GENERAL ELECTRIC

Director - ONMSS
July 25, 1980

APPLICATION FOR REVISION OF
NRC CERTIFICATE OF COMPLIANCE USA/9019/B()F
FOR THE BU-7 TRANSPORT PACKAGE

ENCLOSURE 1

APPLICATION FOR REVISION

A. L. Kaplan
:bmw

8009050419

1.0 INTRODUCTION

The BU-7 package, as described in General Electric's consolidated application to the NRC for a Certificate of Compliance, is currently authorized by NRC Certificate of Compliance USA/9019/B()F, Revision 5, as a Fissile Class I container for the transport of fissile radioactive material in the form of uranium dioxide and pellets.

A complete series of tests were recently conducted on the BU-7 package constructed with an outer container different from that specified in the Certificate, to verify conformance of the package with the requirements of 10 CFR 71. Also, a criticality safety analysis was recently completed to verify that the BU-7 package still meets the Fissile Class I requirements of 10 CFR 71 with an increase in the H/U ratio allowed for the package contents from 0.45 to 1.577.

This application amendment contains a consolidation of all applications and package test results previously submitted in Docket 70-754 (for NRC License SNM-960), Docket 70-1007 (for NRC License SNM-54), and Docket 71-9019 for license and certificate amendments pursuant to 10 CFR 71 related to the General Electric BU-7 package, as well as supporting information for the requested change in allowed H/U ratio for package contents.

2.0 PACKAGE DESCRIPTION

2.1 General

Inner containment is a nominal 16-gallon drum closed by a gasketed, bolted lid, centered and supported within an outer 55-gallon drum by solid insulating media, and containing two or more steel pails which contain UO_2. (See Drawing 112D1592, Revision 0, in Section 6.)

2.2 Gross Weight

320 pounds, maximum

2.3 Uranium Oxide Powder Container

One or more closed containers, 11.25" inside diameter fabricated of minimum 24-gauge steel, vertically stacked in each BU-7 unit.

2.4 BU-7 Inner Containment

A nominal 16-gallon, Uniform Freight Classification Rule 40 drum constructed of 18 gauge steel, modified by the welded attachment of a closure flange to accept a 3/16" thick steel lid which is gasketed for resistance to high temperature as shown in Drawing 112D1592, Revision 0, and attached by twelve 5/16" minimum steel bolts. The inside dimensions of the inner containment drum are 13 5/8" diameter by 26 5/8" high. The maximum hydrogen to uranium atomic ratio in the UO_2 fuel mixtures within the inner containment is 1.577 taking into account all sources of hydrogeneous material mixed in with the UO_2.

2.5 BU-7 Outer Container

A nominal 55-gallon, Uniform Freight Classification Rule 40 18 gauge steel drum with nominal outer dimensions 22 1/2" diameter by 34" high.

2.6 Insulating Material

The inner containment drum is centrally held within the outer container by, and the space between the inner and the outer containers is completely filled with, solid insulating media composed of fire-retardant phenolic foam as spe ified in Drawing 112D1592 . Four 1/4" diameter holes near the top of the outer container, covered with waterproof tape, would permit steam to escape in the event free moisture in the insulating material were exposed to the heat from an accidental fire during transport.

2.7 Package Description - Contents

2.7.1 Type and Form of Material

Uranium oxides enriched to not more than 4% in U-235; and of density not greater than 4.5 grams per cc for powder and not greater than 10.96 grams per cc for pellets. These may contain ammonium oxalate and/or ammonium bicarbonate additives.

2.7.2 Maximum Quantity

For uranium oxide powder, 89 kilograms per package, except that powder at enrichments above 3.00% shall be limited to 35 kilograms of uranium oxide. For mixtures of uranium oxide powder and pellets, 90 kilograms per package, except that such mixtures at enrichments above 2.70% shall be limited to twice the safe batch sizes for pellets given in Paragraph 5.2.3(c) on page A-29 of Appendix A to NRC License SNM-1097 (Docket #70-1113).

3.0 PACKAGE EVALUATION

3.1 General

There are no components of the packaging or its contents which are subject to chemical or galvanic reaction during normal transportation.

The package cannot be opened inadvertently, uses no coolant and has no lifting or tiedown attachments.

3.2 Single Package - Normal Transport Conditions

Between March 20 and April 2, 1980, a series of tests were performed on the BU-7 transport package. These tests are described in a report dated April 25, 1980, which is included in Enclosure 1A to this application.

Included in these tests were some simulated normal transport conditions. Not all such conditions were tested because the package requirements for some of these conditions could be demonstrated to be satisfactory by other means.

Two BU-7 packages were loaded with two 5-gallon steel pails, each pail being filled with 45 kgs of UO_2 powder containing natural uranium, for a total of 90 kgs of UO_2 powder per package. These packages were used for the tests simulating hypothetical accident conditions, as described in the test report (Enclosure 1A).

One BU-7 package was loaded with two 5-gallon steel pails containing a total of 93 kgs of lead shot. This package was subjected to tests simulating normal transport conditions.

A summary of this information is given in Table 1.

TABLE 1

SINGLE BU-7 TRANSPORT PACKAGE - NORMAL TRANSPORT CONDITIONS

Requirements*	Tests Conducted	Results
1. *Heat* Direct sunlight at an ambient temperature of 130°F. in still air.	No tests required.	Temperature of 130° F is within normal operating range for materials of construction.
2. *Cold*-An ambient temperature of -40°F. in still air and shade.	No tests required.	Temperature of -40° F is within normal operating range for materials of construction.
3. *Pressure*-Atmospheric pressure of 0.5 times standard atmospheric pressure.	Package was submerged in water to a pressure of 1.50 kg/cm^2 (50 feet of water), then pressurized and checked for leakage in four increments: o 0.75 kg/cm^2 for 3 hrs o 1.0 kg/cm^2 for 3 hrs o 1.25 kg/cm^2 for 3 hrs o 1.5 kg/cm^2 for 3 hrs	o No water leakage into inner containers after 8 hours of submergence. o No leakage of air from inner containers when pressurized and held at each pressure increment for 3 hours.
4. *Vibration*-Vibration normally incident to transport.	No tests required.	Packages of this type have withstood several years of transport with no occurrences of significant damage due to normal vibration.
5. *Water Spray*-A water spray sufficiently heavy to keep the entire exposed surface of the package except the bottom continuously wet during a period of 30 minutes.	Package was exposed to a water spray sufficiently heavy to keep all exposed surface except the bottom wet for a period of 30 minutes.	There were no signs of water damage to the package.

*Pursuant to Appendices A and B of 10 CFR 71.

Requirements	Tests Conducted	Results
6. *Free Drop* Between 1 1/2 and 2 1/2 hours after the conclusion of the water spray test, a free drop through the distance specified below onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected. FREE FALL DISTANCE *Package weight (pounds)* — *Distance (feet)* Less than 10,000 ------------ 4 10,000 to 20,000 ------------ 3 20,000 to 30,000 ------------ 2 More than 30,000 ------------ 1	The package, loaded with 93 kgs of test weight, was dropped 4 feet with the closure ring impacting onto a flat reinforced concrete pad. The test was conducted 2 hours after the water spray test.	There was a slight deformation of the outer container closure ring that did not impair its function. There was no damage to the inner container seal or the 5-gallon pails, and there was no separation of the closure ring from the lid of the outer container.
7. *Corner Drop*– This test applies only to packages which are constructed primarily of wood or fiberboard, and do not exceed 110 pounds gross weight.	No tests were required.	The package gross weight exceeds 110 pounds.
8. *Penetration*–Impact of the hemispherical end of a vertical steel cylinder 1 1/4 inches in diameter and weighing 13 pounds, dropped from a height of 40 inches onto the exposed surface of the package which is expected to be most vulnerable to puncture. The long axis of the cylinder shall be perpendicular to the package surface.	The package was penetration tested by impacting the hemispherical end of a vertical steel cylinder 1 1/4" in diameter and weighing 13 pounds, and dropped from a height of 40" into the top of the container where it is most susceptible to a projectile penetration.	There was a slight indentation where the 13 pound bar struck the container. It did not penetrate the package.
9. *Compression*–For packages not exceeding 10,000 pounds in weight, a compressive load equal to either 5 times the weight of the package or . pounds per square inch multiplied by the maximum horizontal cross section of the package, whichever is greater. The load shall be applied during a period of 24 hours, uniformly against the top and bottom of the package in the position in which the package would normally be transported.	Weight equal to more than 5 times the weight of the package was applied to the top of the package for a period of 24 hours. The test weight used was 2,440 pounds.	No damage to the package due to compressive loading was found.

The tests and assessments set forth in Table 1 provide assurance that the powder or pellet contents are contained in the pails during normal transport and there is no reduction in effectiveness of the package system.

It has been demonstrated, moreover, that there would be no water inleakage to the product during normal transport conditions.

3.3 Single Package - Accident Evaluation

Between March 20 and April 2, 1980, a series of tests were performed on the BU-7 transport package. These tests are described in a report dated April 25, 1980, which is included in Enclosure 1A to this application. Included in these tests were some done sequentially simulating hypothetical accident conditions during transport. A summary of these tests in given in Table 2.

Upon completion of the four hypothetical accident condition tests, conducted the sequence prescribed in 10 CFR 71, the package subjected to all these tests, was opened and inspected. There was no damage to the inner containment sealing features; the original computer weigh cards were with the 5-gallon pails; they were not wet and there was no moisture in the inner container. The top insulation disc was badly charred and the outside of the bolted cover had some blistered paint, but there was no structural damage, breach of containment, or loss of shielding.

TABLE 2

SINGLE BU-7 TRANSPORT PACKAGE - ACCIDENT CONDITIONS

Requirements*	Tests Conducted	Results
1. *Free Drop.* A free drop through a distance of 30 feet onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.	Each of 2 packages was raised by a crane to a 30-ft height at approximately a 45° angle. The height was determined by a measured, weighed cord hanging from the containers. A quick release mechanism was used to drop the packages, which fell at approximately a 45° angle, landing on the corners of the package.	Both packages impacted at pre-determined angles. Areas at points of impact of both units were without fracture. Beyond this, the only significant damage was a slight opening of the cover where the closure ring of one package was deformed. The bottom corner free-fall test of the other package caused somewhat more crushing of the container than was experienced in the top drop. There was no evidence of fractures or separation of the package side from the bottom; therefore, the package with the slight opening due to the top drop was deemed to have suffered the maximum damage. Post-test inspection showed NO damage to the sealing features of the inner containers or to the 5-gallon pails.

*Pursuant to Appendices A and B of 10 CFR 71.

Requirements	Tests Conducted	Results
2. *Puncture* A free drop through a distance of 40 inches striking, in a position for which maximum damage is expected, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar shall be 6 inches in diameter, with the top horizontal and its edge rounded to a radius of not more than one quarter inch, and of such a length as to cause maximum damage to the package, but not less than 8 inches long. The long axis of the bar shall be perpendicular to the unyielding horizontal surface.	Both packages were free-dropped through a distance of 40", striking the top end of a vertical steel bar mounted on a re-inforced concrete pad. The bar was fabricated per the requirements of 10 CFR 71, Appendix B. A vertical drop with the container impacting on the 18 gauge cover near the outer edge was considered the most vulnerable orientation to puncture.	Both packages were slightly indented about 1/4". There was no puncture of either package.
3. *Thermal* Exposure to a thermal test in which the heat input to the package is not less than that which would result from exposure of the whole package to a radiation environment of 1,475°F for 30 minutes with an emissivity coefficient of 0.9, assuming the surfaces of the package have an absorption coefficient of 0.8. The package shall not be cooled artificially until 3 hours after the test period unless it can be shown that the temperature on the inside of the package has begun to fall in less than 3 hours.	A thermal test of one of the packages (the one that sustained the most damage from the free-drop through 30 feet) followed the 30 foot free-drop and puncture tests. The thermal test conducted required exposure to an environment of 1475° minimum for a period of 30 minutes. Since an actual gasoline fire with open flames provides the most realistic means of satisfying the require-ments of 10 CFR 70 thermal test, this method was chosen for the BU-7 test.	Inspection of the inner container after all the tests showed no damage to the inner container, its sealing features or to the 5-gallon pails that would yield either of them ineffective. The paint was slightly blistered in a small area at the top end of the inner container, but no indication of this on either of the 5-gallon pails containing UO_2 power.

Requirements	Tests Conducted	Results
4. *Water Immersion* (fissile material packages only) Immersion in water to the extent that all portions of the package to be tested are under at least 3 feet of water for a period of not less than 8 hours.	After the fire test, the package was allowed to cool down for the prescribed period of time, and then placed in the water immersion tank under 3 1/2 feet of water. 120 pounds of weights were attached to the unit to insure that it would sink. It remained submerged for 10 hours.	Following immersion as described, the package was opened and inspected. The inner container was dry, the silicone rubber gasket was not damaged, and analysis of the UO_2 powder showed there was no significant increase in the moisture content.

3.4 Acceptance Criteria

Acceptance criteria for meeting the requirements of 10 CFR 71, paragraphs 71.35 and 71.36, are as follows:

- o No water intrusion to the contents.
- o No rupture of the product containers or inner container.
- o No damage to the inner containment sealing features that would yield them ineffective.
- o No significant deformation to the outer container that would affect criticality safety considerations.

We have concluded, as a result of these tests described above, that all tests required by 10 CFR 71, have been conducted, witnessed by Quality Control Engineering, and have passed the acceptance criteria. Test completion check sheets and compliance certificates are included in Enclosure 1A to this application.

4.0 CRITICALITY SAFETY EVALUATION

4.1 Uranium Oxides in Powder Form

For the contents described in Section 2.7.1 (uranium oxide powder), the criticality safety of the BU-7 package is described in Enclosure 1B to this application. These analyses results demonstrate that the BU-7 package can be transported as Fissile Class I, pursuant to the applicable sections of 10 CFR 71, for these contents.

4.2 Uranium Oxides in Pellet Form

For the contents described in Section 2.7.2 (uranium oxide pellets), the criticality safety of the BU-7 package is described in Enclosure 1C to this application, GE Document No. NEDO-11277, "The General Electric Model BU-7 Uranium Shipping Container - Criticality Safety Analysis." These analyses results demonstrate that for these contents, the BU-7 package can be transported as Fissile Class I, pursuant to the applicable sections of 10 CFR 71.

5.0 PROCEDURAL CONTROLS

New containers are inspected prior to first use and used packages are inspected prior to each re-use, in compliance with 10 CFR 71 (71.24 and Appendix E) and with the quality assurance plan submitted to the NRC and approved by the NRC on July 6, 1979, in Quality Assurance Program Approval for Radioactive Material Packages Approval Number 0254, to assure that each of these packages meets the specifications delineated in the applicable NRC Certificate of Compliance and in the supporting documents referenced in this Certificate.

Prior to shipment, limits for package loading and proper closure of package are verified.

Appropriate procedures and instructions have been prepared to accomplish these actions.

6.0 BU-7 TRANSPORT PACKAGE DRAWING

Specifications for the BU-7 transport package are shown on General Electric Drawing 112D1592, Revision 0.

GENERAL ELECTRIC

112D1592 REV. 0

SHIPPING CONTAINER MODEL BU-7

FCF: PDS-022

Page 6-2

License No. SNM-1097 Docket No. 71-9019 Sect. No. 112D1592 Revision 0

Amendment No. T-16 Date 7/25/80 Amends Sect. New

Certificate No. 9610

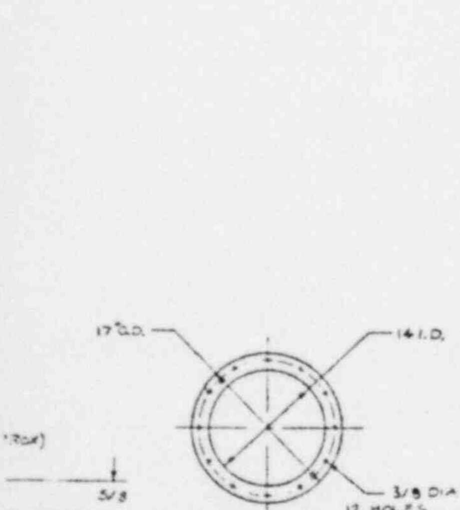
16 GA. COVER WITH ONE CORRUGATION NEAR THE PERIPHERY. 12 GA. CLOSURE RING WITH 5/8 DIA. DRILLED BOLT & NUT. COVER TO BE EQUIPPED WITH GASKET.

GASKET (SEE DET H-7)

FOR FURTHER DETAILS SEE DWG 128D923

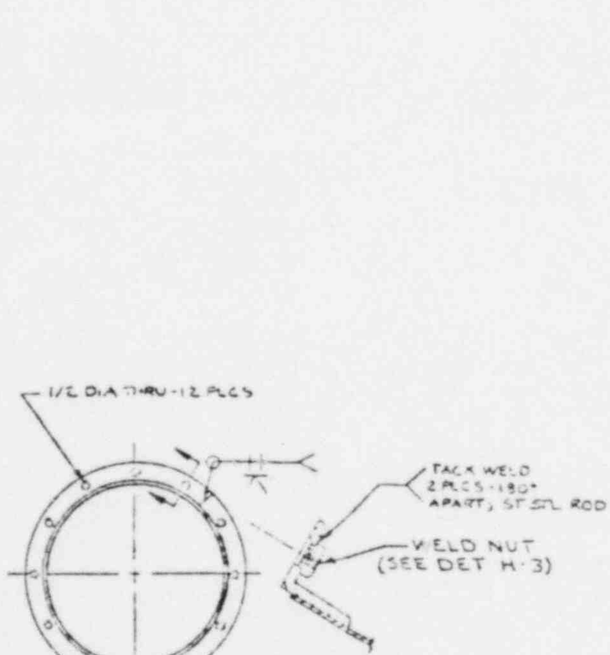
55 GAL. 17H, 18 GA., STL DRUM OR AN EQUIVALENT DRUM WITH ONLY TWO ROLL HOOPS & MEETING ALL OTHER 17H REQUIREMENTS

PHENOLIC FOAM INSULATION (FIRE RET) FOAM IN PLACE PER /SAEC SPEC SP-9. MIN WT: 42 LBS. .5 LBS PER CU. FT.) SEE DETAIL 'A' 'OR UPPER MOLD SURFACE.



1/8 THK, 50 DUROMETER SILICONE RUBBER; 700 TENSILE, 225% ELONGATION 500° F TEMP

GASKET



1 1/2 X 1 1/2 X 3/16 STL ANGLE ROLLED TO A 14 IN. I.D.

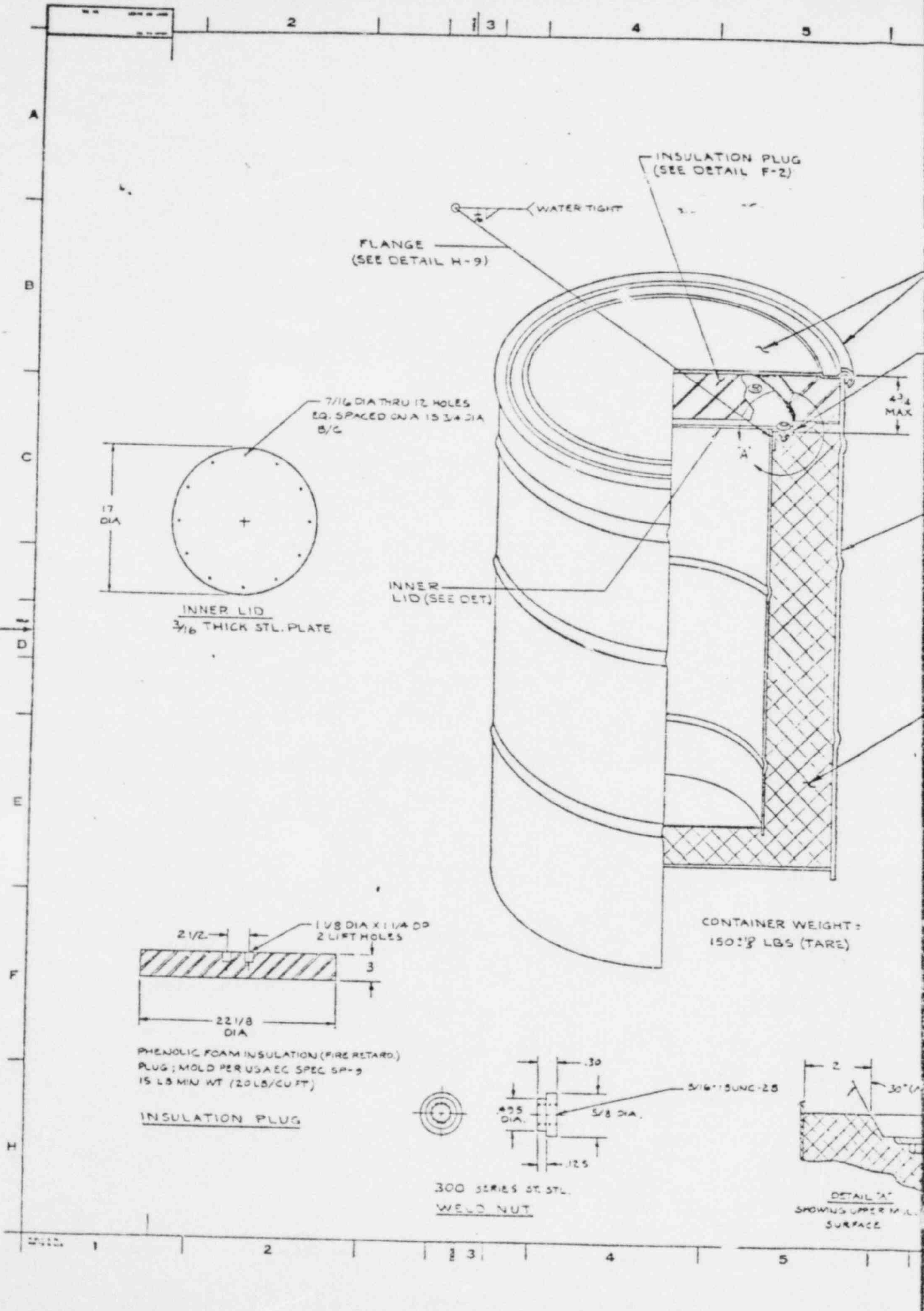
FLANGE

O'FMA-143

112D1592

SAN JOSE

SKETCH



INSULATION PLUG
(SEE DETAIL F-2)
WATER TIGHT
FLANGE
(SEE DETAIL H-9)
7/16 DIA THRU 12 HOLES
EQ. SPACED ON A 15 3/4 DIA
B/C
17
DIA
4 3/4
MAX
'A'
INNER
LID (SEE DET)
INNER LID
3/16 THICK STL. PLATE
1 1/8 DIA X 1 1/4 DP
2 LIFT HOLES
2 1/2
3
22 1/8
DIA
PHENOLIC FOAM INSULATION (FIRE RETARD.)
PLUG; MOLD PER USAEC SPEC SP-9
15 LB MIN WT (20 LB/CU FT)
INSULATION PLUG
CONTAINER WEIGHT:
150±? LBS (TARE)
.30
5/16-18UNC-2B
.495
DIA.
5/8 DIA.
.125
300 SERIES ST. STL.
WELD NUT
2
30°
DETAIL "A"
SHOWING UPPER MILL
SURFACE
A
B
C
D
E
F
H
1
2
3
4
5

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APPLICATION FOR REVISION OF
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ENCLOSURE 1A

REPORT OF PACKAGE EVALUATION TESTS

FOR THE BU-7 BULK URANIUM TRANSPORT PACKAGE

A. L. Kaplan
:bmw

TEST REPORT

FOR

MODEL BU-7 BULK URANIUM SHIPPING CONTAINER

In accordance with criteria for compliance with CFR49, paragraph 173.398 and 10CFR, paragraphs 71.31, 71.32 71.35 and 71.36

BY

John A. Zidak
Manager
Packaging Engineering

General Electric Co.
Nuclear Energy Traffic Operation
San Jose, California

DATE ISSUED April 25, 1980

TEST REPORT

FOR

MODEL BU-7 BULK URANIUM SHIPPING CONTAINER

1.0 INTRODUCTION

1.1 TEST DESCRIPTION

Normal and Hypothetical accident condition tests were conducted on General Electric Model BU-7, Bulk Uranium Shipping Containers in accordance with 10CFR71, "Packaging of Radioactive Materials for Transport and Transportation of Radioactive Material Under Certain Conditions." The tests were conducted at the Wilmington Manufacturing Department facility on March 20th and 21st 1980, and April 1st and 2nd 1980.

The BU-7 Container is intended to be a fissile class I shipping container for shipment of enriched uranium powder.

1.2 PACKAGING DESCRIPTION

Inner containment is a nominal 16-gallon drum closed by a gasketed-bolted lid, centered and supported within an outer 55-gallon drum by a solid insulating media, and containing two steel pails which contain UO_2. (See Drawing 112D5231A and Figure 1.)

1.2.1. Outer Container

A nominal 55-gallon, Uniform Freight Classification Rule 40, 18 gauge steel drum with nominal outside dimensions of 22.82" diameter by 36.5" high. Four1/4" holes near the top of the container are provided for venting and are covered with waterproof tape. The cover is flat 18 gauge steel. The closure ring is 12 gauge steel with 5/8"bolt meeting DOT Specification 17H.

1.2.2. Inner Container

A nominal 16-gallon drum constructed of 18 gauge steel, modified by welding a closure flange to accept a 3/16" thick steel lid. The lid is gasketed for resistance to high temperature and attached with twelve 5/16" steel bolts. The inside dimensions are 13.75" diameter by 27" high.

1.2.3. Insulation

The 16-gallon inner containment drum is centrally held within the outer container by, and the space between the two drums is completely filled with, solid fire-retardant phenolic foam per USAEC Specification SP-9.

1.2.4. Product Container

Two closed 5-gallon containers fabricated of 24 gauge steel, vertically stacked in each BU-7 container.

1.2.5. Test Weight

Each 5-gallon pail contained 45 kgs (99 pounds) of natural UO_2 powder. Total test weight including weight of the 5-gallon pails is 209 pounds. Gross weight of the BU-7 is between 365 and 375 pounds, depending on variations in weights of BU-7 container populations. Actual gross weight of the two 5-gallon pails as recorded on the computer weigh sheets was 94.81 kgs (209 pounds) for container S/N K0174, and 95.29 kgs (210 pounds) for container S/N k1878).

2.0 TESTING

2.1 TEST SUMMARY

The test program consisted of a combination of normal and hypothetical accident condition tests as described in 10CFR71 Appendix A and B. Three BU-7 containers were utilized in the tests. They were taken from the G.E. inventory of containers at Wilmington and are built to same specifications as all model BU-7 Containers. Serial numbers and tests they were subjected to is as follows:

	TEST CONDITION	CONTAINER SERIAL NUMBER TESTED		
Normal Cond. tests	WATER SPRAY TEST	K0319		
	DROP TEST 4 FT.	K0319		
	PENETRATION TEST	K0319		
	COMPRESSION TEST	K0319		
Hypothetical Accident Condition tests	30 FEET FREE DROP		K0174	K1878
	PUNCTURE TEST		K0174	K1878
	THERMAL TEST			K1878
	WATER IMMERSION TEST			K1878

Container No. K0319 was used only for the normal test conditions. K0174 was drop tested 30 feet impacting on the bottom seam, then puncture tested. Container S/N K1878 was drop tested 30 feet impacting on the closure ring, then subjected to all remaining hypothetical accident conditions, that were applied sequentially in the order indicated in 10CFR71 Appendix B, to determine their cumulative effect on the package. All tests were monitored by General Electric Fuel Quality Control Engineering, and certified there completion per test check sheets in the Appendix.

LOADING

2.2.1 Hypothetical Accident Loading

Containers K0174 and K1878 were loaded with approximately 45 kilograms (99 pounds) of natural UO_2 powder, in the Fuel Manufacturing Operation (FMO) powder pack facility, using a computer controlled loading and accountability system, see figures (2 and 3) the computer punch cards remained with the 5 gallon pails of powder during the tests. (Loading Record Sheets and Request Sheet are in the Appendix).

2.2.2 Normal Condition Loading

Container Serial No. K0319 was loaded with lead shot weighing 93 Kg's (205 pounds) gross weight.

2.2.3 Moisture Content

Moisture content analysis of the natural uranium powder was made before and after the Hypothetical accident tests.

2.3 NORMAL CONDITION TESTS NOT CONDUCTED

The following normal conditions tests were not conducted because their requirements have been satisfied for the following reason:

°Heat:	Temperature of 130°F is within normal operating range for materials of construction.
°Cold:	Temperature of -40°F is within normal operating range for materials of construction.
°Reduced Pressure:	Successfully passed this requirement in prior tests. (See GE Packaging Engineering test report dated 2/10/78 included as Appendix 3.)
°Vibration:	Containers of this type have withstood years of transport with no occurences of significant damage due to normal vibration.
°Corner Drop:	Not required since package weight exceeds 110 pounds.

3.0 TEST RESULTS

3.1 Normal Condition Tests. (container S/N 21

3.1.1 Water Spray Test

Container was exposed to a water spray sufficiently heavy to keep all exposed surface except the bottom wet for a period of 30 minutes. (See Fig. 4).

RESULT

There were no signs of water damage to the package.

3.1.2 Four Foot Drop Test

The container, loaded with 205 pounds of test weight was dropped four feet with the closure ring impacting onto a flat reinforced concrete pad. Test was conducted 2 hours after water spray test. (See Fig. 5).

RESULT

There was a slight deformation of the outer container closure ring that did not impair its function. No damage to the inner container seal or the 5 gallon pails.

3.1.3 Penetration Test

Container was penetration tested by impacting the hemispherical end of a vertical steel cylinder 1-1/4 inches in diameter and weighing 13 pounds and dropped from a height of 40 inches into the top of the container where it is most susceptible to a projectile penetration. (See Fig. 6).

RESULT

There was a slight indentation where the 13 pound bar struck the container. It did not penetrate the package.

3.1.4 Compression Test

Weight equal to more than 5 times the weight of the package be applied to top of the containers for a period of 24 hours. (Minimum weight for BU-7 is 5 times 375 pounds, or 1,875 pounds). Test weight used was 2,440 pounds (See Fig. 6).

RESULT

No damage due to compression loading.

3.2 Hypothetical Accident Condition Tests

The hypothetical accident condition tests were conducted in the sequence specified in Appendix B to 10CFR71, to evaluate the ability of the package to withstand cumulative damage of the four tests. To establish the drop orientation that covers the most severe damage, two containers (S/N K1878 and K0174 were selected at random, then one (K1878 was dropped on its top closure ring and the other (Serial No. K0174), impacted on the bottom seam as these are the ones most likely to create a breach; impact angle of both tests was approximately 45°. After completion of the drop test, both containers were puncture tested, then container S/N K1878 was subjected to the thermal and water immersion tests.

3.2.1 Free Drop

The packages were raised by a crane to a 30 foot height at approximately a 45°angle as shown in figure 7. The height was determined by a measured, weighted cord hanging from the containers. A quick release mechanism was used to drop the packages, which fell at approximately a 45° angle, landing on the corners of the containers (See Fig. 8 and 9).

RESULT

Both containers impacted at the pre-determined angles. Areas at points of impact of both units were without fracture. Beyond this, the only significant damage was a slight opening of the cover where the closure ring of container No. K-1878 was deformed, as shown in Figures 10 thru 14. The bottom corner free fall test of container K0174 caused somewhat more crushing of the container than was experienced in the top drop. There was no evidence of fractures or separation of the containers side from the bottom, (See Fig. 15 and 16) therefore the container with the slight opening due to the top drop was deemed to have suffered the maximum damage.

Past test inspection showed NO damage to the sealing features of the inner container or to the 5 gallon pails.

3.3.2 PUNCTURE TEST

Containers K-1878 and K-0174 were free dropped through a distance of 40 inches, striking the top end of a vertical steel bar mounted on a reinforced concrete pad. The bar was fabricated per the requirements of 10CFR71, Appendix B (See Fig. 17).

A vertical drop with the container impacting on the 18 gauge cover near the outer edge was considered the most vulnerable orientation to puncture.

3.3.2 PUNCTURE TEST (cont.)

RESULT

Both packages were slightly indented about 1/4 inch, there was no puncture of either container. (See Figures 18 and 19).

3.2.3 THERMAL TEST

A Thermal Test of container No. K-1878 followed the 30 foot free drop and puncture tests. The thermal test conducted required exposure to an environment of 1475° minimum for a period of 30 minutes. Since an actual gasoline fire with open flames provides the most realistic means of satisfying the requirements of 10CFR70 thermal test, this method was chosen for the BU-7 test.

Test set up as shown in Fig. 20 was used. The gasoline and water supplies were located 100 feet from the fire pan. A thermocouple mounted on the closure ring adjacent to the slight opening of the container lid was monitored using a Honeywell Model R7353A Dial-O-Troll, Serial No. 7812-3849, which was calibrated using a West millivolt pot that has traceability to the National Bureau of Standards.

The eight foot square fire kit with container mounted 3 feet above the surface allowed for approximately 2 feet of flames around all sides of the container. By using the open gasoline fire, the emissivity and absorbtion coefficients were in accordance with those specified in 10CFR71. Appendix B.

3.2.3.1 Test Procedure

Approximately 200 gallons of water were fed into the pit resulting in a water level of 5 inches. Approximately 50 gallons of gasoline were then fed into the steel fire pit to form a layer of fuel about one inch deep on top of the water surface.

After ignition, (See Fig. 21) the fuel and water supplies were turned on and manually controlled to one gallon per minute of water and 5.8 GPM of fuel to maintain a fire that completely enveloped the BU-7 Container. Figures 22 thru 31 are random photographs taken during the test. The temperature measured on the surface of the test container increased rapidly to 1475° F. (See Figs. 32 and 33) and exceeded that throughout the test with a maximum temperature of 2000° F. being reached. The full fire test continued for 42 minutes burning 300 gallons of fuel during that period.

3.2.3.1 Test Procedure (cont.)

RESULTS

Inspection of the inner container after all the tests showed no damage to the inner container, its sealing features or to the 5 gallon pails that would yield either of them ineffective. The paint was slightly blistered in a small area at the top end of the inner container, but no indication of this on either of the 5 gallon pails containing UO_2 powder.

3.2.4 Water Immersion Test

After the fire test, container No. K-1878 was allowed to cool down for the prescribed period of time, and then placed in the water immersion tank (See Fig. 34) under 3 1/2 feet of water. One hundred and twenty pounds of weights were attached to the unit to insure that it would sink; it remained submerged for 10 hours.

RESULTS

Following immersion as described, container No. K-1878 was opened and inspected. The inner container was dry, the silicone rubber gasket was not damaged, and analysis of the UO_2 powder showed there was no significant increase in the moisture content.

3.2.5 Post Test Inspection

Upon completion of the four hypothetical accident condition tests, conducted the sequence prescribed in 10CFR71, container Serial No. K1878 was opened and inspected. As previously mentioned, there was no damage to the inner containment sealing features; the computer weight cards were with the 5 gallon pails; they were not wet and there was no moisture in the inner container. (See Figures 35 thru 38). The top insulation disc was badly charred (See Fig. 39) and the outside of the bolted cover had some blistered paint, but there was no structural damage, breach of containment or loss of shielding. Post Test condition of all three containers tested is shown on Figure 40.

3.3 Acceptance Criteria

Acceptance Criteria for meeting the requirements of 10CFR71, paragraphs 71.35 and 71.36 was as follows:

- No water intrusion to the contents.
- No rupture of the product containers or inner container.
- No damage to the inner containment sealing features that would yield them ineffective.

3.3 Acceptance Criteria (cont.)

- No significant deformation to the outer container that would affect criticality safety considerations.

3.4 Conclusion

All tests required by 10CFR71, have been conducted, witnessed by Quality Control Engineering and have passed the acceptance criteria. Test completion check sheets and compliance certificates are included in Appendices 1 and 2.

