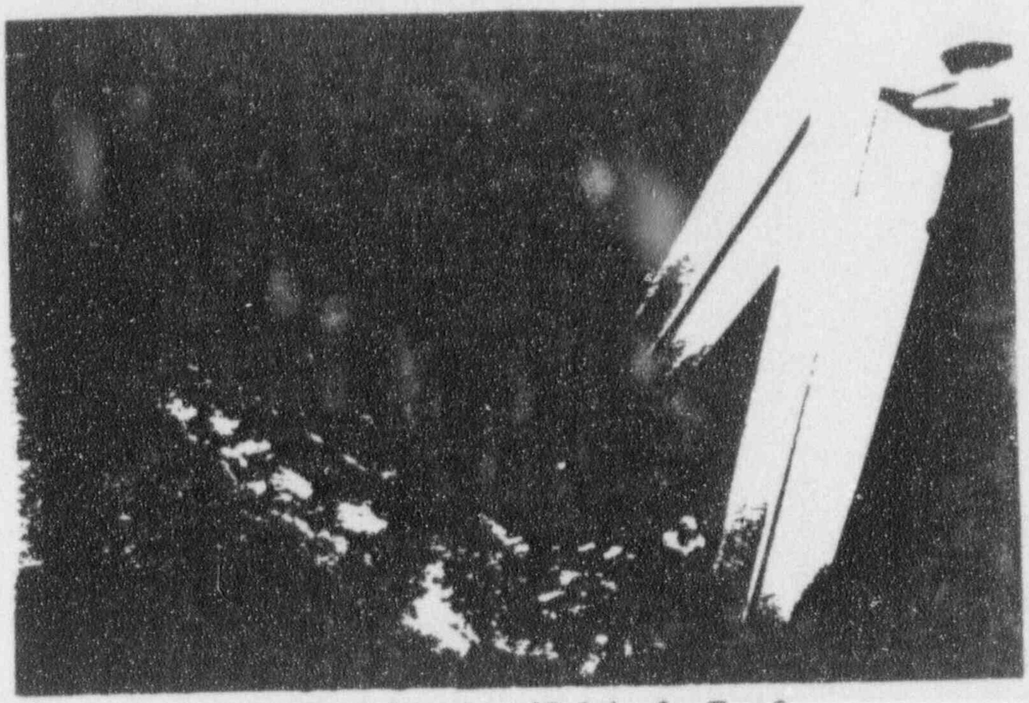


Figure 30: Location of Debris after Test 8

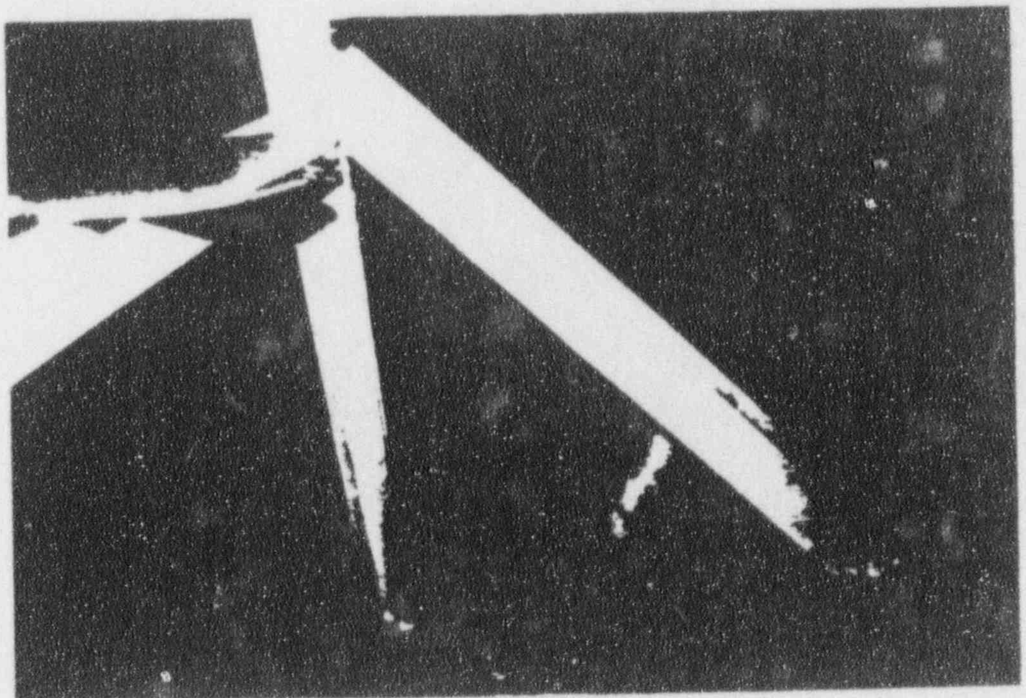


Figure 31: Location of Debris after Test 8

