LAW ENGINEERING
INDUSTRIAL SERVICES
A DIVISION OF LAW ENGINEERING, INC.

CORROSION EVALUATION OF STAINLESS STEEL SAMPLES

400 ppm FERRIC CHLORIDE SOLUTION

PREPARED FOR

NUCLEAR CONTAINERS, INCORPORATED

LAW ENGINEERING INDUSTRIAL SERVICES PROJECT 10832-5-0807

October 6, 1995

LAW
ENGINEERING AND ENVIRONMENTAL SERVICES

October 6, 1995

Mr. William M. Arnold
Nuclear Containers, Incorporated
Route 9 Box 2237
Elizabethton, Tennessee 37643

Subject: **Report of Corrosion Evaluation of Stainless Steel Samples**
400 ppm Ferric Chloride Solution
Nuclear Containers, Incorporated
Elizabethton, Tennessee
Law Engineering Industrial Services Project 10832-5-0807

Dear Mr. Arnold:

As authorized by your purchase order number 5577-A dated February 20, 1995 and in general accordance with our proposal 2521ME5 dated February 7, 1995, Law Engineering Industrial Services has completed short term 400 ppm ferric chloride solution corrosion tests to predict long term behavior of stainless steel material. This report contains project background information, summary of calculations for equivalent temperature and times for accelerated corrosion testing, test results and conclusions relevant to the purpose of our work.

PROJECT BACKGROUND INFORMATION

Nuclear Containers, Incorporated (NCI) manufactures AISI 304 stainless steel shipping containers for transport of nuclear materials. The packages consist of an inner chamber and an outer 14 gauge stainless steel sheet with a phenolic foam between them. In the past, hydrochloric acid was added to the foam to reduce its alkalinity. Since October 1991, this practice has been discontinued. Instead, oxalic acid is used as an additive to reduce the alkalinity of the foam. Laboratory analysis of two foam samples obtained from packages manufactured prior to 1991 indicate chloride contents to be 1,825 and 211 ppm, respectively. At present, the chloride content in the foam is typically less than 100 ppm and does not exceed 200 ppm. Since 1991 the stainless steel surfaces in contact with the foam have been coated with an epoxy primer (DP40 manufactured by PPG Industries, Incorporated). DP401 also manufactured by PPG Industries has been used as a catalyst.

Mixing and application practices as recommended by the manufacturer have been followed. The minimum wet film thickness of the primer is 4 mils (approximately 1.5 mils dry film thickness).

Law Engineering Industrial Services was informed that a twenty year service life for these containers was desired. We were requested to determine the deleterious effects of the chloride in the foam, if any, to the stainless steel material over the twenty year service life of the containers.

METHODOLOGY

The methodology utilized by us consisted of designing short term corrosion tests to predict long term behavior. Calculations were performed to determine the test temperature and duration. Samples of bare stainless steel, stainless steel coated with primer, stainless steel coated with primer containing a scribe, bare stainless steel with foam attached and stainless steel coated with primer and foam attached were subjected to a 30 day 400 ppm ferric chloride solution at 50°C. The following pages describe how we arrived at the test temperature and duration. The corrosion tests were performed in conjunction with Dr. Bryan A. Chin, Professor and Chairman of the Materials Engineering Program at Auburn University, Alabama.

EQUIVALENT TEMPERATURE AND TIMES FOR ACCELERATED TESTING

SUMMARY

The following sections describe the results of a study to determine accelerated corrosion test conditions (temperature and time) that could be used to predict the performance of stainless steel material subjected to 20 years of ambient temperature exposure at specific sites in the United States. Five sites were specified for investigation in this study: Richland, WA; Haematite, MO; Columbia, SC; Wilmington, NC; and Portsmouth OH. Twenty year climatological data was obtained for these sites and incorporated into kinetic equations describing the relationship of temperature and time on corrosion rates. From these studies equivalent, elevated temperatures were obtained for test times of 1.0, 1.5, 2.0 and 3.0 months. The results indicate that an accelerated corrosion test temperature of 107°F for 1 month is equivalent to 20 years of exposure at the worst site (Columbia, SC).

A total immersion 400 ppm ferric chloride test was conducted following ASTM specifications G48-76 and G46-76. The test temperature was 122°F (50°C) for 1 month. Five types of specimens were included in the tests:

1. Bare stainless steel metal
2. Stainless steel metal coated with epoxy primer
3. Stainless steel metal coated with epoxy primer containing a scribe mark (to simulate a defect in the coating)
4. Bare stainless steel with foam attached
5. Stainless steel coated with primer and foam attached

LITERATURE SEARCHED

An extensive search was made of both books and scientific articles. Emphasis was placed on locating articles relating to pitting corrosion in stainless steels in chloride environments and determining the environmental effects on the corrosion rates.

ENVIRONMENTAL DATA SEARCH

Climatological data for the cities under investigation were obtained from the National Oceanic and Atmospheric Administration. Temperature histories for a twenty year period were used in the calculations (1974 through 1993). Exact temperature histories were available for the cities of Wilmington, NC, and Columbia, SC. The temperature histories for Portsmouth, OH; Richland, WA; and Haematite, MO were assumed to be close to the nearest cities in these states namely, Columbus, OH; Walla Walla, WA; and St. Louis, MO respectively.

DETERMINATION OF ACCELERATED TEST CONDITIONS

Experiments have been previously conducted that describe the temperature-time dependence of the pitting corrosion current for stainless steels. We utilized both the temperature time relationships and materials coefficients derived by these investigators in our calculations. The literature indicates a linear time dependence of the current density in pitting corrosion for a chromium-nickel (18-8) steel alloy in a 0.03 MKCI and 0.5 $MKNO_3$ environment. Assuming this linear time dependence for our system, the current density can be described by,

$$J = A_t t$$

Where J is the current density, A_t is a material constant ad t is the test time. Also, the temperature dependence of the current density is given by,

$$J = A_j e\,(^{E}{}_{Aj}{}^{/RT})$$

Where A_j is a temperature dependent materials constant, E_{Aj} is the activation energy for the pitting process, R is the gas constant, and T is the absolute temperature in K. The total current density is therefore,

$$J_{tot} = A\ t\ e\,(^{E}{}_{Aj}{}^{/RT})$$

Since A is a material constant that is unknown, a new parameter J^1 was used in the calculations. J^1 was defined by,

$$J^1 = J_{tot} / A = t\ e\,(^{E}{}_{Aj}{}^{/RT})$$

Monthly average temperatures were used instead of daily temperatures to simplify the calculations. Thus the combined effect of pitting corrosion in 20 years is given by the equation:

$$J^1{}_{20\,yrs} = J^1{}_1 + J^1{}_2 + J^1{}_3 + J^1{}_4 + \ldots\ldots\ldots\ldots + J^1{}_{240}$$

Thus, the combined effect of pitting corrosion for 20 years would include summing the corrosion effect at each month average temperature for 240 months. A further simplification was made, by averaging the monthly temperatures for January, February, etc. over a 20 year period. The result was multiplied by 20 to simulate 20 years since the temperature behavior is cyclic at any given location.

The required temperature , T_{eq}, to complete a simulation of the above effect in x months was then determined from the equation,

$$J^1{}_{20\,yrs} = x\ e\,(^{E}{}_{Aj}{}^{/RT}{}_{eq})$$

The value of E_{Aj} was experimentally determined by previous investigators to be -266,000 J/(mole K) and the value of R was taken to be 8.3144 J/(mole K).

RESULTS

Table 1 shows the test temperatures that were obtained as a result of the above described methodology. It shows the calculated equivalent test temperatures as a function of the location site and the planned duration of the test.

As a result of this study it can be concluded that:

- One month elevated test temperatures required to simulate 20 years of ambient temperature exposure for pitting corrosion have been determined.
- Depending upon site specific ambient temperatures obtained from the National Oceanic and Atmospheric Administration, the equivalent test temperatures for one month elevated temperature pitting corrosion tests range from 98°F to 107°F.

FERRIC CHLORIDE SOLUTION PITTING CORROSION TESTS

SUMMARY OF RESULTS

Ferric chloride corrosion tests were performed in accordance with ASTM G48. Specimens were exposed at 50°C for 30 days and evaluated for weight loss, pitting, blisters and loss of adhesion. Hardness measurements were taken to help evaluate subsurface corrosion effects. Evaluations were conducted in accordance to ASTM specifications G48-76, G46-76 and D1654-79a. Table 2 gives a summary of material performance.

SCOPE

Ferric chloride corrosion tests were performed in accordance with ASTM G48 to evaluate the pitting resistance of the following materials: stainless steel, stainless steel coated with primer (DP-40), stainless steel coated with primer and scribed, stainless steel with foam attached and stainless steel with primer and foam attached. The test provided information on the relative resistance of the stainless steel and the performance of the primer in corrosive environments.

TEST PROCEDURE

Ferric Chloride Bath Preparation

A 400 ppm by weight ferric chloride solution was made using distilled water and $FeCl_3{\cdot}6H_2O$. The solution was filtered through filter paper to remove any insoluble particles. Two baths of 1500 ml each were prepared. The specimens in the baths are shown in Table 3. The baths were maintained at 50°C and the test was conducted for 30 days.

Test Set-Up

The corrosion baths were set-up as shown in Figure 1. The bath temperature was monitored using a thermometer and a thermocouple connected to a chart recorder. Figure 2 shows the chart recorder readout showing a constant temperature of 50°C. In addition a thermometer was used to monitor the temperature of the solution. The temperature was continuously monitored over the 30 day test duration. Figure 3a shows a close up of the sample loading in the bath. ASTM specification G48 glass cradles were used to support the samples at a 45° angle. Figure 3b shows how the stainless steel/foam samples were loaded. The solution was constantly stirred using a magnetic stirrer.

SPECIMEN PREPARATION

As Received Material

Stainless steel plates that were provided were sheared into 1 x 2 inch recommended standard size specimens. The specimen edges were ground to remove any rough edges. Figure 4a shows the stainless steel specimens.

Primer Coated Specimens

Stainless steel standard size 1 x 2 inch specimens were coated with the DP-40 primer using an air gun operating at 40 psi. The coated specimens were air dried for over 72 hours until completely dry. Specimen surfaces were cleaned with acetone to remove any grease or dirt prior to coating. Figure 5a shows the primed stainless steel specimens.

Primer Coated Specimens-Inscribed

Standard size specimens of primer coated stainless steel were inscribed on both sides. The scribe was made using a tungsten carbide cutting tool in accordance with ASTM D1654. The scribes made on both sides of the specimens were in opposite directions to each other. The specimens were used to test adhesion of the coating at the scribe mark when exposed to corrosive environments. Figures 6a, b show both sides of the scribed stainless steel specimens.

Stainless Steel/Foam Specimens

Large sections of the stainless steel/foam material (as provided) were cut into standard specimens of 1 x 2-inch using a band saw. The foam was held together with the stainless steel using rubber bands. The rubber bands were treated in boiling water to remove any water soluble elements prior to actual testing of specimens. The stainless steel/foam specimens are shown in Figures 7a and 8a.

SPECIMEN EVALUATION

Photographic Examination

All test specimens were photographed to record visual changes induced by the test. The specimens were cleaned using running water and acetone to remove corrosion products. The following is a listing of all the specimens photographed in the post test condition:

- Figure 4b - Stainless Steel
- Figure 5b - Stainless Steel+Primer
- Figures 6c,d - Stainless Steel+Primer (Inscribed)
- Figures 7b,c - Stainless Steel/Foam (2UP)
- Figures 8b,c - Stainless Steel/Foam (4P)

A few coated specimens were stripped of the coating to examine the surface underneath. Acetone was used to remove the coating from the specimens. The following is a listing of the specimens that were stripped:

- Figure 5c - Stainless Steel+Primer
- Figure 6e,f - Stainless Steel+Primer (Inscribed)

The colors of the bath solution are shown in Figures 9a, b. Color change indicated the buildup of corrosion products

Specimen Weight Evaluation

All specimens were weighed prior to testing and were weighed again after the 30 day testing period. The specimens were totally dried prior to weighing. Table 4 shows the weight changes for the various specimens.

Pitting Evaluation

All the uncoated specimens and the stripped specimens were examined for pitting. Standard procedures defined by ASTM G48 and G46 were used. However, no pitting was visually observed on any of the specimens. Table 5 shows the details of the measurements.

Blister Evaluation of Coated Specimens

All coated specimens were examined for blisters on the surface. The 10 largest blisters were examined and reported. Table 6 shows the details of the evaluation. The coated specimens which were inscribed were examined for by loss of adhesion. This is reported in Table 7 as the distance from the scribe over which the coating has failed. No loss of adhesion was observed along the scribe.

Performance Based on Surface Area Affected

All bare and coated specimens were evaluated based on the overall performance. A plastic grid was used to determine the percentage of affected area in all of the samples. All uncoated specimens were evaluated for area covered by pitting. Coated samples were evaluated for blister area coverage. Table 8 shows the overall performance of the specimens. Inscribed specimens were not evaluated using this method, but by measuring the distance of creapage in accordance with ASTM D1654 as given in Table 7.

Hardness Measurements

Table 9 shows the hardness measurements made on the specimens after the corrosion test. Changes in surface hardness indicate subsurface corrosion effects. No significant hardness changes were observed in the specimens.

CONCLUSIONS

The 400 ppm ferric chloride corrosion test resulted in the following conclusions:

- Stainless steel (bare) specimens did not show visible pitting and a weight loss of 0.002% was recorded.
- Stainless steel primer coated specimens showed blister attack of coating, but the metal surface was not attacked and a weight loss of 0.009% was recorded.
- Stainless steel coated and inscribed specimens showed a good adhesion of coating, metal surface underneath was not attacked and a weight loss of 0.008% was recorded.
- Stainless steel/foam specimens recorded a weight loss of 0.05%.
- Stainless steel + primer/foam specimens recorded a weight loss of 0.05%.
- No significant hardness changes were noted in the specimens.
- Based on the test data, it is our opinion that a 400 ppm chloride content in the foam will not significantly pit or corrode the stainless steel material over a twenty year service life.

Law Engineering Industrial Services appreciates the opportunity of working with you on this project. If you have any questions concerning this report please contact the writer at (704)-357-8600.

Sincerely,
LAW ENGINEERING INDUSTRIAL SERVICES

Lakshman Santanam
Laboratory Manager
NACE Certified Corrosion Specialist

Hussein M. Sadek
Managing Principal

LS/HMS:mh

Attachments 1 and 2

ATTACHMENT 1

Table 1: Pitting Corrosion Test Temperatures for Different Locations

LOCATION	TEST DURATION (mo.)	TEST TEMP. (°F)
Wilmington, NC	1	105.79
	1.5	103.15
	2	101.30
	3	98.70
Portsmouth (Columbus), OH	1	98.85
	1.5	96.27
	2	94.47
	3	91.93
Richland (Walla Walla), WA	1	98.73
	1.5	96.16
	2	94.35
	3	91.83
Columbia, SC	1	106.90
	1.5	104.25
	2	102.39
	3	99.97
Haematite (St. Louis), MO	1	103.89
	1.5	101.28
	2	99.43
	3	96.86

Table 2. Summary of Corrosion Test Results

(Note Hardness changes indicate subsurface corrosion, not a change in mechanical properties.)

SPECIMEN MATERIAL	30 DAY 400 ppm FERRIC CHLORIDE @ 50°C
Stainless Steel	No visible pitting and 0.002% weight loss.
Stainless Steel+Primer	30% of coating area attacked by blisters, coating protects from pitting, negligible hardness change and 0.009% weight loss.
Stainless Steel+Primer (Inscribed)	40% of coating area attacked by blisters, good coating adhesion at scribe, coating protects from pitting, negligible hardness change and 0.008% weight loss.
Stainless Steel/Foam (2UP)	No visible pitting, 0.05% weight loss, negligible hardness change.
Stainless Steel+Primer/Foam (4p)	No visible pitting, 0.05% weight loss, negligible hardness change.