LIST OF FIGURES

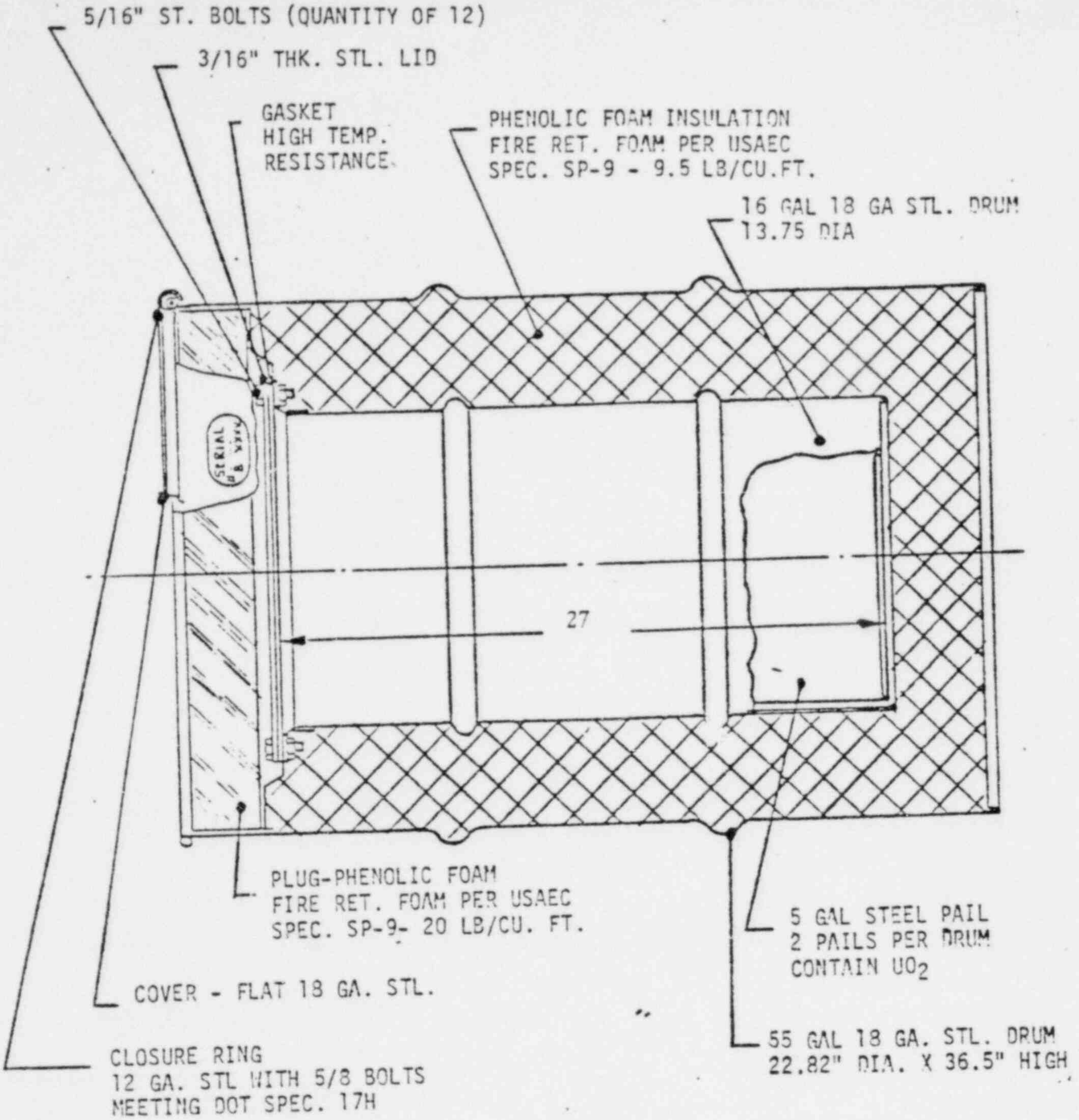


FIGURE 1

BU-7 CONTAINER

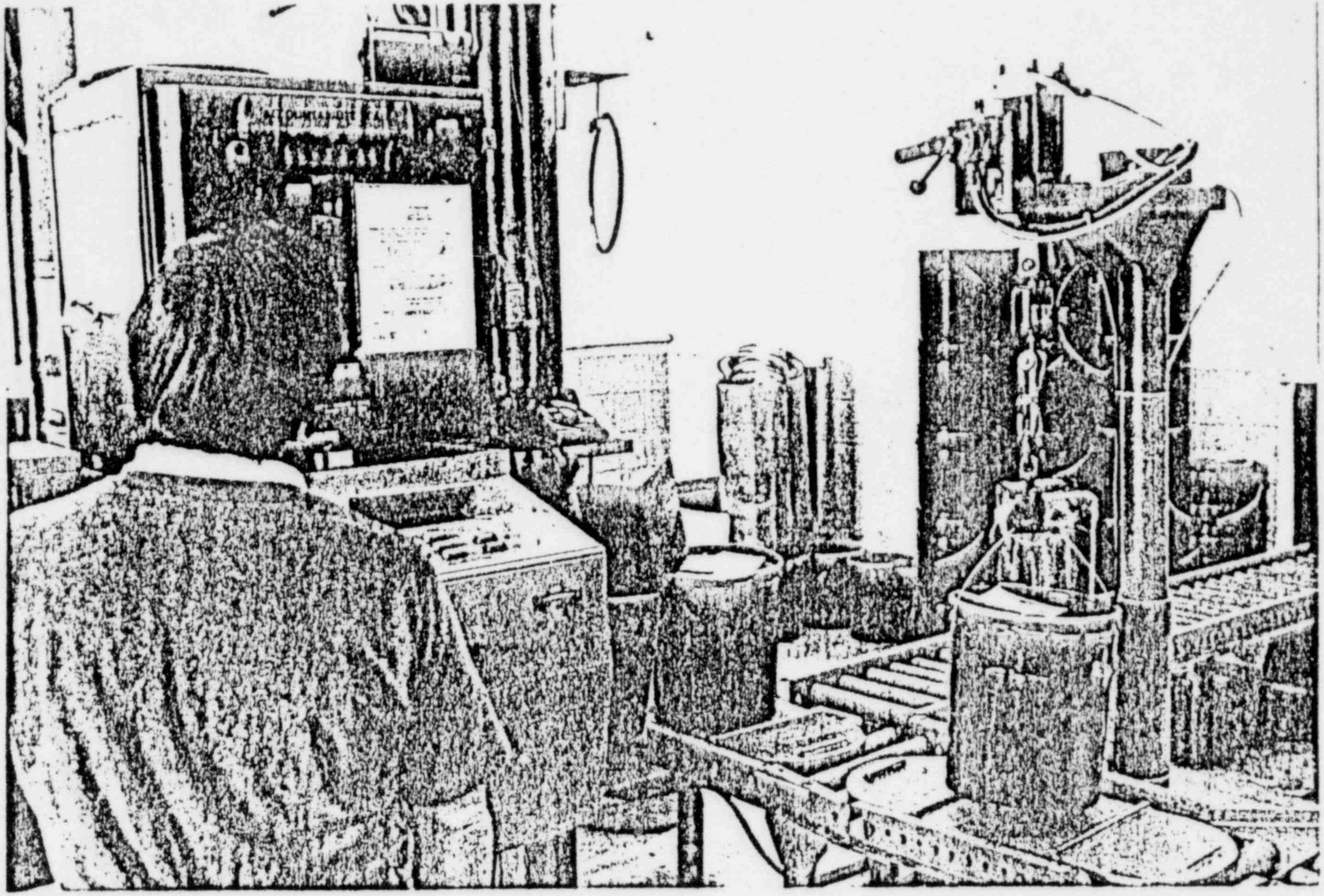


FIGURE 2. WEIGHING UO_2 POWDER

FIGURE 3

LOADING 5 GAL. PAILS INTO BU-7

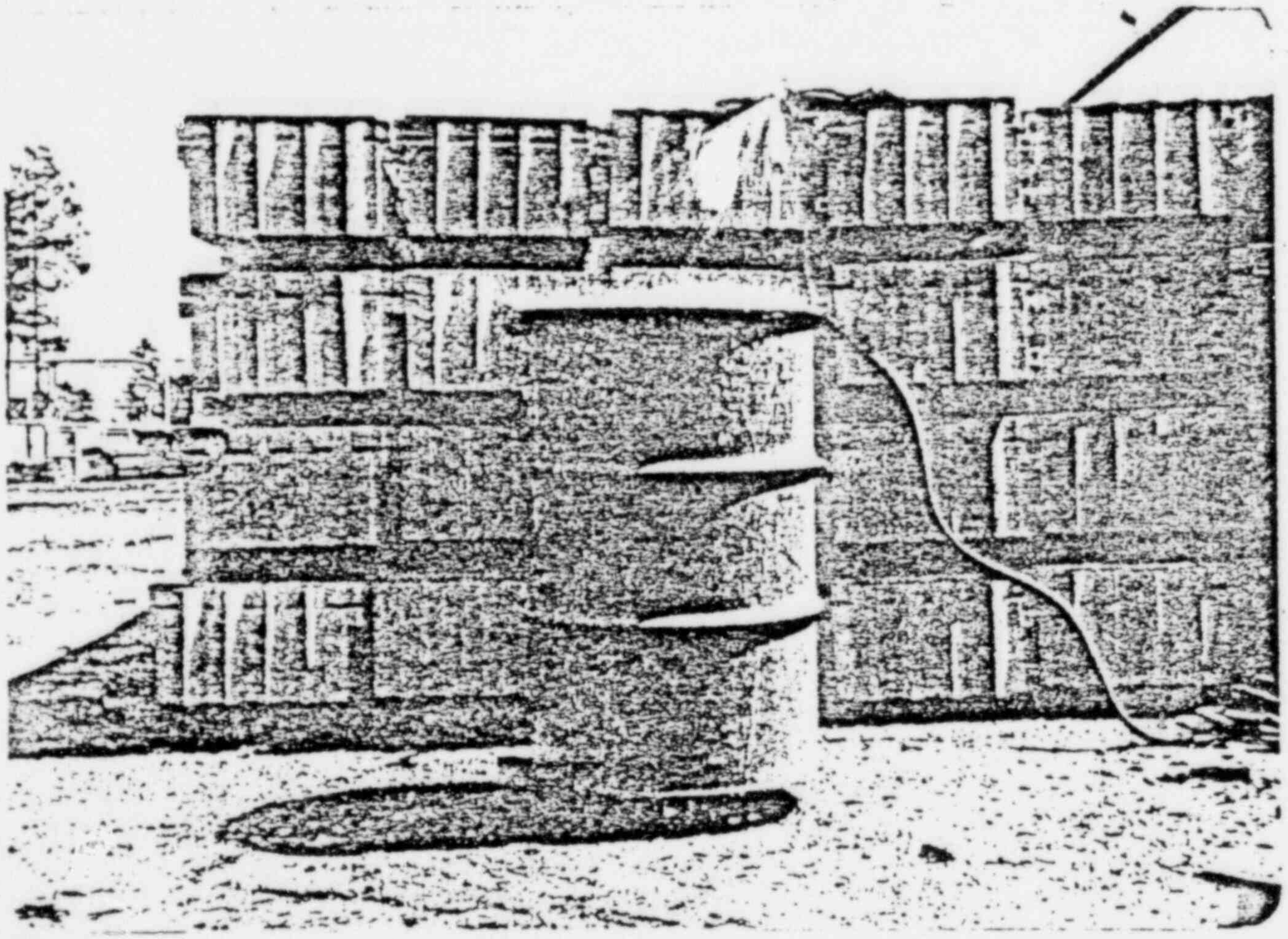


FIGURE 4
NORMAL CONDITION WATER SPRAY TEST

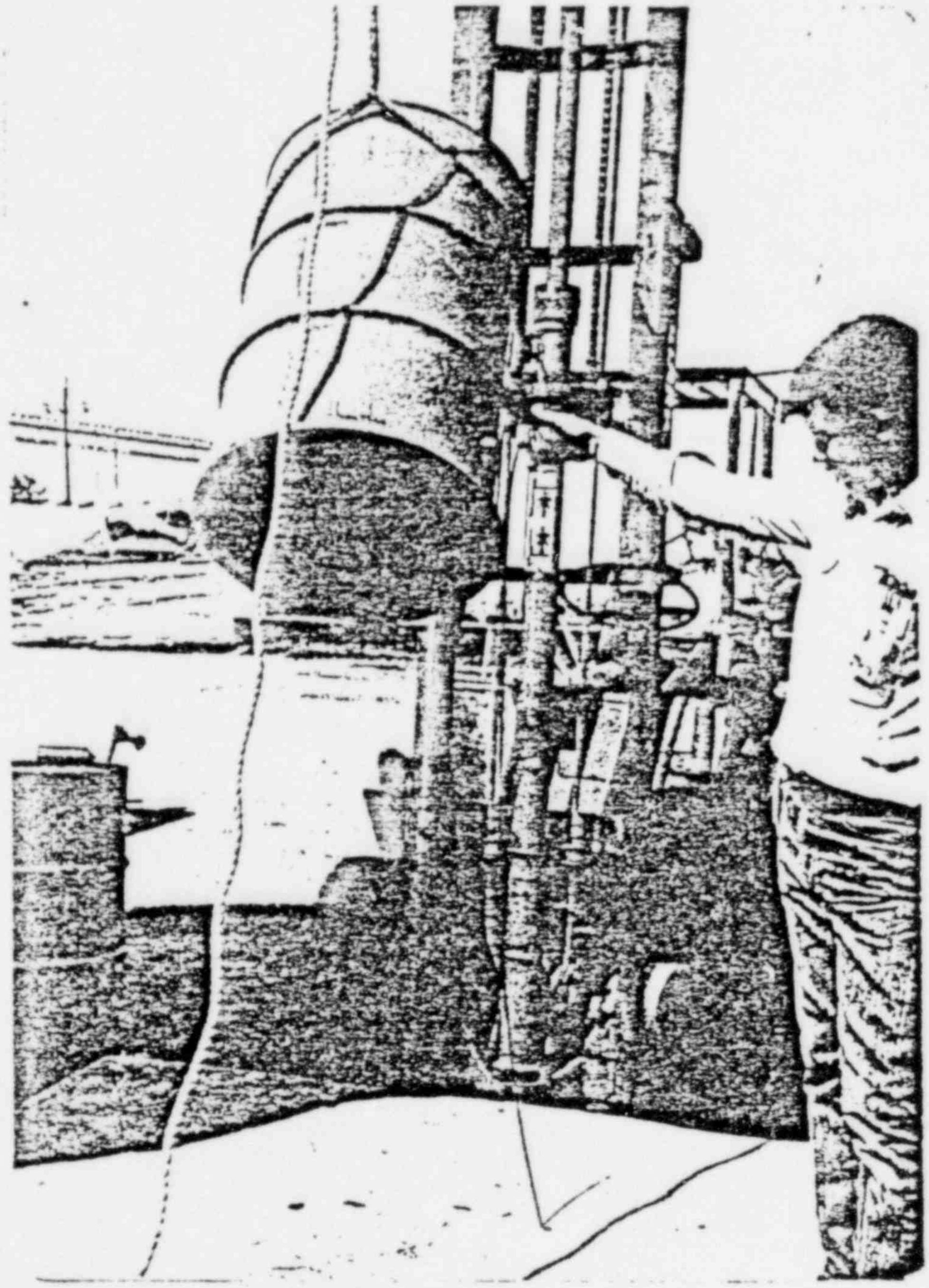


FIGURE 5

NORMAL CONDITION 4 FOOT DROP TEST

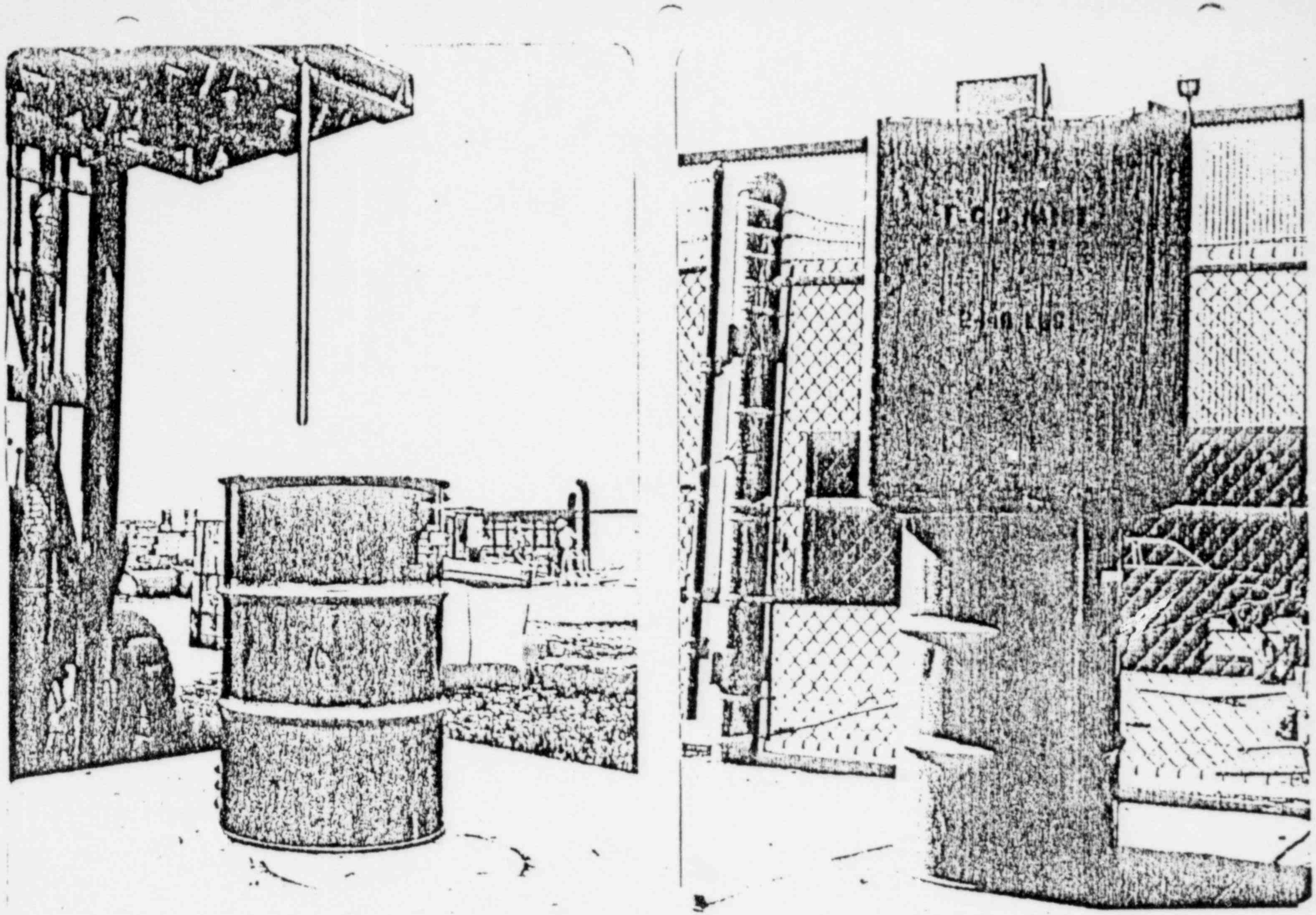


FIGURE 6

NORMAL CONDITION PENETRATION AND COMPRESSION TESTS

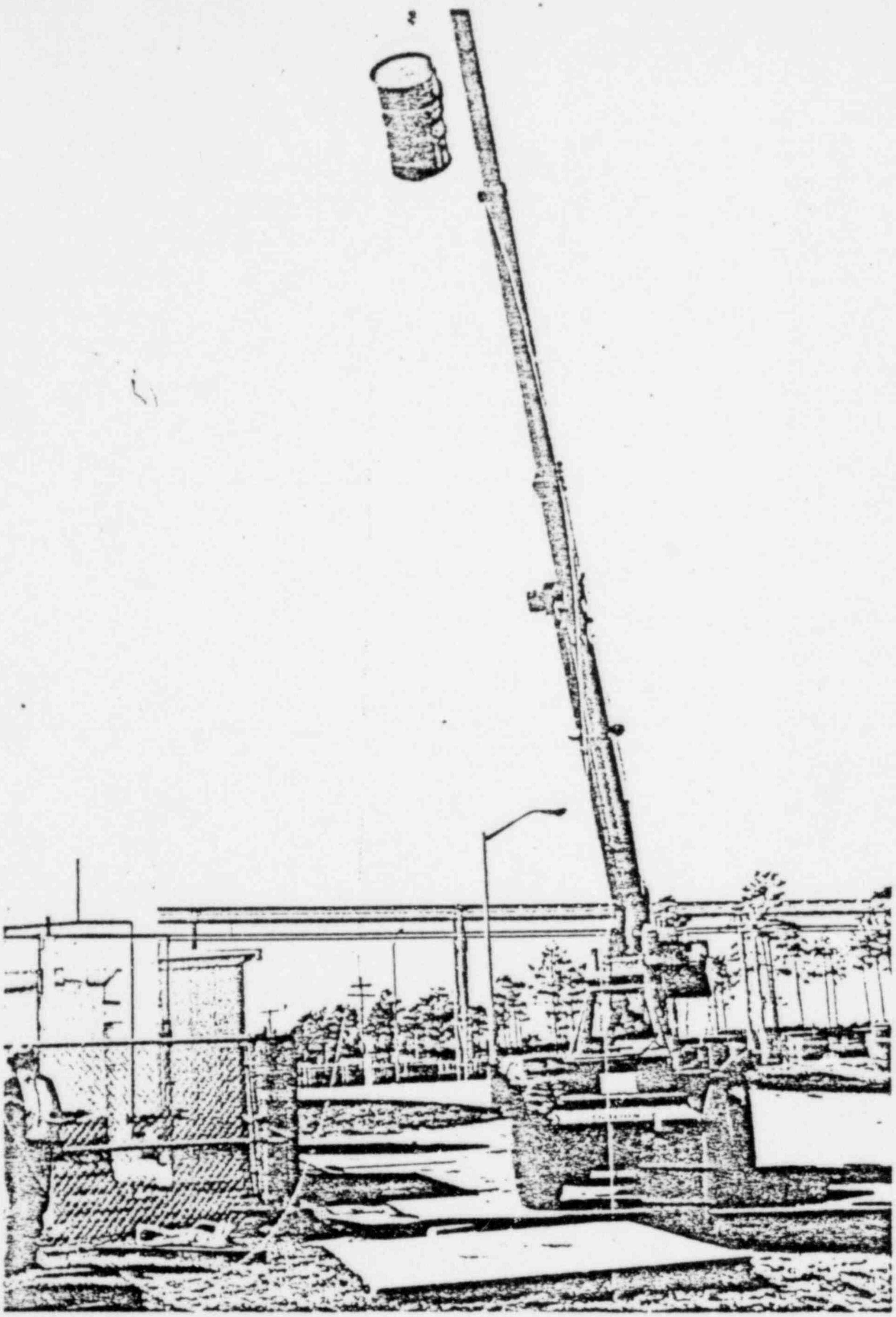


FIGURE 7
30 FOOT DROP TEST

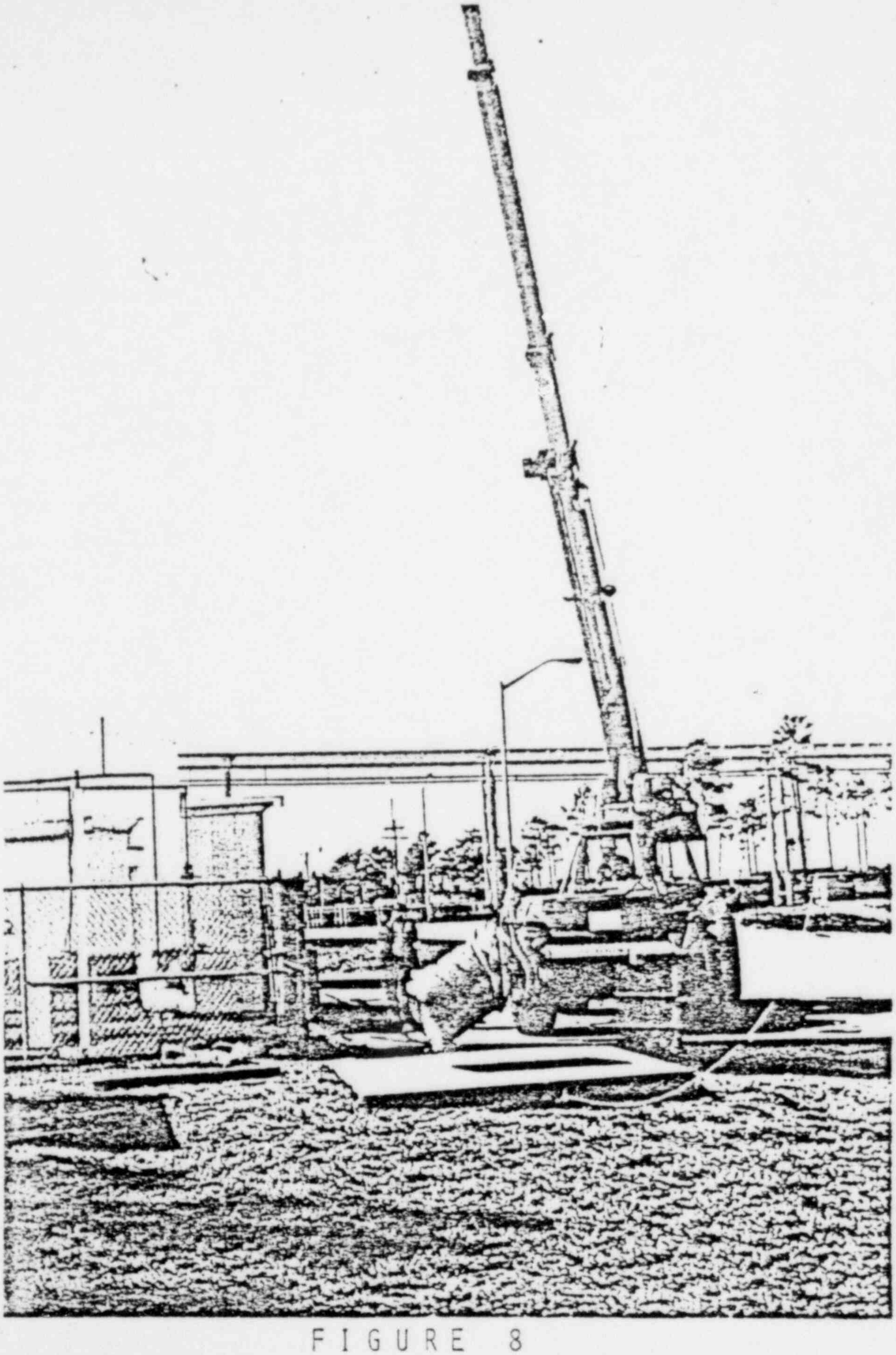


FIGURE 8

CONTAINER NO. K0174 IMPACTING ON THE BOTTOM CORNER

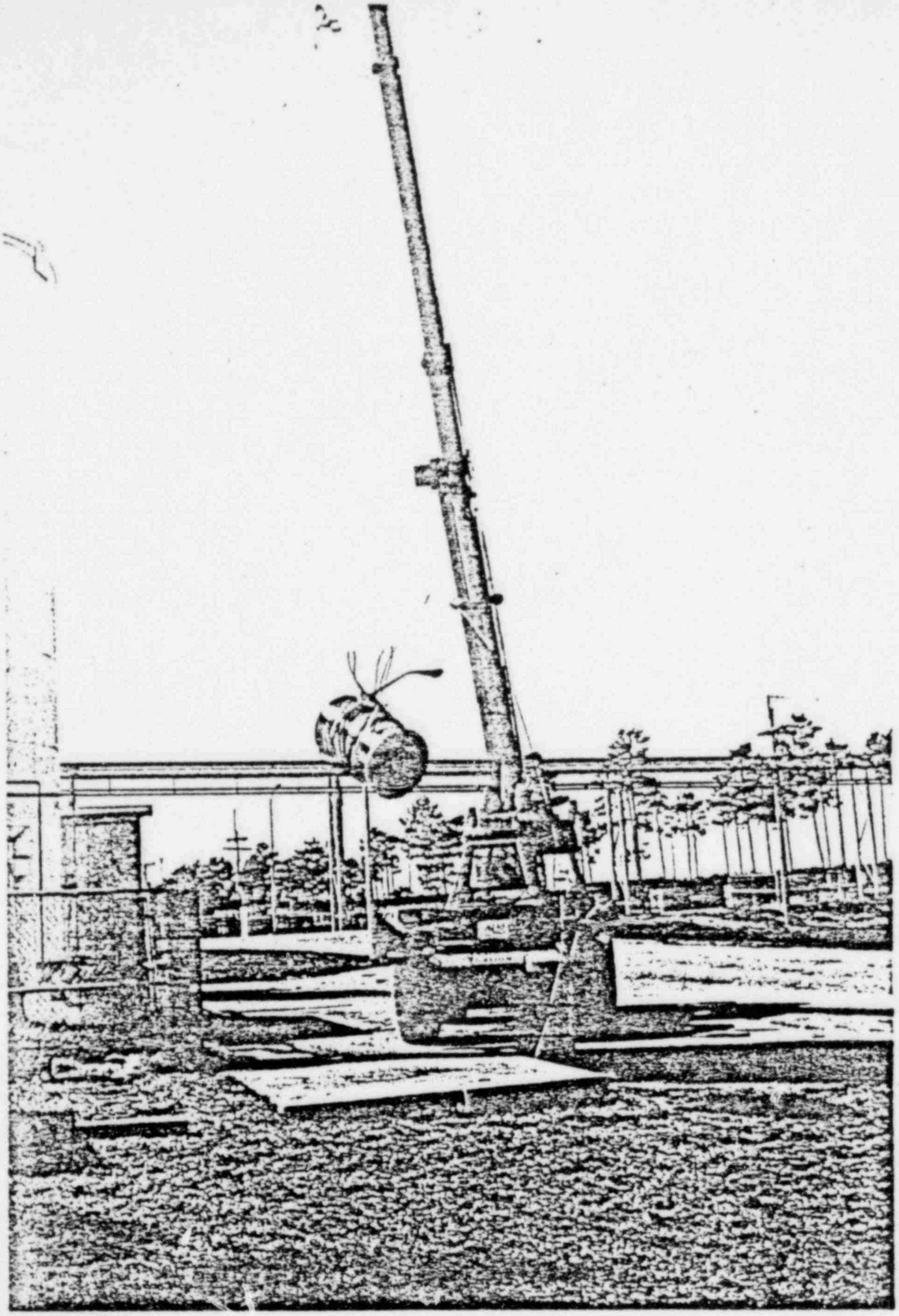


FIGURE 9
CONTAINER NO. K 1878 IMPACTING
ON THE CLOSURE RING

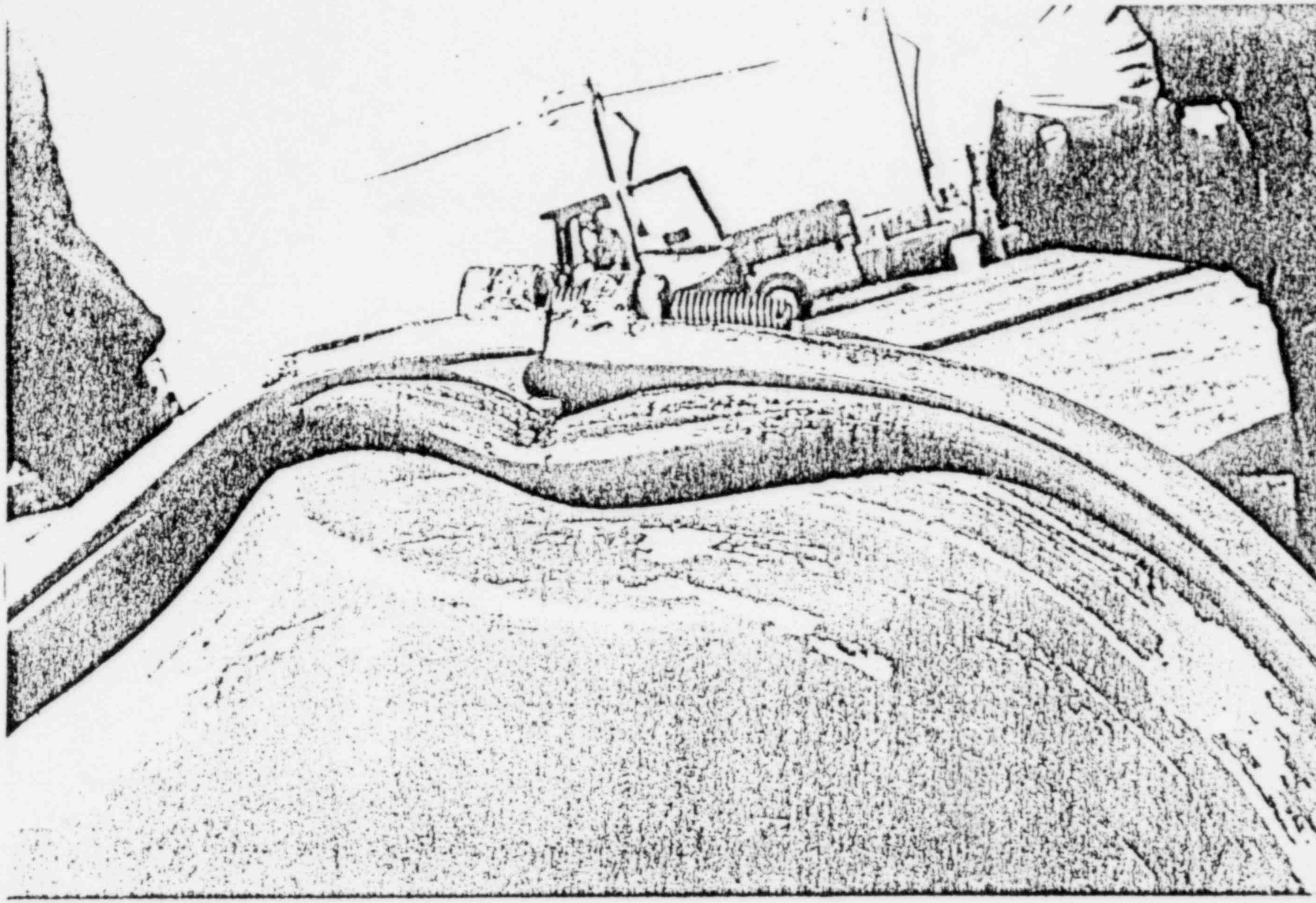


FIGURE 10

SERIAL NO. K-1878 AFTER IMPACT

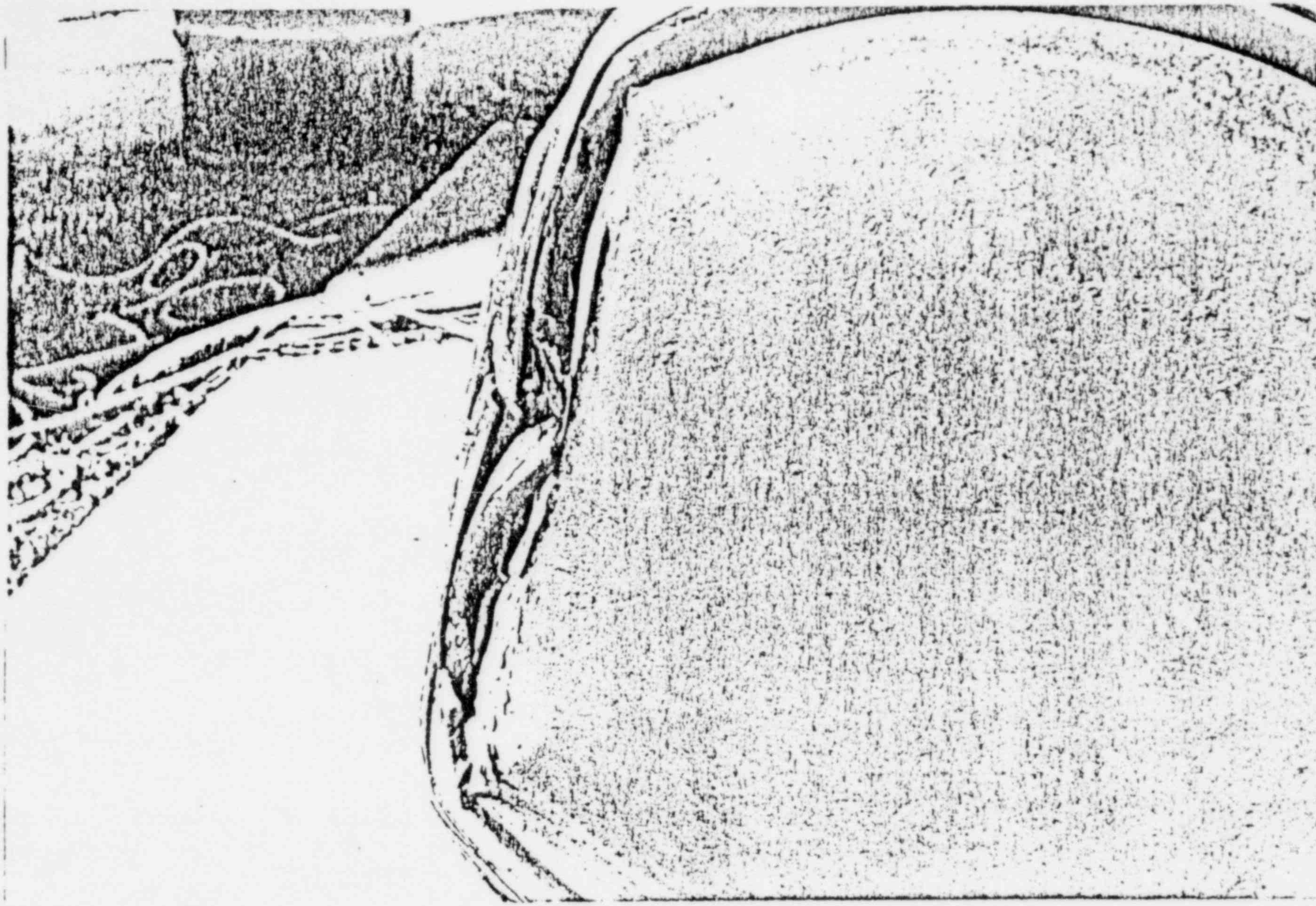


FIGURE 11

SERIAL NO. K-1878 AFTER IMPACT

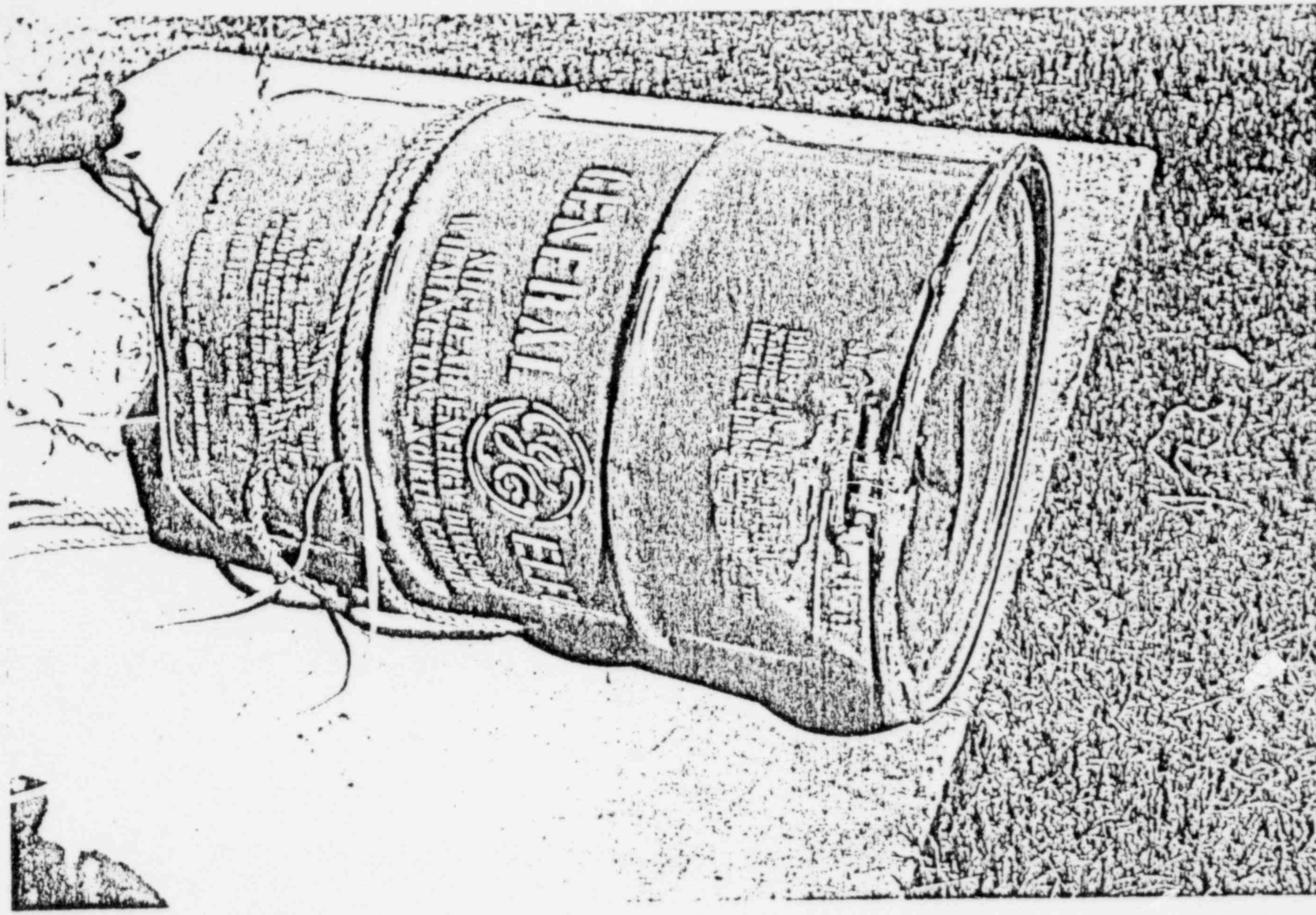


FIGURE 12

SERIAL NO. K-1878 AFTER IMPACT

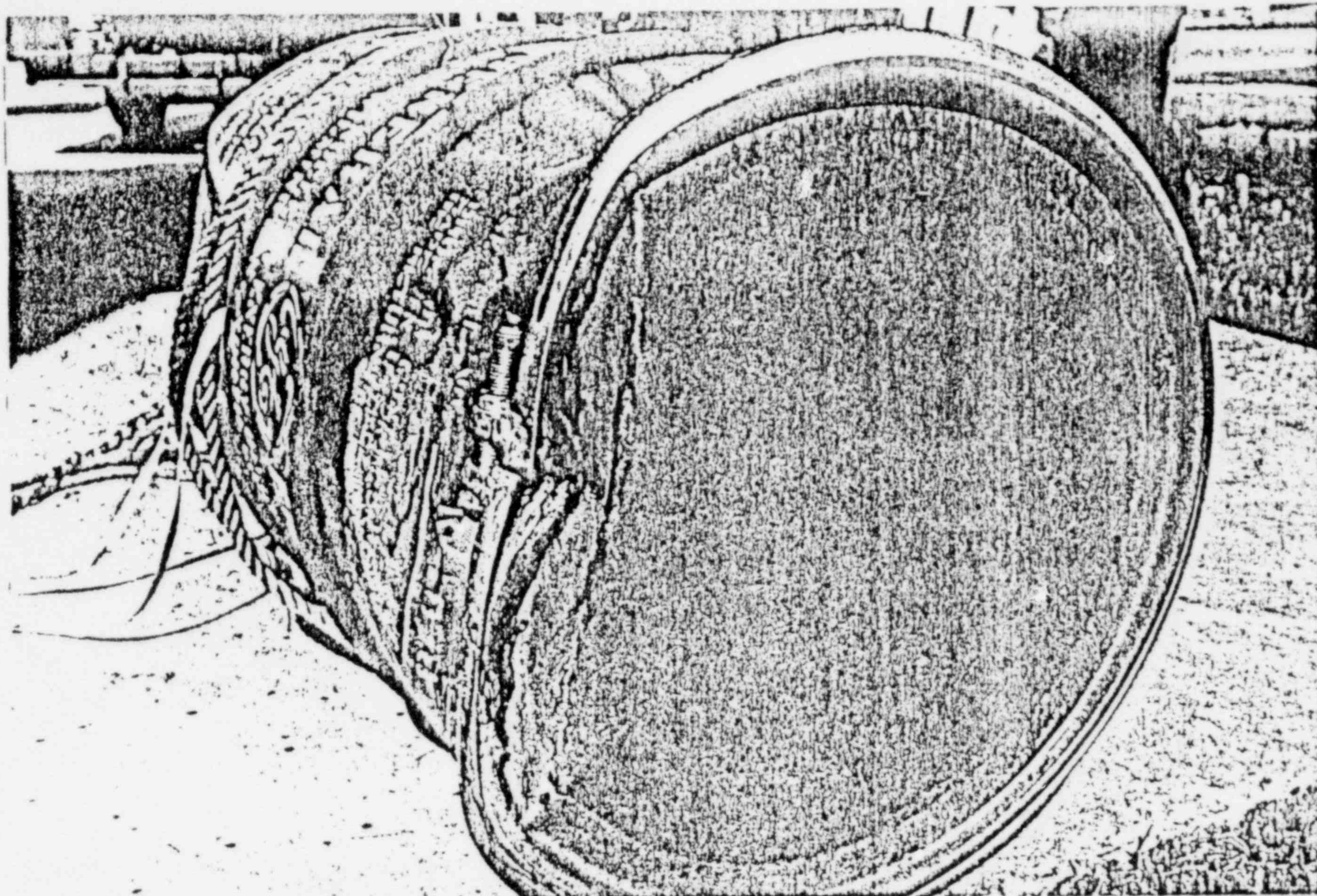


FIGURE 14

SERIAL NO. K-1878 AFTER IMPACT

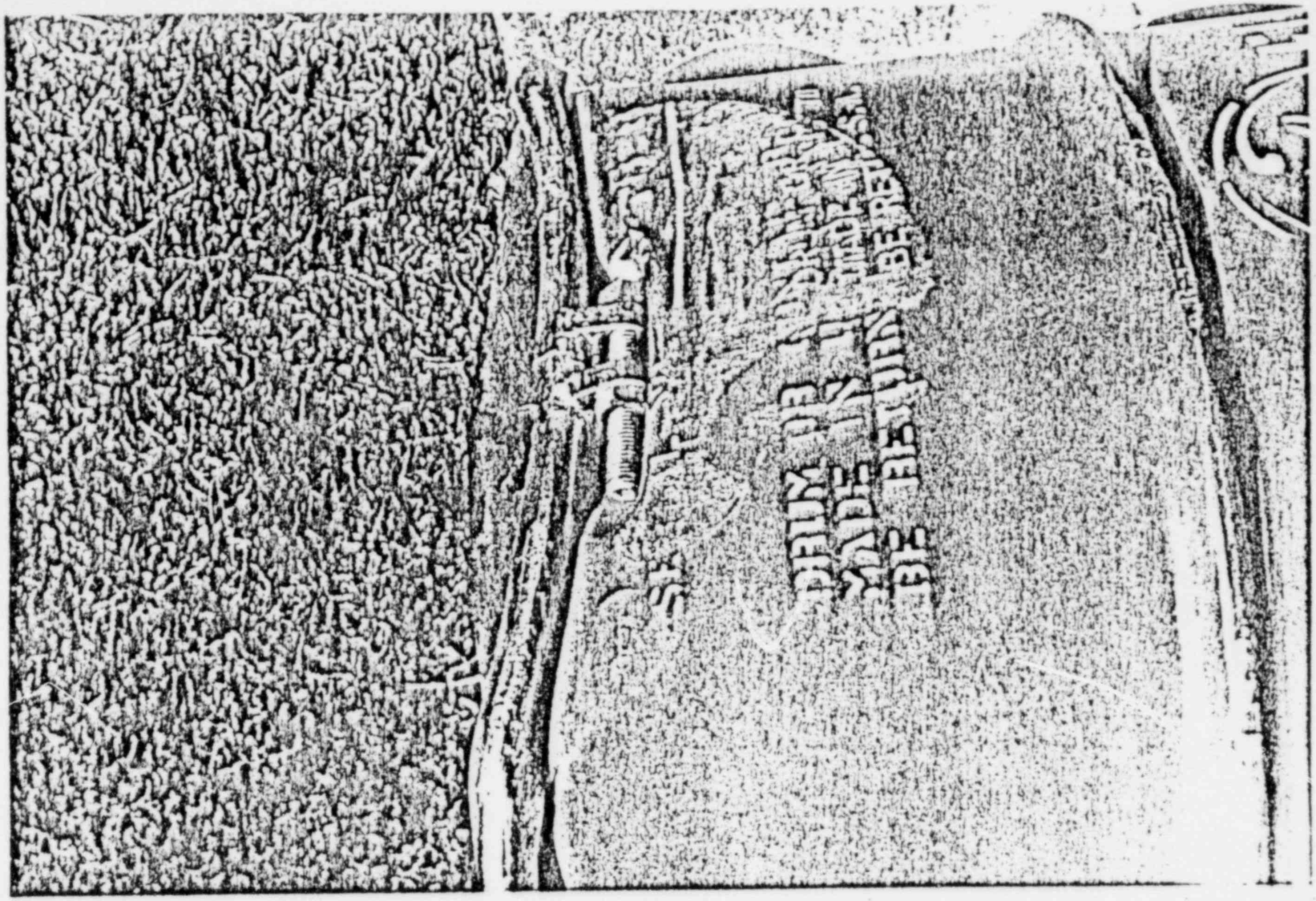


FIGURE 13

SERIAL NO. K-1878 AFTER IMPACT

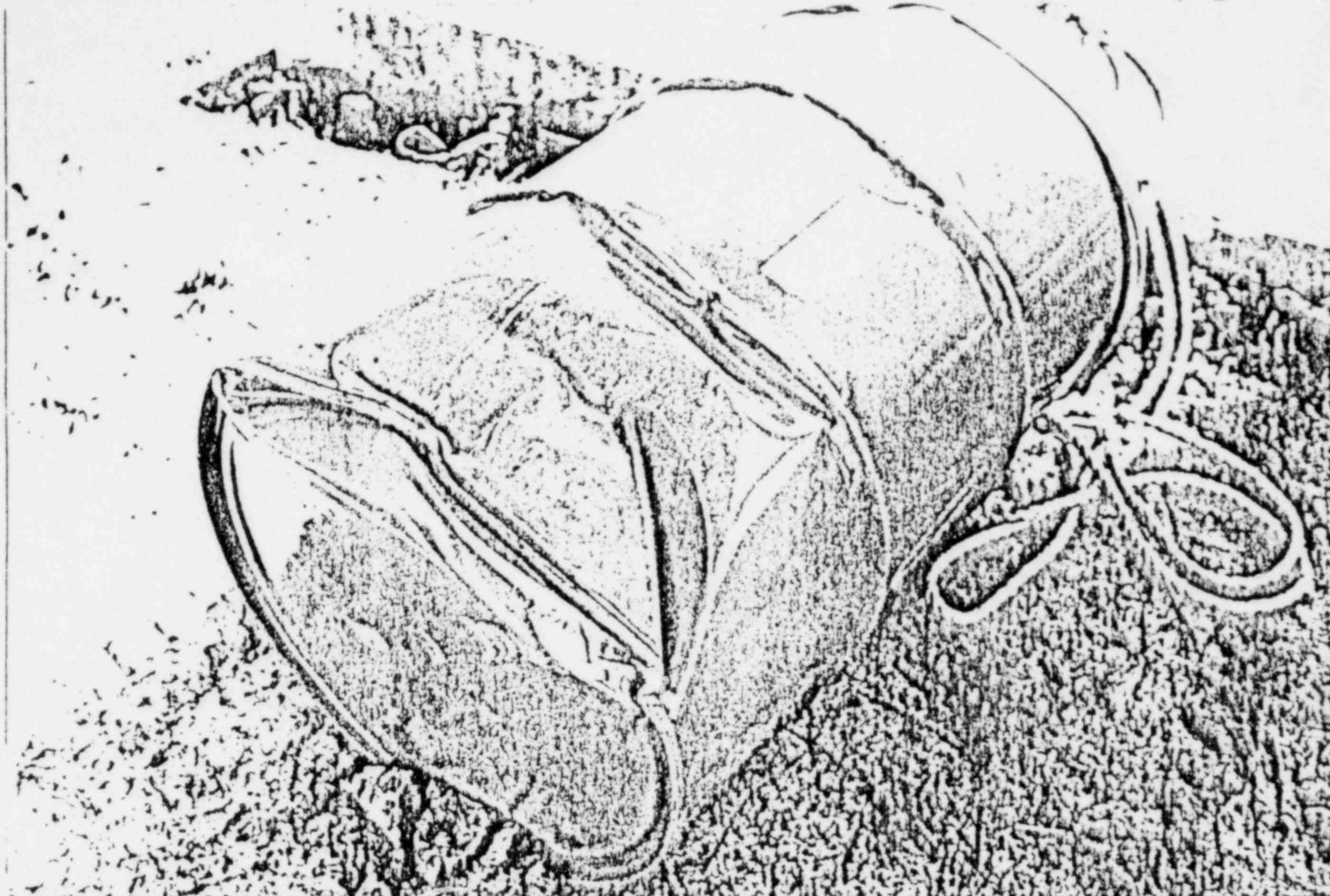


FIGURE 15

CONTAINER NO. K0174 AFTER 30 FOOT DROP

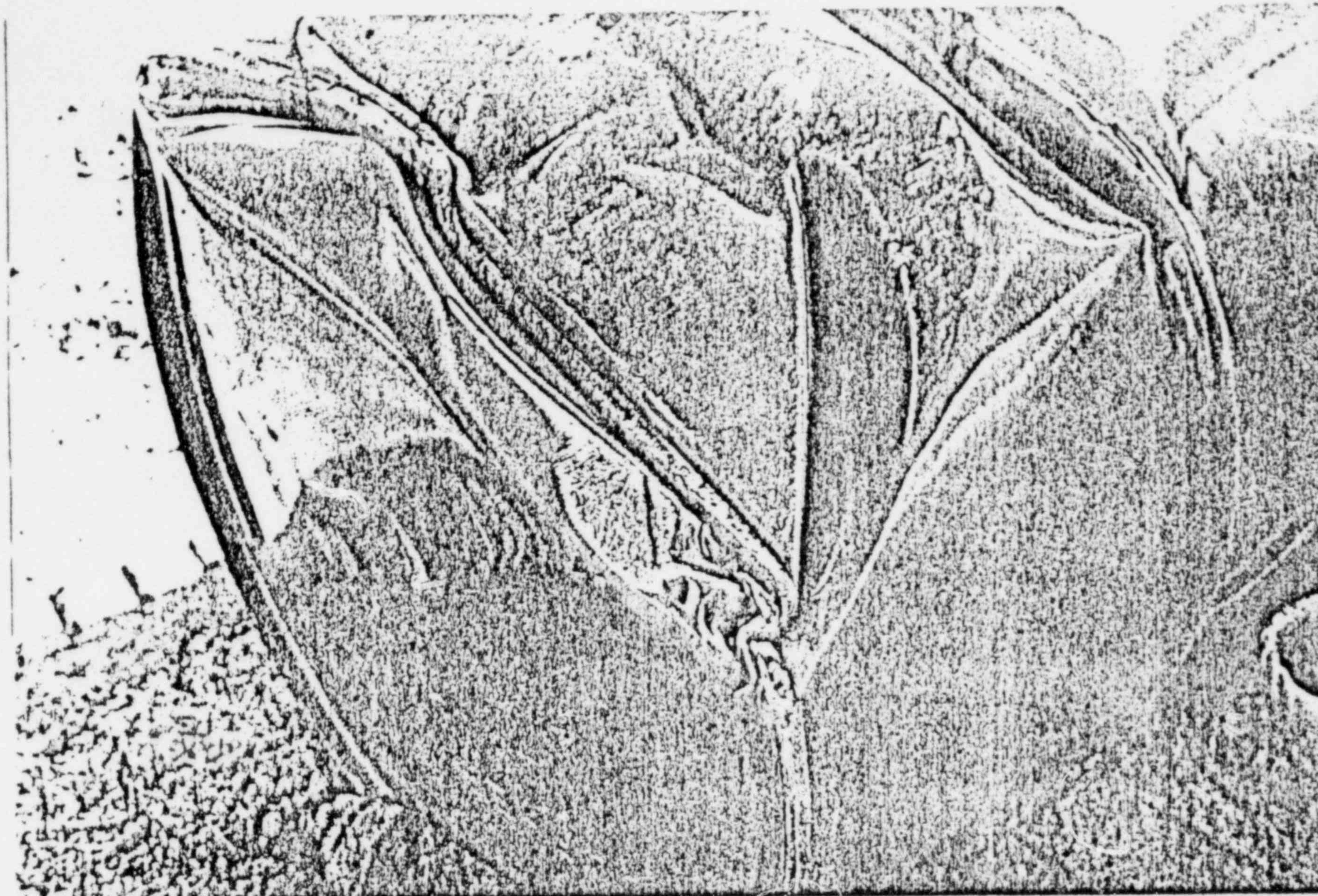


FIGURE 16

CONTAINER NO. K0174 AFTER 30 FOOT DROP

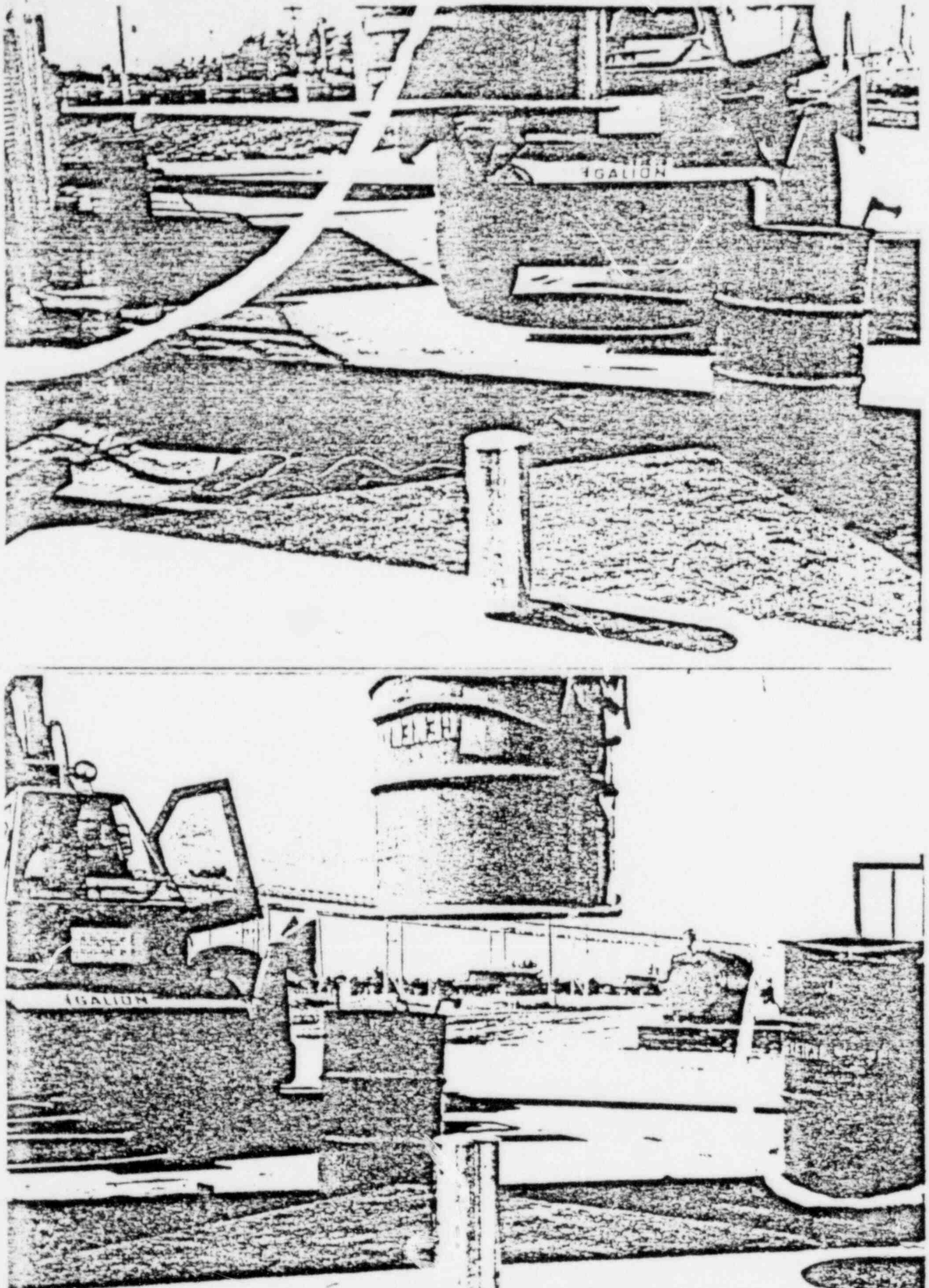


FIGURE 17
CONTAINERS K-1878 AND K-0174 DURING PUNCTURE TEST

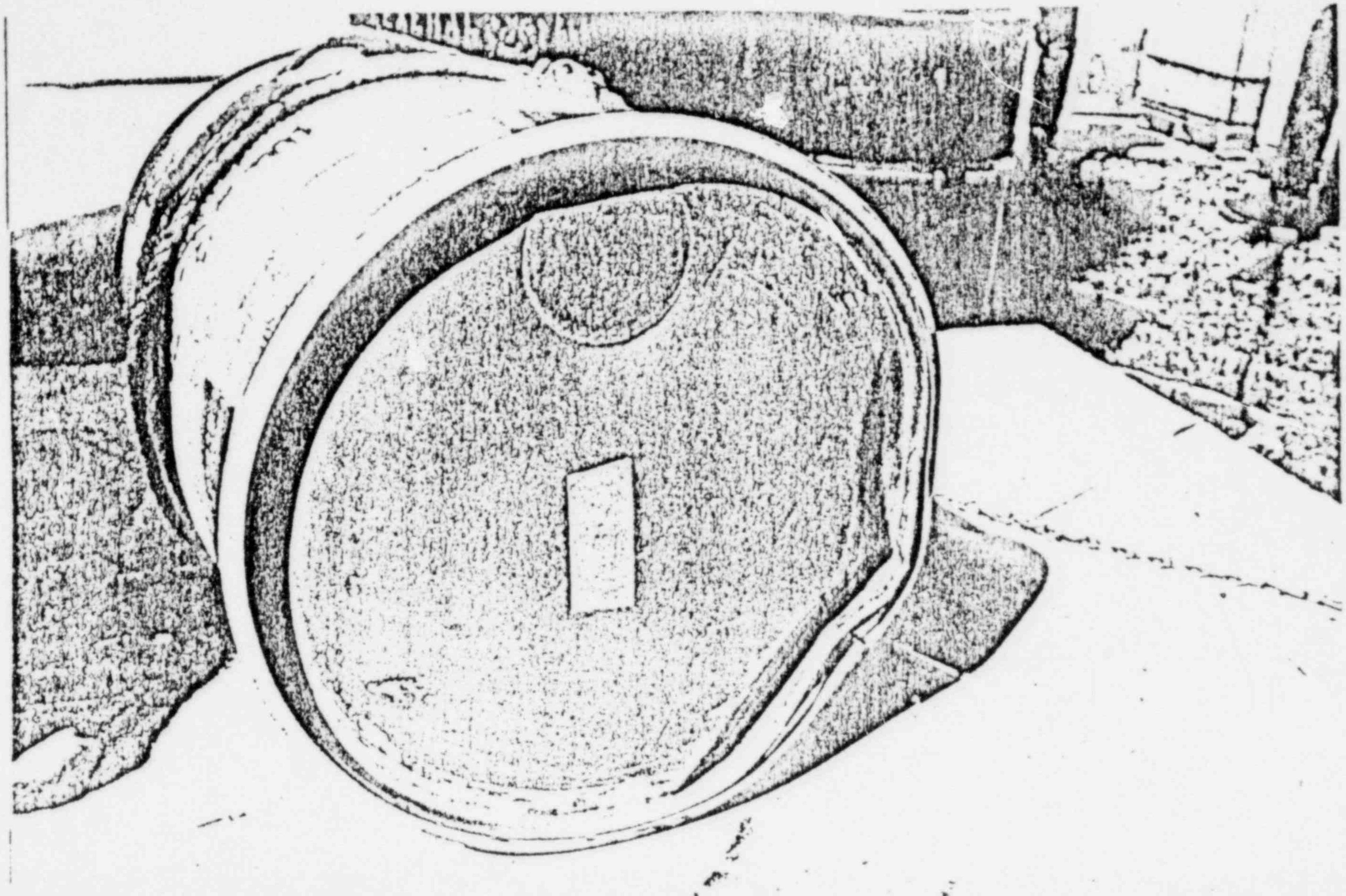


FIGURE 18

CONTAINER NO. K-0174 AFTER PUNCTURE TEST

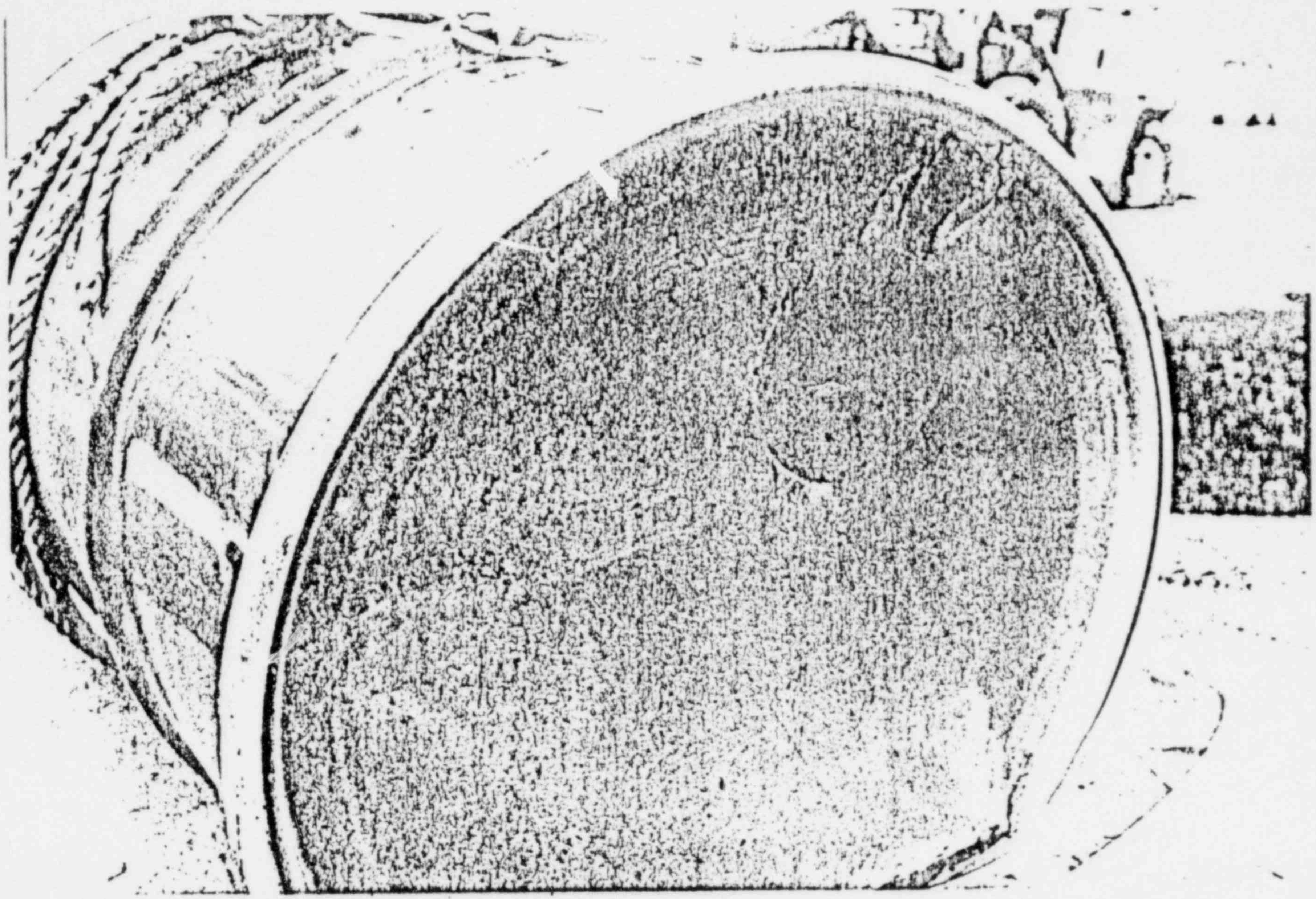


FIGURE 19

CONTAINERS NO. K-1878 AFTER PUNCTURE TEST

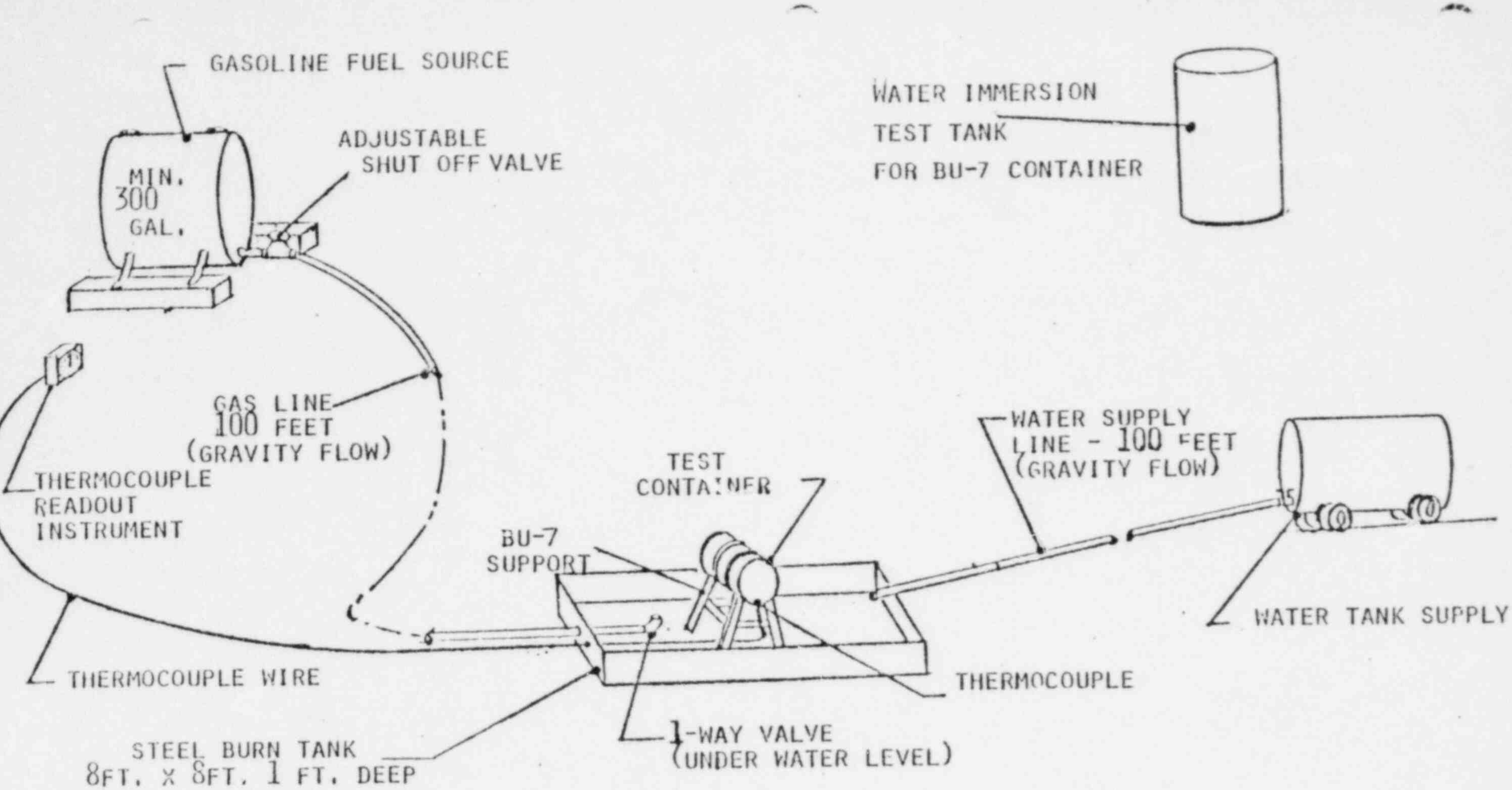