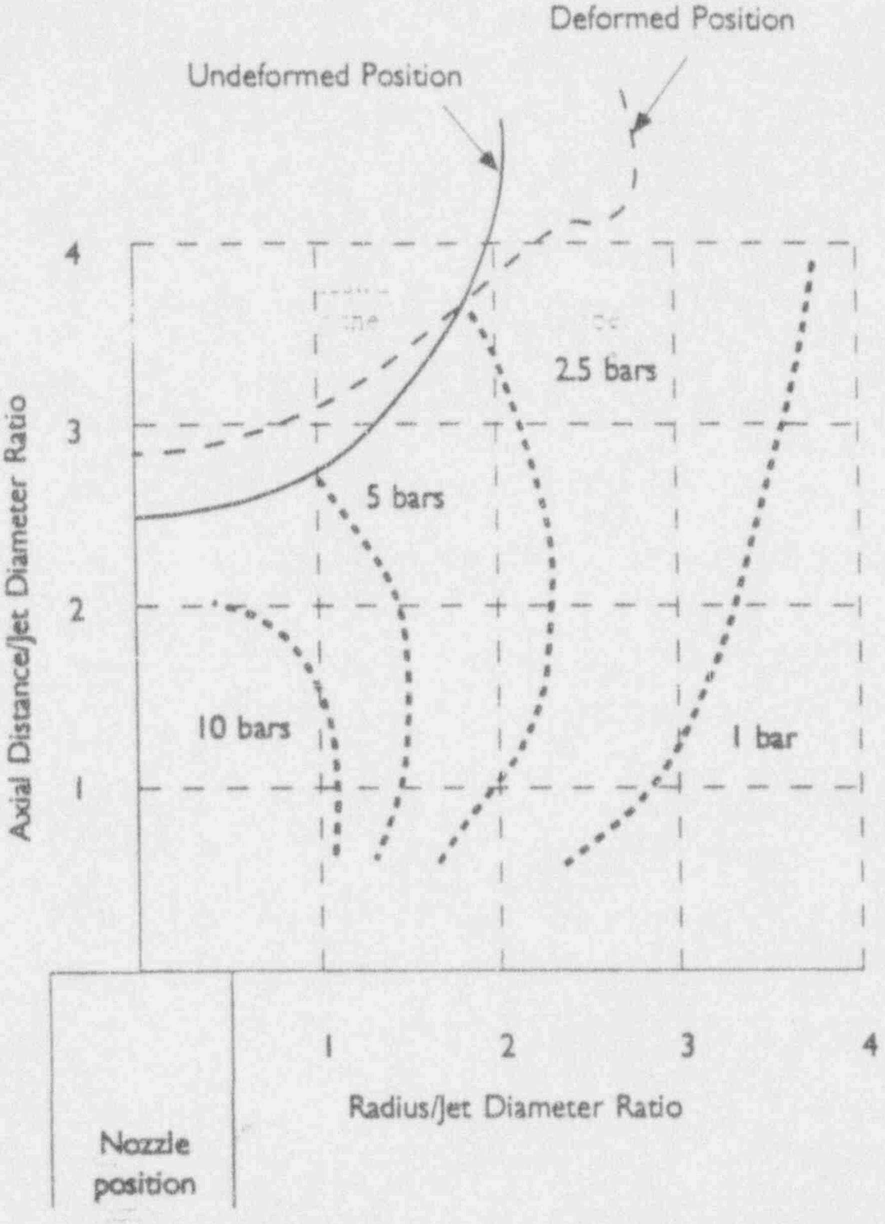


Figure 32: Deformed and undeformed metal jacket shape (from Test 3) and target pressure contours (from NUREG-0897 figure 3.23). View from the top.