Table 3. Specimens in the Corrosion Bath

FERRIC CHLORIDE BATH	SPECIMEN	SPECIMEN NO.
Bath - 1	Stainless Steel Stainless Steel +Primer Stainless Steel +Primer (Inscribed)	SS-A, SS-B SSP-A, SSP-B SSPI-A, SSPI-B
Bath - 2	Stainless Steel/Foam Stainless Steel +Primer/Foam	2UP-A, 2UP-B 4P-A, 4P-B

Table 4. Corrosion Induced Weight Loss

SPECIMEN MATERIAL	SPECIMEN NO.	SPECIMEN WEIGHT LOSS (mg/mm^2)
Stainless Steel	SS-A	1.44×10^{-4}
	SS-B	1.05×10^{-4}
Stainless Steel+Epoxy Primer	SSP-A	1.99×10^{-4}
	SSP-B	8.19×10^{-4}
Stainless Steel+Primer (Inscribed Specimen)	SSPI-A	3.45×10^{-4}
	SSPI-B	5.86×10^{-4}
Stainless Steel/Foam (As received)	2UP-A	2.56×10^{-3}
	2UP-B	3.3×10^{-3}
Stainless Steel+Primer/Foam	4P-A	5.29×10^{-3}
	4P-B	1.11×10^{-3}

Table 5. Corrosion Induced Pitting

SPECIMEN MATERIAL	SPECIMEN NO.	AVERAGE PIT SIZE (mm^2) 10 EACH SIDE	PIT DEPTH (mm) (MAX/AVG.) 10 EACH SIDE	PIT DENSITY ($PITS/m^2$)
Stainless Steel	SS-A	None		
	SS-B	None		
Stainless Steel + Epoxy Primer	SSP-A			
	SSP-B	Primer None	Removed	
Stainless Steel+Primer (Inscribed Specimen)	SSPI-A			
	SSPI-B	Primer None	Removed	
Stainless Steel /Foam (As is)	2UP-A	None		
O-Open Side	2UP-B	None		
F-Foam Side	4P-A	None		
	4P-B	None		

Table 6. Corrosion Induced Blistering of Coated Specimens

SPECIMEN MATERIAL	SPECIMEN NO.	BLISTER DIAMETER (mm) (AVERAGE SIZE)	BLISTER DENSITY (BLISTERS/m²)
Stainless Steel + Epoxy Primer	SSP-A	1, .25, .5, .5, .38, .38, .64, .5, .38, .25, .5 **(0.53)**	259,975
	SSP-B	1.65, 1.4, 1, 1, 1, .5, .5, .38, .64, .25 **(1.28)**	273,056
Stainless Steel +Primer (Inscribed Specimen)	SSPI-A	.5, .38, .64, .25, .38, .25, .5, .38, .25, .5 **(0.4)**	359,240
	SSPI-B	.25, .25, .38, .38, .5, .5, .25, .25, .25, .38, .25 **(0.37)**	331,034

Table 7. Corrosion Induced Primer Adhesion Loss at Scribe

SPECIMEN MATERIAL	SPECIMEN NO.	CREAPAGE FROM SCRIBE/MEAN (mm)
Stainless Steel +Primer (Inscribed Specimen)	SSPI-A	0.25, 0.25, 0.25, 0.25, 0.25 **(0.25)**
	SSPI-B	0.25, 0.25, 0.25, 0.25, 0.25 **(0.25)**

Table 8. Overall Surface Attack of Uncoated and Coated Specimens

SPECIMEN MATERIAL	SPECIMEN NO.	% AREA AFFECTED-PITS, BLISTER
Stainless Steel	SS-A	0
	SS-B	0
Stainless Steel+Epoxy Primer	SSP-A	28
	SSP-B	31
Stainless Steel+Epoxy Primer (Inscribed Specimen)	SSPI-A	41
	SSPI-B	38
Stainless Steel/Foam (As Received)	2UP-A	0
	2UP-B	0
Stainless Steel +Primer/Foam	4P-A	0
	4P-B	0

Table 9. Specimen Hardness in Post Test Condition

SPECIMEN MATERIAL	SPECIMEN NO.	SPECIMEN HARDNESS/MEAN (POST CORROSION TEST)
Stainless Steel	SS-A	74, 73, 72.5, 75, 75 (R_B)/73.9
	SS-B	72.5, 71 70, 71, 71 (R_B)/71.1
Stainless Steel+Epoxy Primer	SSP-A	
	SSP-B	74, 73, 73, 74.5, 74 (R_B)/73.7
Stainless Steel+Epoxy Primer (Inscribed Specimen)	SSPI-A	
	SSPI-B	74.5, 74, 75.5, 74.5, 75 (R_B)/74.7
Stainless Steel/Foam (As Received)	2UP-A	58, 58, 62, 63, 50.5 (R_B)/58.3
	2UP-B	57, 56, 62, 52, 53 (R_B)/56
Stainless Steel +Primer/Foam	4P-A	69.5, 76, 79, 73, 69 (R_B)/73.3
	4P-B	54.5, 56, 53.5, 52, 48 (R_B)/52.8
Stainless Steel (Pretest Condition)		71, 73, 73, 72, 73 (R_B)/72.4
Stainless Steel/Foam 2UP/4P (Thickness = 1/16") (Pretest)		51, 56.5, 56.5, 62, 50 (R_B)/55.2
Stainless Steel/Foam 2UP/4P (Thickness = 0.076") (Pretest)		71.5, 82, 77.5, 81, 79(R_B)/78.2

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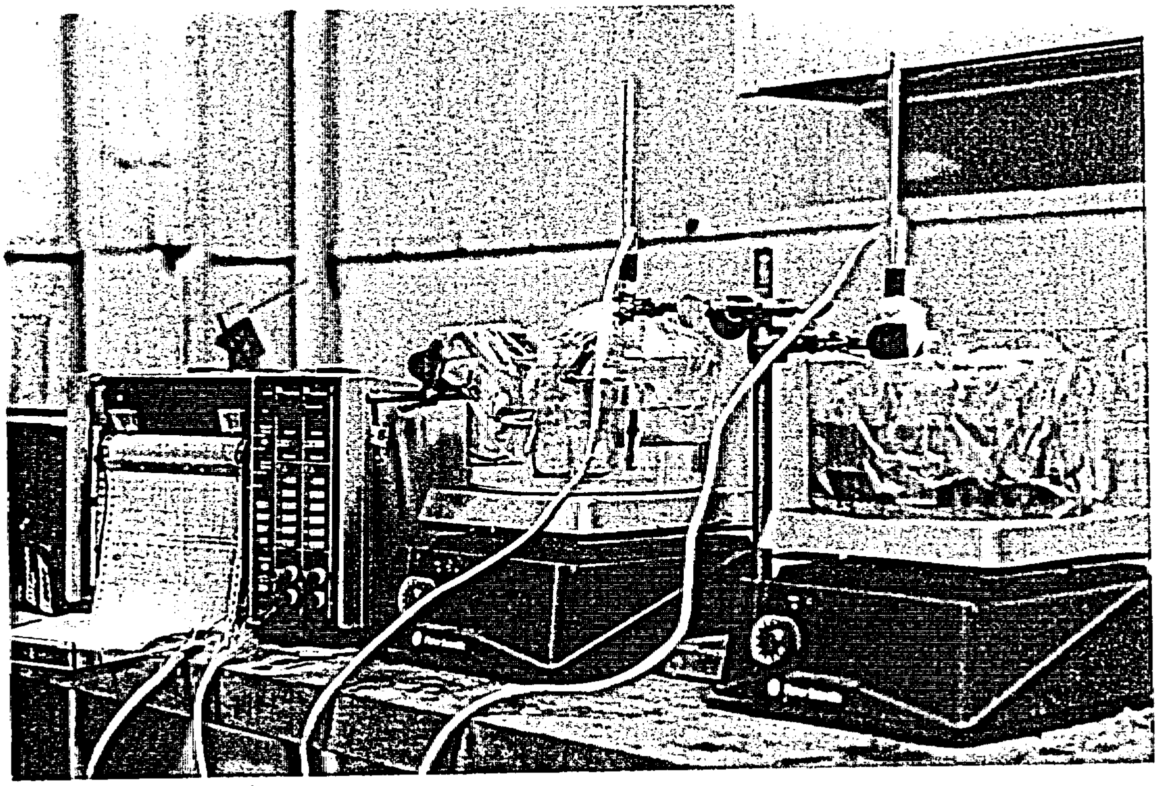


Figure 1. 400 ppm ferric chloride corrosion bath setup.

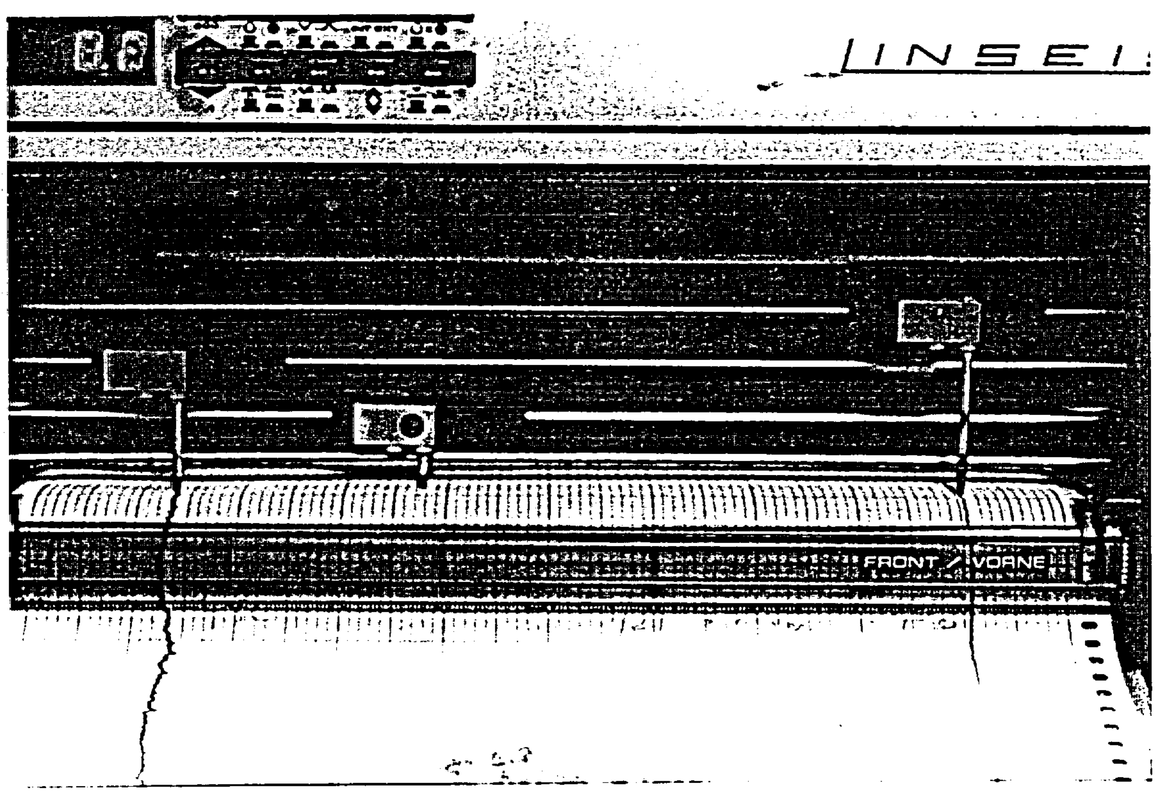


Figure 2. Readout from chart recorder indicating constant bath temperature

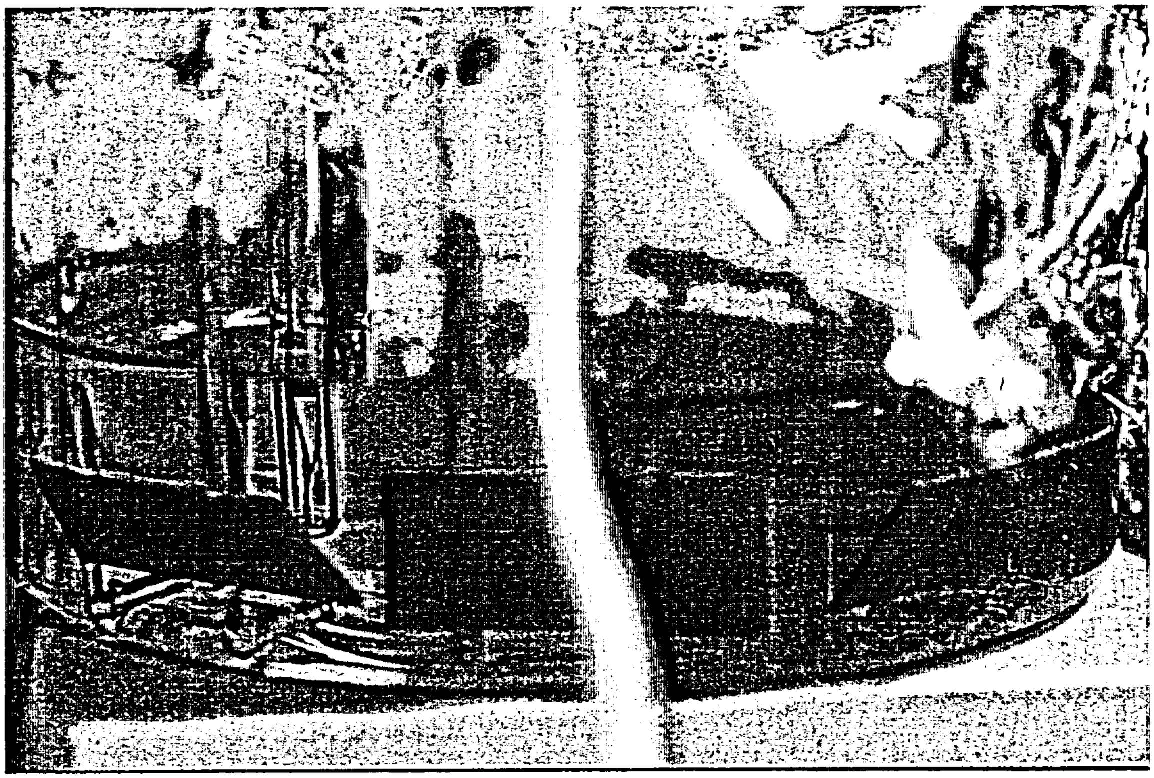


Figure 3a. Close-up showing specimen loading in the bath.

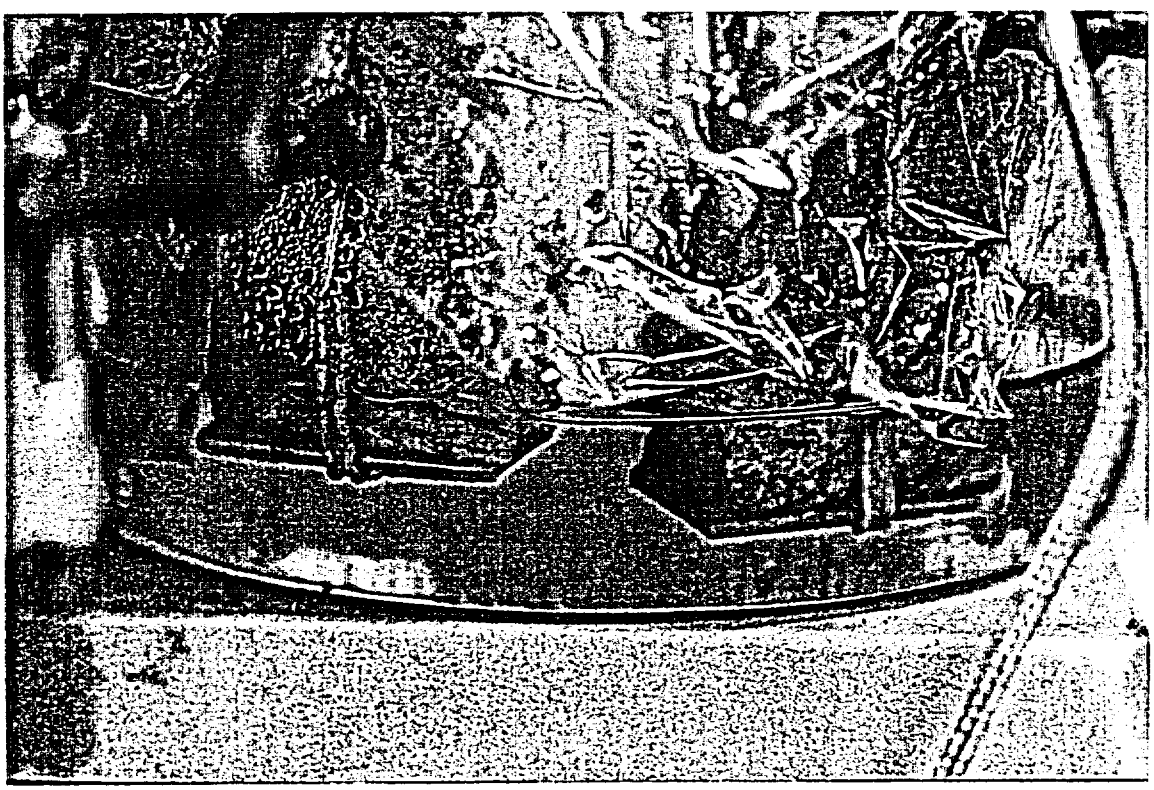


Figure 3b. Close-up showing foam/stainless steel specimen loading.

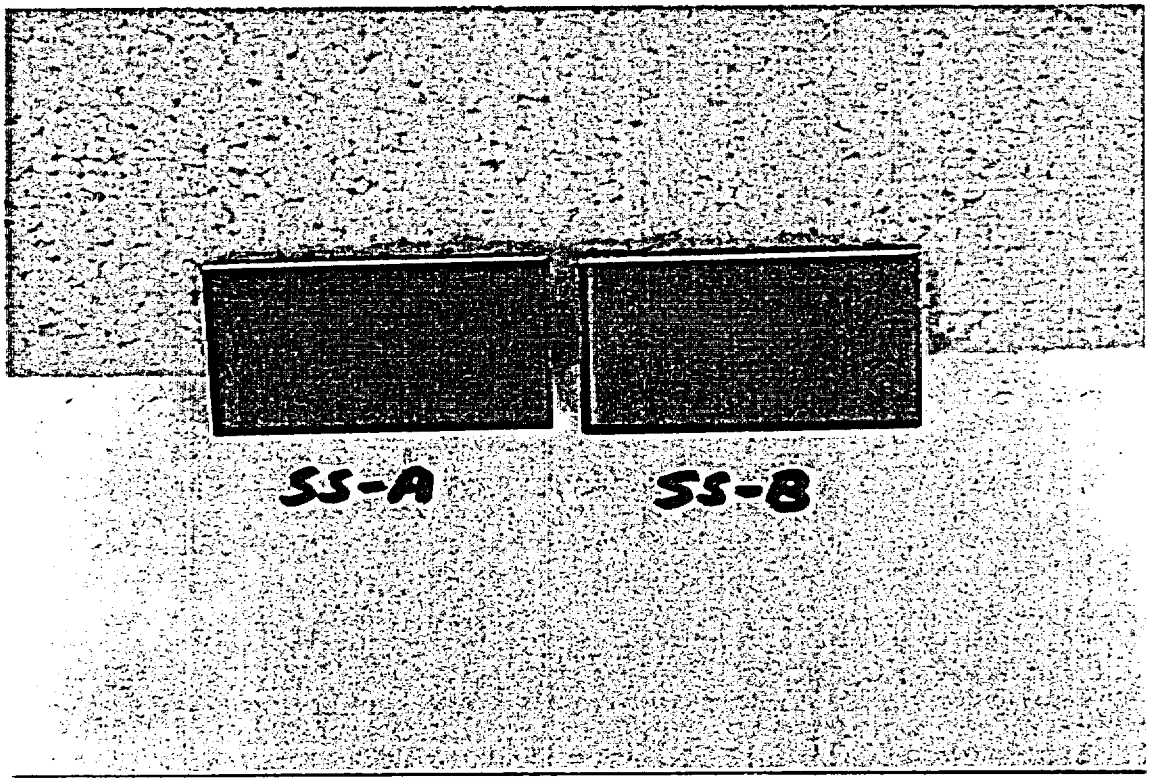


Figure 4a. Stainless steel specimens (SS-A, SS-B) in pretest condition.