FIGURE 20
THERMAL TEST SETUP

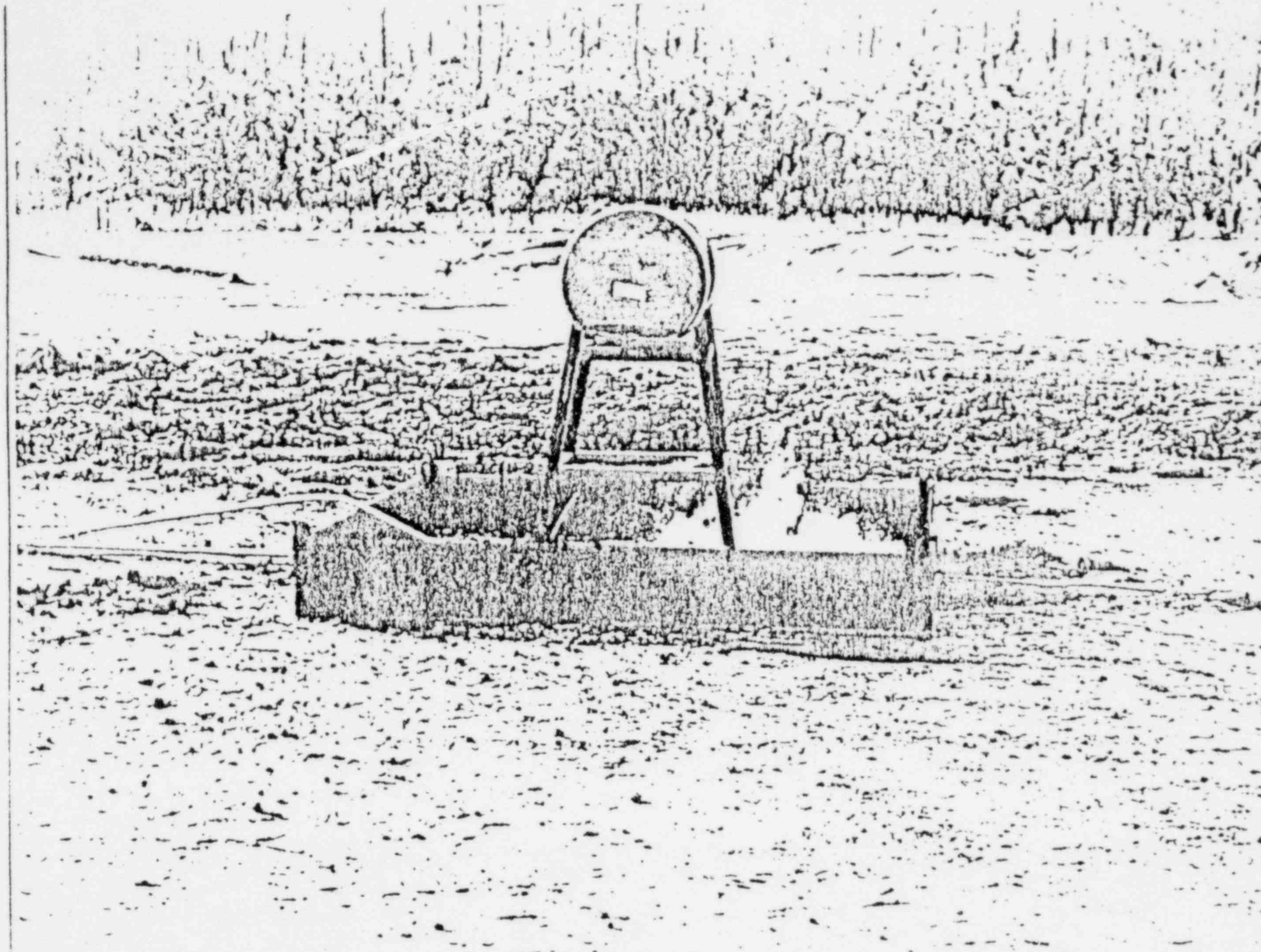


FIGURE 21 IGNITION OF FIRE TEST

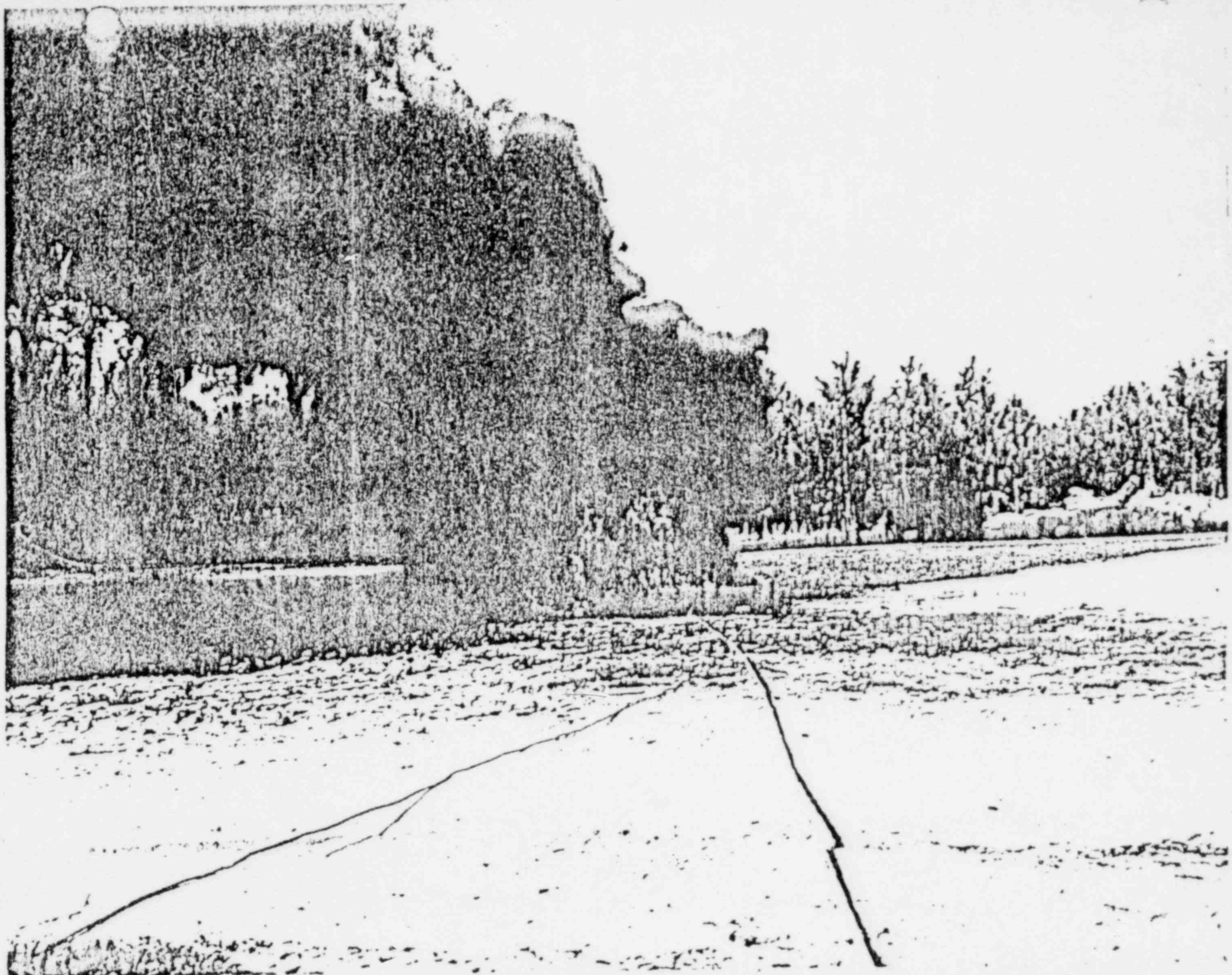


FIGURE 22 THERMAL TEST

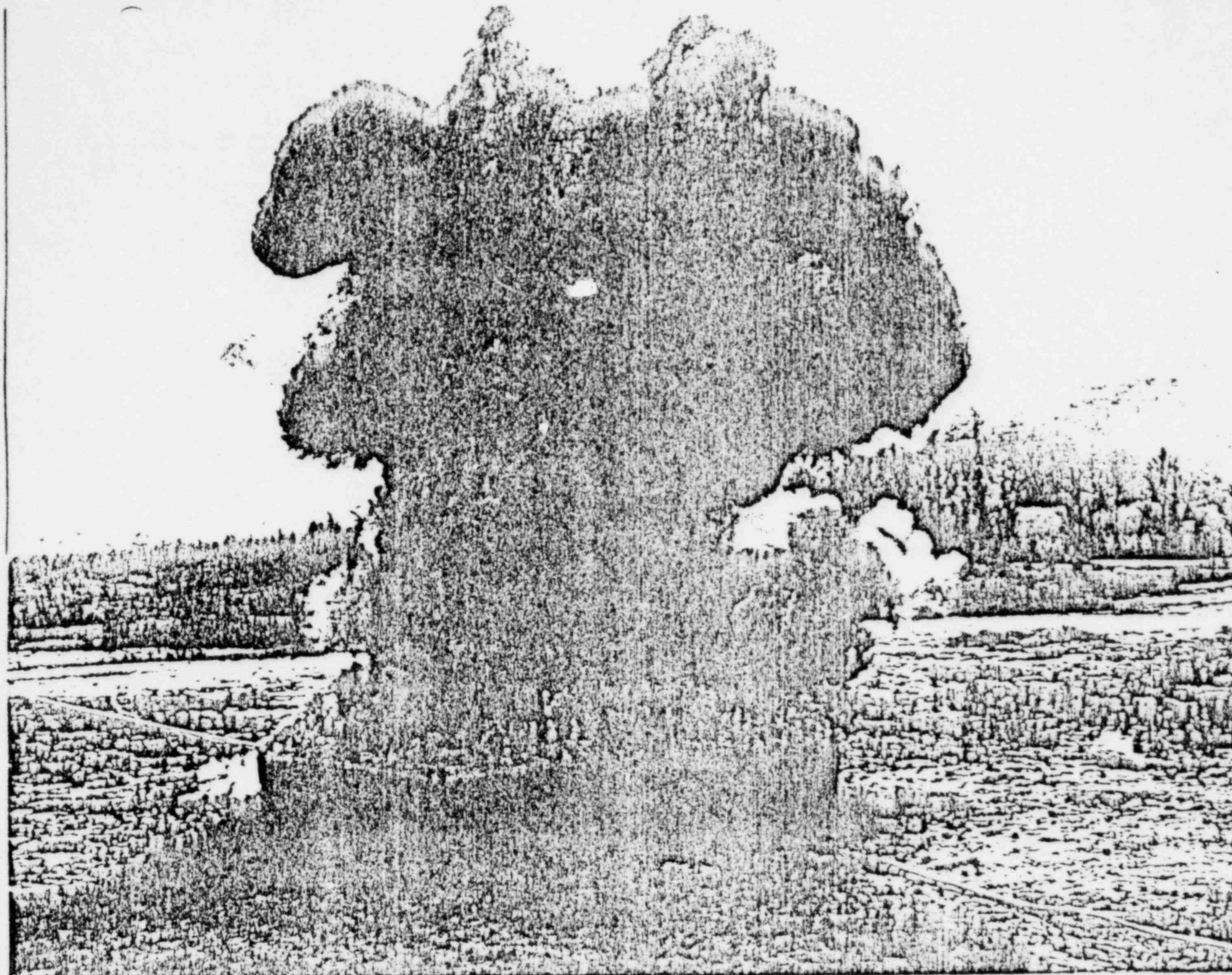


FIGURE 23 – THERMAL TEST

FIGURE 24 THERMAL TEST

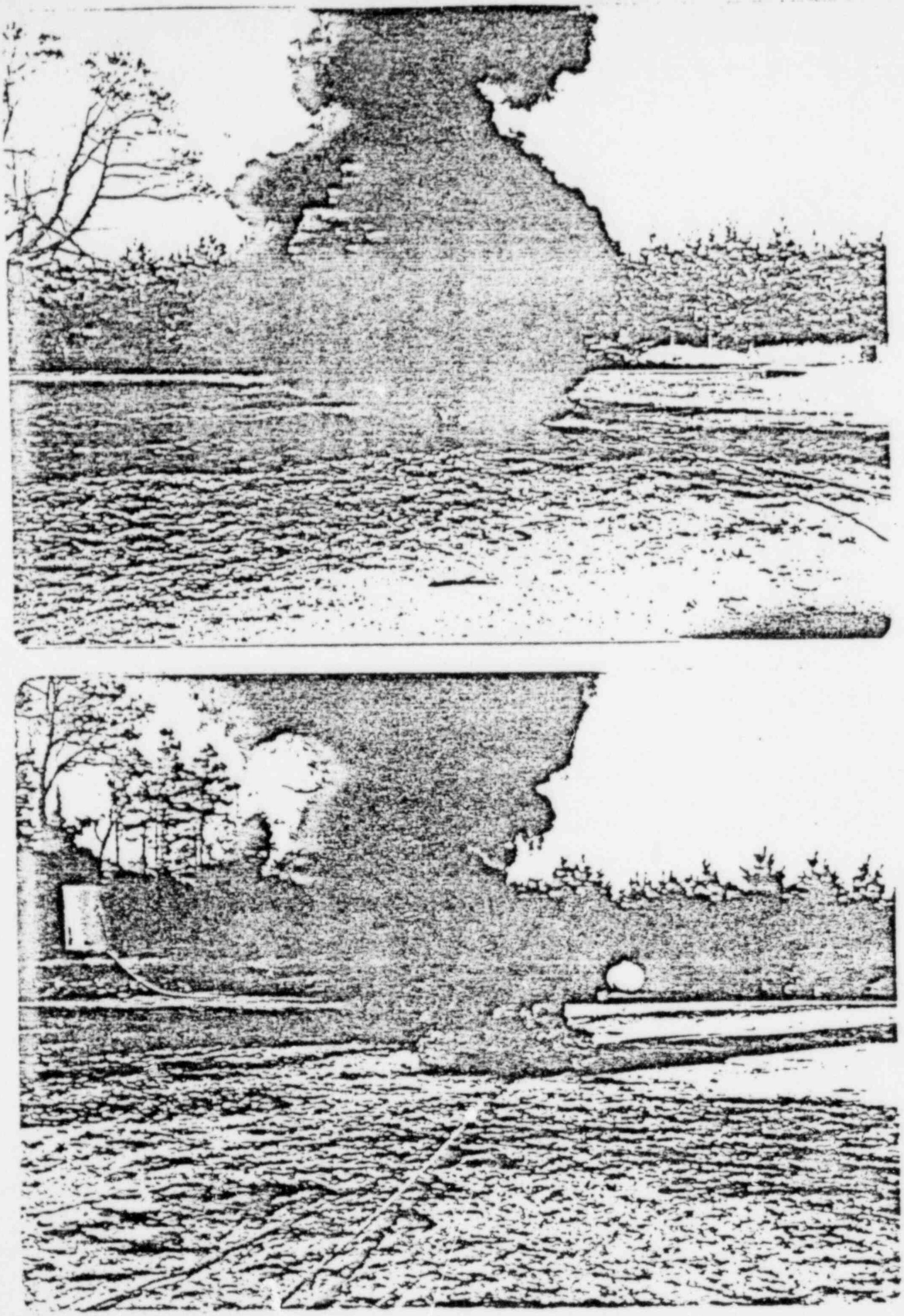


FIGURE 25 THERMAL TEST

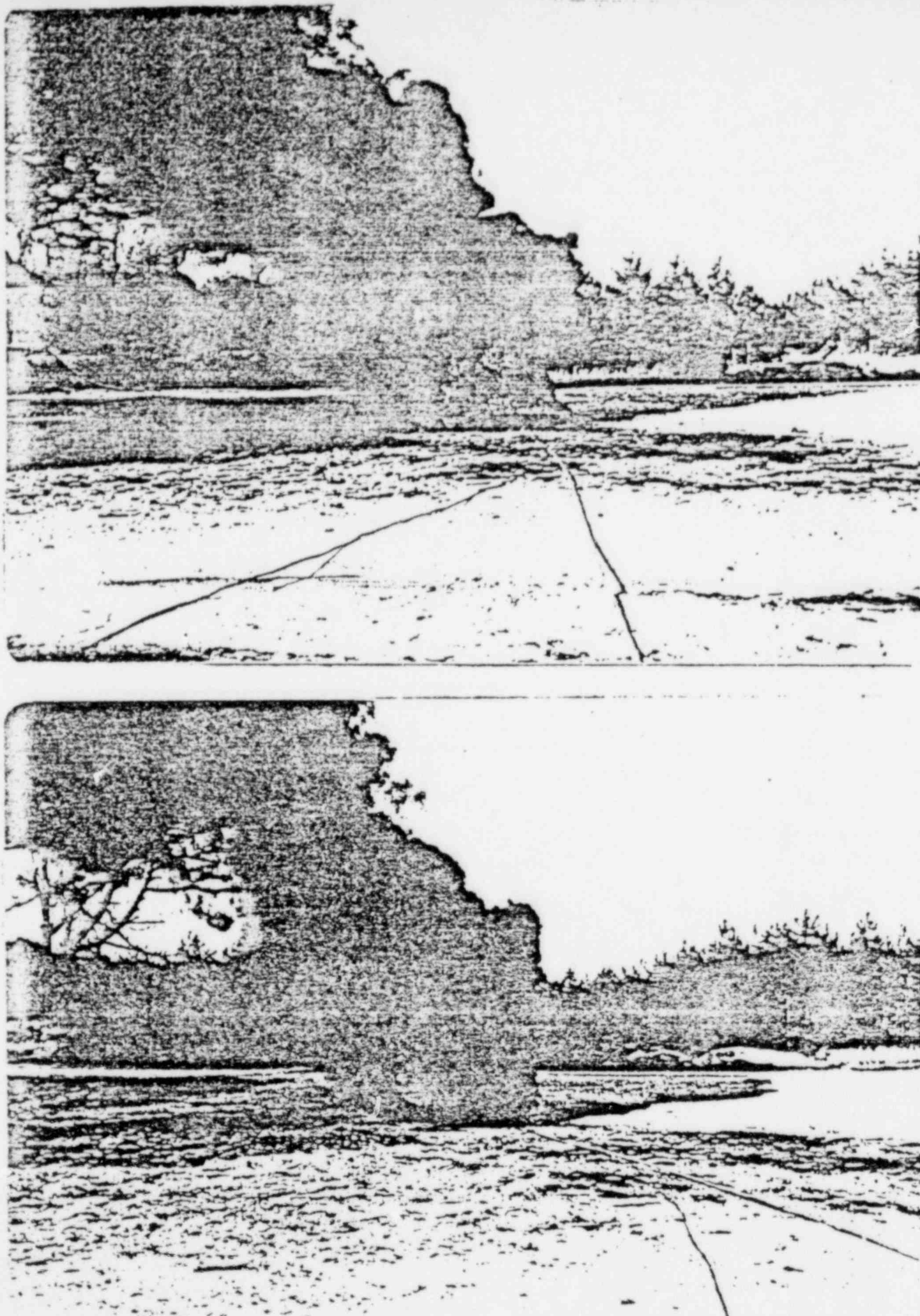


FIGURE 26 THERMAL TEST

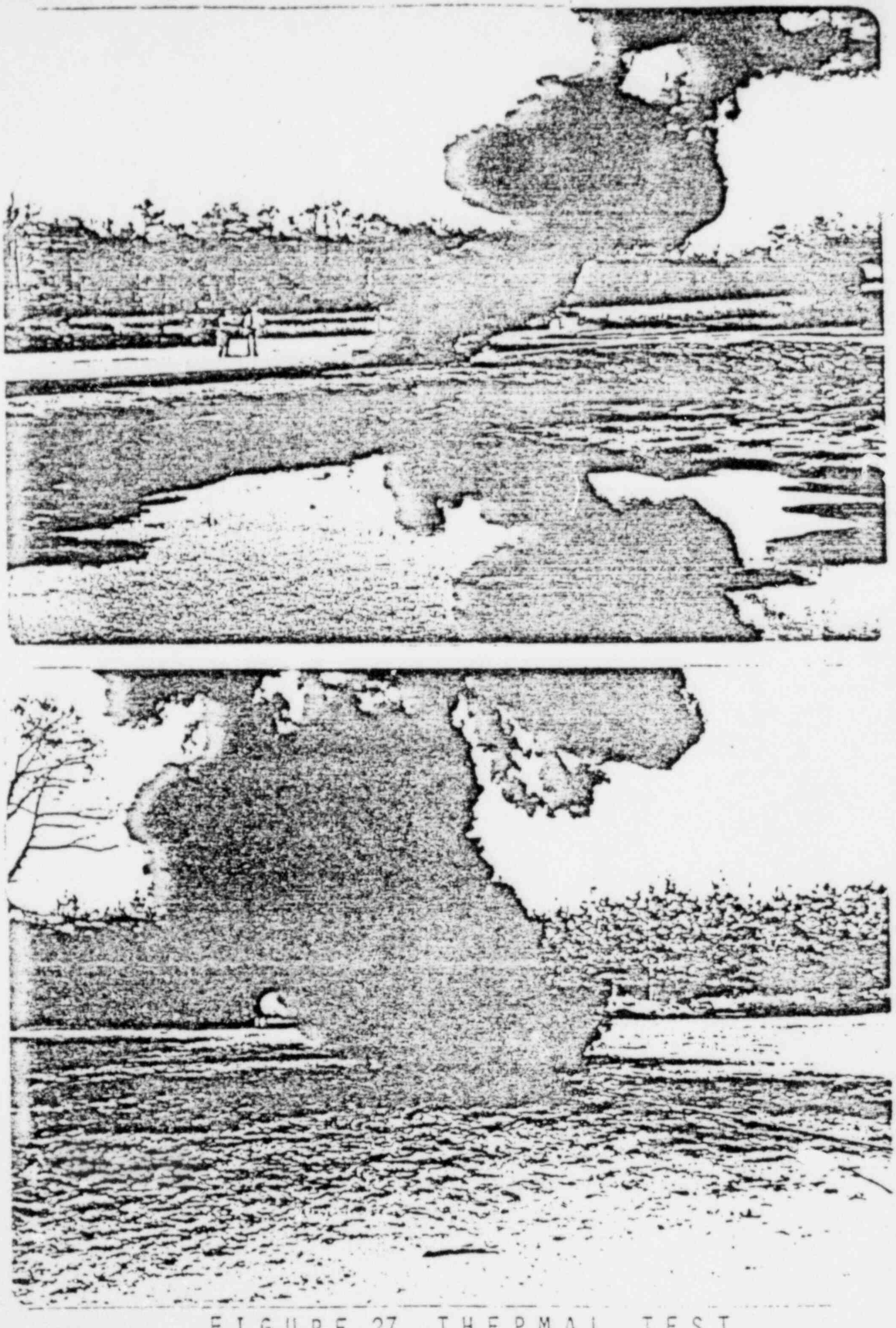


FIGURE 27 THEPMAL TEST

FIGURE 28
THERMAL TEST

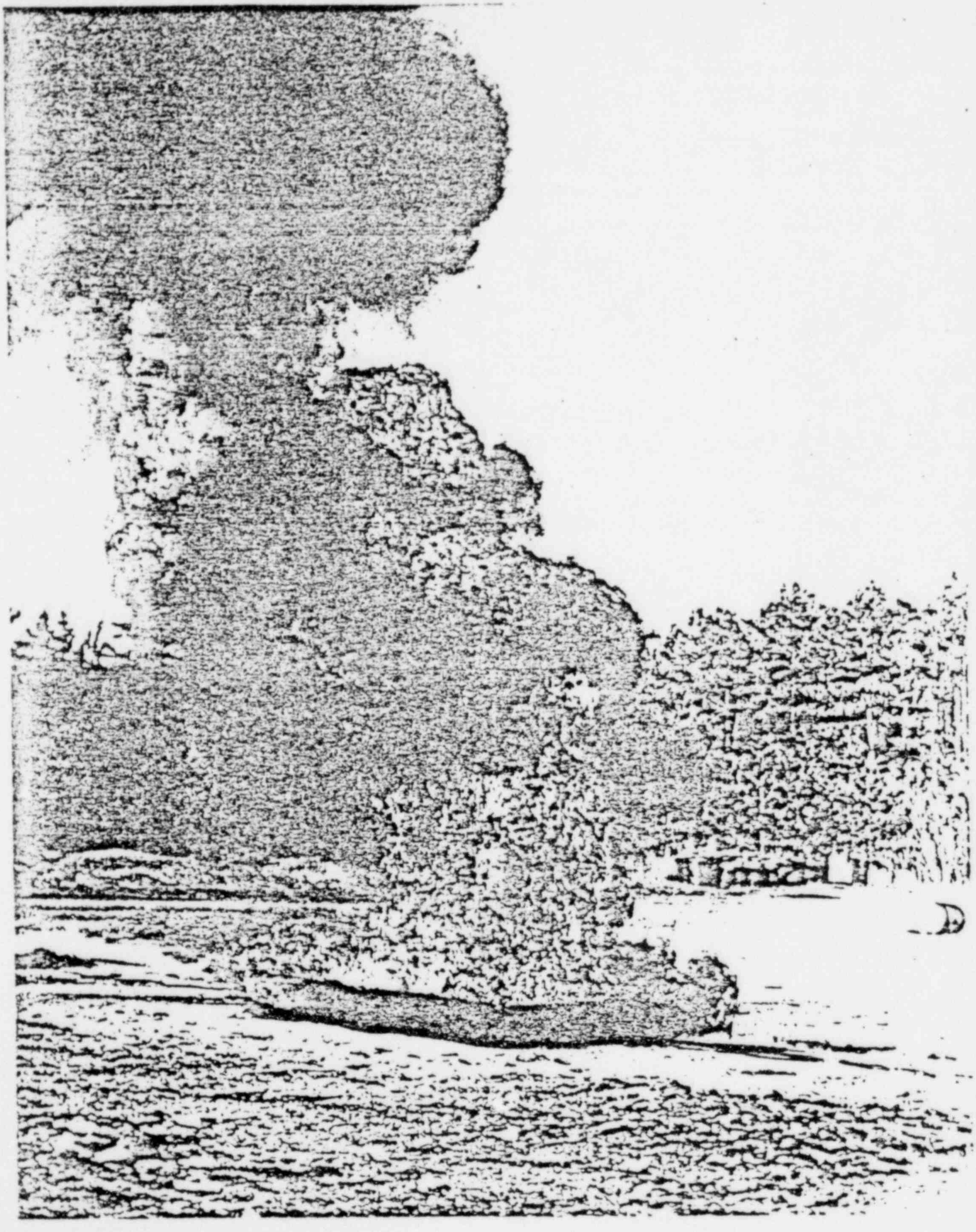


FIGURE 29 THERMAL TEST

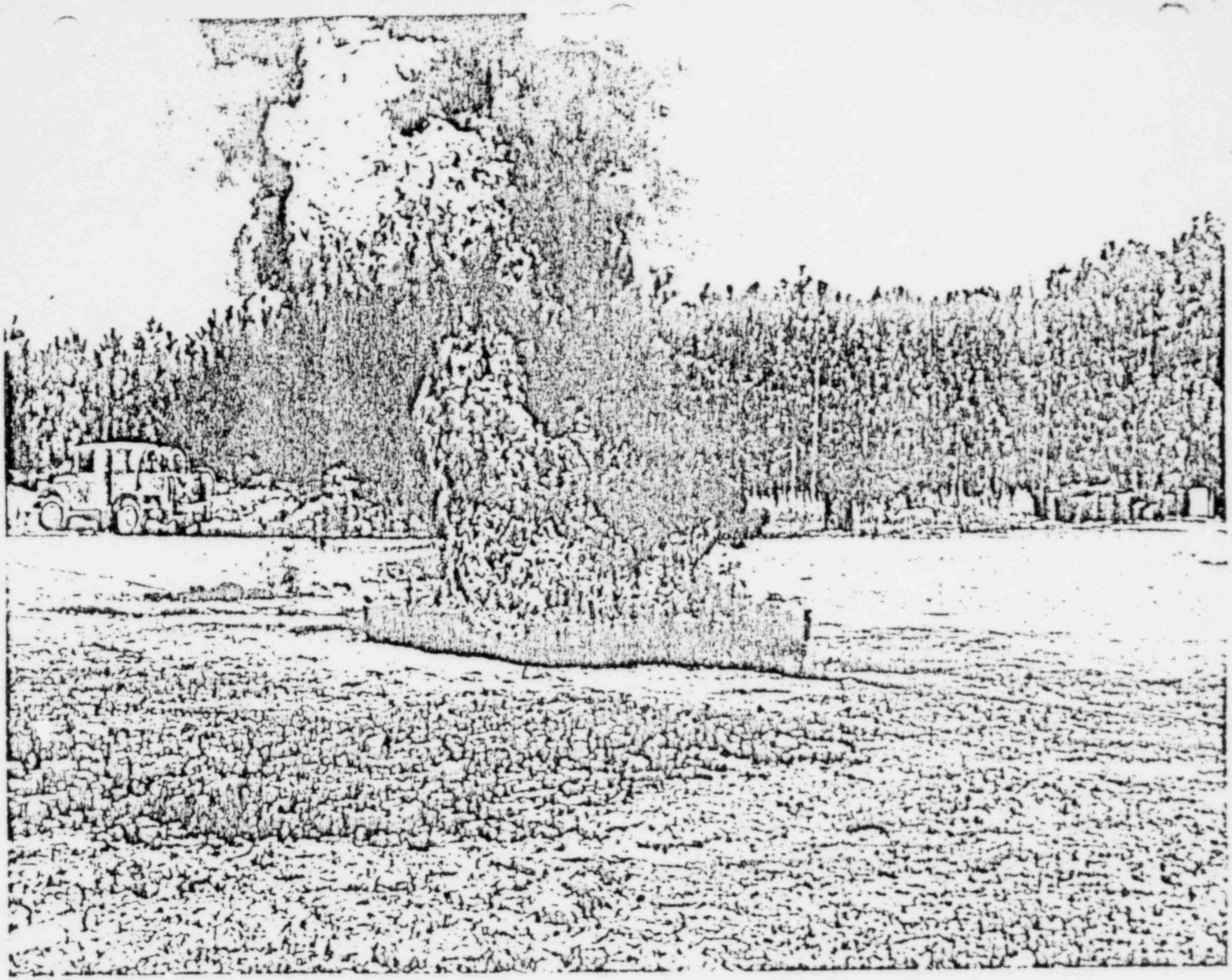


FIGURE 30 THERMAL TEST

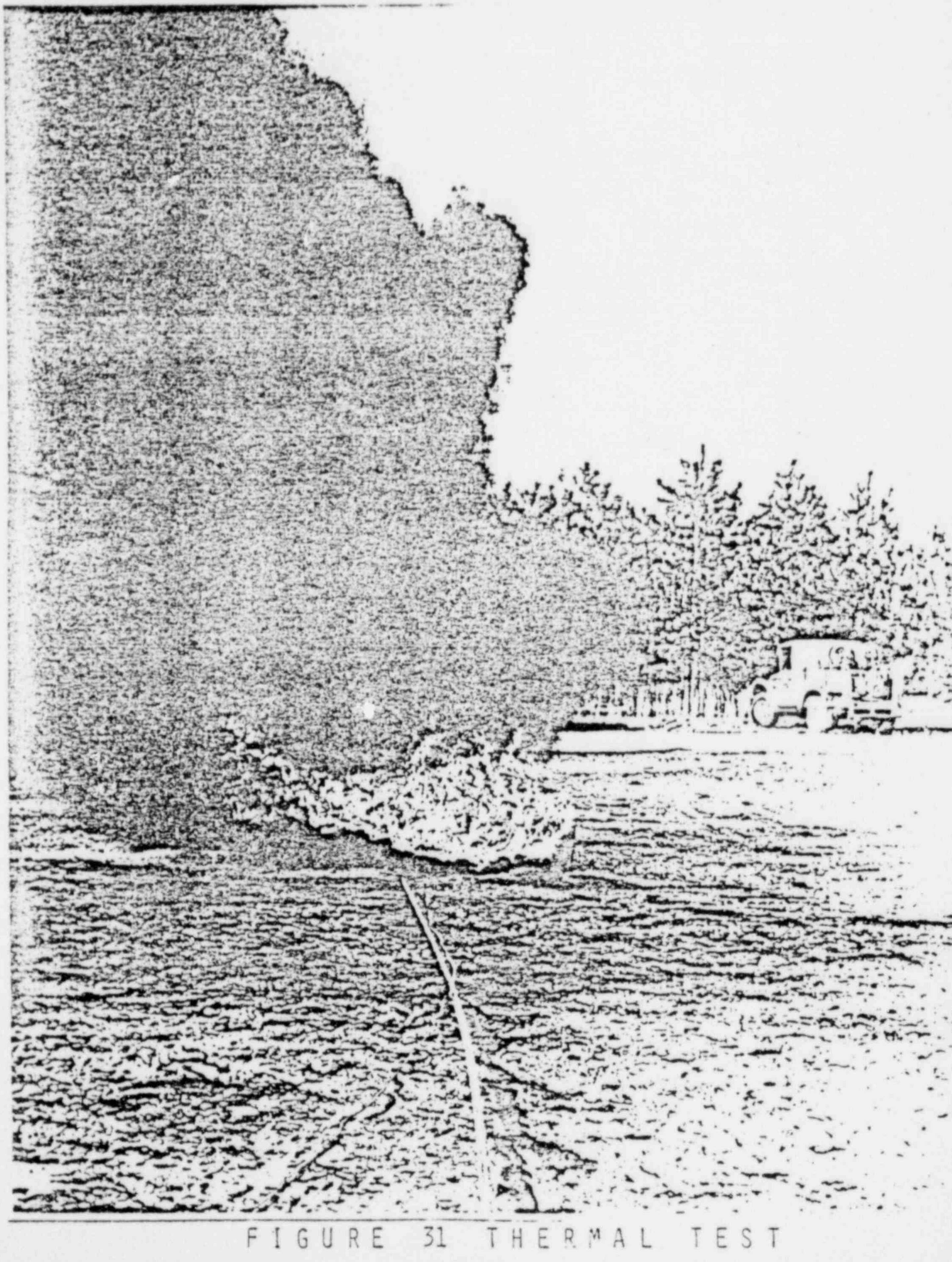


FIGURE 31 THERMAL TEST

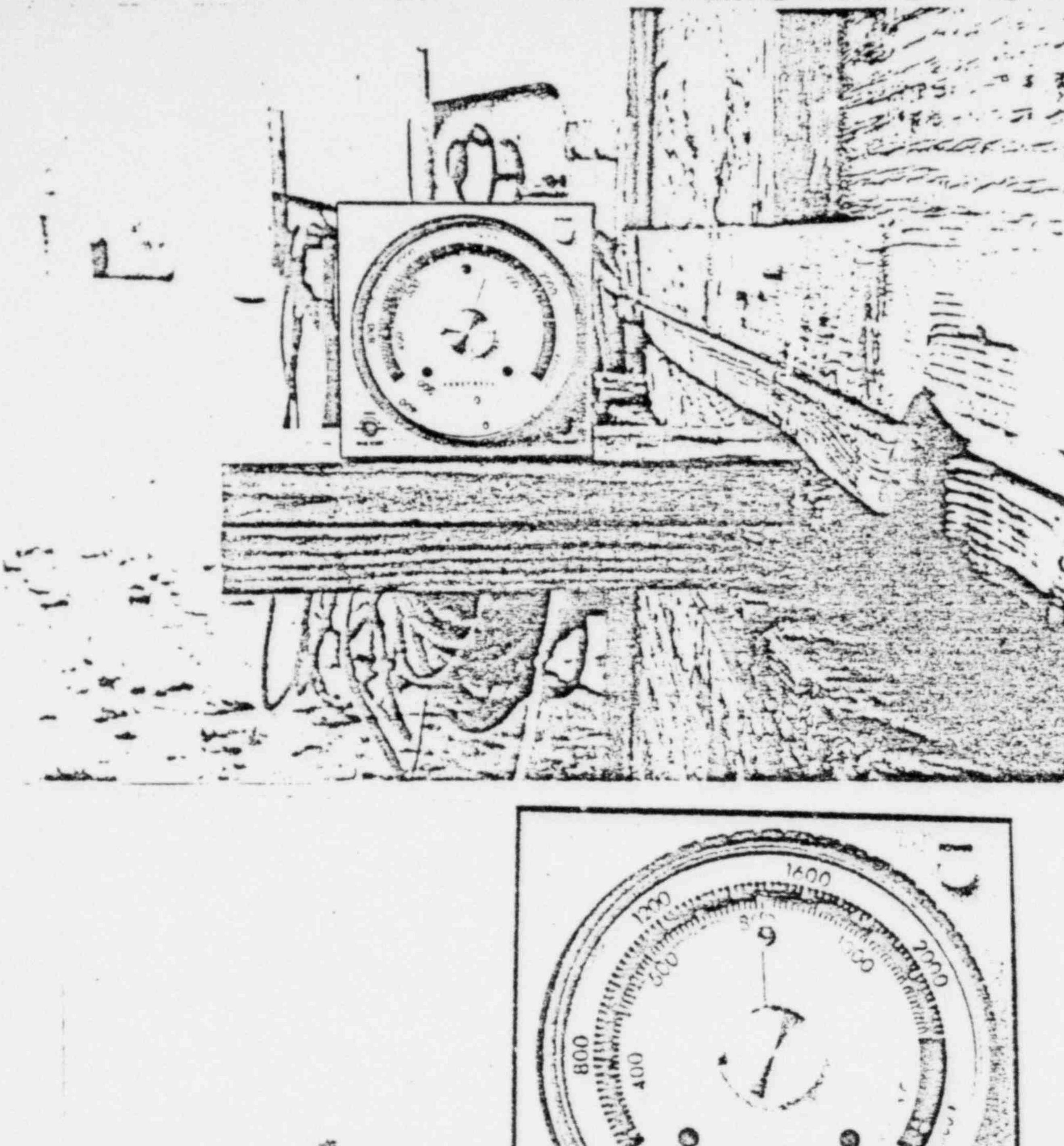


FIGURE 32

HONEYWELL DIAL O TROLL SHOWING TEMPERATURE READING DURING THERMAL

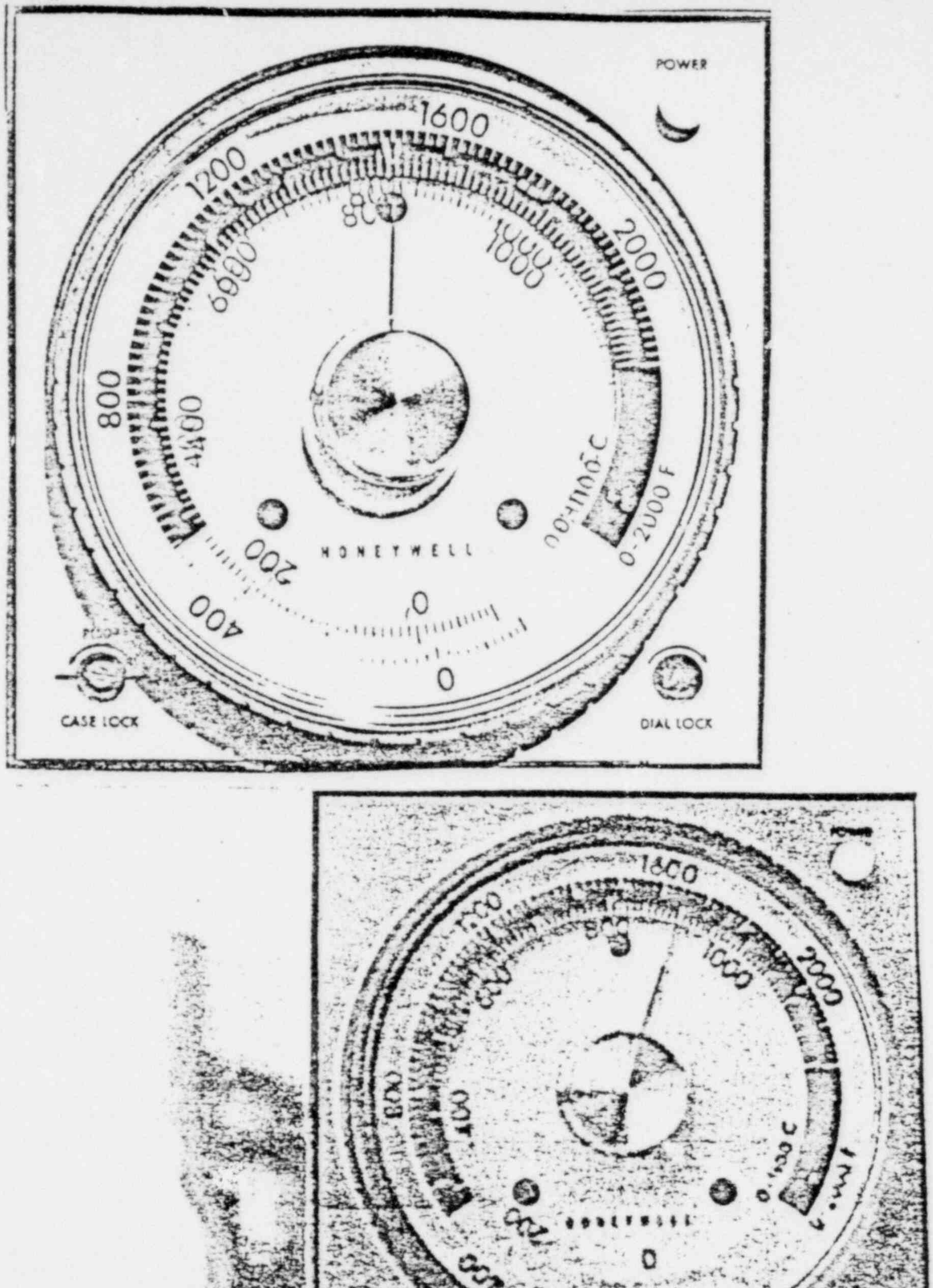


FIG. 33 HONEYWELL DIAL O TROLL SHOWING TEMP. READINGS DURING THERMAL TE

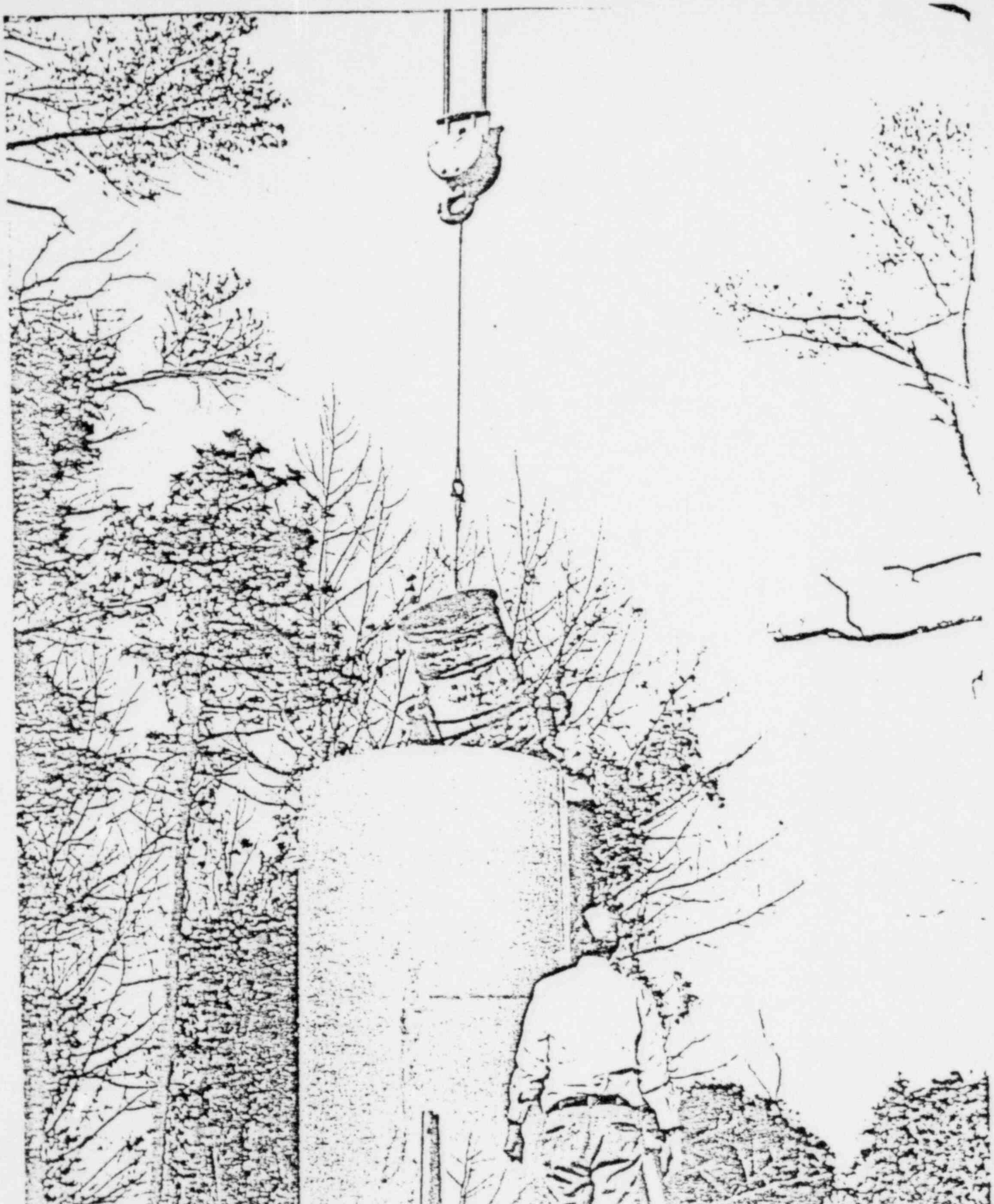


FIGURE 34
WATER IMMERSION TEST

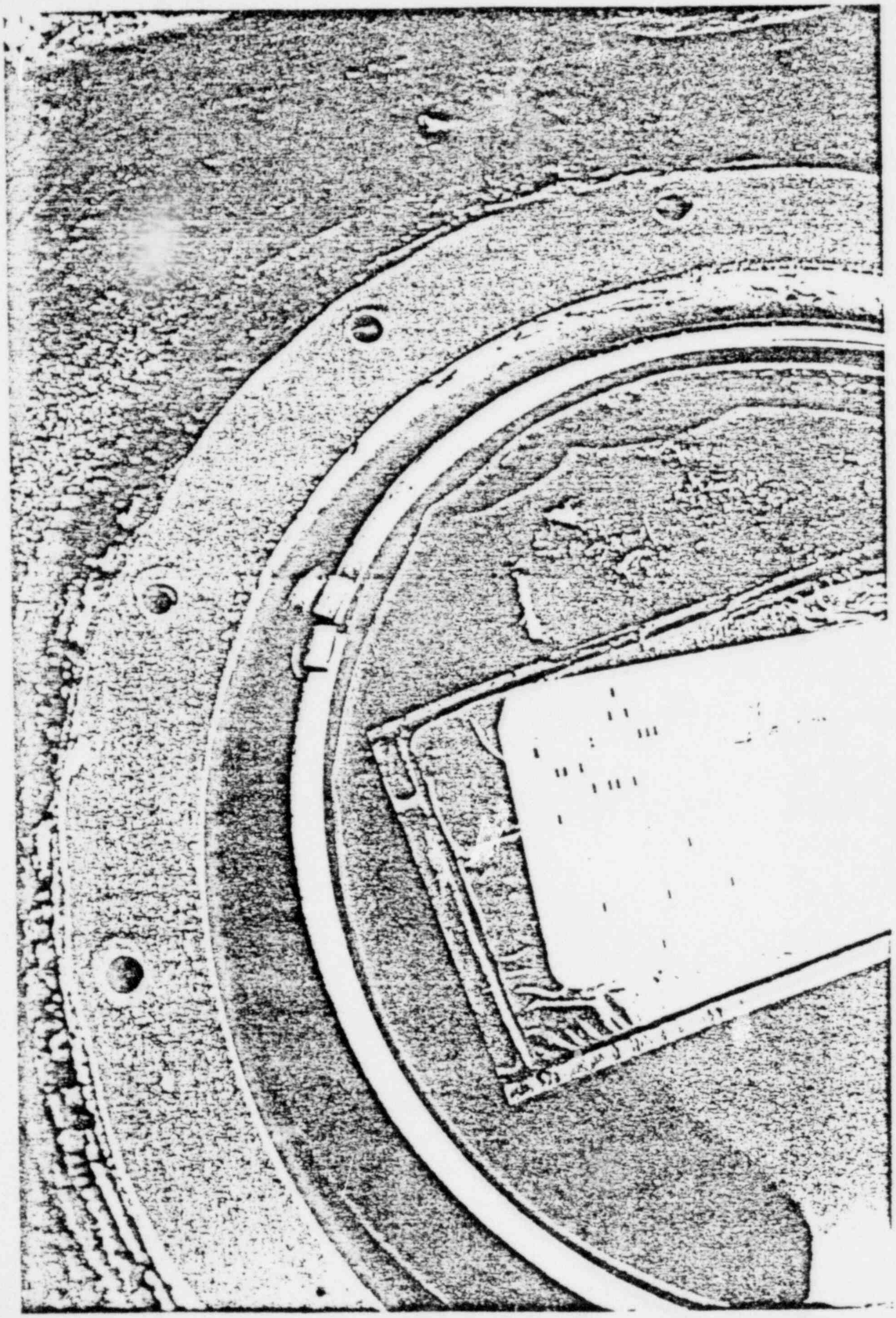


FIGURE 35 POST TEST INSPECTION

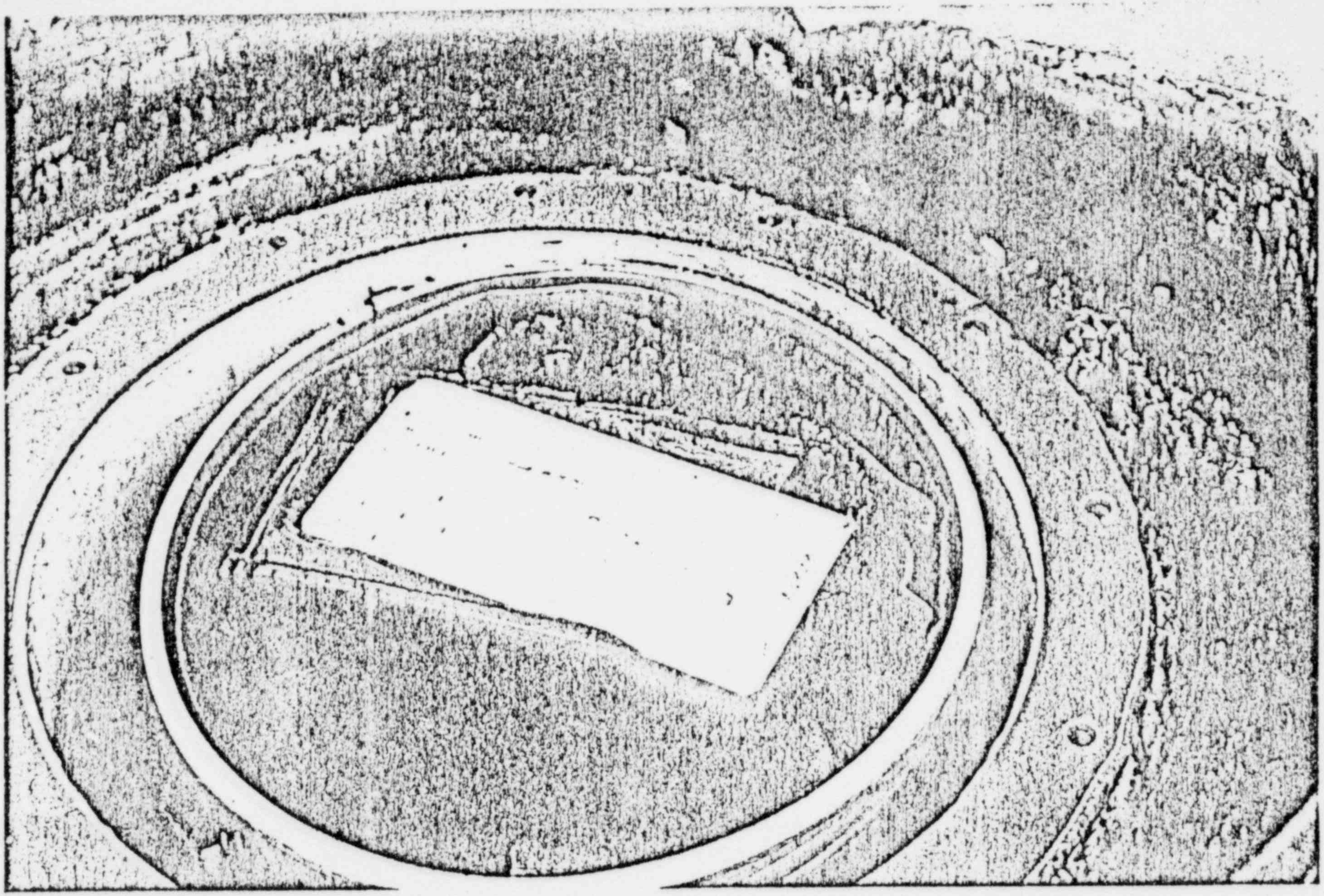


FIGURE 36 POST TEST INSPECTION

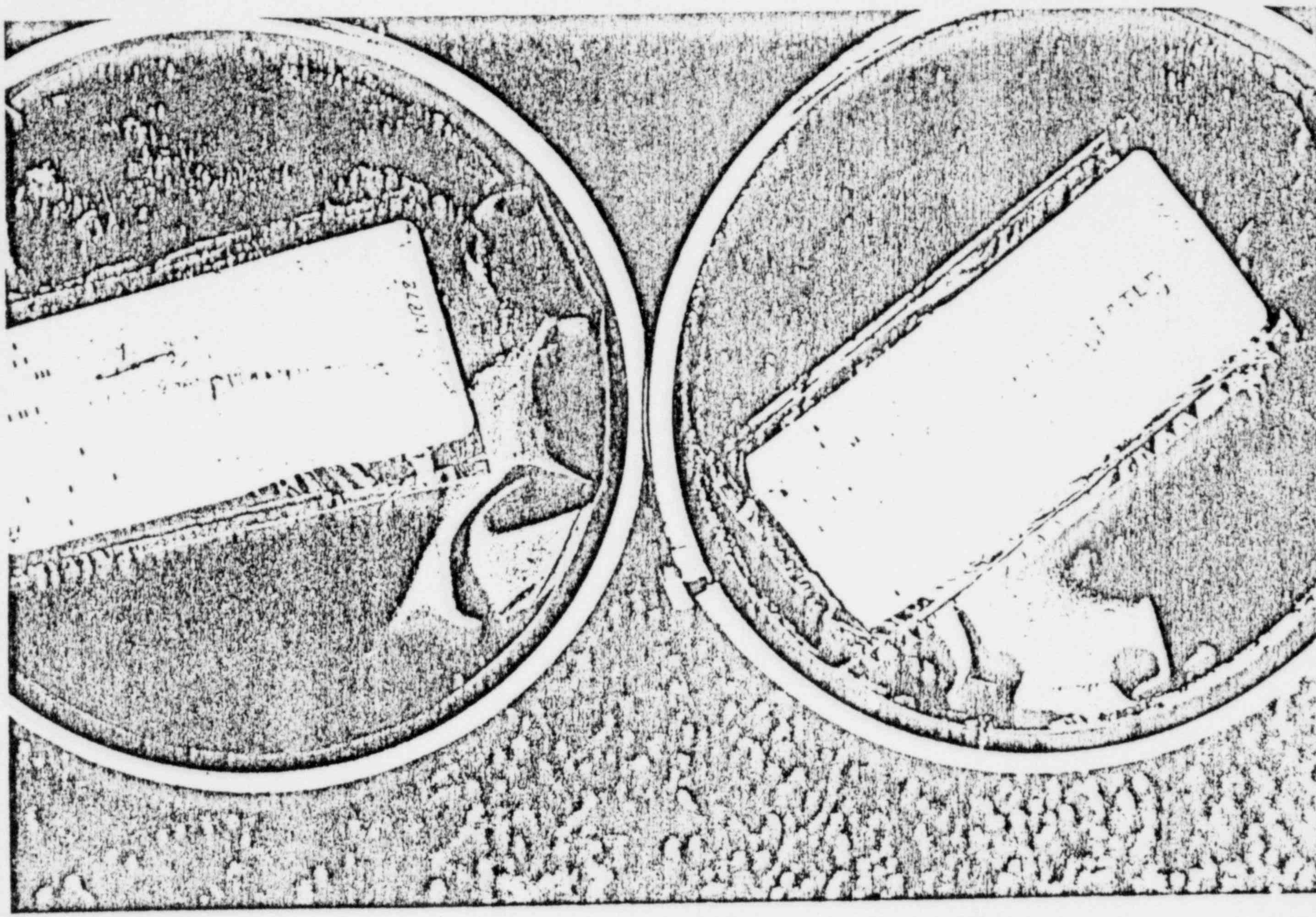


FIGURE 37 POST TEST INSPECTION

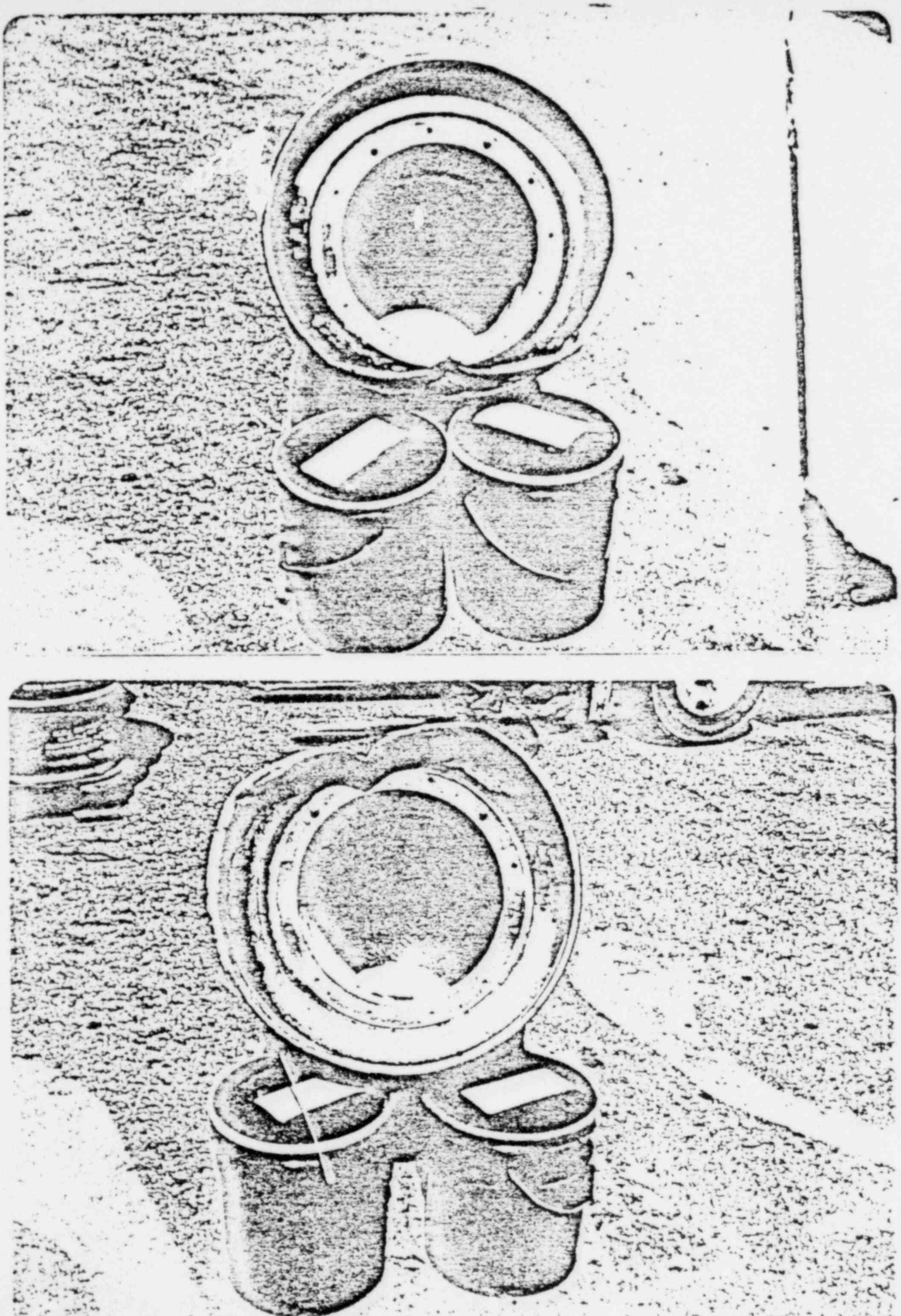


FIGURE 38 POST TEST INSPECTION

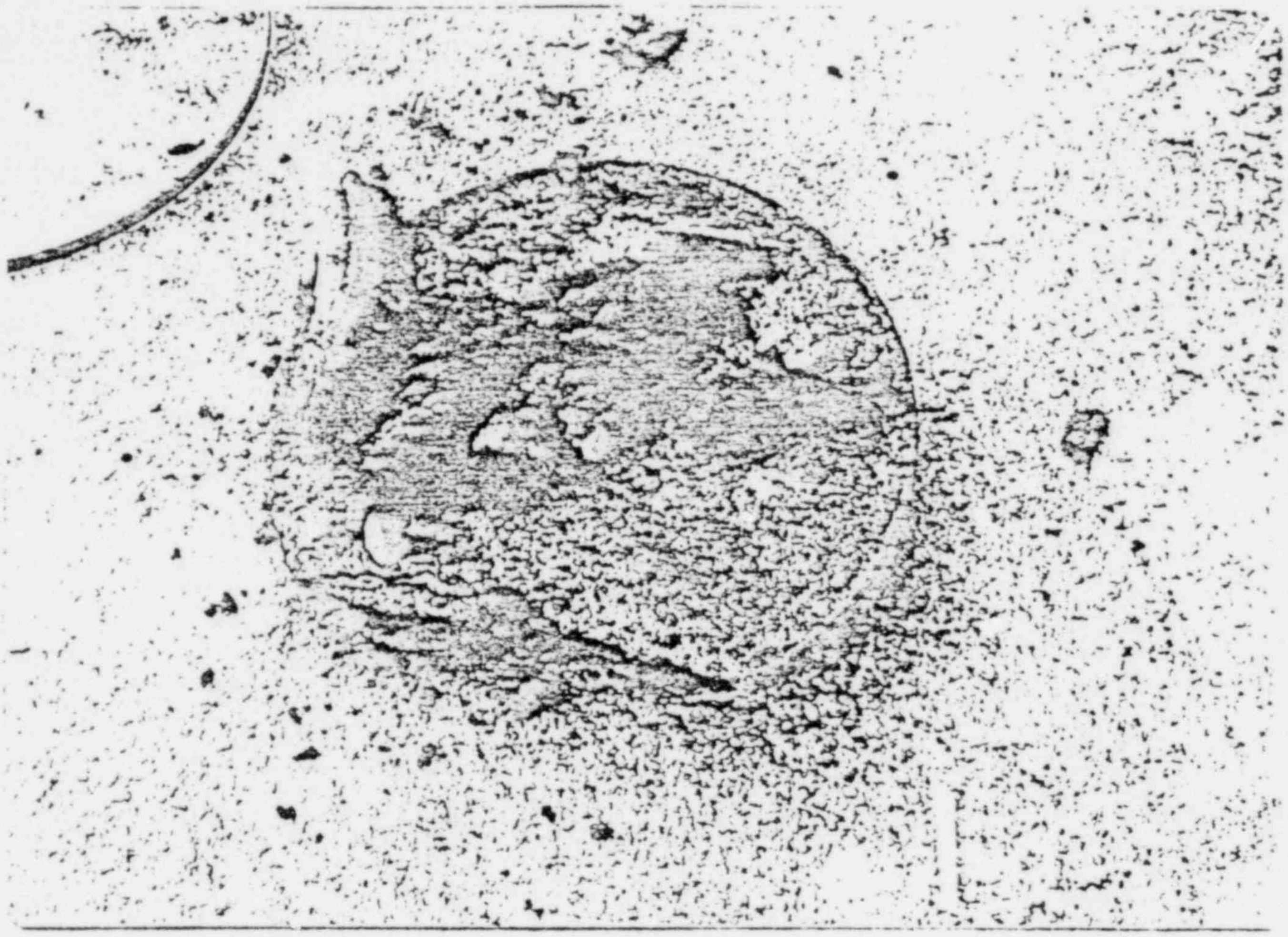


FIGURE 39 CHARRED INSULATION DISC

FIGURE 40
CONTAINERS AFTER COMPLETION OF TESTS
FROM LEFT TO RIGHT, K-1878, K-0174, K319
AND A BU-5 CONTAINER THAT WAS DROP TESTED ONLY

APPENDIX 1

COMPLIANCE

The test referenced in Paragraph 5 have been conducted and satisfactorily meet the acceptance criteria of the test plan.

Container Drawing No. 128D5231