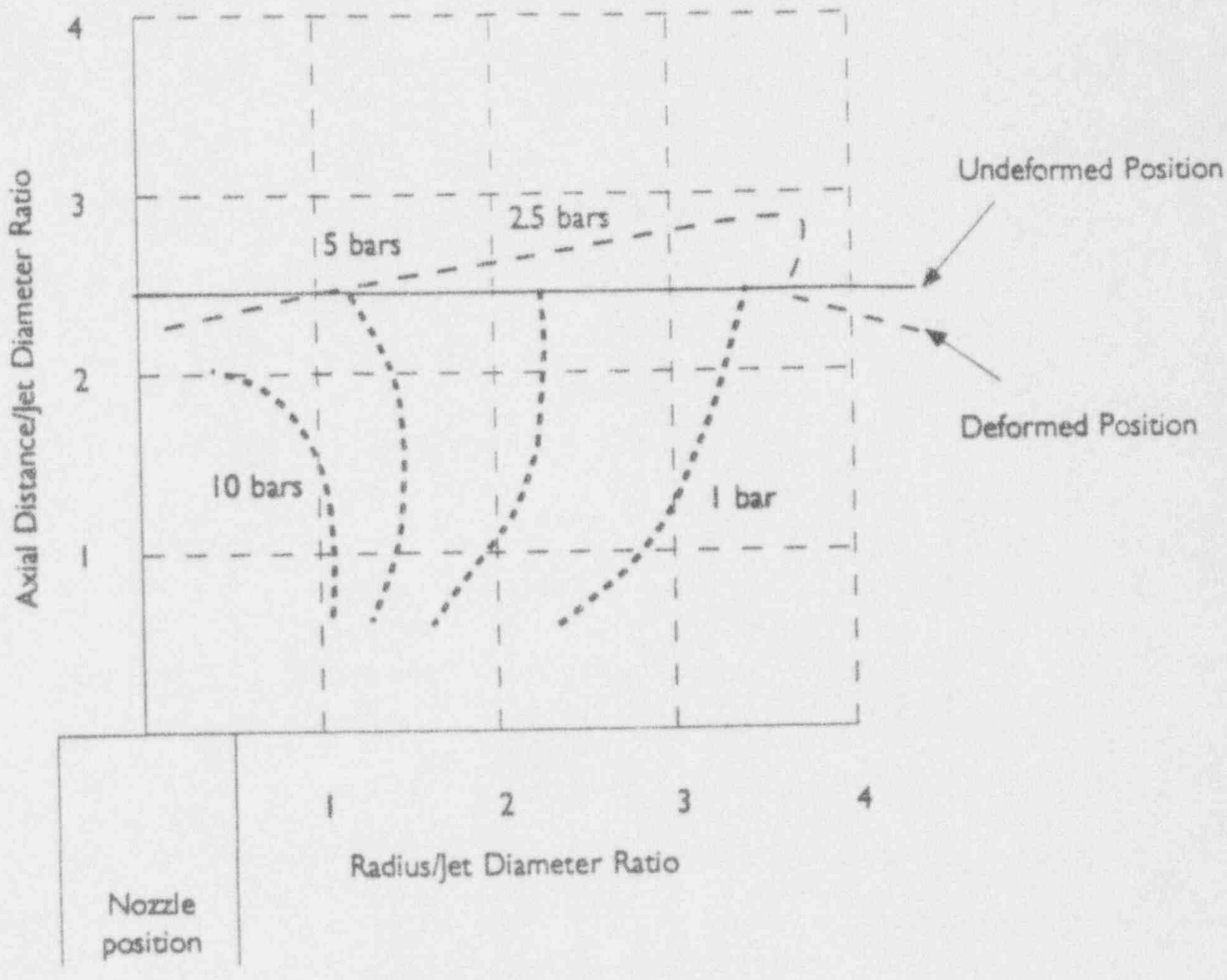


Figure 33: Deformed and undeformed metal jacket shape (from Test 3) and target pressure contours (from NUREG-0897 figure 3.23). View from the side.