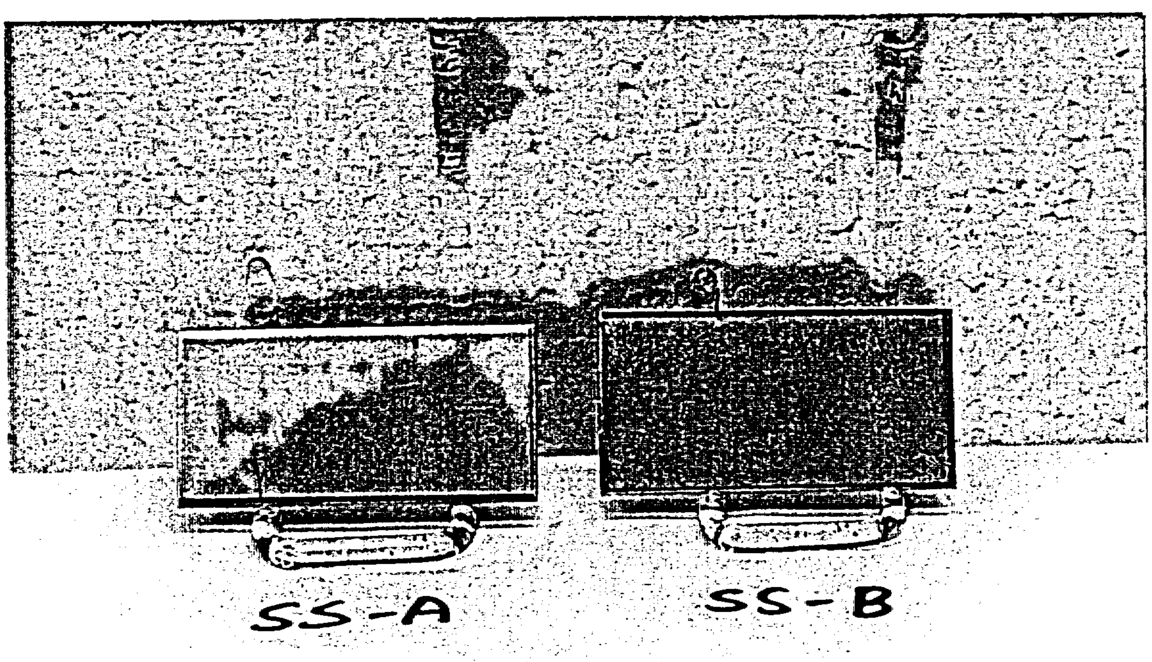


Figure 4b. Stainless steel specimens (SS-A, SS-B) in post-test condition.

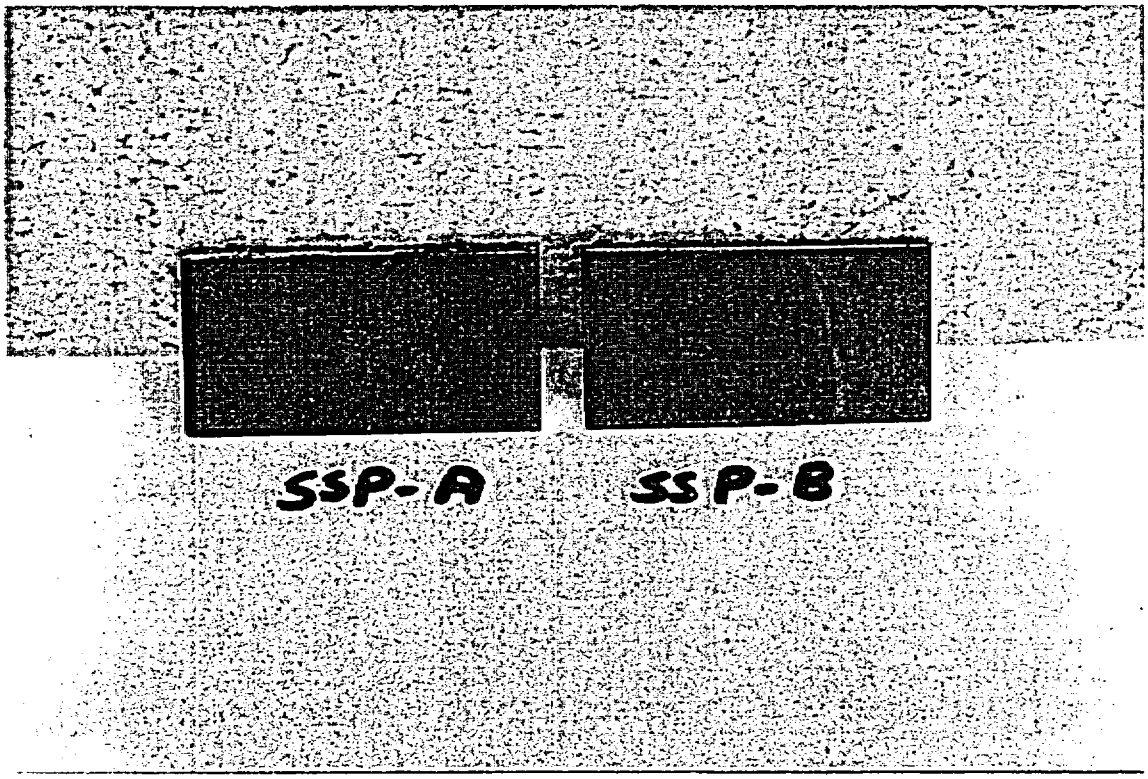


Figure 5a. Stainless steel specimens coated with primer (SSP-A, SSP-B) in pretest condition.

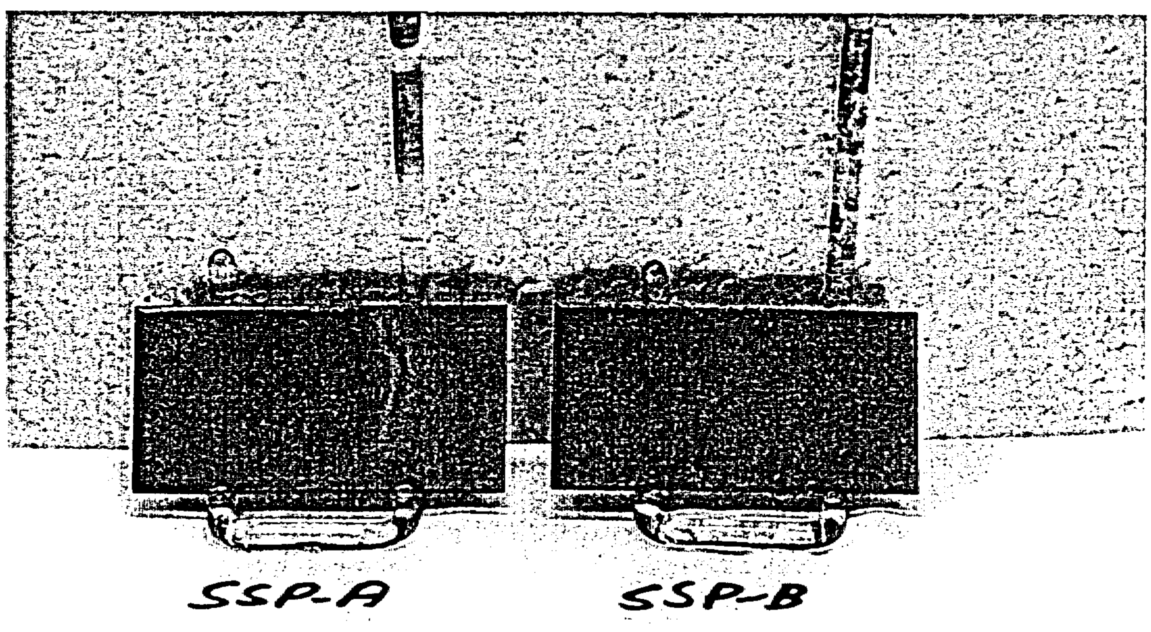


Figure 5b. Stainless steel specimens coated with primer (SSP-A, SSP-B) in post-test condition.

Figure 5c. Stainless steel specimen primer coated (SSP-B) showing after coating was stripped in post-test condition.

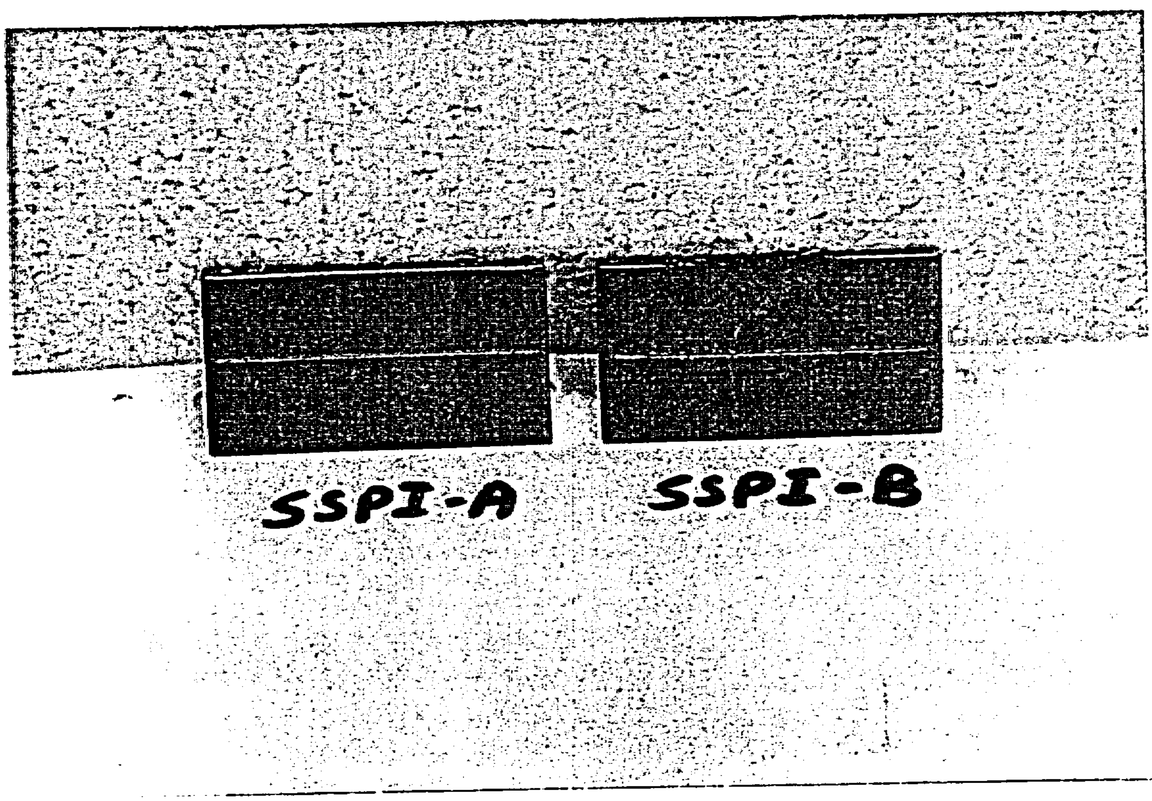


Figure 6a. Stainless steel primer coated and inscribed (SSPI-A, SSPI-B) in the pretest condition. (Top Side).

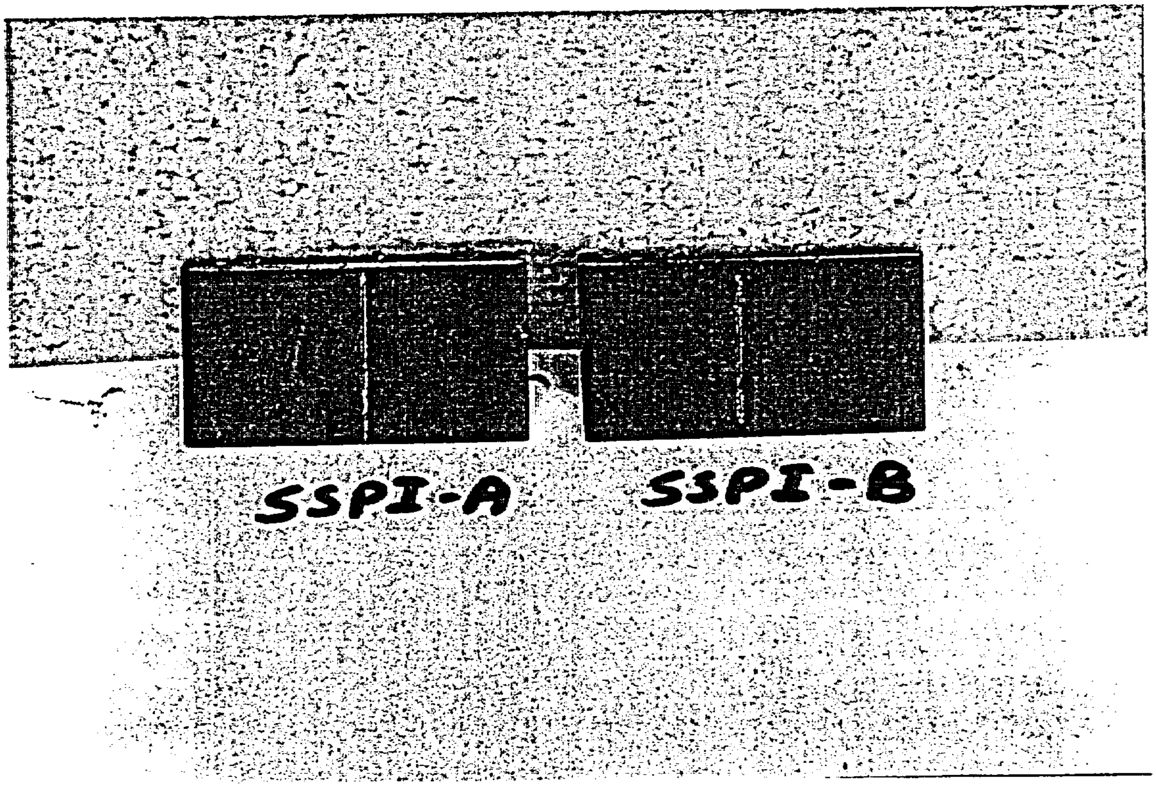


Figure 6b. Stainless steel primer coated and inscribed (SSPI-A, SSPI-B) in the pretest condition. (Bottom Side)

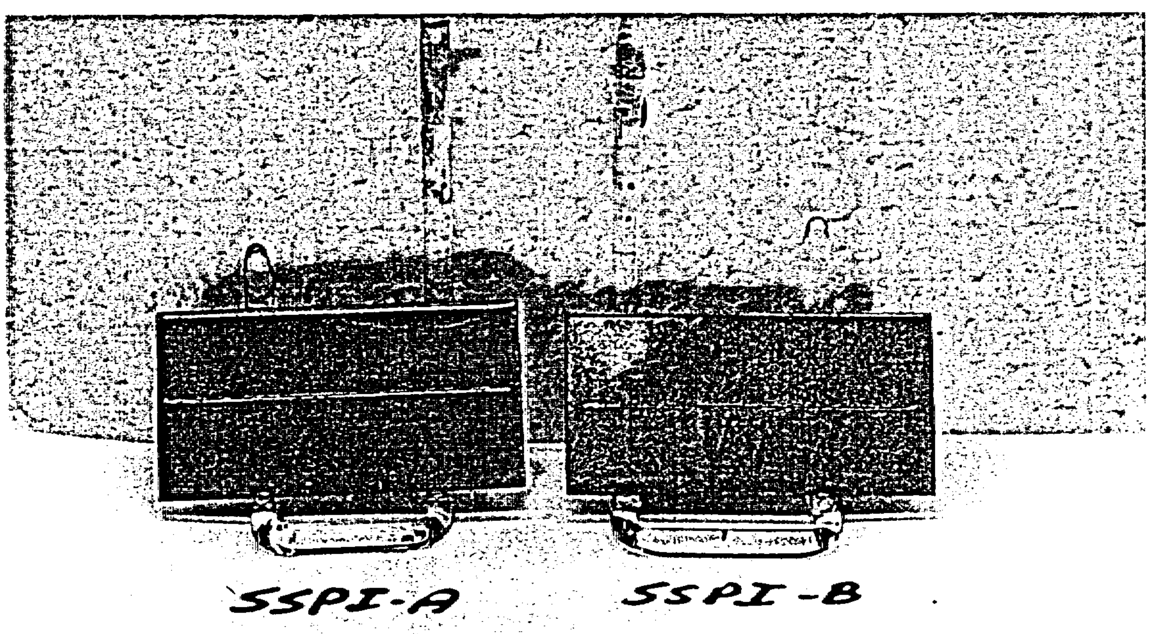


Figure 6c. Stainless steel primer coated and inscribed (SSPI-A, SSPI-B) in the post-test condition. (Top Side).