Container Serial No. K1878

Date Tested 3/20/80, 3/21/80, 4/1/80 and 4/2/80

Packaging Engineer J A Zeitoh 4-2-80

Fuel Quality Control Engineering E D Sieger 4-14-80

Licensing & Compliance Audits Arthur L Kaplan 4/21/80

Traffic & Material Distribution John M Mims 4/21/80

APPENDIX 1

COMPLIANCE

The test referenced in Paragraph 5 have been conducted and satisfactorily meet the acceptance criteria of the test plan.

Container Drawing No. 128D5231

Container Serial No. K 0174

Date Tested 3/20/80 and 3/21/80

Packaging Engineer J A Zidek 4-2-80

Fuel Quality Control Engineering G D Berger 4-14-80

Licensing & Compliance Audits Arthur L Kaplan 4/21/80

Traffic & Material Distribution John M Mims 4/21/80

APPENDIX 1

COMPLIANCE

The test referenced in Paragraph 5 have been conducted and satisfactorily meet the acceptance criteria of the test plan.

Container Drawing No.	128D5231
Container Serial No.	K 0319
Date Tested	April 1, 1980

Packaging Engineer	J A Zidek 4-2-80
Fuel Quality Control Engineering	E D Singer 4-14-80
Licensing & Compliance Audits	Arthur E Kaplan 4/21/80
Traffic & Material Distribution	John M Mims 4/21/80

APPENDIX 2

TEST CHECK SHEETS

Container Drawing No. 128D5231

Container Serial No. K 1878

	Date
Pre Test Visual Inspection per Paragraph 5.1	EL 3/20/80
Loading Pair No. {22RBP005, 22RBP006}	EL 3/20/80
Water Spray Test	—
Drop Test	—
Penetration Test	—
Compression Test	—
30 Feet Free Drop	SLW 3/21/80
Puncture Test	SLW 3/21/80
Thermal Test	KWM 4/1/80
Water Immersion Test	KWM 4/2/80

Fuel Quality Control Engineering KW Martin 4/2/80

APPENDIX 2

TEST CHECK SHEETS

Container Drawing No. 128 D 5231

Container Serial No. K0174

	Date
Pre Test Visual Inspection per Paragraph 5.1	ES 3/20/80