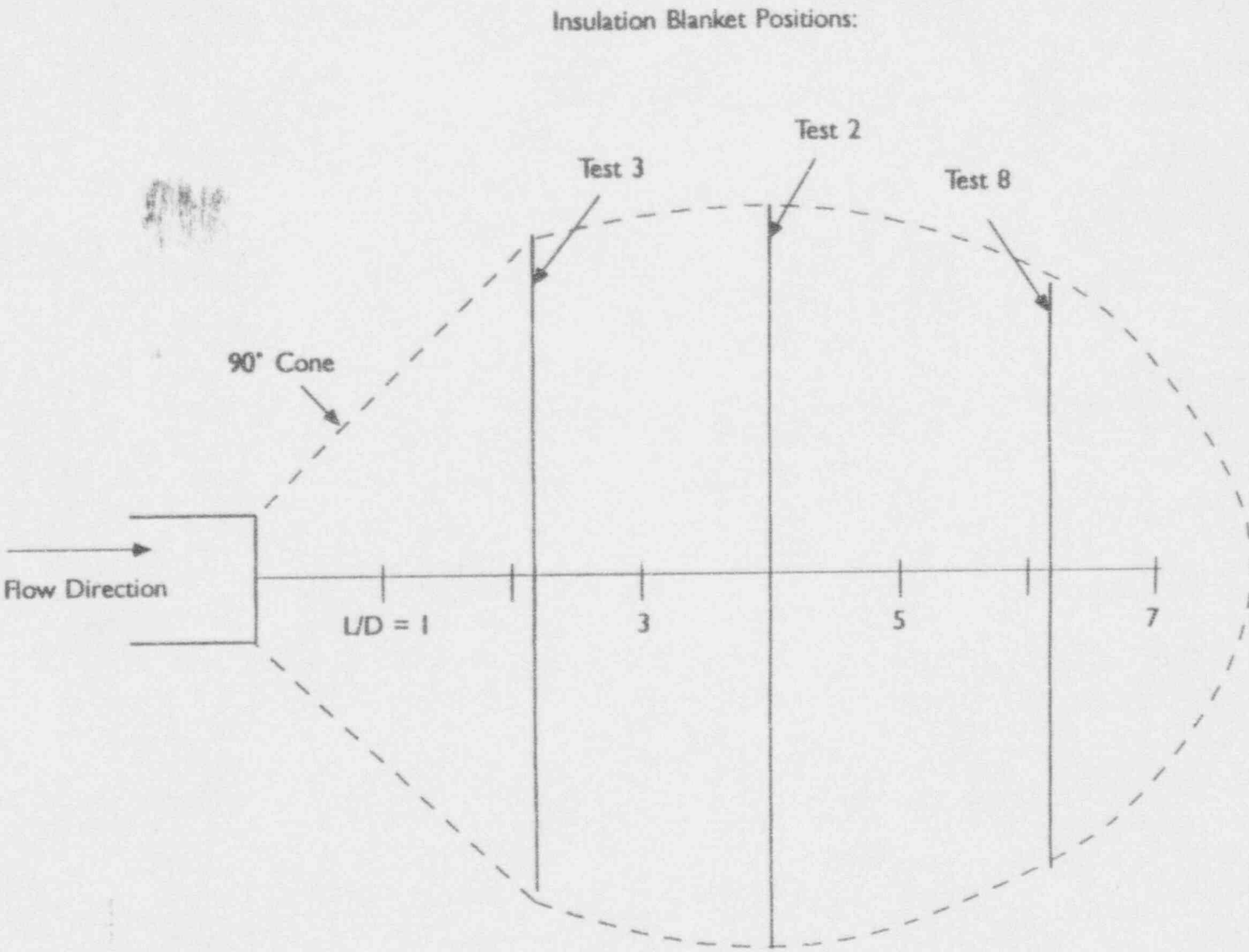


Figure 34: Proposed Shape of Zone of Destruction

APPENDIX A

Certification of work done by

Owens Corning Science and Technology Center

OWENS-CORNING SCIENCE & TECHNOLOGY CENTER
2790 COLUMBUS ROAD, ROUTE 16
GRANVILLE, OHIO 43023.1200
614.587.0610

October 21, 1993

OWENS CORNING

Mr. Gordon H. Hart
Performance Contracting Inc.
4025 Bonner Industrial Drive
Shawnee, Kansas 66226

Gordon,

This letter is to certify that our laboratory conditioned samples at your request. Samples of NUKON blanket material were exposed on a 12-inch IPS heated pipe as described by ASTM C411, Hot Surface Performance of High Temperature Insulation.

The samples were described as follows:

Lot Number BS-5-93, Blanket Numbers 1A, 1B, 1C, 2A, 2B, 2C, 3A, 3B, and 3C.

The blankets were exposed for at least 24 hours, at a temperature of 550 Degrees F. After exposure the blankets were forwarded to Colorado Engineering Experiment Station, Inc. (CEESI) for other tests.

Please be advised that we are certified by NVLAP to perform the ASTM C411 procedure.

Sincerely,

W. S. Miller
Product Technology, Product Testing Laboratory
Tele. 614-587-7003, Fax 614-587-7009

NVLAP

OWENS-CORNING SCIENCE & TECHNOLOGY CENTER
2790 COLUMBUS ROAD, ROUTE 16
GRANVILLE, OHIO 43023-1200
614.587.0610

October 22, 1993

OWENS CORNING