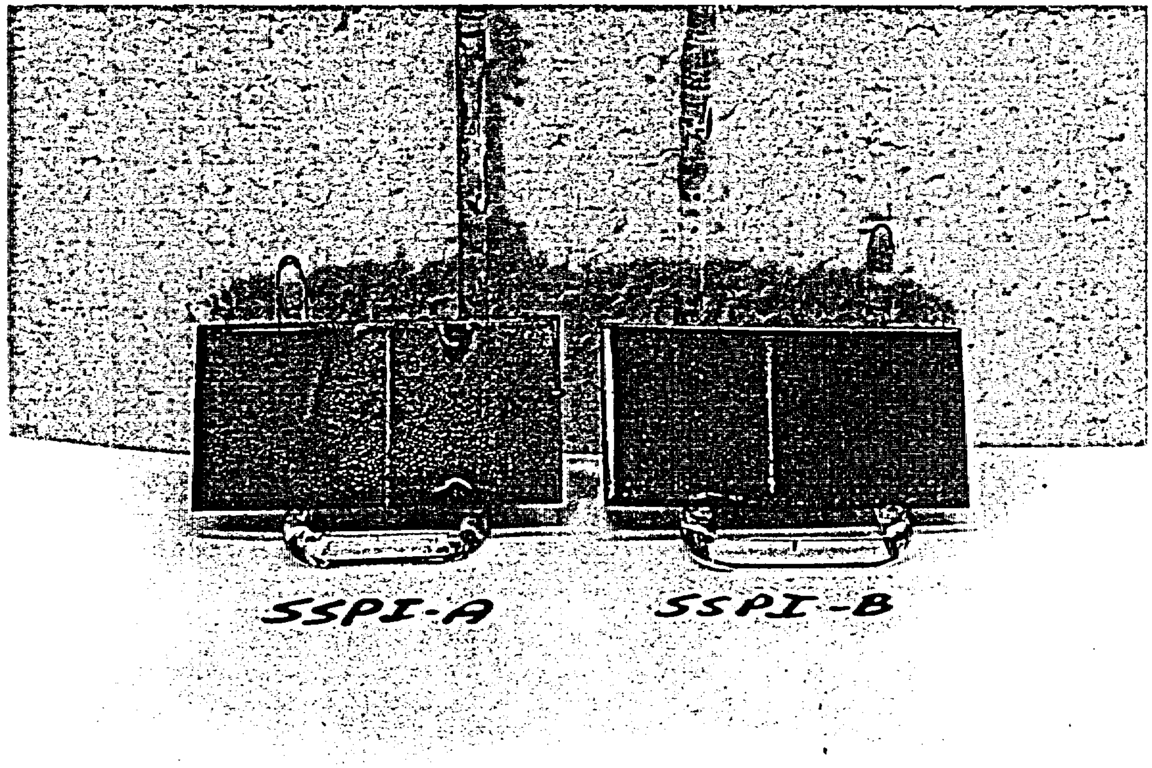


Figure 6d. Stainless steel primer coated and inscribed (SSPI-A, SSPI-B) in the post-test condition. (Bottom Side)

Figure 6e. Stainless steel primer coated and inscribed (SSPI-B)shown after the coating was stripped in the post-test condition. (Top Side).

Figure 6f. Stainless steel primer coated and inscribed (SSPI-B) shown after the coating was stripped in the post-test condition. (Bottom Side)

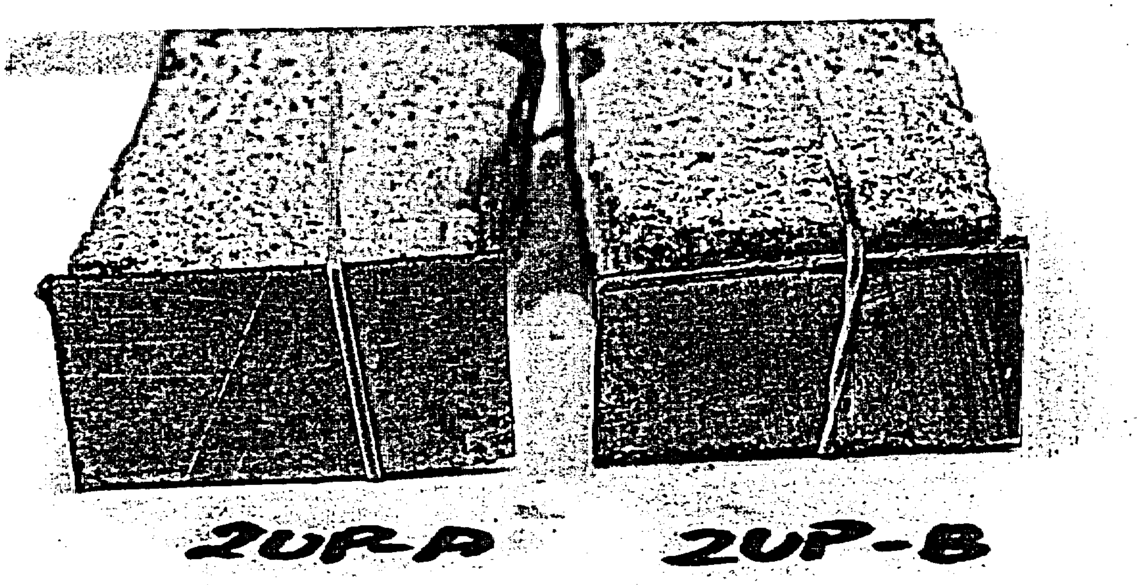


Figure 7a. Stainless steel/foam specimens (2UP-A, 2UP-B) in pretest condition.

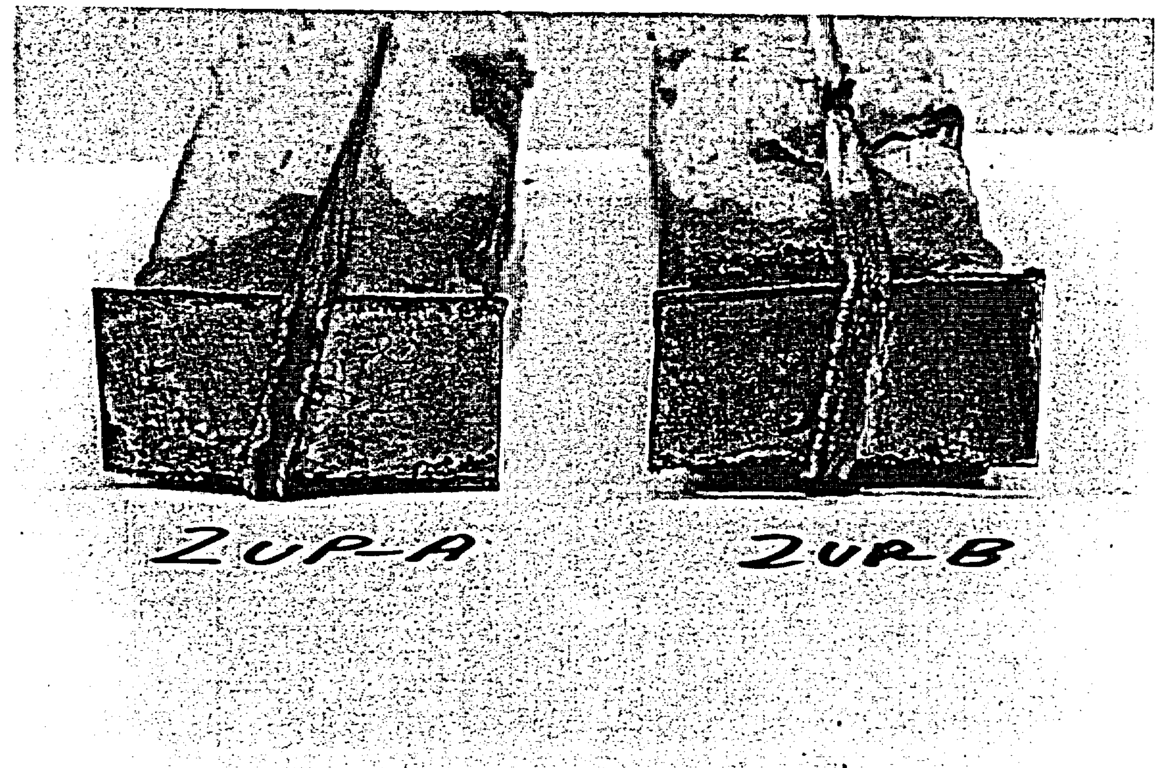


Figure 7b. Stainless steel/foam specimens (2UP-A, 2UP-B) in post-test condition.

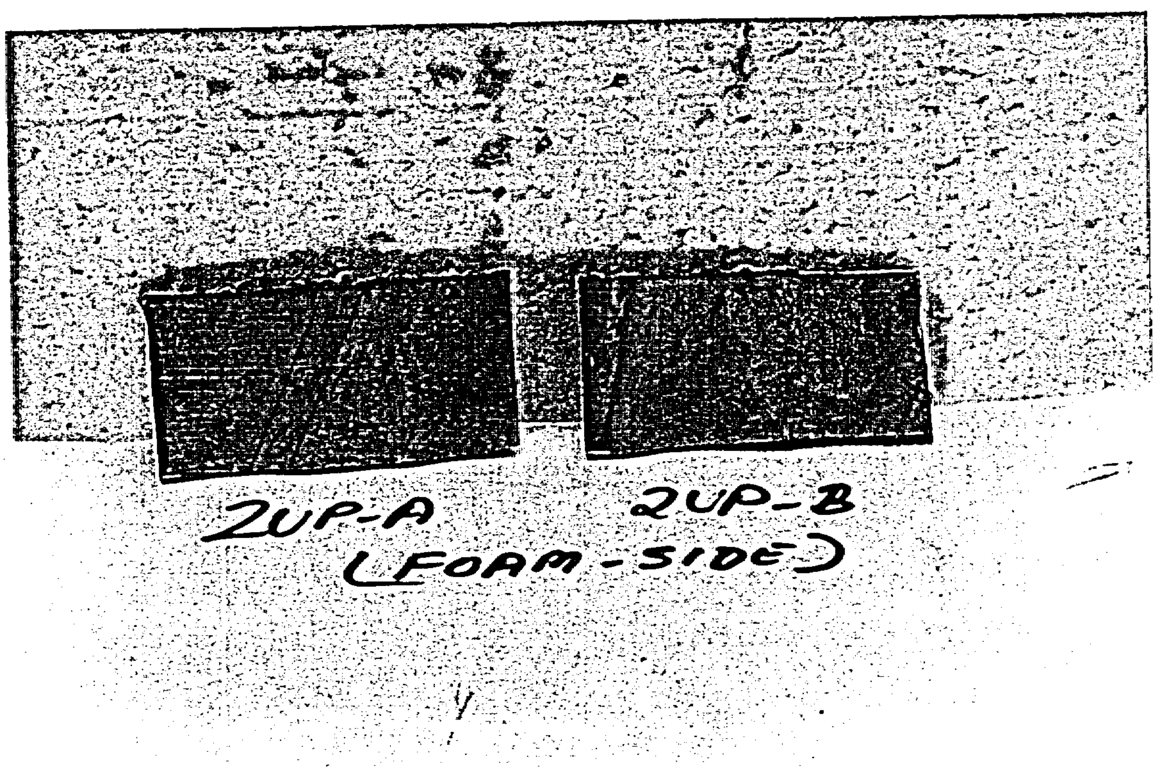


Figure 7c. Stainless steel/foam specimens (2UP-A, 2UP-B) in post-test condition. (Showing the side facing the foam)

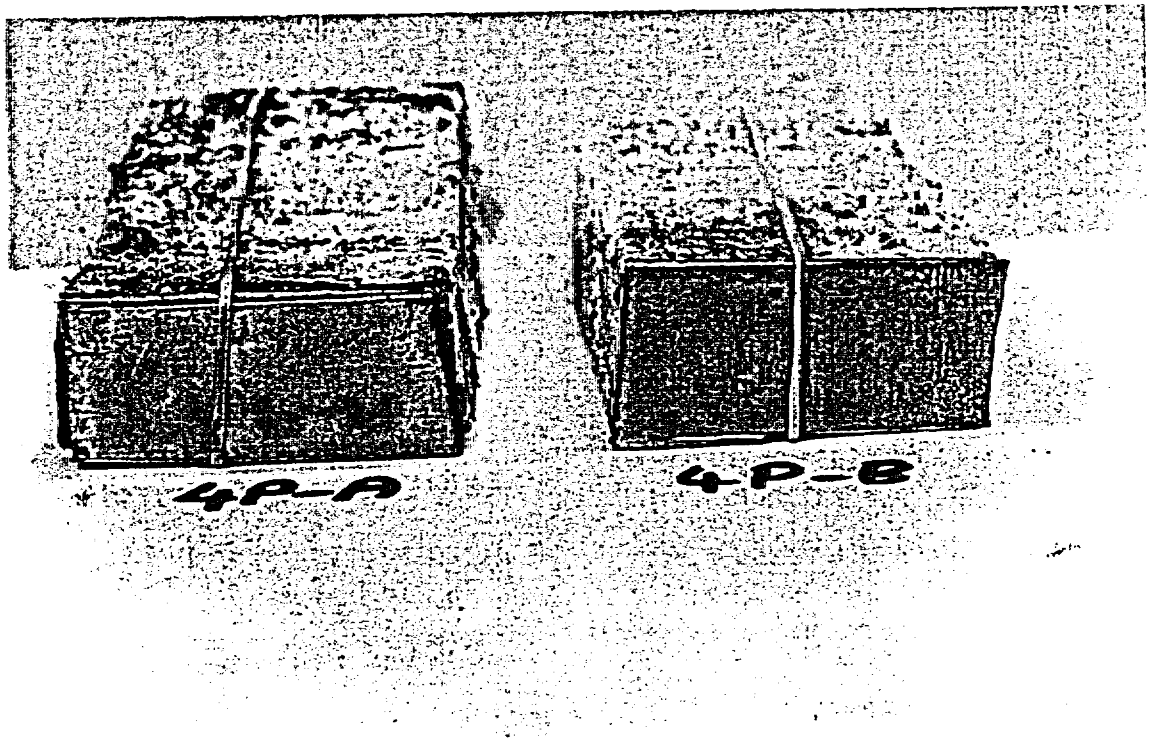


Figure 8a. Stainless steel/foam specimens (4P-A, 4P-B) in pretest condition.