Loading {22RBP001, 22RBP002}	ES 3/20/80
Water Spray Test	—
Drop Test	—
Penetration Test	—
Compression Test	—
30 Feet Free Drop	SLW. 3/21/80
Puncture Test	SLW. 3/21/80
Thermal Test	—
Water Immersion Test	—

Fuel Quality Control Engineering K.W. Martin

APPENDIX 2

TEST CHECK SHEETS

Container Drawing No. 1280523l

Container Serial No. K0319

	Date
Pre Test Visual Inspection per Paragraph 5.1 (205#Gross)	Kwm 3/31/80
Loading	Kwm 3/31/80
Water Spray Test	Kwm 4/1/80
Drop Test	Kwm 4/1/80
Penetration Test	Kwm 4/1/80
Compression Test	Kwm 4/1/80
30 Feet Free Drop	—
Puncture Test	—
Thermal Test	—
Water Immersion Test	—

Fuel Quality Control Engineering KWMartin 4/2/80

PROJECT NO. 98414'

ENRICHMENT 022

MTL. TYPE RBP

GENERAL ELECTRIC

S. S. MATERIAL

LOADING-[illegible] RECORD

WEIGHED BY 16637

DATE 3-21-80

BLEND NO. ______

INNER CONTAINER NO	WEIGHT		SEAL NO.	SCALE CALIBRATION	OUTER CONTAINER NO	WEIGHT VERIFIED BY	
	GROSS	TARE					
022RBP0002	1 7 1 9	0	127015	0 0 0 0 0	K-0174	E.S. 3/20/80	
022RBP0001	1 7 6 2	0	127016	3 5 0 0 0	|	|	
022RBP0006	1 7 7 1	0	127017 [illegible]		K-1878	|	
022RBP0005	1 7 5 8	0	127018		|	|	

APPENDIX B
BU-7 LOADING RECORD

Request No. 80-79

NSR Area No. 1

PROCESS AND EQUIPMENT/FACILITIES CHANGE REQUEST

Requestor

Initiating Component L&CA Installation Responsibility T&MD

Equipment Location [illegible]MO POWDER PACK AREA AND TEST PAD WEST OF FMOX.

Purpose of Change TEST LOADED BU-7 AND BU-5 CONTAINERS FOR RELICENSE BY [illegible] NRC.

Description of Change STANDARD PACK 6 5-GALLON PAILS WITH 45 KGS NATURAL UO_2 POWDER LOAD AND SEAL IN 2 BU-7 AND 1 BU-5 CONTAINERS. TEST CONTAINERS TO NRC TEST STANDARDS ATTACHED (30-FOOT DROP, 40-INCH, FIRE, ETC.)