Mr. Gordon H. Hart
Performance Contracting Inc.
4025 Bonner Industrial Drive
Shawnee, Kansas 66226

Gordon,

This letter is to certify that our laboratory conditioned samples at your request. Samples of NUKON blanket material were exposed on a 12-inch IPS heated pipe as described by ASTM C411, Hot Surface Performance of High Temperature Insulation.

The samples were described as follows:

Lot Number BS-6-93, Blanket Numbers 4A, 4B, 4C, 5A, 5B, 5C, 6A, 6B, and 6C.

The blankets were exposed for at least 24 hours, at a temperature of 550 Degrees F. After exposure the blankets were forwarded to Colorado Engineering Experiment Station, Inc. (CEESI) for other tests.

Please be advised that we are certified by NVLAP to perform the ASTM C411 procedure.

Sincerely,

W. S. Miller
Product Technology, Product Testing Laboratory
Tele . 614-587-7003, Fax 614-587-7009

NVLAP

This laboratory is accredited by NVLAP of the U.S. Department of Commerce as having the competence to perform specified tests in accordance with prescribed test methods and accreditation criteria. We remind you that under NVLAP procedures you must not reference in consumer or product advertising or on product labels the fact that a NVLAP accredited laboratory performed the product tests referenced herein.

TRANSCO PRODUCTS INC.

TEST REPORTS

TO AID IN THE

BWR ECCS ANALYSIS