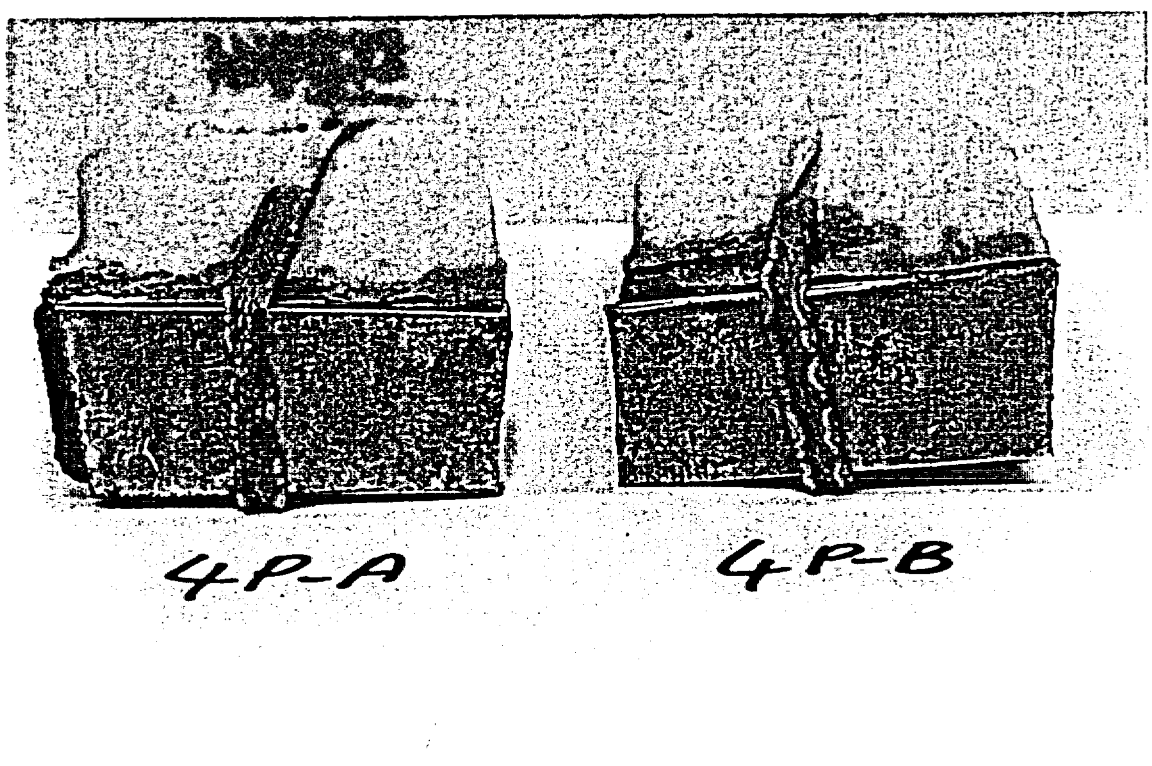


Figure 8b. Stainless steel/foam specimens (4P-A, 4P-B) in post-test condition

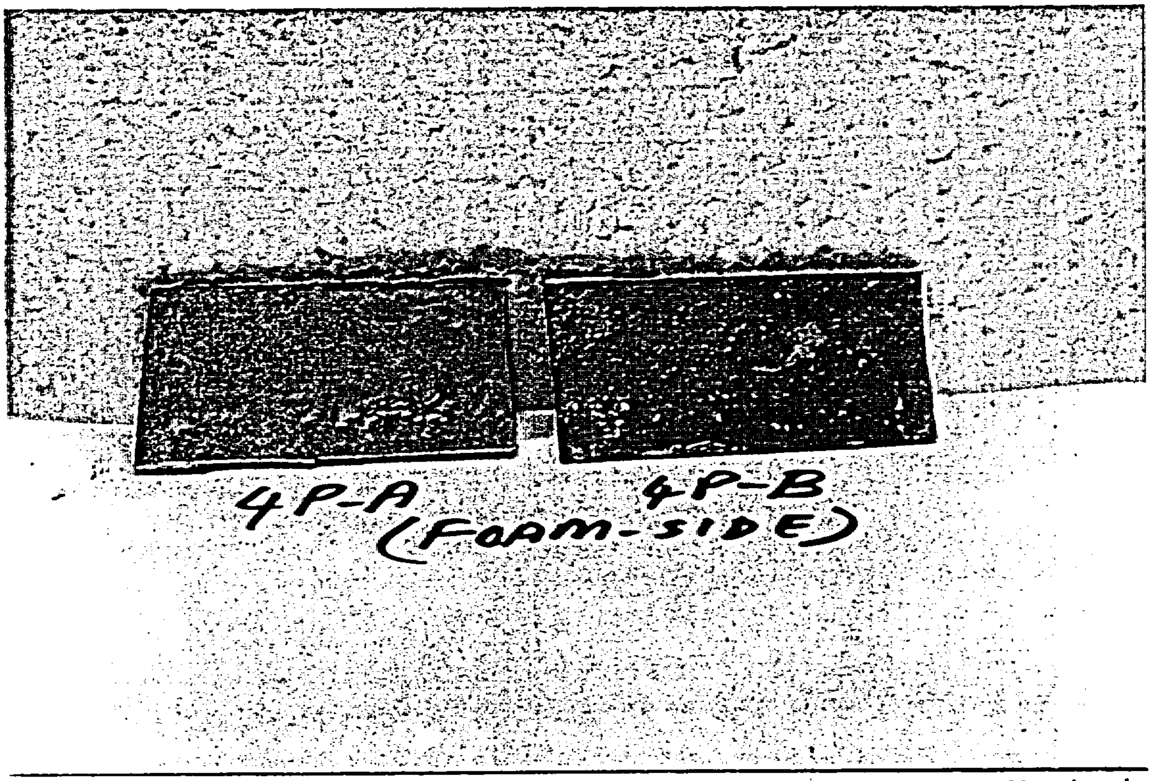


Figure 8c. Stainless steel/foam specimens (4P-A, 4P-B) in pretest condition. (Showing the side facing the foam)

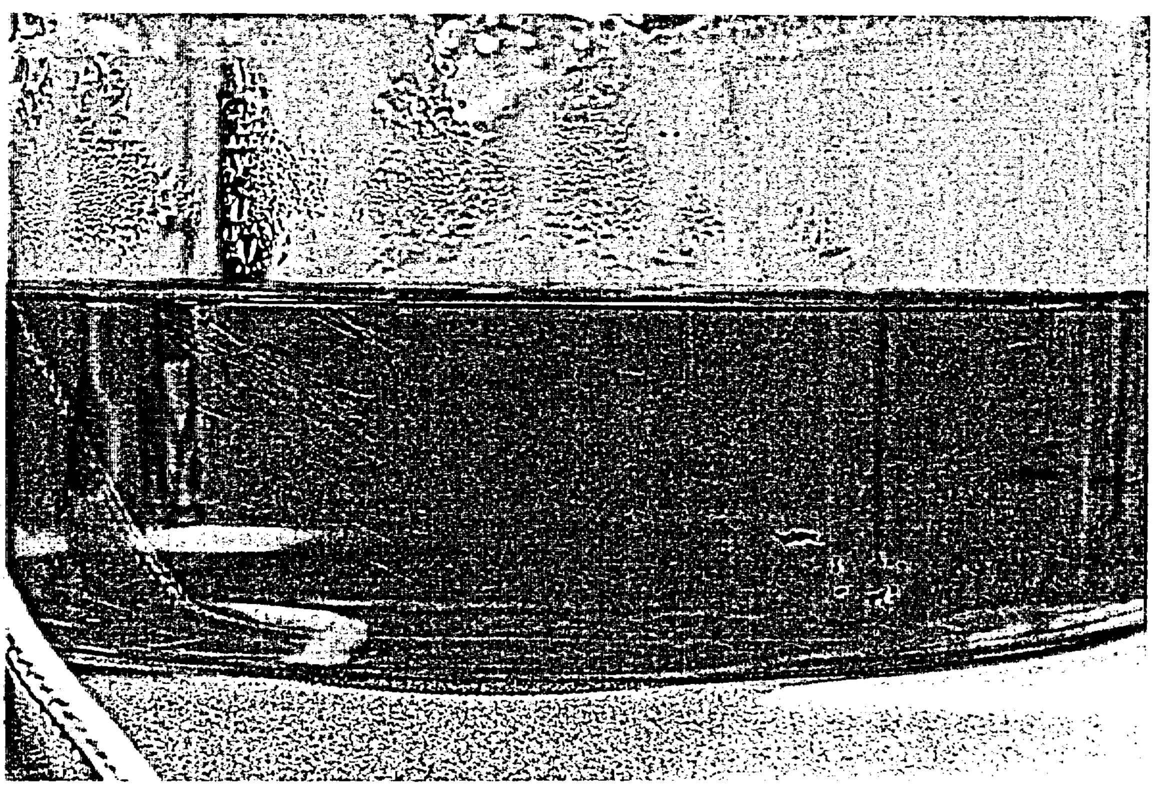


Figure 9a. Color of the bath-1 solution. (Containing SS, SSP and SSPI specimens)

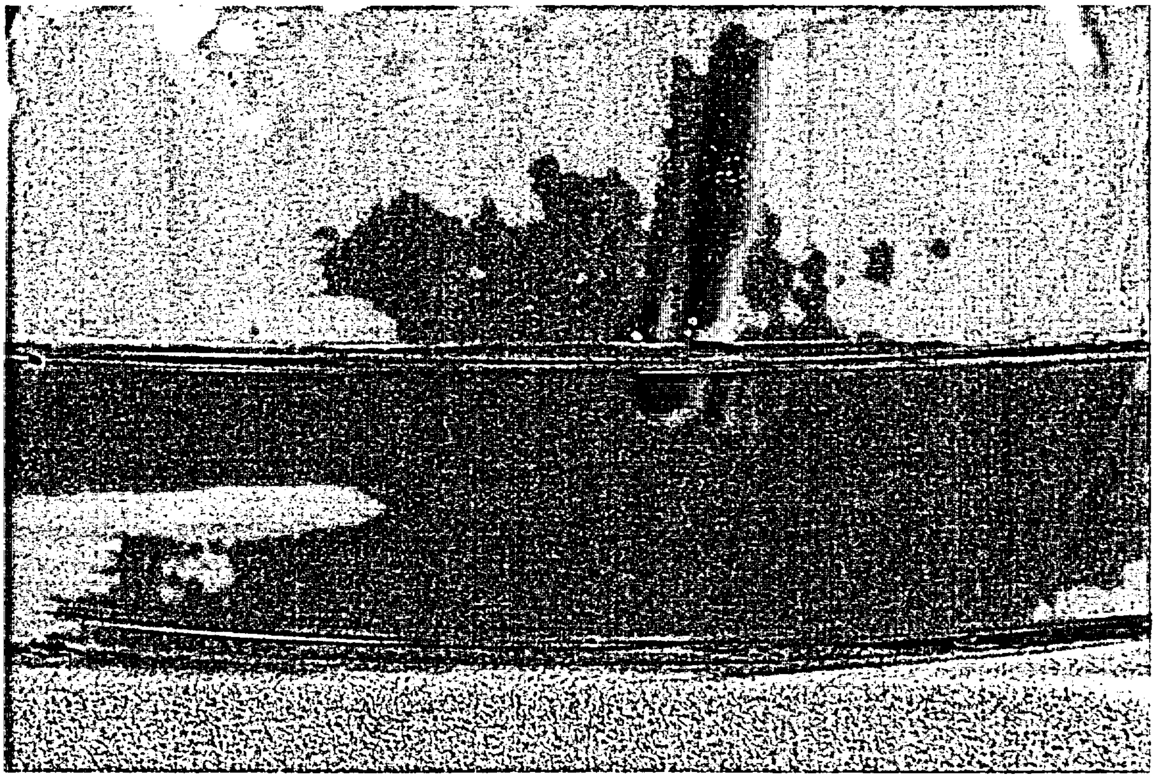


Figure 9b. Color of the bath-2 solution. (Containing 2UP and 4P Specimens)

ATTACHMENT 2

LAW ENGINEERING INDUSTRIAL SERVICES
A DIVISION OF LAW ENGINEERING, INC.
2801 YORKMONT ROAD, SUITE 200 • CHARLOTTE, N.C. 28208
P.O. BOX 19667 • CHARLOTTE, N.C. 28219-9667
PHONE 704-357-8600 •FAX 704-357-8637

REPORT OF MICROSCOPIC EXAMINATION

Client: NUCLEAR CONTAINERS, INC.
c/o Law Engr. Indus. Svcs.
P.O. Box 19667
Charlotte, NC 28219
Attn: Mr. L. Santanam

Project: General
Office: LEIS Charlotte
Lab No.: 10832-5-0807
Page 1 of 1
Date: October 20, 1995

Client P.O. No.: Not Reported
Material: Reported as Submitted Samples from 400ppm Ferric Chloride Corrosion Test, ID (See Below)
Heat/Lot No.: Not Reported
Date Tested: Completed October 20, 1995
Procedure: In accordance with Client's Instructions and ASTM E-3-80(86)

TEST RESULTS

LEIS Piece No.	Results	Comments
10-11-95-SS-A	Photomicrograph - Side 1	See Photo*
10-11-95-SS-B	Photomicrograph - Side 1	See Photo*
10-11-95-SSP-A	Photomicrograph - Side 1	See Photo*
10-11-95-SSP-B	Photomicrograph - Side 2	See Photo*
10-11-95-SSPI-A	Photomicrograph - Side 2	See Photo*
10-11-95-SSPI-B	Photomicrograph - Side 2	See Photo*
10-11-95-2UP-A	Photomicrograph - Side 1	See Photo*
10-11-95-2UP-B	Photomicrograph - Side 2	See Photo*
10-11-95-4P-A	Photomicrograph - Side 1	See Photo*
10-11-95-4P-B	Photomicrograph - Side 1	See Photo*

*Cross Section

Attachment: Photomicrograph (10 Etched)

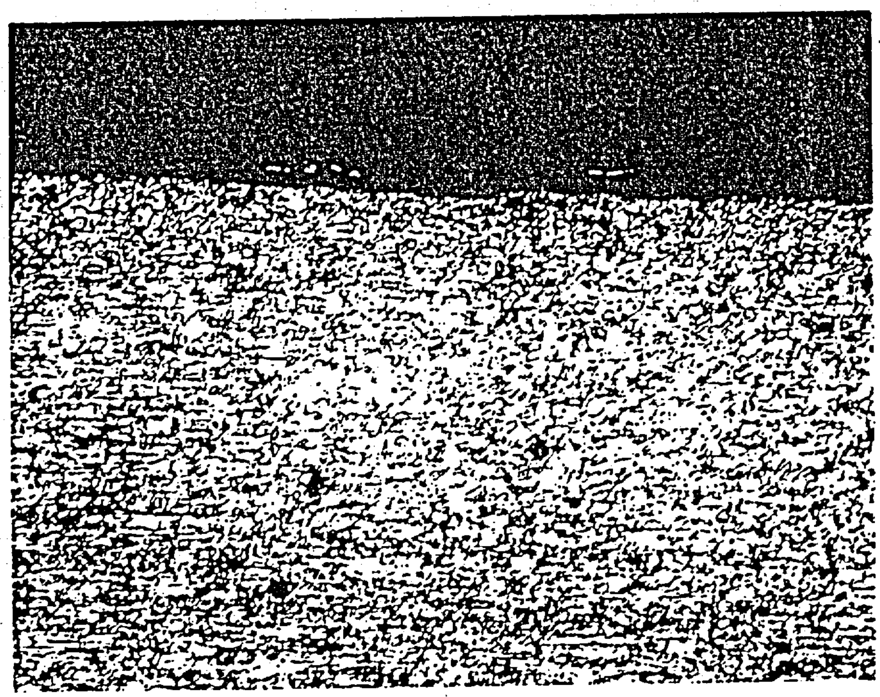
Reviewed by: L. Santanam
Lakshman Santanam
Laboratory Manager

Respectfully Submitted,
LAW ENGINEERING INDUSTRIAL SERVICES

Larry E. Coble, Metals Lab Supervisor

NUCLEAR CONTAINERS, INC.
c/o Law Engr. Indus. Svcs.
Charlotte, NC
LEIS Lab No. 10832-5-0807
October 20, 1995

Piece No. 10-11-95-SSP-A 100X Etched



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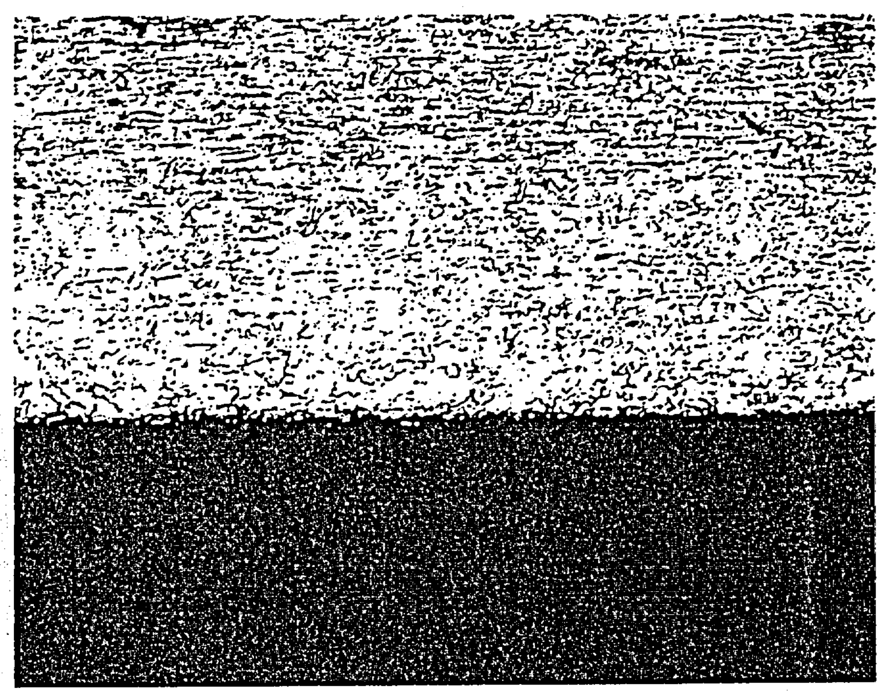

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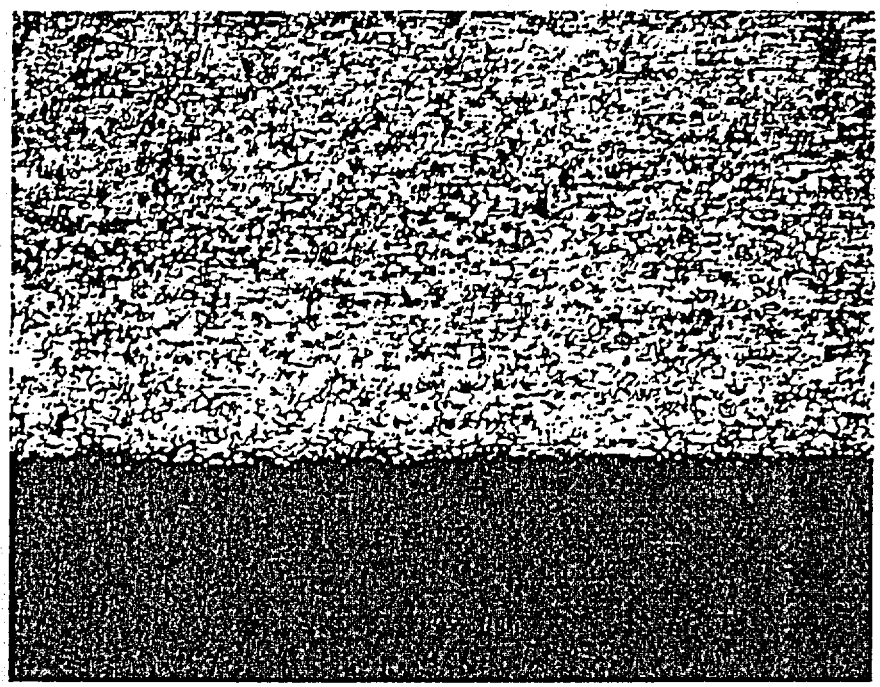
October 20, 1995