Scheduled Project Completion ____ Preliminary NSE Review Needed By 3/18/80

Final NSE Review Needed By 3/18/80 Requestor's Signature/Date [signature] 3/18/80

Nuclear Safety Engineering

1. Type Analysis Required: *Criticality NO *Radiological No None ____
2. New/Updated NSE Method Sheet Required: Crit. NO Radio. NO None ____
3. Anticipated Availability of NSE Method Sheet, If Required ____
4. Signatures: Criticality Safety [signature] Radiological Safety [signature]
5. Remarks: Limited to Natural or Depleted Uranium Only

Fuel Quality Control Engineering No

1. Is New/Changed Quality Instruction Required? Yes ____ No ____
   If Yes, Anticipated Availability of Instruction ____
2. Responsible Fuel Quality Control Engineer ____
3. Approval: Mgr., Fuel Quality Control Engineering ____

Fuel Process Technology No

1. Is New/Changed Instruction Required? Yes ____ No ____
   If Yes, Anticipated Availability of Instruction ____
2. Responsible FPT Engineer ____
3. Approval: Responsible FPT Unit Manager ____

SHOP Burns

Subsection Manager Approval [signature] 3/20/80

Area Manager

1. Priority Assignment For Nuclear Safety Review ____
2. Area Manager Approval ____

Nuclear Safety Engineering

Date Approved Request Received ____ Date Completed ____

Area Manager Acceptance of Completed Project ____ Date ____

*Documented information from requestor required per P/P 40-5 Appx. A

NF-1-014 (11/77)

APPENDIX 4

URANIUM POWDER LOADING REQUEST

KAPLAN

GENERAL ELECTRIC

RELATIONS AND UTILITIES OPERATION
San Jose, California

February 10, 1978

TEST REPORT
BU-5 AND BU-7 CONTAINER PRESSURE TEST

A. OBJECTIVE

The objective of this test was to verify the integrity of the BU-5 and BU-7 containers for the New Japanese Container Regulations. The procedures were presented to the Japanese and approved by them.

B. SUMMARY

The following tests were performed on one BU-5 and one BU-7 container on February 6, 1978 thru February 10, 1978.

1. Both containers were tested under water to 1.50 Kg per CM^2 for eight hours. This was done by submerging them in the test tank in Building G, to a depth of 50 feet above the containers.

2. The containers were then pressurized internally and checked for leakage at four increments:

   a.) .75 Kg/CM^2 for three hours

   b.) 1.0 Kg/CM_2 for three hours

   c.) 1.25 Kg/CM^2 for three hours

   d.) 1.5 Kg/CM^2 for three hours

GENERAL ELECTRIC

C. TEST EQUIPMENT

The following equipment was used in the test:

1. 60 feet deep test tank

2. BU-5 container S/N B-7522

3. BU-7 container S/N K-0397

4. Permagage # 175 0 to 60 psi pressure gage, regulator and valves as shown in Figure 1.

D. CALIBRATION

The pressure gage was calibrated prior to testing. Calibration record and curve (Figure 2) are included in this report. Calibration was made with equipment traceable to the National Bureau of Standards conformance.

E. TEST RESULTS

1. Water Immersion Test
   There was no water leakage in the inner containers after eight hours of submergence in 50 feet of water.

2. Air Pressurization Tests
   There was no leakage of air from the inner containers when pressurized as shown in Figure 1 and held at pressure increments of .75, 1.0, 1.25 and 1.50 Kg per square centimeter for periods of three hours for each pressure increment.

CONCLUSION

The BU-5 and BU-7 containers passed all the pressure test requirements for the New Japanese Container Regulations. In fact, the tests exceeded their requirements. The water submergence test was for eight hours rather than three, and the BU-7 container was tested at

GENERAL ELECTRIC

1.25 gm/cm^2 for 14 hours. There was no leakage in either case.

J. A. Zidak
Packaging Engineer
M/C 512

Certified By: W. S. Cowan 2/13/78

W. S. Cowan, Manager
Packaging Engineering
M/C 512

JAZ/da

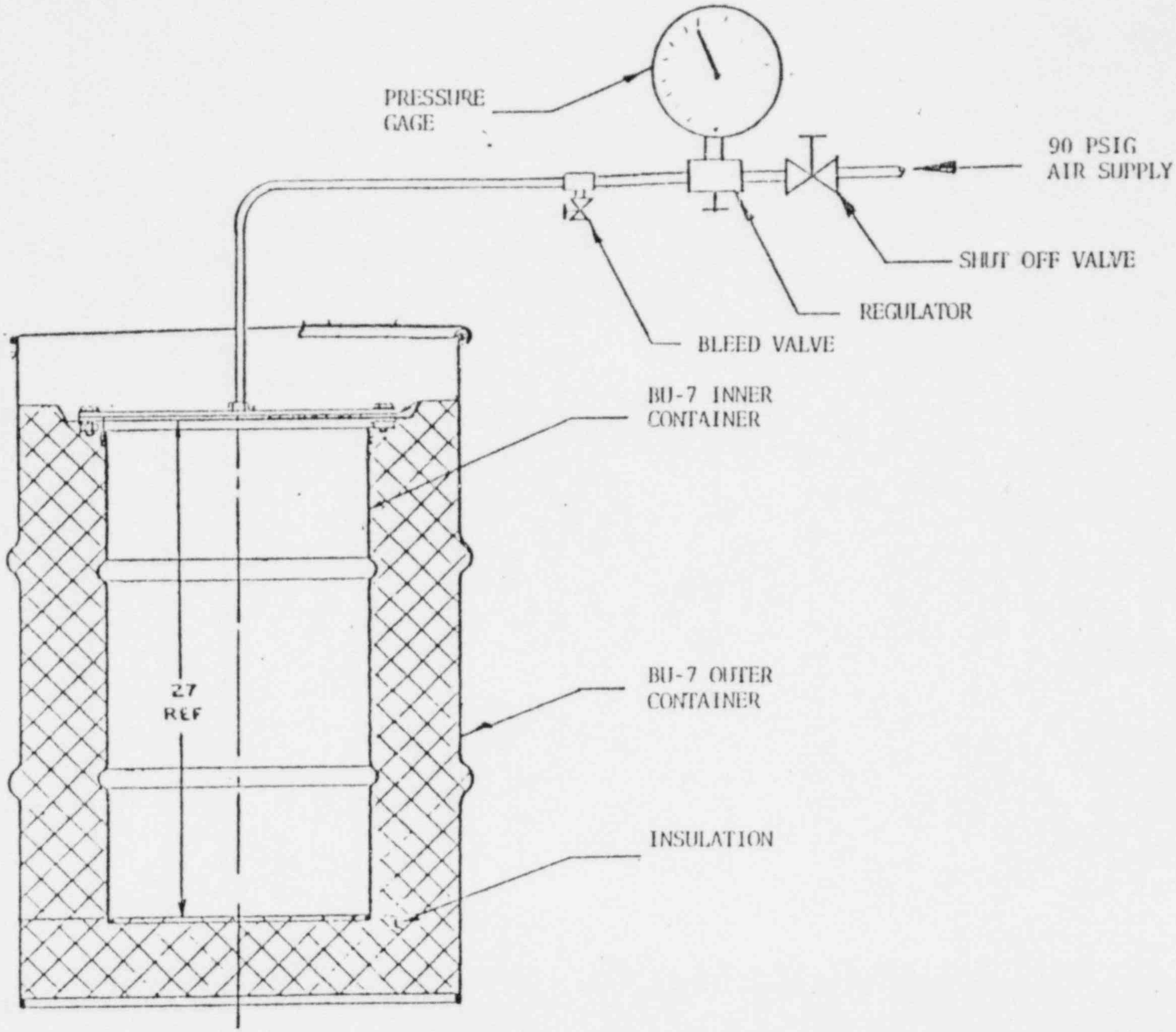


FIGURE 1 TEST SETUP

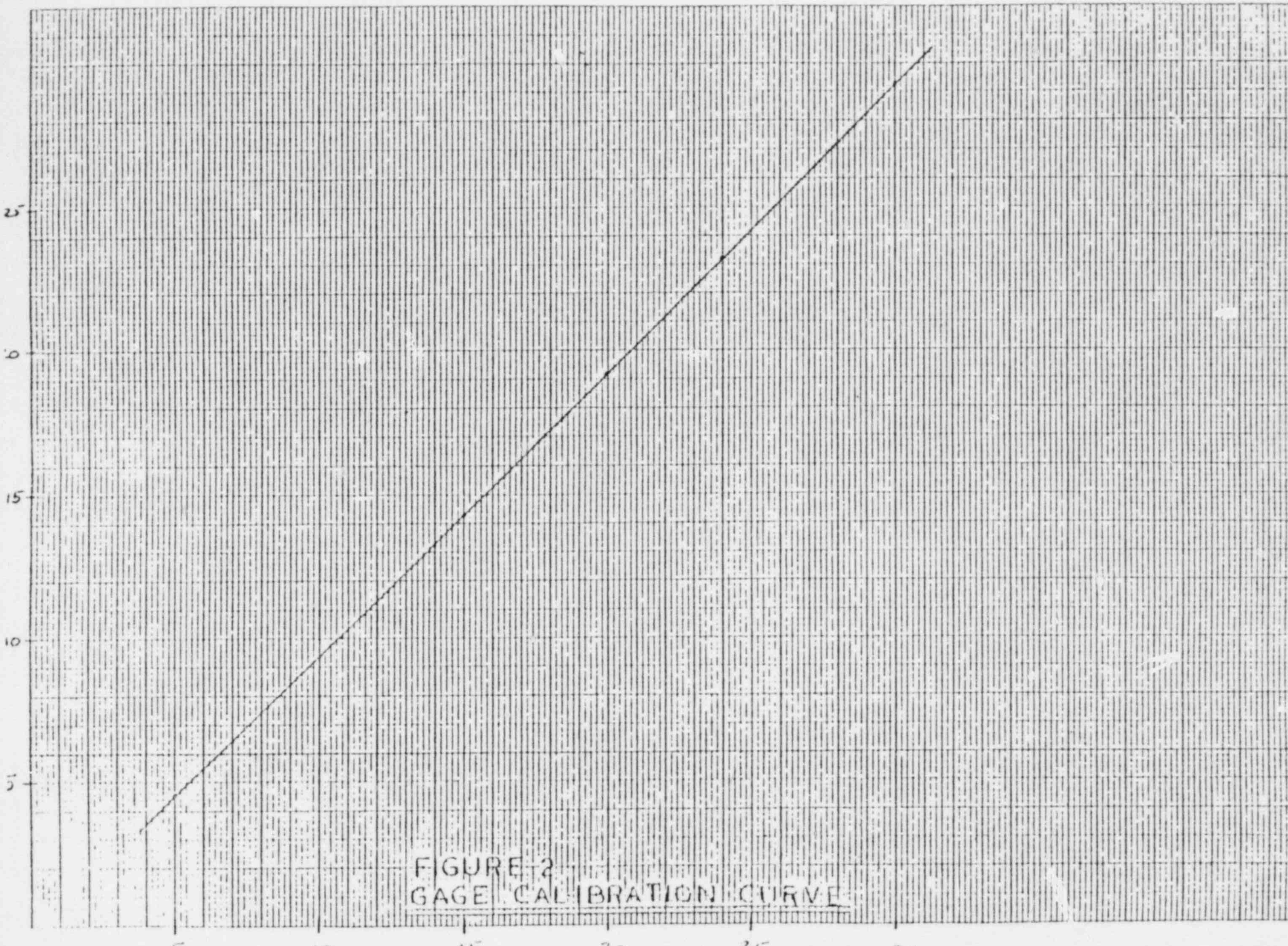


FIGURE 2
GAGE CALIBRATION CURVE

CONTAINERS– BU 5 S/N B-7522
BU 7 S/N KO397
TEST DATA

DATE	TIME	PRESSURE	PERIOD	TEST	RESULT
2-7-78	8:30 AM	50 ft WATER			
	4:30 PM		8 HRS	BU5 AND BU7	DID NOT LEAK
2-8-78	10:00 AM	.75 KG/CM^2			
	1:00 PM	.75 " "	3 HRS	BU5	NO LEAKAGE
	1:10 PM	1.0 KG/CM^2			
	4:15 PM	1.0 KG/CM^2	3¼ HRS	BU5	NO LEAKAGE
2-9-78	7:00 AM	1.25 KG/CM^2			
	10:00 AM	1.25 KG/CM^2	3 HRS	BU5	NO LEAKAGE
	10:10 AM	1.50 KG/CM^2			
	1:10 PM	1.50 KG/CM^2	3 HRS	BU5	NO LEAKAGE.
2-9-78	1:15 PM	.75 KG/CM^2			
-9-78	4:15 PM	.75 KG/CM^2	3 HRS	BU7	NO LEAKAGE
2-9-78	4:18 PM	1.0 KG/CM^2			
2-9-78	7:18 PM	1.0 KG/CM^2	3 HRS	BU7	NO LEAKAGE
2-9-78	7:20 PM	1.25 KG/CM^2			
2-10-78	9:20 AM	1.25 KG/CM^2	14 HRS	BU7	NO LEAKAGE
2-11-78	9:30 AM	1.50 KG/CM^2			
2-11-78	1:00 PM	1.50 KG/CM^2	3½ HRS	BU7	NO LEAKAGE

GENERAL ELECTRIC

TECHNOLOGY & DEVELOPMENT
METROLOGY & CALIBRATION LABORATORIES

CALIBRATION — MAINTENANCE RECORD

1. SERVICED BY: O. Caren	DATE: 1-31-78
2.	
3. REVIEWED BY	DATE

4. FAMILY CODE: PRESSURE	5. MFR CODE: MAR	6. MODEL/DWG NO.: PERMAGAGE 175		18. RACK/SYS IC NO.: N/A
7. IC NO.: N/A	8. STATUS: IN-USE	9. PREVIOUS CYCLE: N/A	10. MOS ELAPSED: N/A	11.
19. OPERATION: PACK. ENG.				
12. DATE SERVICED: FW 5 YR 78	13. DATE DUE: FW AS YR REQ'D	14. CAL HRS: 1.0	15. MAINT HRS: 0.0	16. OTHER HRS: 0.0
17.	20. LOCATION: TRAILER 9			
21. MANUFACTURER: MARSHALLTOWN	22. INSTRUMENT NAME: PRESSURE GAUGE	23. SERIAL NO.: 84155		

24. SPECIFICATIONS

- [x] MFG
- [ ] OTHER (DESCRIBE) –

25. PROCEDURE USED: ILCM-12-005

26. DATA ISSUED? [ ] YES [x] NO

27. REPORT NO.: None

28. TYPE OF SERVICE

- [x] CALIBRATION CERTIFICATION
- [ ] PREVENTIVE MAINTENANCE
- [ ] OTHER (EXPLAIN) –

29. RECEIVED: FW 5 YR 78

30. LAST SERVICED: FW N/A YR

31. ASSIGNED RECALL INTERVAL: AS REQ'D

32. SPECIFICATIONS? [x] IN [ ] OUT

33. LABORATORY ENVIRONMENT: TEMPERATURE 23 °C; RELATIVE HUMIDITY 47 %

34. OPERATIONAL? [x] YES [ ] NO

CALIBRATION INSTRUMENTATION USED

MFR CODE	MODEL DRAWING NUMBER	IC NO.	NEXT DUE FOR CAL	MFR CODE	MODEL DRAWING NUMBER	IC NO.	NEXT DUE FOR CAL
HE	CMM-8324	00053	5-5-78				

35. REMARKS

CALIBRATION DATA

INSTRUMENT NAME: PRESSURE GAUGE

IC NO.: N/A

MFR: MARSHALLTOWN

MODEL DRAWING NO.: PERMAGAGE 175

SERIAL NO.: 84155

FUNCTION AND/OR RANGE TESTED	CALIBRATION TOLERANCES	NOMINAL VALUE	MEASURED VALUES		
			INITIAL RUN	OUT OF TOL (✓)	FINAL RUN
0-60 PSIG			STANDARD		TEST GAUGE
		0	0		0
		5	4.5		5
		10	9.35		10
		15	14.25		15
		20	19.25		20
		25	24.20		25
		30	29.25		30
		40	39.60		40
		50	49.60		50
		60	59.60		60

GENERAL ELECTRIC

Director - ONMSS
July 25, 1980

APPLICATION FOR REVISION OF
NRC CERTIFICATE OF COMPLIANCE USA/9019/B()F
FOR THE BU-7 TRANSPORT PACKAGE

ENCLOSURE 1B

CRITICALITY SAFETY ANALYSIS

OF THE BU-7 SHIPPING PACKAGE FOR URANIUM OXIDE POWDER

A. L. Kaplan
:bmw

Prepared: 3/6/80

CRITICALITY SAFETY ANALYSIS OF BU-7 SHIPPING CONTAINER FOR UO_2 POWDER

1.0 INTRODUCTION

Model BU-7 shipping containers are used by the General Electric Company for the transportation of low-enriched unirradiated uranium oxide powder. The BU-7 container is a fissile Class I package which is currently licensed for a maximum U-235 enrichment of 4.0% with no more than two five-gallon containers, each limited to no more than one safe batch of UO_2 powder. In addition, it is required that the H/U ratio in the fuel in each five-gallon container must be no more than 0.45. The purpose of the present analysis is to extend the Fissile Class I certification for the BU-7 to include the following:

1.1 Increased water moderation by increasing the fuel H/U limit from 0.45 to 1.577.

1.2 Replacement of the safe batch limit with a limit of 35 Kg UO_2 per five-gallon container. The total BU-7 container mass limit is still 89 Kg.

1.3 Reduced levels of insulating media (phenolic resin) composition and densities requiring that at least 60% by weight of each of the constituents of the full density phenolic resin must be present.

1.4 The presence of carbon in the UO_2 fuel provided that the C/U ratio in the UO_2 fuel mixture does not exceed 1.262.

All other limits and requirements for the BU-7 container are unchanged.

2.0 ANALYSIS SCOPE

The present analysis has been undertaken to demonstrate that the GE Model BU-7 shipping container meets the applicable criticality safety standards for Fissile Class I shipping packages as required by Part 71, Title 10, of the Code of Federal Regulations.

2.1 BU-7 Container Specifications

This analysis is valid for the following BU-7 container specifications.

2.1.1 Outer Container

18-gauge, 55 gallon steel drum, or similar drums larger in dimensions or with thicker steel walls (reference Drawing 128D5231). Drums with smaller dimensions or with steel walls which are thinner than 18 gauge are not covered by this analysis.

2.1.2 Insulation

Phenolic resin containing the amounts of hydrogen, boron, carbon, nitrogen and chlorine and minimum resin density as shown in Table 4.1.

2.1.3 Inner Container

16-gallon, 18-gauge steel drum with an inner diameter of 13.75 ± 0.25 inches and an inner height of 27.75 ± 0.25 inches. This container must have a leak-proof seal and cover as described in Drawing 128D5231.

2.1.4 Contents

Two five-gallon steel containers or three three-gallon steel containers with an inner diameter no greater than 11.25 inches and with a total stacked height of no more than 27.64 inches. The steel containers must be at least 0.0206 inches thick.

Plastic bags wrapped around the five-gallon container or used as a liner inside of the container are permitted.

2.1.5 Fuel

Up to 70 Kg of UO_2 powder per BU-7 container at a U-235 enrichment of no more than 4.0%. Each five-gallon product container may hold no more than 35 Kg of UO_2. The UO_2 powder may be mixed with water or hydrogen-carbon additions subject to the requirements that the fuel-additive mixture may not exceed:

.1 an H/U ratio of 1.577

.2 a C/U ratio of 1.262

In addition, the bulk density of the UO_2 powder may not exceed 4.5 gm/cc.

2.2 Fissile Class I Criteria

To demonstrate that the BU-7 shipping container as described in Section 2.1 meets the criticality safety standards for Fissile Class I packages as defined in Part 71, Title 10, of the Code of Federal Regulations, the following calculations have been performed.

2.2.1 Normal Case

The K_∞ of an infinite array of BU-7 containers has been calculated for three cases: full density phenolic resin, 80% of full density phenolic resin and 60% of full density phenolic resin.

2.2.2 Accident Case

The K_{eff} of a 256 unit array has been calculated for the conditions of optimum interspersed moderation and full reflection of the array. This analysis was performed for BU-7 containers limited to 2 x 35 = 70 Kg of UO_2 as well as for the case of the two product (five gallon) containers filled with powder at a UO_2 density of 4.5 gm/cc (202 Kg UO_2 total).

2.2.3 Evaluation of Carbon

The most reactive cases in 2.2.1 and 2.2.2 (with 35 Kg UO_2/five-gallon container limit) were reanalyzed for UO_2-H_2O mixtures to which an additional amount of carbon was added. The atom density of the carbon was taken to be 80% of the atom density of hydrogen in the mixture to simulate mixtures of UO_2, 10,000 ppm by weight of water and 40,000 ppm by weight of H-C additives.

2.2.4 Accidents Involving a Single BU-7 Container

To demonstrate the safety of a single BU-7 container under extraordinary upset conditions, two five-gallon product containers have been analyzed for optimum moderation and full reflection by water.

2.2.5 Concrete Reflection

The impact of concrete reflection of the most reactive 256 unit array as described in Section 2.2.2 has been analyzed.

2.2.6 Code Validation

To demonstrate the validity of the computational codes used in this analysis, validation calculations have been made for the following cases:

.1 Comparison between codes for:

- Normal case (K_∞) BU-7 container

- 256 unit array of BU-7 containers with optimum interspersed moderation and full reflection by water

- A single BU-7 container with 0.075 gm/cc of interspersed water

- Two five-gallon containers in a vertical column with optimally moderated UO_2 and with full reflection by water

.2 Calculation of the K_{effs} of the low enriched U_3O_8 low moderated benchmark critical experiments described in Reference 7.

2.3 Analytical Methods

The criticality analysis of the BU-7 container has been performed with the General Electric Company MERIT and GEMER codes and with the KENO IV Monte Carlo Code. MERIT and GEMER are Monte Carlo neutron transport codes which employ 190 broad group cross section sets generated from ENDF/B-IV and which treat resonance absorption by explicitly modelling the resonance parameters on a discrete energy basis. The difference between MERIT and GEMER is that the former has a geometry package especially designed to model BWR lattices while the latter has an enhanced version of the regular and generalized geometry packages in the KENO IV code.

The KENO IV Monte Carlo Code was used in this analysis with 16 group modified Hansen and Roach cross section sets (Reference 5).

3.0 SUMMARY AND CONCLUSIONS

The results of this analysis have demonstrated that the GE Model BU-7 shipping container meets the criticality safety requirements of 10 CFR 71 for a Fissile Class I package for the transportation subject to the conditions specified in Section 2.1 of this analysis. In summary, these results are:

3.1 Normal Case

The K_∞ calculated with KENO IV for the normal case BU-7 container is 0.903 ± 0.003.

3.2 Accident Case

The K_{eff} calculated with KENO IV for the 256 unit array of BU-7 containers with the most reactive degree of interspersed moderation and with full reflection by water is

0.955 ± 0.005 for 202 Kg UO_2 per BU-7 container

and

0.750 ± 0.005 for 70 Kg UO_2 per BU-7 container

3.3 Presence of Carbon

The presence of carbon in amounts which result in a C/U ratio in the fuel of no more than 1.262 increases the $K_{effective}$ of the BU-7 container by less than 1.25%. Applying this to the values in 3.2 and 3.1 above for BU-7 containers limited to not more than 70 Kg UO_2 per container does not result in critically unsafe reactivities for these cases.

3.4 Two Five-Gallon (Product) Containers

The K_{eff} calculated with KENO IV of two closely packed five-gallon product containers with optimum moderation and full reflection by water is

K_{eff} = 0.968 ± 0.006 if the UO_2 contents of the containers are not restricted (approximately 65 Kg UO_2 per container)

or

K_{eff} = 0.909 ± 0.005 if the UO_2 contents of each of the containers are restricted to 35 Kg.

3.5 Concrete Reflection

Concrete reflection on all six sides of the 256 unit accident array of BU-7 containers (limited to 70 Kg UO_2 per container) results in a K_{eff} of 0.789 ± 0.004, an increase of 5.2% over the water reflected system.

3.6 Code Validation

The validation calculations performed in this analysis have demonstrated that

3.6.1 For infinite or finite arrays of BU-7 containers, MERIT and GEMER predict neutron multiplication factors from 2 to 5% lower than the values calculated by KENO IV. MERIT and GEMER results are in excellent agreement. The discrepancy with KENO is due in part to the cross-section sets used in the KENO calculations. The cross-section sets were determine based only upon the moderation in the fuel mixture.

3.6.2 For a single BU-7 container, MERIT, GEMER and KENO IV all agree with 0.4%.

3.6.3 Likewise, MERIT, GEMER and KENO IV are in excellent agreement for the case of two closely-packed optimally moderated fully reflected five-gallon containers (with UO_2 contents of 65.8 Kg or more per container).

3.6.4 For the Rocky Flats low enriched U_3O_8 low moderated benchmarks, the KENO IV calculated K_{eff} averaged over the 10 cases is 0.997 $\pm$ 0.002 and the GEMER value is 1.003 $\pm$ 0.003.(for 7 cases)

4.0 PACKAGE DESCRIPTION

BU-7 shipping containers are 55-gallon drums constructed of 18 gauge steel which contain an inner 16-gallon, 18 gauge steel drum enclosed in and supported by a phenolic resin liner. Specifications of the BU-7 shipping container are given in Figure 4.1, Drawing 128D5231, Figure 4.2 (ANSI MN 2.2-1974, UFC-Rule 40 55-gallon drum) and Figure 4.3 (ANSI MH 2.5-1974, DOT specification 17H 55-gallon drum), and include:

55 gallon drum dimensions:	Diameter	22½ inches
	Height	33 5/8 inches
	Thickness	0.0473 inches
	Material	Carbon steel
16 gallon drum inner dimensions:	Diameter	13 15/16 inches
	Height	27 inches
	Thickness	0.0428 inches
	Material	Carbon Steel
5 and 3 gallon product container:	Diameter	11 1/4 inches
Inner Dimensions	Height	13.5 inches (5 gallon)
		7.5 inches (3 gallon)
	Thickness	0.0208 inches
	Material	Carbon Steel

FIGURE 4.1 - BU-7 SHIPPING CONTAINER

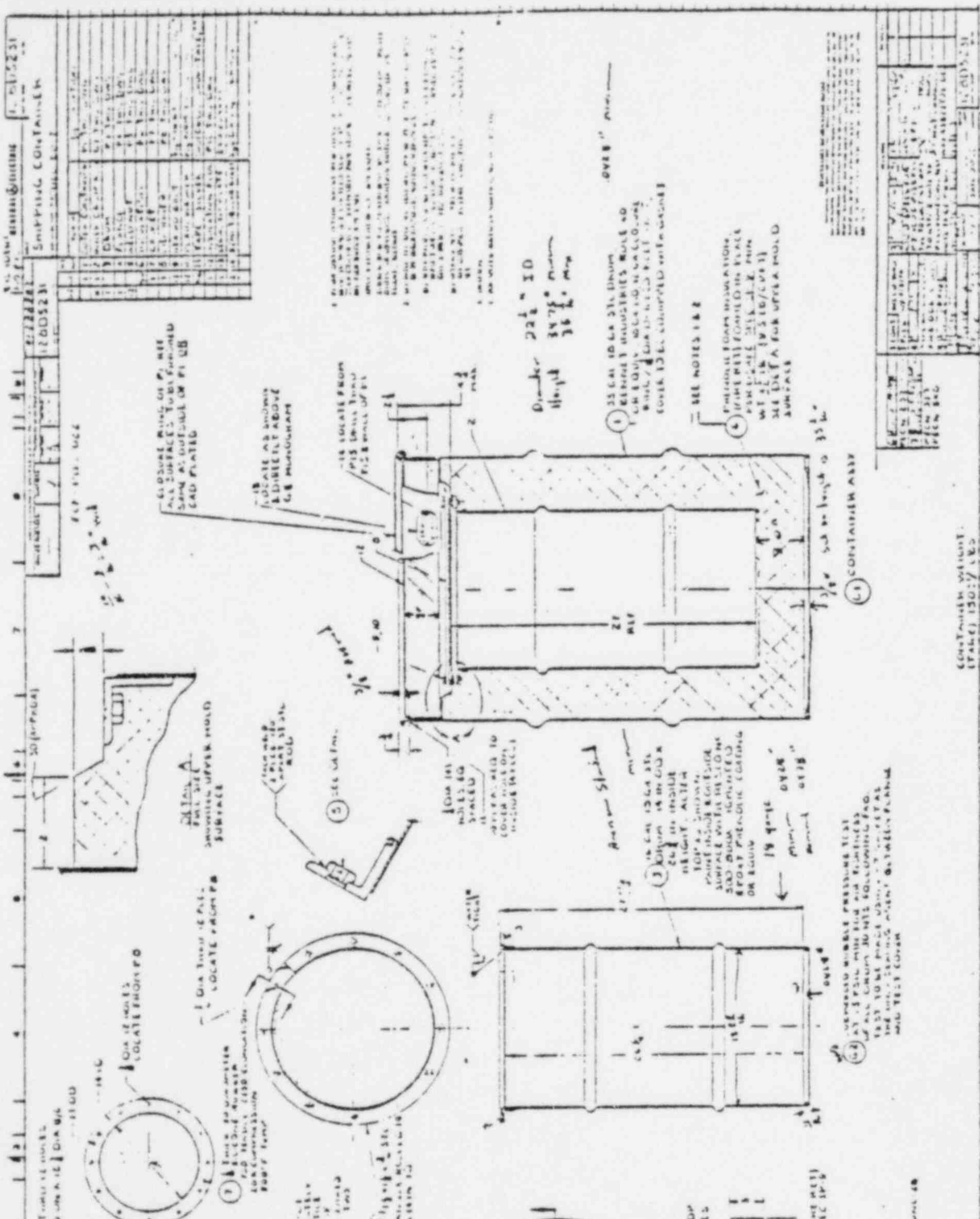
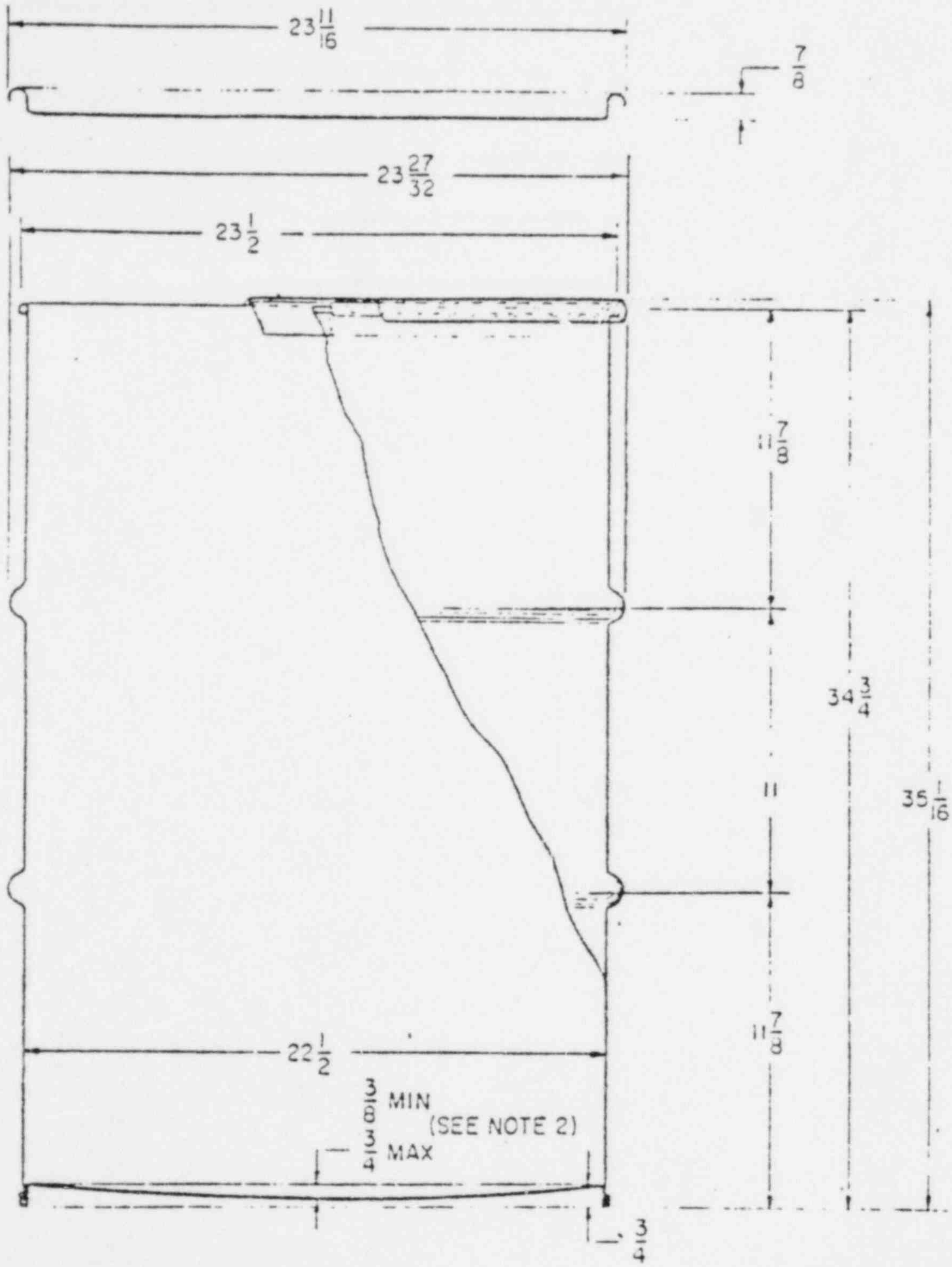


FIGURE 4.2 - UFC-RULE 40 55-GALLON DRUM

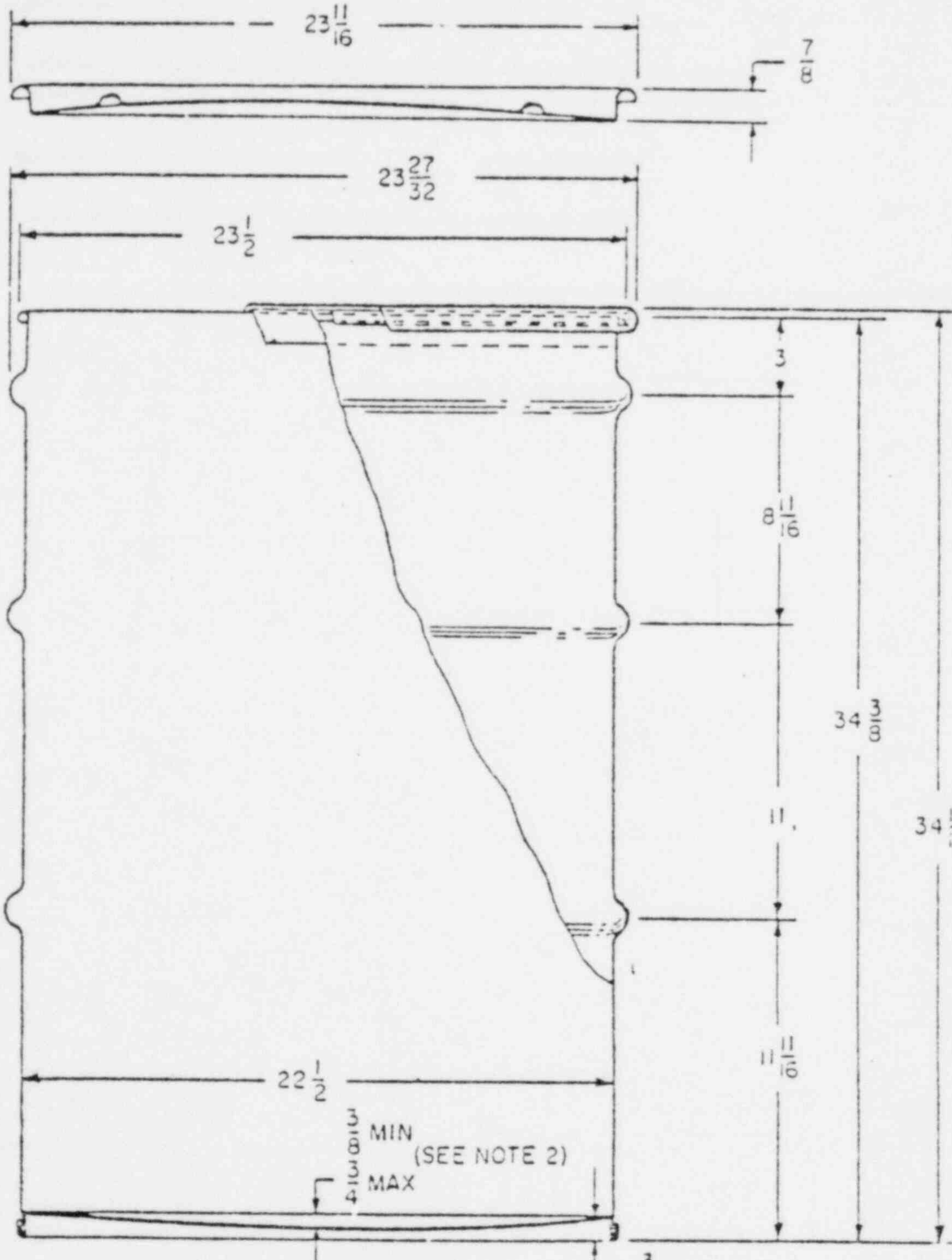


NOTES:

(1) All dimensions are in inches.