Piece No. 10-11-95-SSPI-A 100X Etched



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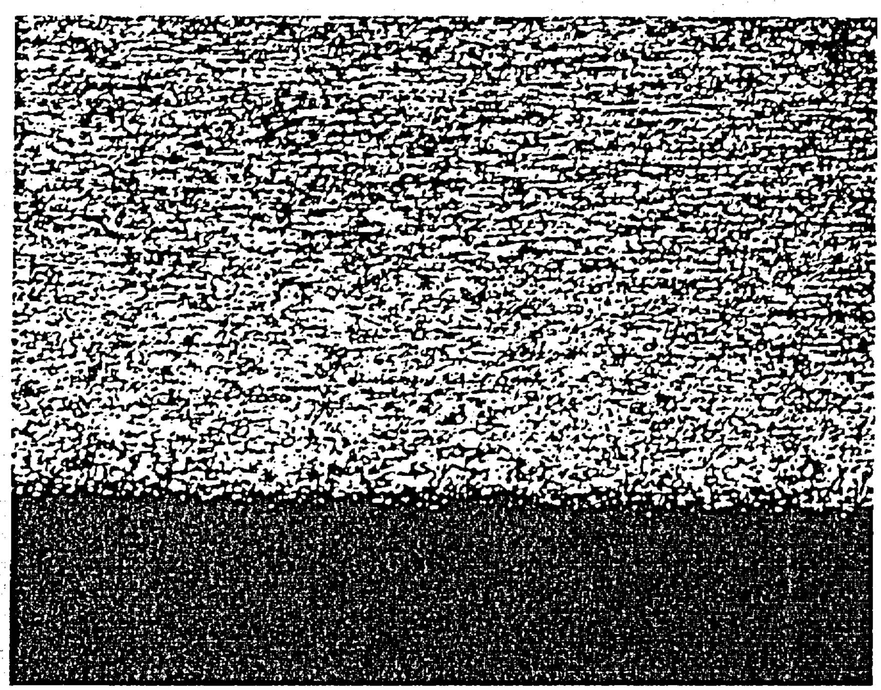

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October 20, 1995

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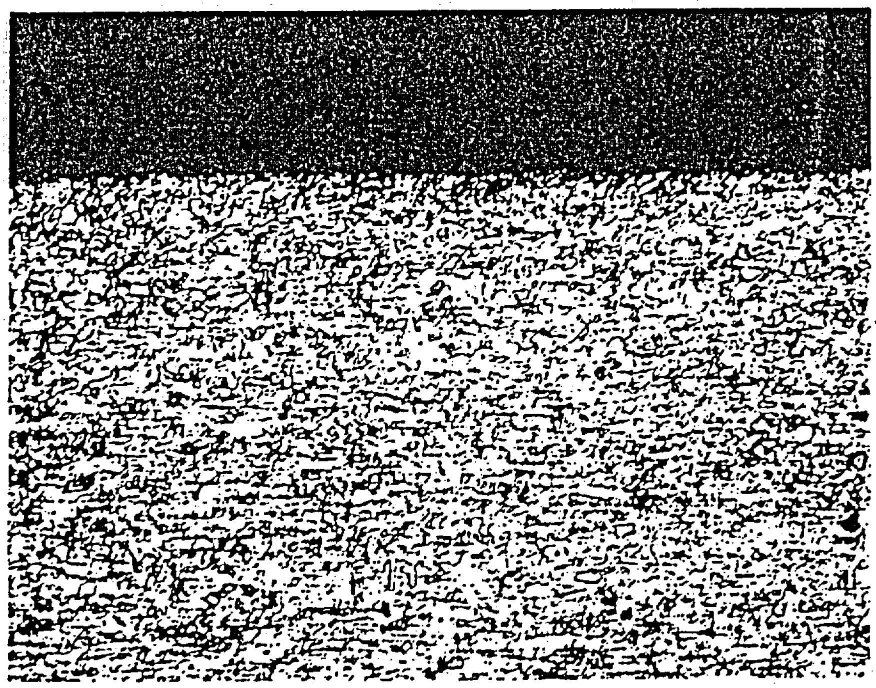

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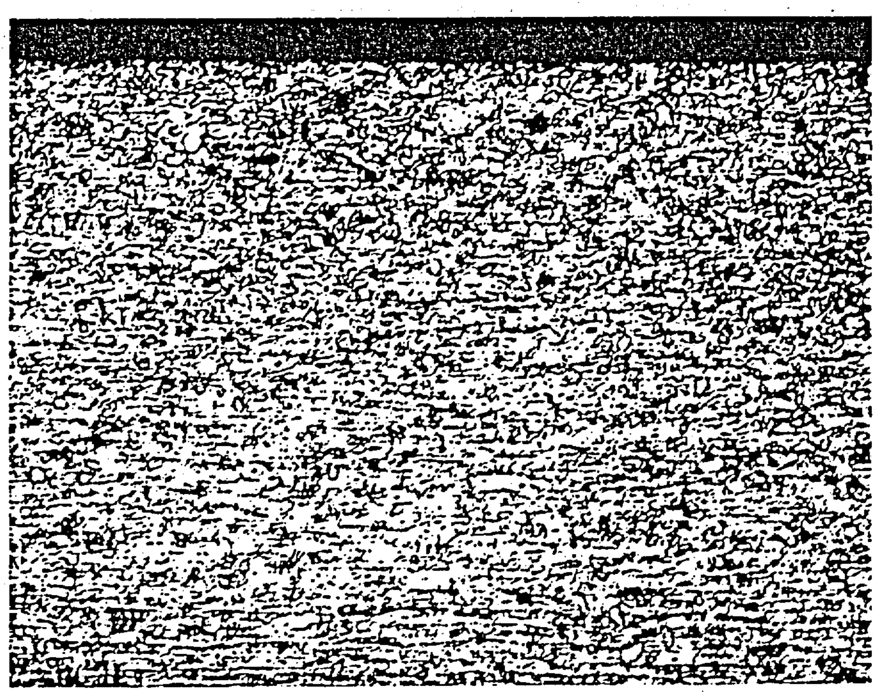

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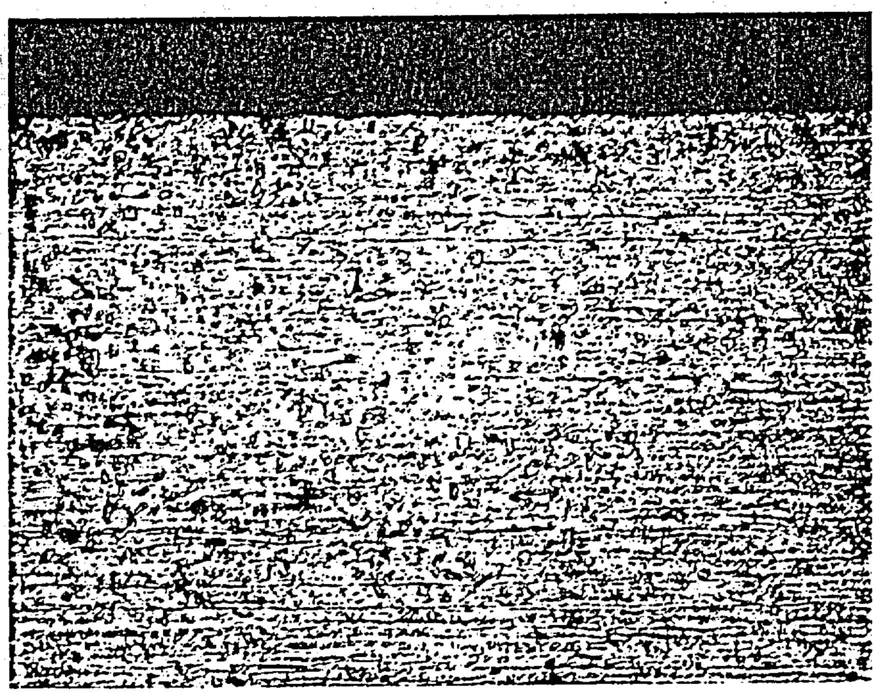
October 20, 1995

Piece No. 10-11-95-2UP-A 100X Etched



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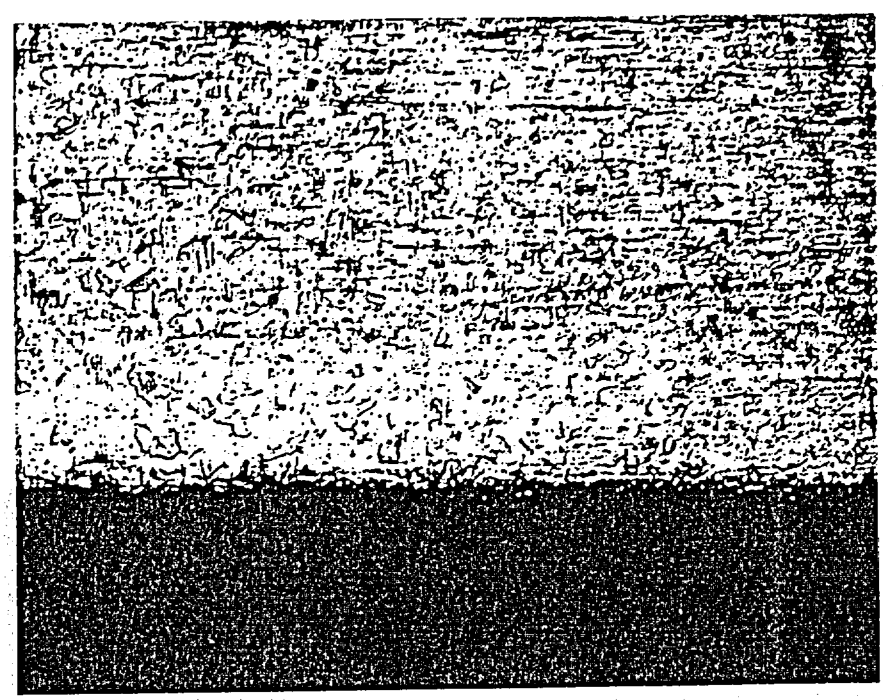

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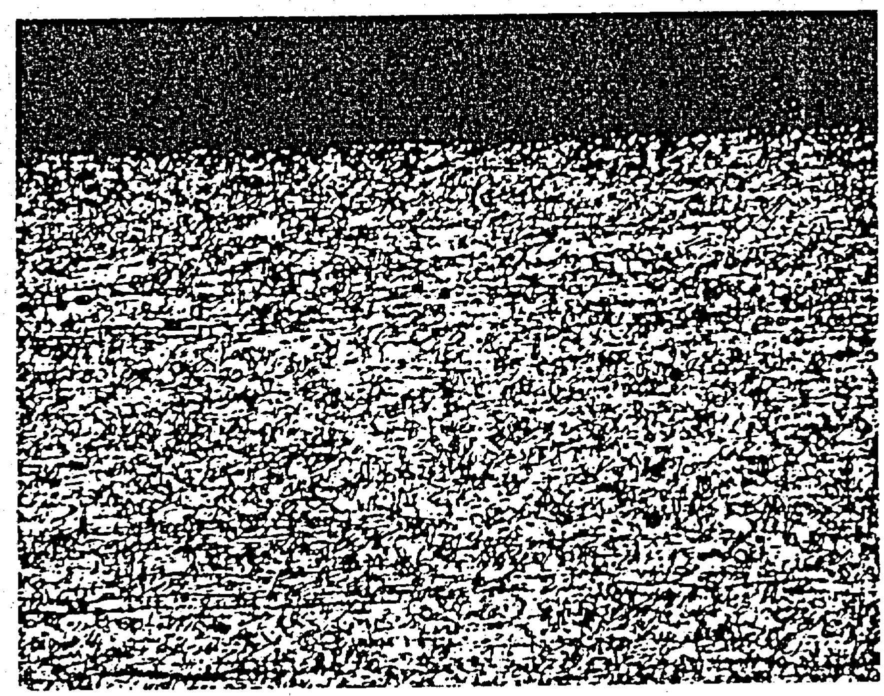
Charlotte, NC
LEIS Lab No. 10832-5-0807
October 20, 1995

Piece No. 10-11-95-4P-A 100X Etched



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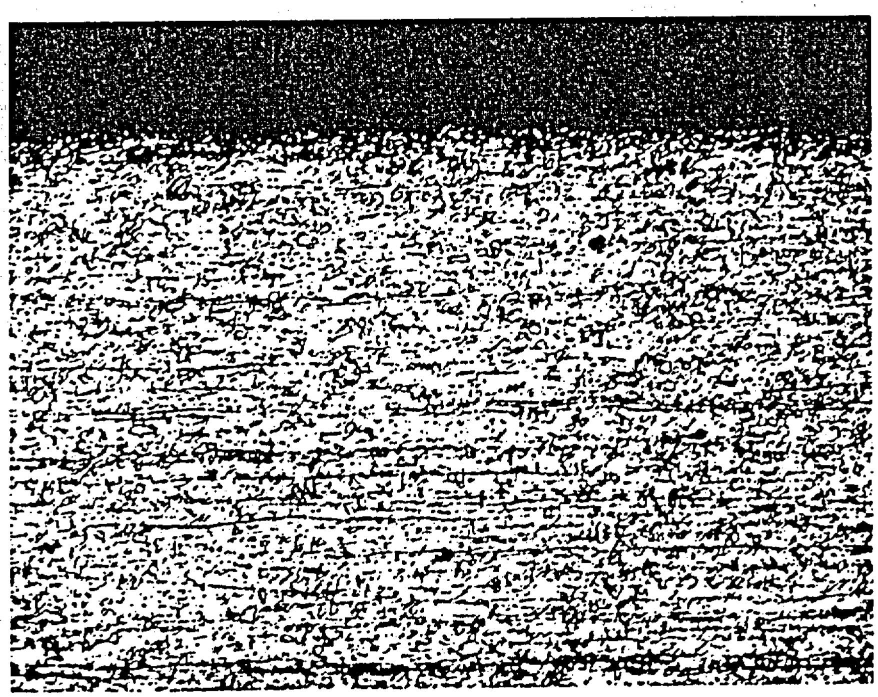


APPENDIX 2.10.4
BUCKLING ANALYSIS OF THE 30B CYLINDER

TABLE OF CONTENTS

2.10.4.1 Introduction 2.10.4-1

2.10.4.2 30B Cylinder Maximum Allowable Working Pressure 2.10.4-1

2.10.4.3 Conclusion 2.10.4-3

APPENDIX 2.10.4
BUCKLING ANALYSIS OF THE 30B CYLINDER

2.10.4.1 Introduction

The 30B cylinder is subjected to various loading during operation. The stresses in the cylinder have been conservatively evaluated and are shown to be acceptable in Chapter 2. The purpose of this appendix is to calculate the maximum allowable external working pressure of the 30B cylinder.

2.10.4.2 30B Cylinder Maximum Allowable External Working Pressure

The maximum allowable external working pressure will be calculated using the ASME Boiler & Pressure Vessel Code, Under UG-28 of ASME Section VIII, Division 1, "Thickness of Shells and Tubes Under External Pressure." Symbol definition:

A = factor determined from Fig. G in Subpart 3 of Section II, Part D.

B = factor determined from the applicable material in Subpart 3 of Section II, Part D for maximum design metal temperatures.

D_o = outside diameter of cylindrical shell course or tube, in.,30 inches

L = total length, in., of a tube between tube sheets, or design length of a vessel section between lines of support. For LU-0812, the cylinder body was measured at 56 in. The cylindrical portions of the heads are added to this, therefore: 56" + 2 (0.333 × 10"), 63 in.

P = external design pressure, psi. For this analysis, the pressure is equal to 20 psia.

P_a= calculated value of maximum allowable external working pressure for the assumed value of t, psi

t = minimum required thickness of cylindrical shell or tube, in. Under Reference 2.4, Section 6.3.2, 30B cylinders must be removed from service when their shell thicknesses have decreased below 5/16 inch thickness.

Under UG-28:

Step 1 Determine ratios L/D_o and D_o/t:

$L/D_o = 63 \text{ in} / 30 \text{ in} = 2.1$
$D_o/t = 30 \text{ in} / 0.3125 \text{ in} = 96 > 10$

Step 2 Enter Fig G in Subpart 3 of Section II, Part D at the value of L/D_o.

Step 3 Move horizontally to the line for the value of D_o/t determined in Step 1. Interpolation for intermediate values is acceptable. From point of intersection move vertically down and determine the value A.

A = 0.0007

Step 4 Using A, enter the applicable material chart in Subpart 3 of Section II, Part D for the material under consideration. (From Section II, Table 1A, for A516, Grade 55, 60, 65 or 70 use External Pressure Chart No. CS-2. From ANSI N14.1, the maximum design temperature is 250°F.) Move vertically to an intersection with the material/temperature.

Step 5 From intersection obtained in Step 4, move horizontally, determine the value B.

B = 10,000

Step 6 Using this B, calculate the maximum allowable external working pressure, P_a:

$$P_a = \frac{4B}{3(D_o/t)}$$

$$P_a = \frac{40{,}000}{288}$$

$$P_a = 139 psig$$

Performing a similar analysis for the heads on the 30B Cylinder, from *UG-33, "Formed heads pressure on Convex Side"*. Symbols:

A, B same as above.

R_o= for torispherical heads, the outside radius of the crown portion of the head, in. = D_o = 30 in.

t = minimum required thickness of head after forming, in. = 5/16 inch.

Step 1 Calculate the value of factor A using the following formula:

$$A = \frac{0.125}{R_o/t}$$
$$A = \frac{0.125}{30/0.3125}$$
$$A = 0.0013$$

Step 2 Using the value of A, enter the applicable material chart in Subpart 3 of Section II, Part D for the material under consideration. (Similar to above, Chart No CS-2 was used.)

Step 3 Read value of factor B.

B = 13,000

Step 4 Calculate the value of maximum allowable working pressure, P_a:

$$P_a = \frac{B}{(R_o/t)}$$
$$P_a = \frac{13{,}000}{30/0.3125}$$
$$P_a = 135 psig$$

The maximum allowable working pressures are:

For 30B Cylinder Body, P_a = 139 psig
For 30B Cylinder Heads, P_a = 135 psig
Increased external pressure, P = 20 psia, 34.7 psig.

2.10.4.3 Conclusions

The maximum allowable working pressures of the 30B cylinder body and heads are significantly higher than the increased external pressure specified under normal conditions. Therefore, the compressive stresses in the cylinder body and heads are acceptable based on the buckling requirements of the ASME Code.

APPENDIX 2.10.5
COMPLIANCE TESTING OF THE NCI-21PF-1 PACKAGE

TABLE OF CONTENTS

2.10.5.1	Introduction	2.10.5-1
2.10.5.2	Test Articles	2.10.5-1
2.10.5.3	Test Facility	2.10.5-2
2.10.5.4	Testing Equipment and Calibration	2.10.5-4
2.10.5.5	Testing Description	2.10.5-5
2.10.5.6	Summary and Results of Tests	2.10.5-9
2.10.5.7	Conclusion	2.10.5-12

LIST OF FIGURES

2.10.5-1	NCI-21PF-1 Package - Thermocouples and Temperature Tapes Location on the Cylinder	2.10.5-13
2.10.5-2	NCI-21PF-1 Package -Time vs Temperature Data (Thermocouples 3-5)	2.10.5-14
2.10.5-3	NCI-21PF-1 Package -Time vs Temperature Data (Thermocouples 6-10)	2.10.5-15
2.10.5-4	NCI-21PF-1 Package -Time vs Temperature Data (Thermocouples 11-15)	2.10.5-16
2.10.5-5	NCI-21PF-1 Package -Time vs Temperature Data (Thermocouples 16-21)	2.10.5-17

LIST OF PHOTOS

2.10.5-1	Drop Pad and Plywood Photographic Backdrop	2.10.5-18
2.10.5-2	Punch	2.10.5-18
2.10.5-3	Wind Speed and Direction Instrumentation	2.10.5-19
2.10.5-4	Cooling Chamber	2.10.5-20
2.10.5-5	Crane	2.10.5-21
2.10.5-6	Test Article Release Mechanism	2.10.5-21
2.10.5-7	Video Equipment	2.10.5-22
2.10.5-8	Fire Test Pool and Fire Test Stand	2.10.5-23
2.10.5-9	Leak Test Equipment, Calibrated Leak at Test Port	2.10.5-24
2.10.5-10	Leak Test Equipment, Calibrated Leak at Valve	2.10.5-24
2.10.5-11	Bending the 30B Cylinder Skirt	2.10.5-25
2.10.5-12	Repairing the 30B Cylinder Skirt	2.10.5-25
2.10.5-13	Damaged and Repaired 30B Cylinder Skirt	2.10.5-26
2.10.5-14	Valve Installation Tool	2.10.5-26
2.10.5-15	Valve Protection Device - Honeycomb Insert	2.10.5-27
2.10.5-16	Typical - Checking Fit Between Valve and Honeycomb Insert	2.10.5-28
2.10.5-17	Valve Protection Device Installed in Cylinder Skirt	2.10.5-29
2.10.5-18	Cylinder with Temperature Indicating Instrumentation	2.10.5-29
2.10.5-19	NCI-21PF-1 Overpack	2.10.5-30
2.10.5-20	Loading the Cylinder into the NCI-21PF-1 Overpack	2.10.5-30
2.10.5-21	NCI-21PF-1 Package - 30 Foot Free Drop	2.10.5-31
2.10.5-22	NCI-21PF-1 Package - Damage Following 30 Foot Free Drop	2.10.5-31
2.10.5-23	NCI-21PF-1 Package - 40 Inch Puncture	2.10.5-32
2.10.5-24	NCI-21PF-1 Package - Damage Following 40 inch Puncture	2.10.5-32
2.10.5-25	NCI-21PF-1 Package - Preparing for Fire Testing	2.10.5-33
2.10.5-26	NCI-21PF-1 Package - Fully Engulfed	2.10.5-33
2.10.5-27	NCI-21PF-1 Package - Fire Complete	2.10.5-34
2.10.5-28	NCI-21PF-1 Package - Package Condition Following Cooldown	2.10.5-34
2.10.5-29	NCI-21PF-1 Package - Opening the Package after the Fire Test	2.10.5-35
2.10.5-30	NCI-21PF-1 Package - Aluminum Honeycomb Condition Following Testing	2.10.5-36

APPENDIX 2.10.5
COMPLIANCE TESTING OF THE NCI-21PF-1 PACKAGE

2.10.5.1 Introduction

This appendix describes the compliance testing of the NCI-21PF-1 overpacks with the Valve Protection Device (VPD) installed. The drop orientations for compliance testing were selected based on a review of previous testing of similar overpacks as described in Appendix 2.10.6. The conclusions from these tests are provided in Section 2.7 of this SAR.

This testing was designed to evaluate the performance of the valve protection device in the 30 foot drop and the 40 inch puncture tests in both the 13.5° and 30° from vertical orientations. These orientations were determined to be the worst orientations based on previous testing See Appendix 2.10.6. It was also determined to perform the drop testing cold (at approximately -20°F) in order to maximize the g loading during the drop tests. As discussed below, the overpack insulating properties prevented the package from reaching -20°F during a practical time period. However, subzero temperatures were attained.

The package which exhibited the maximum amount of damage from the drop tests, which might influence the overpack performance during fire testing was used in the subsequent fire test.

Both packages were leak tested and hydrostatically tested after completion of the tests.

2.10.5.2 Test Articles

Each test article consisted of a UF_6 30B cylinder, a valve protection device, and an NCI-21PF-1 overpack (with NCI-PF-1 foam, in accordance with Appendix 2.10.2).

30B Cylinder

A representative 30B cylinders, not specifically built for this program was used. The cylinder used had never been used in drop and puncture testing (the skirt was bent and repaired as described in Section 2.10.5.5). The empty 30B cylinder weighed 1,387 pounds.

Valve Protection Device

The valve protection device consisted of the three aluminum castings, a steel spider and a steel spacer as shown in Appendix 1.3. The two bottom aluminum castings are identical, and the third aluminum casting fits over the valve. The bottom castings are designed so that they cannot fit in the valve location. A steel spacer two inches thick fits between the aluminum castings over the cylinder head. A steel spider fits over the spacer and between the aluminum castings and holds the valve protection device in place by clamping against the inside wall of the cylinder skirt. The valve protection device weighed 165.3 pounds.

NCI-21PF-1 Overpack

The overpack was a representative NCI-21PF-1 overpack which was had been taken out of service for this testing. The overpack was inspected prior to the drop testing, and no significant damage was identified. The overpack toggle bolts were torqued to a value of 110 ft-lb prior to testing (in accordance with the procedure described in Chapter 8). The NCI-21PF-1 overpack weighed 2,311 pounds empty.

2.10.5.3 Test Facility

The test facilities are described below.

Drop Pad

The drop pad, an existing test facility that was specifically designed for this type of testing, is shown in Photo 2.10.5-1. The test facility consists of a 10' x 10' x 6' reinforced concrete slab embedded in the ground. The upper surface of the concrete slab is covered by a 1" thick steel plate that is attached to the slab using J-bolts. The heads of the bolts were covered during drops with wood to limit secondary damage to the test item. The entire drop pad weight is estimated to be 95,000 lbs. This does not include any effective mass of the surrounding soil, which is very compact.

Punch

For the puncture testing a puncture bar was attached, using 8 bolts, to the center of the drop pad, Photo 2.10.5-2. The puncture bar was fabricated out of a 6 inch diameter solid steel section welded to a two inch thick steel plate. The 6 inch diameter section was recessed into the plate to insure adequate strength. The distance from the top of the steel plate to the top of the puncture bar was 16 inches. There was no significant damage to the puncture bar as a result of the testing. There was no indication of motion of the puncture bar during any testing.

Wind Speed

The wind speed and direction instrumentation was in an open air site adjacent to the test facility, Photo 2.10.5-3. The mast mounted system was place on top of a van to place the instrumentation at approximately 18 feet above the ground. Signal conditioning and data acquisition was contained in the van.

Cooling Chamber

Low temperature conditioning of the test item prior to testing was done in a chamber built specifically for this project. The facility, Photo 2.10.5-4, was constructed in close proximity to the drop test site to minimize time between removal of the test item from conditioning and drop testing. The structure was plywood lined with 3-4" of insulating styrofoam. Cooling to the facility was supplied by liquid nitrogen. A removable top allowed for insertion and removal of the test items. Personnel access was through a single door in the side of the chamber. Thermal monitoring was routed from the chamber to an adjacent building for acquisition and control of the flow of liquid nitrogen.

Crane

A crane was used to handle the test items for the drop testing. The crane was situated so that it could pull the items out of the conditioning box and handle them for the drops, Photo 2.10.5-5. During all testing there was no tendency of the test item to move, prior to the drop, as a result of crane operations or wind conditions.

Test Article Release Mechanism

For drops, the test item was released using a quick release mechanism. Under normal conditions the jaws of the release hold a D-ring pin in place. The D-ring is attached to the wire rope sling supporting the test item. For release, pneumatic pressure is supplied to release the locking pin and allow the jaws to open (Photo 2.10.5-6). The release was controlled by the high speed camera operator to insure that the film was up to speed prior to drop.

Video Equipment

High speed films and normal speed videos were used to document the drop, Photo 2.10.5-7. The film was taken from two locations. The first was a side view showing the angle of the test item during drop. The second location was 43° from the first location and approximately 10 feet above the ground level. Two cameras were used at each location to insure coverage if one camera failed. One camera was an overall view and one was a close-up of the impact location.

A plywood photographic backdrop was constructed for this project, Photo 2.10.5-1. Each side of this structure was 12 feet high and 16 feet wide. The backdrop was painted off-white and had a grid of black lines on one foot centers covering the surface. The horizontal lines were parallel to the drop pad.

Furnace

A furnace was used to condition the package prior to fire testing. The inside dimensions of the furnace are 13 ft (wide) by 17 feet (long) by 9 feet (high). The temperature inside the furnace is maintained by a series of burners fired by natural gas that are spaced around the interior walls. Test articles are placed into the furnace using an overhead crane.

Fire Site

The fire tests were conducted at a remote test facility. The site is equipped with a portable control room and weather station.

Three containment pans were used to provide the prescribed fire while maintaining personnel safety. The sections were fabricated out of steel structural sections and plates. The pool consisted of a series of three square sections 15' x 15', 25' x 25', and 30' x 30'. Water was placed in each section to about 2-4 inches below the top of the pool structure. Diesel fuel was floated on the inner two sections to provide the engulfing flame. Sufficient fuel was placed in the sections at the beginning of the test to achieve the required burn time. (Photo 2.10.5-8)

Fire Test Stand

A welded steel structure was centered in the 15' x 15' containment pan to support the test article during the fire. The support structure was cooled with a water jacket to prevent buckling during the fire. Water was pumped through the support structure using an immersion pump. (Photo 2.10.5-8)

2.10.5.4 Test Equipment and Calibration

All inspection and test equipment was calibrated in accordance with Nationally recognized standards.

In addition, a system calibration of the helium leak detection equipment was performed. A leak, nominal 2.6×10^{-6} std cc/sec, was placed on the intake port of the helium leak detector. A bag was placed over the leak and helium was constantly introduced. The indicated leak was monitored until it stabilized. With the leak attached at the intake port of the helium leak detector, it took less than 5 minutes to stabilize the leak rate, with an almost immediate indication of leakage. (Photo 2.10.5-9)

This known leak was then placed in a modified cap that was placed on the valve. (The valve had been previously tested and found to be "leak tight".) The leak was again bagged for the introduction of helium. Helium was introduced and the valve was opened. A leak was indicated by the detector almost immediately. The indicated leak rate was monitored for approximately 1 hr 45 min. The leak rate reached 3.2×10^{-6} std cc/sec which compared favorably to the pre-test results (Photo 2.10.5-10).

This system calibration verified that the helium leak detector would detect a leak almost immediately and that the final indicated leak rate would be comparable to actual.

2.10.5.5 Test Description

The testing program is described below.

Removing the 30B Cylinder Valve

The valve was removed from the cylinder.

Bending of 30B Cylinder Skirt

Following the removal of the cylinder valve, each cylinder skirt in the region of the valve was bent inward to simulate damage which could occur during cylinder use. A special fixture was fabricated to perform this operation. It consisted of a steel ring, that surrounded the skirt and provided a reaction point for the hydraulic cylinder used to apply the load (Photo 2.10.5-11). Unsuccessful attempts were made to bend the cylinder skirt without heating the skirt material.

The skirt in the region of the valve was heated to a red color (approximately 700°F). Using the hydraulic cylinder, a load of 31,000 lbs was applied to bend the region a minimum of 1". Once the bending was completed, the cylinder skirt was heated again and then straightened as well as possible to bring the cylinder skirt back to its original configuration. The straightening was also done using a hydraulic cylinder, but final shape was attained with the help of a sledge hammer (Photos 2.10.5-12 and 2.10.5-13).

Filling the 30B Cylinder and Replacing the 30B Cylinder Valve

The steel shot used for the simulated cargo was small diameter (< 1/16 inch) and oddly shaped. Approximately 5,020 pounds of steel shot were loaded into the cylinder. The steel filled a volume of approximately 18 ft^3 of the total internal volume of 26 ft^3. This allowed for movement of the steel shot during handling and testing. Because of the small size and odd shapes of the steel shot, it provided a minimal restriction of the flow of helium from the valve location to the port location.

Following cylinder loading, the 1-inch 30B cylinder valve was installed using standard procedures. The threads in the boss were cleaned with a tap and the first five threads on the valve were chased with a die. The valve was hand threaded at first. A special valve installation tool was fabricated and used to install the valve to a torque of 400 ft-lbs (Photo 2.10.5-14). The following torque levels were confirmed: 55 ft-lbs on the valve stem, 110 ft-lbs on the packing nut, and 50 ft-lbs on the valve cap.

Normal Conditions Leak Testing

A bubble leak test was performed on the valve cap, valve stem, valve packing nut and the valve seat with a cylinder internal pressure of 100 psig nitrogen or air. The internal pressure was held for a period of 15 minutes, and no bubbles were permitted.

A helium mass spectrometer test was performed by evacuating the cylinder and introducing helium around the valve cap, valve stem, valve packing nut and the valve seat for a period of at least 2 minutes. The acceptance criterion was an air leakage rate of less than 1×10^{-7} std cc/sec.

If either of these leakage tests were not successful, the valves were removed, and new valves were installed until the leak tests were performed successfully.

Preparation of the 30B Cylinder and the NCI-21PF-1 Overpack

30B Cylinder: The location of the valve protection device with respect to the valve and the cylinder was recorded. Aluminum honeycomb was epoxied to the inside of the aluminum casting around the valve area to record the minimum clearance between the valve and the valve protection device during the drop testing (Photos 2.10.5-16 and 2.10.5-17). Aluminum honeycomb was selected because it would maintain its shape after the drop and during subsequent handling and could withstand the cold conditioning temperature and the maximum temperature anticipated in the fire. A thermocouple was attached to the cylinder skirt to determine cylinder temperature prior to drop and puncture testing.

The cylinder was instrumented with thermocouples, maximum temperature sensors and heat sensitive paint. Fifteen thermocouples were installed on the cylinder, and an additional thermocouple was used to monitor the temperature of the fire. The maximum temperature sensors had a range of 150°- 500°F and were in the form of irreversible self-adhesive temperature monitors consisting of heat sensitive indicators sealed under transparent heat resistant windows. Heat sensitive colored paint (range from 125°F - 1100°F) was also used to monitor the maximum temperature during the test and cool down period.

All thermocouples consisted of 20 gage, type K, Chromel-Alumel grounded junctions with magnesium oxide insulation and Inconel 600 sheath. A 1/2" x 1" x 1/8" weld pad was attached to the sheath for welding to the cylinder (Photo 2.10.5-18).

NCI-21PF-1 Overpack: The cylinder was placed horizontally into the bottom half of the overpack. The seals were inspected to ensure that no debris was present. A 1" hole was drilled in the end of the overpack opposite the valve to serve as a conduit for the thermocouple wires. The hole was packed with insulation. A metal cover was installed over the thermocouple leads to protect them from secondary impacts during the drop testing.

Loading Cylinder into Overpack and Cooling of Overpack

The 30B cylinder with valve protection device was loaded into the overpack with the valve in the 12 o'clock position (Photos 2.10.5-19 and 2.10.5-20).

The test article was installed in the cooling chamber for a period of at least 96 hours prior to testing. The cylinder, valve protection device and overpack halves were all cooled. To prevent additional moisture from entering the overpack, the overpack was closed prior to placement in the cooling chamber.

Remove Overpack from Storage

The test article was removed from the cooling chamber and quickly upended for the drop testing. The location of the valve was marked on the external surface of the overpack. The temperature of the test article was measured using the thermocouple attached to the cylinder skirt.

Perform 30 ft Free Drops and Record Damages

The test article was positioned at an orientation of 13.5° from vertical with the package center of gravity over the valve. The temperature of the test article, the wind speed, and the ambient temperatures were recorded prior to the drop.

The package was lifted to a height of 30 ft (a 30 ft rope with a plumb bob was attached to the lowest point on the package) using a crane. The release of the test item was by a pneumatically-actuated quick release mechanism. No guidance of the test item was provided during the drop.

Deformation data of the overpack was measured and recorded. High speed video were taken of the drop event. Color photographs of the extent of damage were taken. The overpack was not opened, it was placed into the cooling chamber until the 40 inch puncture test could be performed.