(2) Minimum convexity of bottom head is 3/8 inch.

FIGURE 4.3 - DOT SPECIFICATION 17H 55-GALLON DRUM



NOTES:
(1) All dimensions are in inches.
(2) These dimensions are applicable to both the top and bottom heads. Minimum convexity of each head is 3/8 inch.

The 16 gallon drum has been modified by the welded attachment of a closure flange to accept a 3/16 inch thick steel cover which is gasketed for resistance to high temperature and is attached by twelve 5/16-inch steel bolts. This gasket has been demonstrated to survive the drop, flame, flood and impact tests required by 10 CFR 71 and insures that the five gallon product pails contained within the 16 gallon drum do not come into contact with additional moderating materials (for example, water) as a result of the postulated accident conditions.

Due to the 11.25 inch inner diameter and maximum height of 13.5 inches, a single standard product pail has a volume of no more than 22.5 liters. This is less than the 29.0 liter safe volume limit for containers of optimally moderated UO_2 powder at enrichments not exceeding 4.0% U-235.

As described in Figure 4.1, the space between the concentric inner 16 gallon and outer 55 gallon drums is completely filled with a solid phenolic resin insulating material. The chemical composition of full density (8 ± 1 lbs/ft^3) phenolic resin is shown in Table 4.1.

TABLE 4.1 CHEMICAL COMPOSITION OF FULL DENSITY PHENOLIC RESIN INSULATION

ELEMENTAL WEIGHT PER CENT			ORGANIC COMPOUNDS-WEIGHT PER CENT	
Element Element		Full Density Weight Per Cent	Material	Weight Per Cent
Hydrogen		4.5	Union Carbide Phenolic Resin BRL 2760	65.8
Boron		3.2	Silicone Surfactant LS30	2.0
Carbon		41.0	Boric Anhydride B-203	8.2
Nitrogen	(approx)	0.0	Anhydride Oxalic Acide	8.2
Oxygen		48.6	Freon 113	6.6
Fluorine	(approx)	0.0	Fiberglass Roving	9.6
Silicone		2.2		
Chlorine		0.5		
Total		100.0		100.4

Density = 8 ± 1 lb/ft^3

Minimum Permissible Density 4.8 lb/ft^3

5.0 TECHNICAL CONSIDERATION

5.1 Mixtures Densities

The mixture atom densities used in this criticality safety analysis are tabulated in Appendix A. The 16 group modified Hansen and Roach U-235 and U-238 cross section sets used in the KENO IV Monte Carlo calculations were taken to be the sets corresponding to

$$\sigma^{min}_{U-235} \quad \text{and} \quad \sigma^{min}_{U-238}$$

with

$$\sigma^{min} \leq \sigma_p$$

as described in Table 5.1 and with no other σ satisfying

$$\sigma_p \leq \sigma \leq \sigma^{min}$$

The σ's are the potential scattering cross section values (in barns) corresponding to U-235 and U-238 cross-section sets (Reference 4).

TABLE 5.1 KENO IV RESONANCE ABSORPTION CROSS SECTION CALCULATIONS

$$\sigma_p = \frac{\sum^{i} N_i \sigma_i}{No}$$

where N_i = atom density of isotope i in mixture

σ_i = potential scattering cross section for material i as tabulated below

N_o = atom density of isotope whose effective resonance absorption cross section is being computed

Material/Isotope	σ_i (barns)
Hydrogen	20.0
Carbon	4.7
Oxygen	3.8
U-235	15.0
U-238	10.7
Water	43.8

5.1.1 Moderation of Fuel Mixture

As noted in Section 4.0, in leakage of water into the 16 gallon inner drum (and consequently into the five or three gallon product containers) does not occur under the postulated accident conditions (drop, flame, flood or impact). The level of moderation in the five or three gallon product containers will therefore not change when the BU-7 containers are subject to the postulated accident conditions. The maximum normal levels of water or hydrogeneous moderation in the UO_2 powder are:

.1 from 0.3 to 1.0% by weight of moisture (H_2O)

.2 for certain blends of UO_2 powder up to 4.0% by weight of hydrogen-carbon materials for which

- the hydrogen content is less than the equivalent of 4.0 weight per cent of water
- the ratio of atoms of hydrogen to atoms of carbon in the additive is no less than one.

5.1.2 Fuel Mixture

Atom densities of the fuel mixtures for 4.0% enriched UO_2 powder and water used in the present analysis are tabulated in Appendix A. These mixture densities were computed in one of two ways:

.1 Mixtures with 50,000 ppm of water or its equivalent

For systems of UO_2 powder and water in which the water content is restricted to low volumes, fuel-water mixtures may be determined by taking the maximum UO_2 density and water density possible. For UO_2 powder, the maximum density possible is less than 4.5 gm/cc unless mechanical presses (etc.) have been used to compress the powder. Mixtures of UO_2 and 50,000 ppm H_2O are then specified by

$$\rho_{UO_2} = 4.5$$

$$\rho_{H_2O} = \left(\frac{UO_2}{0.95}\right) * 0.05 = 0.23684 \text{ gm/cc}$$

$$N_{carbon} = 0.80 * N_H \quad \text{(atom densities)}$$

This last condition simulates a mixture of 10,000 ppm H_2O and 40,000 ppm of hydrogen-carbon additive in which the weight fraction of hydrogen is the same as that in water (11.19%) and for which the ratio of hydrogen atoms to carbon atoms (in the additive) is no less than one.

.2 UO_2 - H_2O Mixtures Occupying Minimum Theoretical Volumes

Given a weight fraction of water in the mixture, the densities of UO_2 and water are specified by

$$\rho_{UO_2} = \frac{\left(1 - WF_{H_2O}\right)}{\left(\frac{1 - WF_{H_2O}}{10.96}\right) + WF_{H_2O}}$$

and

$$\rho_{H_2O} = 1 - \frac{\rho_{UO_2}}{10.96}$$

As in 5.3.1, maximum permissible carbon content is determined by

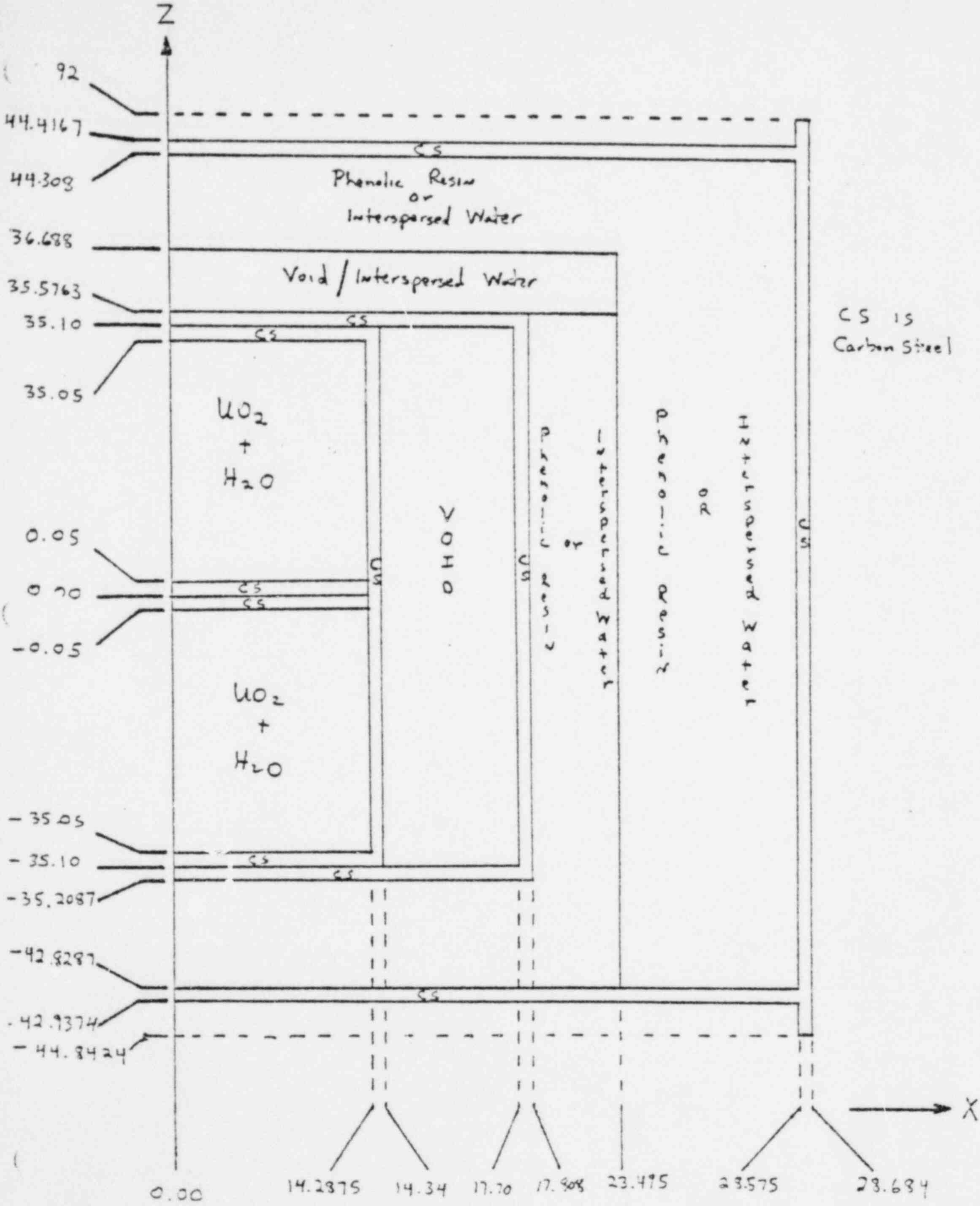
$$N_C = 0.80 * N_H$$

5.2 BU-7 Geometry model

The geometry model used in this analysis is illustrated in Figure 5.1 and the KENO IV and GEMER geometry input is tabulated in Tables 5.2 thru 5.4. For the normal case, the Figure 5.1 model was spacially reflected on all six sides (J = 0) to simulate an infinite array. Calculations were then performed for the phenolic resin insulation mixtures in Regions 6 and 8 or for varying amounts of interspersed water in Regions 6, 7, 8, 10 and 12. Calculations were also performed with interspersed water in Region 4 as well in order to evaluate the impact of close-packed moderation about the five or three gallon product pails. The three-gallon product pails were not explicitly modeled since it is readily evident that they are less reactive than the five-gallon containers (less UO_2, more carbon steel and smaller volumes).

For the accident analysis, a 256 unit array was defined with the same Table 5.2 - 5.4 geometry but with eight containers in the X and Y directions and four containers in the Z direction. The 8 x 8 x 4 configuration gives the array with the minimum geometrical buckling and is therefore the most reactive case from an array geometry standpoint.

FIGURE 5.1: KENO/GEMER GEOMETRY MODEL FOR BU-7 CONTAINER



All Dimensions in CM

TABLE 5.2: BU-7 CONTAINER INFINITE ARRAY GEOMETRY MODEL (KENO/GEMER INPUT)

Region	Geometry Type	Material	Radius* or ± X	±Height* or ± Y	± Z*
1	Cylinder	Carbon Steel	14.2875	± 0.05	
2	Cylinder	UO_2-H_2O Fuel Mixture	14.2875	± 35.05	
3	Cylinder	Carbon Steel	14.34	± 35.1	
4	Cylinder	Void	17.70	± 35.1	
5	Cylinder	Carbon Steel	17.808	35.5763	- 35.2087
6	Cylinder	Phenolic Resin or Interspersed Water	23.495	35.5763	- 42.8287
7	Cylinder	Void or Interspersed Water	23.495	36.688	- 42.8287
8	Cylinder	Phenolic Resin or Interspersed Water	28.575	44.308	- 42.8287
9	Cylinder	Carbon Steel	28.575	44.4167	- 42.9374
10	Cylinder	Void or Interspersed Water	28.575	45.3692	- 44.8424
11	Cylinder	Carbon Steel	28.684	45.3692	- 44.8424
12	Cuboid	Void or Interspersed Water	±28.684	± 28.684	45.3692 - 44.8424
13	Core	Void	±28.684	± 28.684	45.3692 - 44.8424
14	Cuboid	Void	±28.684	± 28.684	45.3692 - 44.8424

* Dimensions in cm

TABLE 5.3: GEOMETRY MODEL MODIFICATIONS FOR 35 KG UO_2 CALCULATIONS (KENO/GEMER INPUT)

Region	Geometry Type	Material	Radius+	± Height+	
1*	Cylinder	Carbon Steel	14.2875	± 0.05	
1A	Cylinder	Void	14.2875	0.05	A
2	Cylinder	$UO_2 - H_2O$ Fuel Mixture	14.2875	B	-35.05
2A	Cylinder	Void	14.2875	35.05	-35.05
3	Cylinder	Carbon Steel	14.34	± 35.1	

Fuel Mixture No.	Height of+ Fuel in Container	A+	B+
1	12.128	- 22.922	12.178
2	20.0	- 15.05	20.05
3	35.0	- 0.05	35.05

*Unchanged

+Dimensions in cm

TABLE 5.4: GEOMETRY MODEL MODIFICATIONS FOR 8 x 8 x 4 FINITE ARRAY (KENO/GEMER INPUT)

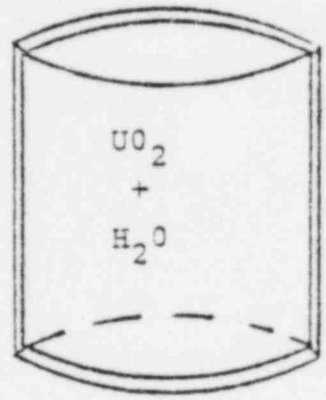
Region	Geometry Type	Material	± X[+]	± Y	±Z[+]
12*	Cuboid	Carbon steel	± 28.684	± 28.684	45.3692
13	Core	Void	± 229.472	±229.472	±180.4232
14	Cuboid	Full Density Water (or concrete)	± 260.0	±260.0	±212.0

*Unchanged

+Dimensions in cm

FIGURE 5.2 - FIVE-GALLON PRODUCT CONTAINER GEOMETRY MODEL

A. SINGLE CONTAINER (FGC)



ID = 28.575 cm
IH = 35.0 cm

OD = 28.680 cm
OH = 35.1 cm

Walls - carbon steel

B. TWO FIVE-GALLON CONTAINERS

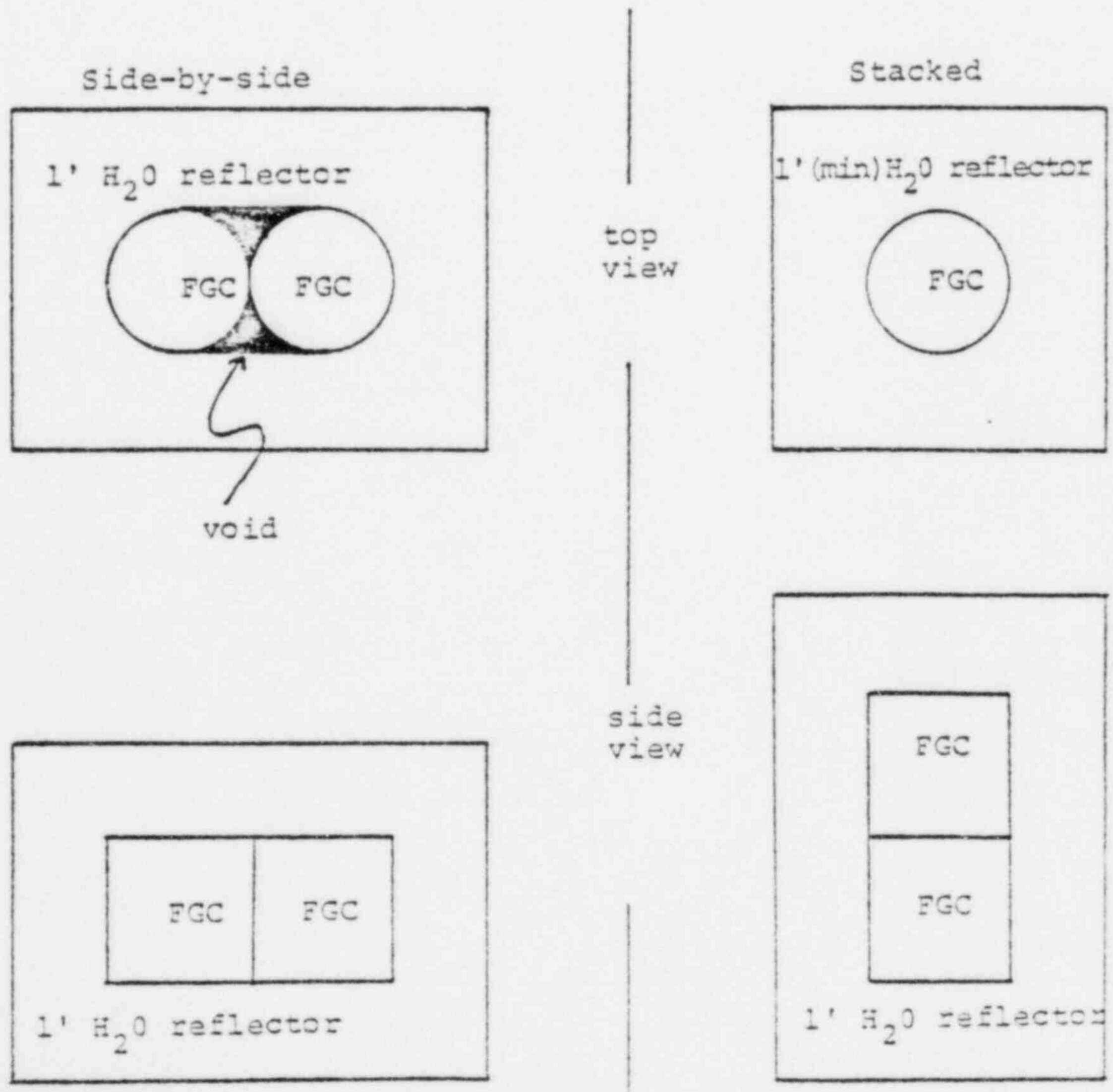
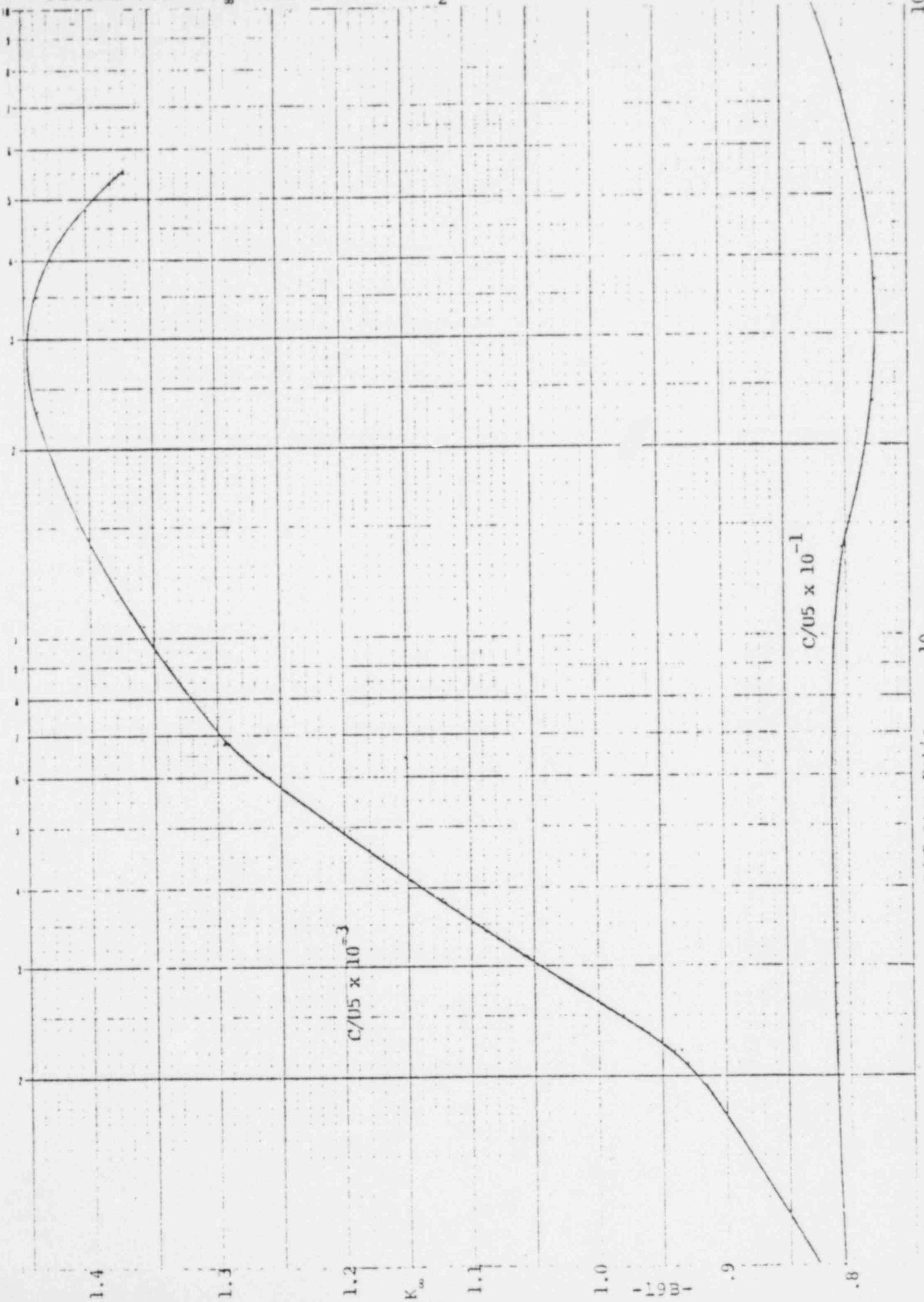


FIGURE 6.1 - K_∞ for U (4.05) O_2 - Carbon System



Tight reflection of the 256 unit array was modeled by 12-inch thick slabs of full density water on all six sides of the array. For the case of concrete reflection, the 12-inch thick slabs were replaced with 16-inch thick concrete slabs (KENO IV material number 300).

One aspect of the Figure 5.1 geometry model that should be noted is that the dimensions used are conservative as compared to the actual BU-7 container described in Figures 4.1 and 4.2. This especially applies to the use of the 22.5 inch inner diameter for the maximum size of the 55 gallon drum rather than taking credit for the 23½ inch diameter of the drum provided by the two or three corrugations along the length of the container. This constitutes a reduction by at least 4½% in the diameter and 9% in the volume of the drum and is a significant factor of conservatism in the analysis of the 256 unit accident array. This reduction of 9% in the volume conservatively simulates the collapsing of the rolling heaps on the lateral surface of the drums under the postulated accident conditions (drop, flame, flooding).

It is advised that the geometry model used in this analysis for the BU-7 container is different from that used in the Reference 3 analysis. The Figure 5.1 model is more conservative than the one previously used.

5.3 Five Gallon Product Container Geometry Model

The five gallon product containers have been modeled in this analysis as shown in Figures 5.2. The ID = 28.575 cm, IH = 35.0 cm dimensions slightly overestimate the true size of a five-gallon product container (the value is 22.44 liters as compared to the true value of less than 22.0 liters), and the model is therefore conservative, especially since the carbon steel walls are modeled as being less than 0.0207 inches thick.

6.0 RESULTS

6.1 BU-7 Container Analysis

Tables 6.1 through 6.5 show the results of the MERIT/GEMER/KENO IV calculations for the BU-7 container.

6.1.1 Normal Case

TABLE 6.1 NORMAL CASE K_∞s for BU-7 CONTAINER*

PERCENT OF FULL DENSITY OF PHENOLIC RESIN	$K_\infty \pm \sigma$ GEMER	MERIT	KENO IV
100	0.758 ± 0.004	0.753 ± 0.004	0.790 ± 0.004
80	0.799 ± 0.004	0.804 ± 0.003	0.843 ± 0.004
60	0.853 ± 0.004	0.850 ± 0.003	0.903 ± 0.003

*with 202 Kgs UO_2 per BU-7 container

These results show that the normal case infinite array of BU-7 containers is critically safe and that the phenolic resin serves as an "overmoderating" influence in that the more resin present the lower than K_∞.

Comparison of MERIT, GEMER and KENO show that MERIT and GEMER are in good agreement but that KENO overpredicts the K_∞s relative to them by from five to six per cent.

6.1.2 Accident Case - Optimum Interspersed Water

.1 Infinite Arrays

These calculations were performed in order to compare MERIT/GEMER and KENO. (The MERIT geometry package is unable to model the 256 unit finite array.)

TABLE 6.2 - K_∞ FOR BU-7 CONTAINER† WITH OPTIMUM INTERSPERSED WATER *

		$K_\infty \pm \sigma$	
INTERSPERSED WATER (gm/cc)	GEMER	MERIT	KENO IV
0.000	1.111 ± 0.003	1.106 ± 0.003	1.163 ± 0.003
0.025	1.147 ± 0.003	1.147 ± 0.003	1.182 ± 0.004
0.050	1.117 ± 0.003	1.116 ± 0.003	1.153 ± 0.004
0.075		1.067 ± 0.003	1.099 ± 0.004
0.100		1.021 ± 0.003	1.046 ± 0.003
0.200		0.829 ± 0.003	0.848 ± 0.004
0.500		0.634 ± 0.004	0.642 ± 0.004
1.000		0.610 ± 0.004	0.617 ± 0.004

† With 202 Kg UO_2 per BU-7 container

* Interspersed water in Regions 6, 7, 8, 10 and 12 (Table 5.2)

TABLE 6.3 - K_∞ FOR BU-7 CONTAINER† WITH CLOSE PACKED OPTIMUM INTERSPERSED WATER*

Interspersed Water (gm/cc)	KENO IV $K_\infty \pm \sigma$
0.000	1.163 ± 0.004
0.025	1.185 ± 0.003
0.050	1.144 ± 0.004
0.075	1.065 ± 0.004
0.100	1.008 ± 0.004
0.200	0.792 ± 0.004
0.500	0.641 ± 0.005
1.000	0.657 ± 0.004

† With 202 Kg UO_2 per BU-7 container

* Interspersed water in Region 4 as well as in Regions 6, 7, 8, 10 and 12 (Table 5.2)

Table 6.2 indicates the same trends as shown in Table 6.1. GEMER and MERIT are in good agreement but KENO IV overpredicts the K_∞s relative to them by three to five per cent in the region around optimum interspersed moderation.

Table 6.3 indicates that, as is to be expected, a slight shift may exist in the density of interspersed water corresponding to optimum moderation, but the impact on the K_∞s is smaller than the Monte Carlo statistical uncertainties. This is evidence that the addition of hydrogen anywhere outside of the UO_2 fuel has been implicitly considered by analyzing the BU-7 container arrays for optimum interspersed moderation between containers (and within the 55 gallon drums).

.2 Single Container

To provide a further comparison between MERIT, GEMER and KENO IV, the K_{eff} of a single BU-7 container was calculated. The conditions for this calculation were 202 Kg UO_2 in the container and 0.075 gm/cc of water in Regions 6, 7, 8, 10 and 12 (see Table 5.2). The results were:

Code	K_{eff}	$\pm$	σ
GEMER	0.355	$\pm$	0.004
MERIT	0.356	$\pm$	0.003
KENO IV	0.356	$\pm$	0.004

.3 Accident Case - 8 x 8 x 4 Arrays of BU-7 Containers

The GEMER and KENO IV results for the analysis of the 8 x 8 x 4 arrays of BU-7 containers with optimum interspersed water are given in Tables 6.4 and 6.5. Table 6.4 is for the case in which the BU-7 containers each hold 202 Kg UO_2 (full five-gallon product pails at 4.5gm UO_2/cc) while Table 6.5 contains the results for the containers limited to 70 Kg UO_2 each (35 Kg UO_2 per five-gallon product pail).

TABLE 6.4 - K_{eff}s for 8 x 8 x 4 ARRAY[†] OF BU-7 CONTAINERS (202 Kg UO_2 PER CONTAINER)

Interspersed Water (gm/cc)	$K_{eff} \pm \sigma$ GEMER	KENO IV
0.000		0.853 ± 0.004
0.025	0.884 ± 0.004	0.906 ± 0.004
0.050	0.924 ± 0.004	0.955 ± 0.005
0.075	0.928 ± 0.005	0.944 ± 0.004
0.100		0.929 ± 0.005
0.200		0.802 ± 0.003
0.500		0.637 ± 0.004
1.000		0.617 ± 0.005

† The array is tightly reflected on all six sides by 12 inches of water. No interspersed water is placed in Region 4 (see Table 5.2)

TABLE 6.5 - K_{eff}s for 8 x 8 x 4 Array† of BU-7 Containers (70 Kg UO_2 Per Container)

Interspersed Water (gm/cc)	KENO IV $K_{eff} \pm \sigma$ Height in Can of 12.128 cm	Height in Can of 20.0 cm	Height in Can of 35.0 cm (Full)
0.000	0.534 ± 0.004	0.530 ± 0.003	0.532 ± 0.003
0.025	0.609 ± 0.004	0.624 ± 0.005	0.655 ± 0.005
0.050	0.637 ± 0.004	0.679 ± 0.004	0.731 ± 0.004
0.075	0.656 ± 0.004	0.693 ± 0.004	0.750 ± 0.005
0.100	0.641 ± 0.004	0.681 ± 0.005	0.743 ± 0.004
0.200	0.537 ± 0.004	0.573 ± 0.004	0.623 ± 0.004
0.500	0.419 ± 0.004	0.410 ± 0.004	0.427 ± 0.004
1.000	0.417 ± 0.004	0.406 ± 0.004	0.401 ± 0.005
0.075 Single BU Container	0.149 ± 0.002	0.231 ± 0.002	0.351 ± 0.003

†The array is tightly reflected on all sides by 12 inches of water. No interspersed water is placed in Region 4 (see Table 5.2).

It is concluded from those two tables that the BU-7 container array is critically safe under the postulated optimum interspersed moderation, full reflection accident condition even if the individual BU-7 container mass limit of 70 Kg UO_2 is exceeded. This assumes that the H/U = 1.577 and C/U = 1.262 limits are still met.

As in the previous cases, the KENO IV results around the optimum interspersed water level are one to three per cent higher than the corresponding GEMER values. (The 8 x 8 x 4 array cannot be modeled in MERIT due to geometry limitations.)

The K_{eff} for the 8 x 8 x 4 array with optimum interspersed water and full reflection and with the 70 Kg UO_2 limit per container is 0.750 ± 0.005 (at 0.075 gm H_2O/cc interspersed water.) For comparison, this case was analyzed replacing the tight water reflector by a tight 16-inch thick concrete reflector (on all six sides). The KENO IV K_{eff} for this case was 0.789 ± 0.004, an increase of 5.2%.

6.2 EVALUATION OF CARBON ADDITIVES

From Reference 8, the relative moderating factor for a mixture of water and carbon can be determined to be:

$$\text{Moderating factor} = 20\, N_H + 0.76\, Nc + 0.50\, No$$

where N_H, Nc, and No are the corresponding atom densities for hydrogen, carbon, and oxygen in the moderator. It follows from this relationship that the worth of carbon as a moderator is 0.76 ÷ 20 = 0.038 times the worth of hydrogen. Applying this value to the mixture of UO_2, water and hydrogen-carbon additives which is approved for the BU-7 container, (an H/U atomic ratio of 1.577 and a C/u atomic ratio of 1.262) then results in an equivalent UO_2 - H_2O mixture with 51438 ppm H_2O as opposed to the 50,000 ppm H_2O limit for the H/U ratio of 1.577.

The effect of the additional 1438 ppm H_2O equivalence can be estimated from existing tabulated data (Reference 6) to be less than 1.0% in K. However, as part of the present analysis of the BU-7 container, additional calculations have been made using the KENO IV Monte Carlo code to evaluate the effect of carbon on 4.0% enriched UO_2 systems. The results of these are given in Tables 6.6 through 6.10.

TABLE 6.6 K_∞ s of $U(4.05)O_2$ - Carbon[†] Systems

Weight Fraction of Carbon in Mixture	C/U-235 Atomic Ratio	KENO IV $K_\infty \pm \sigma$
0.00	0.0	0.806 ± 0.002
0.10	61.6	0.814 ± 0.002
0.20	138.7	0.803 ± 0.002
0.30	237.8	0.778 ± 0.002
0.40	369.9	0.775 ± 0.002
0.50	554.9	0.788 ± 0.002
0.60	832.4	0.809 ± 0.003
0.70	1294.8	0.867 ± 0.003
0.80	2219.6	0.936 ± 0.003
0.85	3144.4	1.056 ± 0.003
0.875	3884.3	1.122 ± 0.003
0.90	4994.1	1.196 ± 0.003
0.925	6843.7	1.303 ± 0.003
0.95	10543.	1.359 ± 0.003
0.975	21641.	1.438 ± 0.003
0.982	30273.	1.448 ± 0.003
0.990	54935.	1.377 ± 0.003

† The theoretical density of carbon was taken to be 2.25 gms/cc

TABLE 6.7 MINIMUM CRITICAL MASSES OF $U(4.05)O_2 - H_2O$ CARBON* SYSTEMS

Weight Fraction of H_2O	Weight Fraction of Carbon	C/U-235 Atomic Ratio	KENO IV calc. Min. Critical Mass of UO_2 (Kg)
0.0	0.975	21641	140.9
	0.982	30273	128.1
	0.990	54935	147.4
0.05	0.0	0.00	2208
		22.84	1954.5
		30.0	1658.0
		200.0	861.3
		1000.0	419.8
0.10	0.0	0.00	337.5
		22.84	277.6
		200	262.3
		1000	164.0
0.20	0.0	0.00	101.0
		22.84	104.9
		200	108.9
		1000	93.7
0.30	0.0	0.00	74.4
		22.84	70.9
		200	76.7
		1000	101.8
0.40	0.0	0.00	65.9
		22.84	66.2
		200	73.2
		1000	331.6
0.50	0.0	0.00	68.6
		22.84	73.5
		200	96.9

* ρ_c^T = 2.25 gm/cc

+ Water reflected

TABLE 6.8 MINIMUM CRITICAL MASSES OF U(4.05) O_2 - H_2O SYSTEMS

Weight Fraction of H_2O	H/U Atomic Ratio	KENO IV Calculated Minimum Critical Mass of UO_2 (Kg)
0.05	1.577	2208.
0.10	3.330	337.5
0.20	7.492	101.0
0.30	12.84	74.4
0.40	19.98	65.9
0.50	29.97	68.6
0.60	44.95	113.7
0.70	69.92	1770.

TABLE 6.9: MERIT VERIFICATION OF KENO IV UO_2 MINIMUM CRITICAL MASSES †

C/U-235 Atomic Ratio	Weight Fraction of Water	Critical Radius	UO_2 Critical Mass (Kg)	MERIT $K_{eff} \pm \sigma$
0	0.30	20.98	74.4	1.0031 ± 0.0042
0	0.40	22.84	65.9	1.0041 ± 0.0039
0	0.50	26.14	68.6	0.9941 ± 0.0033
22.84	0.30	21.12	70.9	0.9895 ± 0.0048
22.84	0.40	23.34	66.2	1.0019 ± 0.0043
22.84	0.50	27.23	73.5	1.0016 ± 0.0034
1000	0.10	36.24	164.0	0.9926 ± 0.0048
1000	0.20	33.01	93.7	0.9963 ± 0.0042
1000	0.30	37.16	101.8	0.9819 ± 0.0039

† See Table 6.7

TABLE 6.10 - BU-7 CONTAINER ANALYSIS WITH CARBON[+]

A. Normal case K_∞ with 60% of full density phenolic resin (202 Kg UO_2 per BU-7 container)

KENO IV K_∞ without carbon	0.903 ± 0.003
KENO IV K_∞ with carbon	0.913 ± 0.005

B. Accident case: 8 x 8 x 4 water reflected array with 70 Kg UO_2[*] per BU-7

Density of Interspersed H_2O (gm/cc)	KENO IV K_{eff} (without carbon)	KENO IV K_{eff} (with carbon)
0.025	0.655 ± 0.005	0.663 ± 0.004
0.050	0.731 ± 0.004	0.731 ± 0.004
0.075	0.750 ± 0.005	0.757 ± 0.005
0.100	0.743 ± 0.004	0.745 ± 0.004

[+] C/U = 1.262

[*] Height of fuel in five gallon product pails is 35.0 cm

The K_∞ results in Table 6.6 can be compared with the tabulated values in Reference 6 for $U(4.0)\ O_2 - H_2O$ in which the maximum K_∞ is no greater than 1.40. Figure 6.1 is a plot of the Table 6.6 results. In addition, if all the moderator in the UO_2 - moderator mixture in the BU-7 containers were carbon, Table 6.6 indicates that the K_∞ of the fuel would be less than 0.8. (An H/U ratio of 1.577 and C/u ratio of 1.262 imply an effective "C/U" ratio of 42.737 when using the 0.038 equivalence factor between carbon and hydrogen). The K_∞ of a $U(4.0)\ O_2 - H_2O$ mixture with 40000 ppm H_2O (a H/U ratio of 1.577) is greater than 1.0.

Tables 6.7 and 6.8 show minimum critical masses calculated with KENO IV for $U(4.05)O_2 - H_2O$-C and $U(4.05)O_2 - H_2O$ systems. These two tables indicate that the minimum critical mass occurs for pure UO_2-H_2O mixtures and that the presence of carbon therefore results in dilution of the fuel mixture. Table 6.7 clearly establishes however that carbon moderation can be appreciable for under moderated systems such as the BU-7 container. In this regard, the entries in Table 6.7 for 0.05 weight fraction of water indicate the impact of the C/U = 1.262 BU-7 container limit. With no carbon, the minimum critical mass at the H/U ratio of 1.577 (i.e., 0.05 weight fraction water) is 2208 Kg UO_2. With a mixture containing carbon with a C/U-235 ratio of 30, (an H/U of about 1.2), the critical mass decreases to 1657.7 Kg UO_2, a 33% effect.

Table 6.9 presents a verification of the KENO IV UO_2 minimum critical masses which was performed with the MERIT Monte Carlo code. The MERIT code was used to calculate the K_{eff} of the UO_2 spheres determined to be critical with KENO IV (via the search option). The results show excellent agreement between MERIT and KENO IV for these $UO_2 - H_2O$-carbon systems.

Finally, Table 6.10 summarizes the results of KENO IV calculations for the BU-7 container normal case and accident case analyses described in Section 6.1 with the addition of carbon in the fuel mixtures. The C/U ratio for these calculations is 1.262. As can be seen, the addition of the carbon increases the K_∞ and K_{eff} values by no more than 1.25%. In both cases, the BU-7 container system is still subcritical.

6.3 Analysis of five Gallon Product Pails

The safety of individual BU-7 containers has been analyzed by calculating the effective neutron multiplication factors of two five gallon product pails under conditions of optimum moderation and full reflection. The results of these calculations are shown in Tables 6.11 and 6.12. Table 6.11 gives the results of KENO IV calculations for two five gallon containers placed side by side (and touching) with tight water reflection in all areas except immediately between the two containers. The maximum K_{effs} for this case are:

0.968 ± 0.006 for 65.8 Kg UO_2 per container

and

0.909 ± 0.005 for 35.0 Kg UO_2 per container

Table 6.12 gives the results of calculations for the two five gallon containers stacked in a vertical column. Again, the containers are touching and the assembly is tightly reflected by at least 12 inches of water. The maximum K_{effs} for the vertical arrangement are:

0.964 ± 0.005 for 65.8 Kg UO_2 per container

and

0.904 ± 0.004 for 35.0 Kg UO_2 per container

Since the BU-7 shipping container is limited to 35.0 Kg per five gallon product pail, the criticality safety of an individual container is established for the case of optimum moderation and full reflection.

TABLE 6.11 - ANALYSIS OF TWO FIVE GALLON CONTAINERS SIDE BY SIDE

A. Full Containers with Maximum UO_2 Masses

Weight Fraction of H_2O in Fuel	Mass of UO_2 in Single Container (Kg)	KENO IV $K_{eff} \pm \sigma$
0.05	156.0	0.805 ± 0.004
0.10	110.9	0.890 ± 0.005
0.20	65.8	0.968 ± 0.006
0.30	43.2	0.947 ± 0.006
0.40	29.6	0.909 ± 0.005
0.50	20.6	0.841 ± 0.003

B. Containers with 35 Kg UO_2 Mass Limits

Weight Fraction of H_2O in fuel	KENO IV K_{eff}s Minimum Height in cans	Intermediate Height in cans	Full cans 35.0 cm
0.05	0.581 ± 0.004 (12.128 cm)	0.538 ± 0.004 (20.0 cm)	0.534 ± 0.004
0.10	0.639 ± 0.005 (12.128 cm)	0.579 ± 0.004 (20.0 cm)	0.537 ± 0.004
0.20	0.801 ± 0.005 (18.624 cm)	0.746 ± 0.004 (25.0 cm)	0.688 ± 0.004
0.30	0.885 ± 0.005 (28.370 cm)		0.851 ± 0.004
0.40	0.909 ± 0.005 (35.0 cm)		
0.50	0.841 ± 0.003 (35.0 cm)		

TABLE 6.12 - ANALYSIS OF TWO FIVE GALLON CONTAINERS STACKED VERTICALLY

A. Full Containers with Maximum UO_2 Masses

Weight Fraction of H_2O in Fuel	Mass of UO_2 in Single container	KENO IV $K_{eff} \pm$	MERIT $K_{eff} \pm$	GEMER $K_{eff} \pm$
0.05	156.0	0.804±0.004		
0.10	110.9	0.902±0.006		
0.20	65.8	0.964±0.005	0.955±0.004	0.953±0.006
0.30	43.2	0.954±0.005		
0.40	29.6	0.904±0.004		
0.50	20.6	0.850±0.005		

B. Containers with 35 Kg UO_2 Mass Limits

Weight Fraction of H_2O in Fuel	KENO IV Keffs: Minimum Height in Cans	KENO IV Keffs: Intermediate Height in Cans	KENO IV Keffs: Full Cans (Height=35.0cm)
0.05	0.586±0.005 (12.128 cm)	0.550 ± 0.004 (20.0 cm)	0.519 ± 0.004
0.10	0.633±0.004 (12.128 cm)	0.578 ± 0.005 (20.0 cm)	0.536 ± 0.005
0.20	0.793 ± 0.005 (18.624 cm)	0.736 ± 0.005 (25.0 cm)	0.678 ± 0.005
0.30	0.881 ± 0.005 (28.370 cm)		0.851 ± 0.005
0.40	0.904 ± 0.004 (34.0 cm)		
0.50	0.850 ± 0.005 (35.0 cm)		

The K_{eff} = 0.909 ± 0.005 and 0.904 ± 0.004 results listed above constitute upper limits for extreme accident conditions since the moderation limit in the containers is limited by BU-7 specifications to 50,000 ppm H_2O or less. (50,000 ppm is the same as a weight fraction of 0.05.)

In Table 6.12 K_{eff} results have also been presented for MERIT and GEMER calculations of the vertically stacked assembly with 65.8 Kg UO_2 (weight fraction of water = 0.20). The MERIT and GEMER results for this case are in excellent agreement and are about 1% lower than the KENO IV result.

Finally, it is noted that the presence of carbon in these containers has been found in Section 6.2 to increase the K_{effs} by no more than 1.25% provided that the H/U = 1.577 and C/U = 1.262 limits are met. The conditions analyzed in Tables 6.11 and 6.12 would in such accident conditions still correspond to a C/U = 1.262 case but the H/U ratio would exceed 7.5 (see Table 6.8). In this case the presence of the low level of carbon would have an even smaller effect on the system K_{effs}. Nevertheless, if the system K_{effs} were to increase by 1.25%, the two 5 gallon containers with 35 Kg UO_2 in either geometry arrangement would still be critically safe since most K_{effs} would be no higher than 0.920.

6.4 Evaluation of Rocky Flats Low Enriched Low Moderation U_3O_8 Benchmark Critical Experiments

Reference 7 describes a set of benchmark critical experiments that were performed by Rockwell International (Rocky Flats Plant) to provide data for low enriched Uranium Oxide systems with low levels of moderation. The Rocky Flats experiments consisted of a 5X5X5 array of Aluminum tins which contained 4.46% enriched U_3O_8 powder and for which the average hydrogen content in the entire assembly resulted in an H/U ratio of 0.77. Ten different cases were run for the critical experiments corresponding to the type of fully enriched Uranium Driver (metal, low Uranium content solution or high Uranium content solution) and to the type of reflector (concrete, metal or plastic). Measured amounts of water were added to the U_3O_8 in the Aluminum tins through drilled holes (56 per tin). The measured critical parameter in the experiments was the separation distance between halves of the 125 unit array.

Both KENO IV and GEMER calculations have been performed for the Rocky Flats experiments with very detailed modeling of the assemblies in regular and enhanced KENO IV geometries. The major area in which the geometry models differed in the true configuration was in the smearing of the holes in the Aluminum tins which were used to add the measured amounts of water. The impact of this smearing has been evaluated however by analyzing the K_∞ of a single Aluminum tin with and without the Aluminum holes. From KENO IV with enhanced geometry these results are

For single oxide can without holes ("smeared")	$K_\infty = 1.0838 \pm 0.0040$
For single oxide can with holes ("unsmeared")	$K_\infty = 1.0830 \pm 0.0053$

Any difference is completely masked by the 0.3 to 0.5% statistics.

Table 6.13 shows the results of the KENO IV and GEMER calculations for the Rocky Flats experiments. Cases 1-3 were not performed with GEMER because of geometry modeling difficulties. (These cases require the use of the enhanced geometry option not currently available in GEMER.)

The results of the benchmark calculations are that KENO IV predicts an average $K_{eff} = 0.997 \pm 0.002$ and GEMER predicts an average K_{eff} 1.003 ± 0.003.

TABLE 6.13 - KENO IV AND GEMER CALCULATIONS FOR ROCKY FLATS LOW ENRICHED U_3O_8 LOW MODERATION BENCHMARK CRITICAL EXPERIMENTS

EXPERIMENT NO.	DRIVER	REFLECTOR	$K_{eff} \pm \sigma$ KENO	GEMER
1	Metal	Concrete	1.0060±0.0057	
2	Metal	Plastic	0.9931±0.0064	
3	Metal	Steel	1.0075±0.0067	
4	High Uranium Content Solution	Concrete	0.9948±0.0052	0.9961±0.0060
5	High Uranium Content Solution	Plastic	0.9984±0.0052	1.0115±0.0059
6	High Uranium Content Solution	Steel	0.9819±0.0055	0.9816±0.0082
7	Low Uranium Content Solution	Concrete	0.9950±0.0048	1.0219±0.0087
8	Low Uranium Content Solution	Plastic (Spacing 1)	0.9981±0.0045	1.0045±0.0064
9	Low Uranium Content Solution	Plastic (Spacing 2)	0.9970±0.0050	1.0138±0.0079
10	Low Uranium Content Solution	Steel	0.9979±0.0051	0.9898±0.0080
Average values			0.997± 0.002	1.003 ± 0.003

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Appendix A. Mixture Densities

A.1 Fuel Mixtures

A.2 Phenolic Resin and Carbon Steel

A.3 Interspersed Water

TABLE A.1 UO_2-H_2O-C MIXTURE DENSITIES

A. 4.5 gm UO_2/cc + 0.23684 gm H_2O/cc Mixtures

Material	MERIT/GEMER Atom Density (atoms/barn-cm)	KENO IV Atom/Material Density (atoms/barn-cm)	HANSEN-ROACH 16 Group Material ID
U-235	4.0657 E-04	4.0657 E-04	92508
U-238	9.6344 E-03	9.6344 E-03	92810
Oxygen	2.8001 E-02	2.00828 E-02	8100
Hydrogen	1.58365 E-02	--	--
Water	--	0.237269[+]	502
Carbon (Optional)	--	1.26692 E-02	6100

Use: 101 Kg UO_2 in 5 gallon container occupying entire volume of can (height = 35 cm)

or 35 Kg UO_2 in 5 gallon container occupying minimum volume of can (height = 12.128 cm)

[+] = 0.23684/0.9982, which is the KENO input density (gm/cc in this case - not atoms/barn-cm).

B. 2.7288 gm UO_2/cc + 0.14362 gm H_2O/cc

MATERIAL	MERIT/GEMER Atom Density (atoms/barn-cm)	KENO IV Atom/Material Density (atoms/barn-cm)	HANSEN-ROACH 16 Group Material ID
U-235	2.46546 E-04	2.46546 E-04	92508
U-238	5.84235 E-03	5.84235 E-03	92810
Oxygen	1.69800 E-02	1.21783 E-02	8100
Hydrogen	9.60334 E-03	--	--
Water	--	0.143881†	502

Use: 35 Kg UO_2 in 5 gallon container occupying partial volume of can (height = 20.0 cm)

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† = KENO input density (gm/cc in this case - not atoms/barn-cm).

C. 1.5593 gm UO_2/cc + 0.08207 gm H_2O/cc

MATERIAL	MERIT/GEMER Atom Density (atoms/barn-cm)	KENO IV Atom/Material Density (atoms/barn-cm)	HANSEN-ROACH 16 Group Material ID
U-235	1.40883 E-04	1.40883 E-04	92508
U-238	3.33849 E-03	3.33849 E-03	92810
Oxygen	9.70284 E-03	6.95903 E-03	8100
Hydrogen	5.48763 E-03	--	--
Water	--	0.0822179†	502
Carbon	--	4.39009 E-03	6100

Use: 35 Kg UO_2 in 5 gallon container occupying entire volume of can (height = 35 cm)

† KENO input density (gm/cc in this case - not atoms/barn-cm).

D. FULL THEORETICAL DENSITY[+] UO_2-H_2O MIXTURES

1. KENO Mixtures

WF H_2O	Atom/Material Density (Atoms/barn-cm) U-235 (Material)	U-238 (Material)	Oxygen (Material 8100)	Water* (Material 502)
0.10	4.46492 E-04 (92509)	1.058505 E-02 (92818)	2.20548 E-02	0.550088
0.20	2.64765 E-04 (92510)	6.27409 E-03 (92825)	1.30783 E-02	0.733941
0.30	1.73810 E-04 (92511)	4.11875 E-03 (92831)	8.58547 E-03	0.824960
0.40	1.19208 E-04 (92512)	2.82485 E-03 (92835)	5.88836 E-03	0.881201
0.50	8.27944 E-05 (92512)	1.9619 E-03 (92840)	4.08969 E-03	0.918040

Oxygen - Material
Water - Material

2. MERIT/GEMER Mixture: WF H_2O = 0.20

Material	Atom Density (atoms/barn-cm)
U-235	2.64765 E-04
U-238	6.27409 E-03
Oxygen	3.75717 E-02
Hydrogen	4.89868 E-02

[+]Partial density atom densities are determined by the ratio of the height of the fuel in the container to the height of theoretical density mixture in container divided into the densities in Table D.1

* KENO input density (gm/cc in this case - not atoms/barn-cm).

TABLE A2 PHENOLIC RESIN AND CARBON STEEL

A. Phenolic Resin

Material	Full Density	80% Density (atoms/barn-cm)	60% Density
Hydrogen	3.0140 E-03	2.4112 E-03	1.8084 E-03
B-10	4.2688 E-05	3.4151 E-05	2.5613 E-05
B-11	1.6726 E-04	1.2581 E-04	9.4356 E-05
Carbon	2.3050 E-03	1.8440 E-03	1.3830 E-03
Nitrogen	5.2890 E-05	4.2312 E-05	3.1734 E-05
Oxygen	2.0510 E-03	1.6408 E-03	1.2306 E-03
Boron+	1.997 E-04	1.5976 E-04	1.1982 E-04

B. Carbon Steel

Material	Density (atoms/barn-cm)
Carbon	3.921 E-03
Iron	8.3491 E-02
Material 100 (Hansen-Roach)	1.0000

+KENO IV Material

TABLE A.3 INTERSPERSED WATER DENSITIES

KENO Material[+] Density	MERIT/GEMER Densities (atoms/barn-cm)	
	Hydrogen	Oxygen
0.010	6.6866 E-04	3.3433 E-04
0.025	1.67173 E-03	8.35816 E-04
0.050	3.3433 E-03	1.6716 E-03
0.075	5.01489 E-03	2.50745 E-03
0.100	6.6866 E-03	3.3433 E-03
0.200	1.3373 E-02	6.6866 E-03
0.500	3.3433 E-02	1.6716 E-02
1.000	6.6866 E-02	3.3433 E-02

[+]Material 502

GENERAL ELECTRIC

Director - ONMSS
July 25, 1980

APPLICATION FOR REVISION OF
NRC CERTIFICATE OF COMPLIANCE USA/9019/B()F
FOR THE BU-7 TRANSPORT PACKAGE

ENCLOSURE 1C

CRITICALITY SAFETY ANALYSIS

OF THE BU-7 SHIPPING PACKAGE FOR URANIUM OXIDE PELLETS

A. L. Kaplan
:bmw

NEDO-11277
74NED7
CLASS I
February 1974

THE GENERAL ELECTRIC MODEL BU-7 URANIUM SHIPPING CONTAINER – CRITICALITY SAFETY ANALYSIS

Ricardo Artigas

Approved: B. D. Wilson, Manager
Radioactive Materials Safety Assurance

PRODUCT & QUALITY ASSURANCE OPERATION • GENERAL ELECTRIC COMPANY
SAN JOSE, CALIFORNIA 95125

GENERAL ELECTRIC

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TABLE OF CONTENTS

ABSTRACT

The General Electric Model BU-7 Shipping Container has been shown to meet the specific criticality standards for a Fissile Class I Package as required in Title 10, Part 71 of the U.S. Atomic Energy Commission's Code of Federal Regulations (10CFR71). Each BU-7 container is restricted by the results of the analysis to contain limited quantities of dry, unirradiated uranium compounds enriched up to four percent in the U-235 isotope.

The KENO Monte Carlo criticality code was used with a modified Hansen and Roach 16-Group set of cross sections in the analysis.

INTRODUCTION

General Electric now uses the Model BU-5 shipping container for the transportation of low-enriched, unirradiated, uranium oxides. The GE Model BU-5 contains a solid insulating medium called VPAC, an acronym for vermiculite, plyamine and powdered ammonium chloride catalyst.

In order to lighten the net weight of the container and thus effect savings in the cost of transporting the fuel, a phenolic resin has been proposed as a substitute insulating medium. The phenolic resin has a density of approximately 8 pounds per cubic foot.

The GE Model BU-7 shipping container is thus identical to the GE Model BU-5, except that a lighter phenolic resin insulation is used instead of the VPAC insulation.

ANALYSIS SCOPE

To demonstrate that the GE Model BU-7 package meets the specific criticality safety standards for a Fissile Class I package as required by Part 71, Title 10, of the U.S. Atomic Energy Commission's Code of Federal Regulations.

SUMMARY AND CONDITIONS

The results demonstrate that the GE Model BU-7 shipping container meets the specific standards of the U.S. Atomic Energy Commission's Title 10 Part 71 for a Fissile Class I package when used for the transportation of dry, unirradiated, low-enriched, uranium compounds.

The GE Model BU-7 and the insulating mixture are to be as described in the Package Description section of this report. The insulating mixture shall have a density of 8 ± 1 pounds/cubic foot.

The fuel content of *each package* (BU-7) is to be restricted as follows:

Enrichment:	Uranium enriched up to a maximum of 4% in the U-235 isotope.
Moderation:	Dry uranium compounds. A maximum hydrogen-to-uranium ratio of 0.45, considering all sources of hydrogenous moderators in the inner containment.
Physical Form:	Uranium compounds in the form of powder, pellets or powder-pellet mixtures

Contents: Not to exceed the lesser of:

(1) Two safe batches (90% of a minimum critical mass) of UO_2 as a function of the maximum enrichment and physical composition[a] (powder or pellets) of the uranium in the container, or

(2) 89 kilograms of total contents.[b]

[a] The safe batch values for pellets shall be used whenever a combination of powder and pellets is present.

[b] The 89 kilogram limit is not a criticality limit but one based on the load drop-tested.

PACKAGE DESCRIPTION

The BU-7 inner containment is a nominal 16-gallon Department of Transportation (DOT) Specification 17H drum constructed of 18-gauge steel, modified by the welded attachment of a closure flange to accept a 3/16-inch thick steel lid which is gasketed for resistance to high temperature and is attached by twelve 5/16-inch steel bolts. The inside dimensions of the inner containment drum are 13.75 inches in diameter by 27 inches high. The outer containment is a nominal 55-gallon, DOT Specification 17H, 18-gauge steel drum, 22.32 inches outer diameter and 36.5 inches high.

The space between the concentric inner and outer containers is completely filled with a solid insulating medium-phenolic resin. The phenolic resin is the same as that used in the FL-10-1 package, and the 5A and 30AB overpacks. The resin has a density of 8 ± 1 pounds/cubic foot. Its chemical composition is shown in Table 1.

Table 1
CHEMICAL COMPOSITION OF THE PHENOLIC RESIN INSULATION

Elemental Weight Percent*	
Carbon	41.0%
Hydrogen	4.5%
Boron	3.2%
Silicon	2.2%
Chlorine	0.5%
Nitrogen	~0
Fluorine	~0
Oxygen	48.6%

*Density = 8 ± 1 lb/cubic foot

Organic Compounds – Weight Percent	
Union Carbide Phenolic Resin BRL2760	65.8%
Silicone Surfactant LS30	2.0%
Boric Anhydride B-203	8.2%
Anhydride Oxalic Acid	8.2%
Freon 113	6.6%
Fiberglass Roving	9.6%

The uranium is contained in two nominal 5-gallon pails, or two or more nominal 2.5-gallon pails, fabricated of minimum 24-gauge steel. The pails have an inside diamter of 11.25 inches and are vertically stacked in the inner containment of each BU-7.

TECHNICAL CONSIDERATIONS

The KENO[1] Monte Carlo criticality code was used for the computations with a Knight-modified[2] Hansen and Roach[3] set of cross sections obtained from Oak Ridge National Laboratory.

Tests[4] performed by the General Electric Company demonstrate that the capacity of a 5-gallon can is 84 kilograms of randomly stacked pellets, indicating a void fraction of approximately 62%. We have, therefore, very conservatively, assumed for computational purposes that each 5-gallon can is full of about 85 kilograms of 4%-enriched UO_2 pellets. Note that in reality the maximum amount of 4%-enriched pellets to be allowed in any 5-gallon can is 24.7 kilograms – a safe batch.

Since the pellets, which come from a dry environment, are loaded into the essentially dry inner containment of the BU-7, there is practically no hydrogenous moderation present between the fuel lumps. Therefore, pellets in the 5-gallon cans are considered to be a homogeneous mixture, with a density of 4.2 grams UO_2/cc [ρ theoretical UO_2 x (1-void fraction)]. This homogeneous mixture density also covers cans full of powder, since the density of UO_2 powder will not exceed 4.2 grams UO_2/cc. The fuel mixture number densities corresponding to 4% enriched UO_2 at an H-to-U ratio of 0.45 are given in Table 2.

Table 2
NUMBER DENSITIES OF FUEL MIXTURE

Element	Number Density, Atoms/Barn-cm
U-235	0.0003796
U-238	0.008996
O (in fuel)	0.0187
H	0.0042165
O (in water)	0.002108

Since the H/U ratio is constant, the value of σ_p (barns per absorber atom) is also constant. A σ_p of 29.5 barns per U-238 atom was computed. A conservative value of 12 barns per U-238 atom was used in the calculations. This low value will underestimate the resonance absorptions in U-238 and yield larger values of the multiplication constant.

The BU-7 was represented in the KENO computer program by the same geometric model used in the analysis of the BU-5 package.[5]

RESULTS

- **Normal Conditions of Transport**

  The reactivity of an infinite array of undamaged BU-7's loaded with approximately 171 kilograms of dry, 4%-enriched UO_2 (number densities as given in Table 2), was shown to be subcritical under two sets of conditions:

  1. Insulating mixture with a density of 3 pounds/cubic foot –

$$k_\infty = 0.55037 \pm 0.0054 \ (1\sigma).$$

2. Insulating mixture with a density of 7 pounds/cubic foot –

$$k_\infty = 0.57659 \pm 0.00487\ (1\sigma).$$

The number densities of the insulating mixtures as used in the analysis are given in Table 3.

- **Accidental Conditions**

  An array of 256 (8 x 8 x 4) BU-7's, loaded as above and fully water-reflected, was shown to be subcritical under conditions of optimum inter-unit moderation.

  For the analysis of the accident conditions, no credit was taken at all for the insulating mixture, and the spaces in between inner containments, not occupied by steel, were assumed to contain water of various densities.

The reactivity of the fully water-reflected array is given in Table 4 as a function of inter-unit water density. It can be seen from the table that the maximum reactivity for the array occurs at an inter-unit water density of 0.125 grams/cc, and it is less than 0.81.

Table 3
NUMBER DENSITIES OF THE INSULATING MIXTURE

Density = 8 lb/ft^3 of Insulation		Density = 7 lb/ft^3 of Insulation	
Element	**Number Density Atoms/Barn-cm**	**Element**	**Number Density Atoms/Barn-cm**
Carbon	2.634×10^{-3}	Carbon	2.305×10^{-3}
Hydrogen	3.445×10^{-3}	Hydrogen	3.014×10^{-3}
Boron	2.282×10^{-4}	Boron	1.997×10^{-4}
Silicon	6.044×10^{-5}	Silicon	5.289×10^{-5}
Chlorine	1.088×10^{-5}	Chlorine	9.520×10^{-6}
Oxygen	2.344×10^{-3}	Oxygen	2.051×10^{-3}

Table 4
Keff OF FULLY WATER REFLECTED ARRAY OF
256 (8 x 8 x 4) BU-7'S

Inter-Unit H_2O Density, gm/cc	99% Confidence Interval
0.25	0.67615 to 0.72590
0.125	0.77043 to 0.80995
0.05	0.71741 to 0.77316
0.025	0.64876 to 0.69431

REFERENCES

1. G. E. Whitesides and N. F. Cross, "Keno – A Multigroup Monte Carlo Criticality Program," CTC-5, Oak Ridge Computing Technology Center (1969).

2. G. E. Whitesides, KENO Cross Section Library.

3. G. E. Hansen and W. H. Roach, "Six and Sixteen Group Cross Sections for Fast and Intermediate Critical Assemblies," LAMS-2543, Los Alamos Scientific Laboratory.

4. Internal Document, General Electric Company, San Jose, California (1967).

5. License No. SNM-54 (Docket #70-1007), Appendix D, Modification 18, April 14, 1972, Table V (p. 1–65) and Figure 1.6 3 (p. 1–69).

NUCLEAR ENERGY DIVISION • GENERAL ELECTRIC COMPANY
SAN JOSE, CALIFORNIA 95125

GENERAL ELECTRIC

TECHNICAL INFORMATION SERIES

TITLE PAGE

AUTHOR	SUBJECT	NO.
Ricardo Artigas	Shipping Container	74NED7
		DATE February 1974
TITLE The General Electric Model BU-7 Uranium Shipping Container – Criticality Safety Analysis		GE CLASS I
		GOVT. CLASS None
REPRODUCIBLE COPY FILED AT TECHNICAL PUBLICATIONS, R&UO, SAN JOSE, CALIFORNIA		NO. PAGES

SUMMARY

GE Model BU-7 Shipping Container meets criticality standards of 10CFR71. Report states the calculational methods used in testing the container.

By cutting out this rectangle and folding on the center line, the above information can be fitted into a standard card file.

NED DOCUMENT NUMBER NEDO-11277

INFORMATION PREPARED FOR Nuclear Energy Division

TESTS MADE BY Ricardo Artigas

COUNTERSIGNED B. D. Wilson SECTION RMSA

BUILDING AND ROOM NO. M/C 273 LOCATION San Jose, CA.

GENERAL ELECTRIC

Director - ONMSS
July 25, 1980

APPLICATION FOR REVISION OF
NRC CERTIFICATE OF COMPLIANCE USA/9019/B()F
FOR THE BU-7 TRANSPORT PACKAGE

ENCLOSURE 2

PROPOSED REVISIONS TO NRC CERTIFICATE OF COMPLIANCE 9019

FOR THE BU-7 TRANSPORT PACKAGE

A. L. Kaplan
:bmw

Form NRC-618
(12-73)
10 CFR 71

U.S. NUCLEAR REGULATORY COMMISSION

CERTIFICATE OF COMPLIANCE

For Radioactive Materials Packages

1.(a) Certificate Number	1.(b) Revision No.	1.(c) Package Identification No.	1.(d) Pages No.	1.(e) Total No. Pages
9019	6	USA/9019/AF	1	3

2. PREAMBLE

2.(a) This certificate is issued to satisfy Sections 173.393a, 173.394, 173.395, and 173.396 of the Department of Transportation Hazardous Materials Regulations (49 CFR 170-189 and 14 CFR 103) and Sections 146-19-10a and 146-19-100 of the Department of Transportation Dangerous Cargoes Regulations (46 CFR 146-149), as amended.

2.(b) The packaging and contents described in item 5 below, meets the safety standards set forth in Subpart C of Title 10, Code of Federal Regulations, Part 71, "Packaging of Radioactive Materials for Transport and Transportation of Radioactive Material Under Certain Conditions."

2.(c) This certificate does not relieve the consignor from compliance with any requirement of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies, including the government of any country through or into which the package will be transported.

PROPOSED REVISION

3. This certificate is issued on the basis of a safety analysis of the package design or application—

3.(a) Prepared by (Name and address):	3.(b) Title and identification of report or application:
General Electric Company P.O. Box 780 Wilmington, NC 28401	General Electric Company application dated May 24, 1974, as supplemented.
	3.(c) Docket No. 71-9019

4. CONDITIONS

This certificate is conditional upon the fulfilling of the requirements of Subpart D of 10 CFR 71, as applicable, and the conditions specified in item 5 below.

5. Description of Packaging and Authorized Contents, Model Number, Fissile Class, Other Conditions, and References:

(a) Packaging

(1) Model No.: BU-7.

(2) Description

The packaging consists of either two, 5-gallon or three, 2.5-gallon, 11.25-inch ID, minimum 24-gauge steel pails contained in a 13.75-inch diameter by 27-inch long inner container constructed of minimum 18-gauge steel, with bolted and gasketed top flange closure. The inner container is centered and supported in a 22.5-inch ID, 18-gauge steel 55-gallon capacity DOT Specification 17H steel drum by solid insulating material composed of fire-retardant phenolic foam. The maximum weight of the package is 320 pounds.

(3) Drawing

This container is constructed in accordance with Drawing 112D1592, Revision 0, of General Electric Company's application dated July 25, 1980. *

(b) Contents

(1) Type and form of material

(i) Uranium oxide powder with a maximum bulk density not greater than 4.5 grams/cc. Uranium may be enriched to not more than 4.0 w/o in the U-235 isotope. The maximum H/U atomic ratio considering all sources of the hydrogeneous material within the inner container shall not exceed 1.577. *

(ii) Uranium oxide as pellets with a maximum bulk density of 10.96 grams/cc. Uranium may be enriched to a maximum 4.0 w/o in the U-235 isotope.

(2) Maximum quantity of material per package

(i) For the contents described in 5(b)(1)(i):

The maximum contents of uranium oxide powder per package and pail shall be limited to 70 kgs and 35 kgs, respectively. *

(ii) For the contents described in 5(b)(1)(ii):

The maximum contents per package and pail for the maximum U-235 enrichment shall be limited in accordance with the following table:

Maximum U-235 enrichment, w/o	Maximum UO_2 per pail, kgs	Maximum UO_2 per package, kgs
2.7	35.0	70.0
2.8	35.0	70.0
2.9	35.0	70.0
3.0	35.0	70.0
3.2	34.1	68.2
3.4	31.0	62.0
3.6	28.5	57.0
3.8	26.4	52.8
4.0	24.7	49.4

(c) Fissile Class I

6. For mixtures of contents (powders and pellets) described in 5(b)(1), the maximum quantity of material per package shall be limited to the quantity given in 5(b)(2)(ii).

7. For mixtures of contents as described in 5(b)(1)(i), ammonium oxalate (AO) and/or ammonium bicarbonate (ABC) additives are permitted in the UO_2 powder to the extent that the C/U ratio does not exceed 1.262. | *

8. The density of the package insulation shall not be less than 4.8 lbs/cu ft. | *

9. The four, 1/4-inch diameter holes located near the top of the outer DOT Specification 17H steel drum as shown in Drawing 112D1592, Revision 0, shall be covered with weatherproof tape to preclude the entry of water. | *

10. An alternative to the 55-gallon capacity DOT Specification 17H steel drum is a drum meeting all requirements of the Specification 17H except the drum may have two (2) rolling hoops.

11. The package authorized by this certificate is hereby approved for use under the general license provisions of 10 CFR §71.12(b).

12. Expiration date: July 31, 1984.

(c) Fissile Class I

6. For mixtures of contents (powders and pellets) described in 5(b)(1), the maximum quantity of material per package shall be limited to the quantity given in 5(b)(2)(ii).

7. For mixtures of contents as described in 5(b)(1)(i), ammonium oxalate (AO) and/or ammonium bicarbonate (ABC) additives are permitted in the UO_2 powder provided that their presence is taken into account in the determination of the H/U ratio in the package as follows:

$$H/U = \frac{N_H\ (\text{water}) + N_H(\text{additive}) + 0.038\ N_C\ (\text{additive})}{N_U\ (UO_2\ \text{powder})}$$

≤ 1.577

Where N_H (water) = atom density of hydrogen in the UO_2 powder mixture in the form of water

N_H (additive) = atom density of hydrogen in the UO_2 powder mixture in the form of AO and/or ABC

N_C (additive) = atom density of carbon in the UO_2 powder mixture in the form of AO and/or ABC

N_U = atom density of uranium in the UO_2 powder mixture

8. The density of the package insulation shall not be less than 4.8 lbs/cu ft. | *

9. The four, 1/4-inch diameter holes located near the top of the outer DOT Specification 17H steel drum as shown in Drawing 112D1592, Revision 0, shall be covered with weatherproof tape to preclude the entry of water. | *

10. An alternative to the 55-gallon capacity DOT Specification 17H steel drum is a drum meeting all requirements of the Specification 17H except the drum may have two (2) rolling hoops.

11. The package authorized by this certificate is hereby approved for use under the general license provisions of 10 CFR §71.12(b).

12. Expiration date: July 31, 1984.

REFERENCES

General Electric Company application dated July 28, 1980.

Supplements dated: March 14 and 17, and May 15 and 24, 1980. *

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

(Proposed Revision)

Charles E. MacDonald, Chief
Transportation Certification Branch
Division of Fuel Cycle and
Material Safety

Date: ____________________