Perform 40 inch Puncture Tests and Record Damages

The test article was positioned at an orientation of 13.5° from vertical with the location of the valve positioned directly above the puncture bar. The temperature of the test article, the wind speed, and the ambient temperature were recorded prior to the drop.

The package was lifted to a height of 40 inches (a 40 inch rope with a plumb bob was attached to the lowest point on the package) using a crane. The release of the test item was by the pneumatically-actuated quick release mechanism. Again, no guidance of the test item was provided during the drop.

Deformation data of the overpack was measured and recorded. High speed video was taken of the drop event. Color photographs of the extent of damage were taken. The overpack was not opened.

Warm Test Article to 100°F

The test article was installed in a furnace and a nominal temperature of 100°F was maintained on the test article for a period of 24 hours prior to fire testing. The test article was transported to the fire facility wrapped in blankets within a wooden box to minimize cooling.

Perform 30 minute Fire Event

The test article was placed on the test stand with its tie down bases 40 inches from the fuel source. The thermocouple wires were connected instrumentation leads. Both the thermocouple wires and instrumentation leads were protected in an insulated pipe to the instrumentation trailer. At the instrumentation trailer, the temperature of the cylinder and the fire were recorded.

Prior to initiation of the fire, the wind speed was continuously monitored. Wind speeds of 4 mph with some gusts up to 6 mph were considered acceptable for conducting the test. In addition the wind direction was monitored to ensure that the flame did not roll over onto instrumentation leads.

A 25' x 25' fire pan was filled with water and No. 2 diesel fuel. The required amount of fuel was estimated and filled in the pan prior to the test. The package was set on a stand 40 inches above the fuel surface. The stand was water cooled to prevent collapse during the fire. The fire pan was surrounded by a 30' x 30' primary containment pan filled with water only (Photo 2.10.6-31). Six thermocouples were placed around the perimeter of the test article to monitor the fire temperature.

This resulted in a fire are slightly greater than that specified in the regulations on the sides of the package, but within the regulations for the ends of the package.

The standing diesel fuel was lit with a torch. The NCI-21PF-1 package (with valve protection device installed) was subjected to a 30 minute fully engulfing fuel/air fire

Cool Package and Record External Damage

Following the fire, the package was allowed to cool naturally. No external sources were used to stop any continued burning of the package.

Open Package and Record Internal Damage

The packages were opened carefully for post-test inspection. The cylinder and its valve protection device were carefully removed and measurements were taken.

Leak Testing

Once the package was opened, the cylinder was removed from the overpack and the valve protection device was removed from the cylinder skirt. The following leak tests were performed on the 30B cylinder after drop and puncture testing:

- A bubble leak test was performed on the valve cap, valve stem, valve packing nut and the valve seat with a cylinder internal pressure of 100 psig nitrogen (due to the cold temperature of the cylinders we did not want the moisture in air to freeze in the cylinder). The internal pressure was held for a period of 15 minutes. Any indication of bubbles were noted.

- A helium mass spectrometer test was performed by evacuating the cylinder and introducing helium around the valve cap, valve stem, valve packing nut and the valve seat for a period of at least 2 minutes. If no leakage was indicated then this leak test was ended. If leakage was indicated, the valve was bagged and continuously sprayed with helium. The helium leak indicator was monitored until the readings stabilized. Both the indicated leak rate and the time to stabilization were recorded.

- Following the helium leak test, the cylinder was emptied through the bottom plug and then a 19 psig hydrostatic test was performed on the cylinder. The cylinder with the valve in the 6 o'clock position was filled with tap water and a blue dying agent. The pressure in the cylinder was increased to 19 psig and held for a minimum of eight hours. Periodically the valve cap, valve stem, valve packing nut and the valve seat were checked for any indication of water leakage from the cylinder.

2.10.5.6 Summary and Results of Tests

Testing was conducted at Southwest Research Institute (SwRI), San Antonio, Texas in accordance with written test procedures.

The ambient temperature was about 80°F during the drop sequences. The wind speed was 7 mph. The cylinder skirt temperature was 8°F (measured on cylinder skirt) and the overpack wood temperature was -21°F.

The overpack was positioned at an orientation of 13.5° from vertical, and raised 30 feet as measured from the lowest position on the overpack. The overpack was rotated so that the impact would be into the valve location. (Photo 2.10.5-21) The weight of the test article was 8,880 lbs. No closures broke or loosened. The two toggles at the impact end were bent.

One of the pins on the non impact end had come loose and fallen out of place. No tears or breaks in the overpack were observed. The seam of the overpack had opened up approximately 0.25 inch at the impact end. The rest of the seams were snug. The top of the overpack had shifted slightly axially about 0.3 inch, with respect to the bottom of the overpack. Figure 2.7-6 illustrates the overpack deformation from the 30 foot drop test.. (Photo 2.10.5-22).

Following the 30 foot drop test, the overpack was positioned at an orientation of 13.5° from vertical, and raised 40 inches above the puncture bar as measured from the lowest position on the overpack. (Photo 2.10.23) The temperature of the wood during the puncture test was -6°F, and the temperature of the cylinder skirt was 7.5°F. The overpack was rotated so that the puncture would be into the valve location. The overpack deformed at the puncture location. All closures remained intact. The punch did not expose any wood. Photographs were taken, measurements made, and the overpack was sent for conditioning for fire testing. Figure 2.7-7 illustrates the overpack deformation from the 40 inch puncture test (Photo 2.10.5-24).

The package was moved to the furnace for conditioning prior to the fire test.

A 25' x 25' fire pan was filled with water and No. 2 diesel fuel. The required amount of fuel was estimated and filled in the pan prior to the test. The package was set on a stand 40 inches above the fuel surface. The stand was water cooled to prevent collapse during the fire. The fire pan was surrounded by a 30' x 30' primary containment pan filled with water only (Photo 2.10.5-25).

This resulted in a fire area slightly greater than that specified in the regulations on the sides of the package, but within the regulations for the ends of the package.

The fire was performed at dusk, when wind speed was lowest. Wind conditions were continuously monitored prior to the fire. Steady wind speeds of 4 mph with gusts up to 6 mph were recorded prior to the fire. Wind direction was closely monitored as well. Once wind direction was steady and away from the instrumentation, conditions were considered acceptable for fire testing. The cylinder temperature immediately prior to the test was approximately 98°F.

The standing diesel fuel was lit with a torch. The test article was subjected to a 31 minute fully engulfing fuel/air fire (Photo 2.10.5-26). The wood in the overpack continued to burn for about 10 minutes after the fire. The toggle closures continued to glow dull red for some time. (Photo 2.10.5-27)

The package was left on the test stand and its temperature was continuously monitored for the duration of the night. It was moved from the fire facility the following morning. (Photo 2.10.5-28)

The locations of the thermocouples and the temperature tapes on the cylinder are illustrated in Figure 2.10.5-1. This figure also provides the maximum temperatures indicated from both thermocouples and the irreversible temperature tapes. Thermocouples 1 and 2 were damaged during the drop and puncture testing.

Plots of the temperature data versus time for the cylinder and the fire are provided in Figures 2.10.5-2 through 2.10.5-5. The maximum temperature data indicates that the cylinder was hottest on the port end (where the hole was drilled into the overpack for the thermocouple leads) and on the top of the cylinder (where no steel shot is present).

A post test inspection was conducted on the package once it was returned to the main test facility. The toggle closures did not open due to the fire, although several were loose following the cool down period. The seam between the two halves of the overpack did not open significantly as a result of the fire testing. There was localized buckling of the overpack outer skin.

The overpacks were opened carefully for post test inspection. The overpack gasket was severely burned on the end which had previously opened during drop and puncture testing. All other portions of the gasket were intact. The paint on the cylinder was discolored and bubbled. It also appeared that the foam had burned and formed a dark combustion residue that coated the surface of the cylinder (Photos 2.10.5-28 and 2.10.5-29).

This residue that formed on the surface of the cylinder rendered reading the temperature sensitive paints impossible. Maximum temperatures were recorded from the temperature sensitive labels. This data was used to confirm the thermocouple data.

Deformation measurements of the cylinder and valve protection device were taken (Photo 2.10.5-30, and Figures 2.7-8 and 2.7-9, respectively).

A soap bubble test was conducted. The cylinder was pressurized to 100 psig with air and this pressure was held for 15 minutes. The soap film was applied to the valve threads, stem, packing nut, and cap. No leaks were detected on the valve area.

The cylinder was evacuated for helium leak testing. No leaks greater than 1×10^{-7} std cc/sec were detected.

For the hydrostatic testing, the majority of the steel shot was removed from the cylinder through the port plug. The 19 psig hydrostatic test was performed. No water leakage was detected.

2.10.5.7 Conclusion

The compliance testing of the NCI-21PF-1 packaging resulted in the following:

- The valve protection device satisfactorily protected the valve during the 13.5° drop test series.

- Some deflection of the cylinder skirt was evident as shown in the Pre-Test and Post-Test measurements shown in Figures 2.7-8.

- The valve protection device deformed 0.146 inches due to the drop tests as shown in Figure 2.7-9.

- During the fit up of the valve protection devices in several cylinders for testing it was apparent that the cylinder dimensions A, B, and C on Figure 2.7-8 were not good indicators of how the valve protection device would fit in the cylinder due to the large variation in cylinder head dimensions.

- In order to ensure that the valve will be protected by the valve protection device (VPD) during the 30 foot drop, the following pre-test dimensions must be considered prior to installation of the valve protection device (Refer to Figure 2.7-8):

  (*g*, Distance between valve stem and VPD "bridge") minus (*Gap*, distance between underside of VPD and 30B cylinder head) ≥ 3/16 inches (5 mm)

Figure 2.10.5-1
NCI-21PF-1 Package
Thermocouples and Temperature Tape Locations on the Cylinder

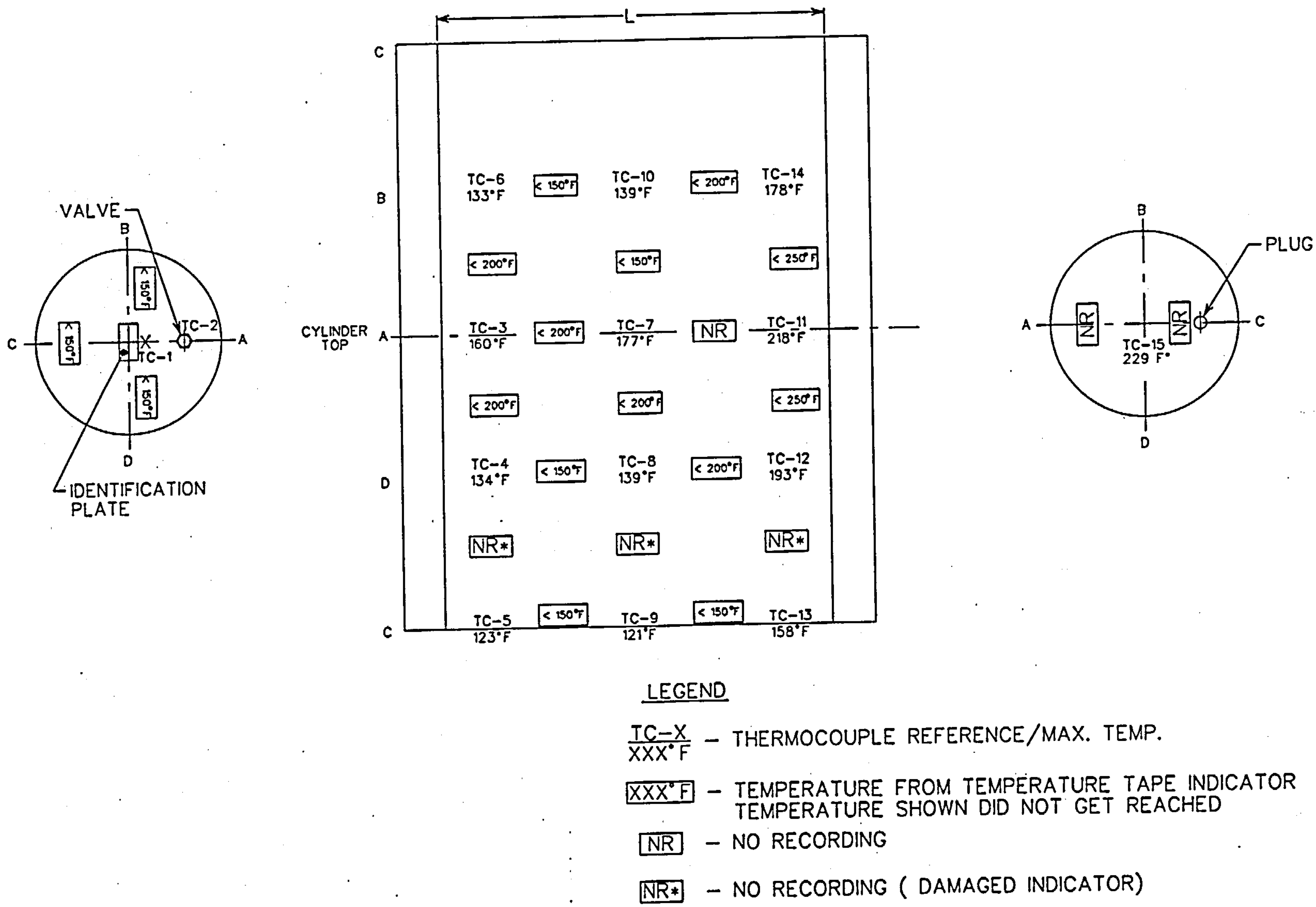


Figure 2.10.5-2
NCI-21PF-1 Package
Time vs Temperature Data (Thermocouples 3 to 5)
30B Cylinder

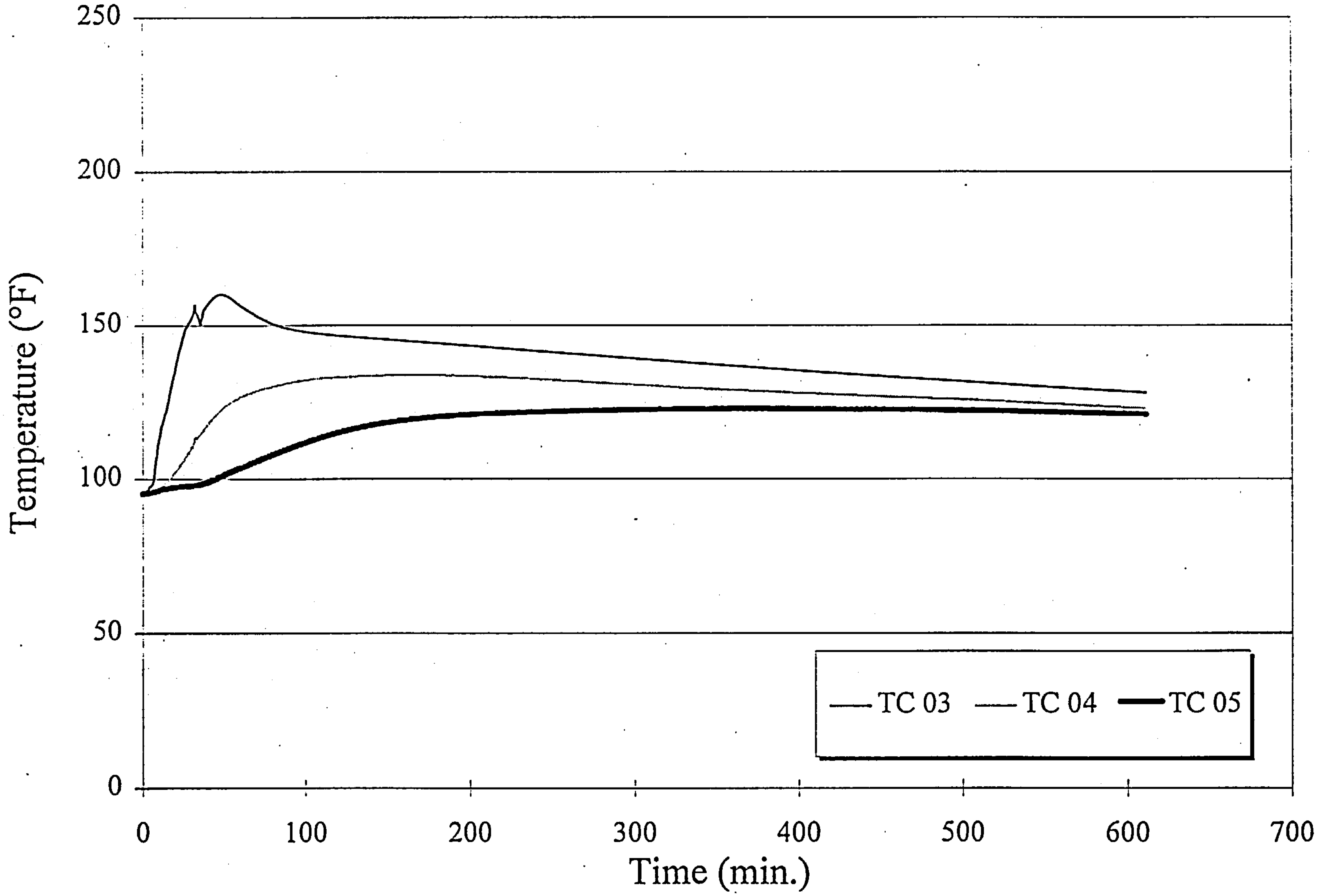


Figure 2.10.5-3
NCI-21PF-1 Package
Time vs Temperature Data (Thermocouples 6 to 10)
30B Cylinder

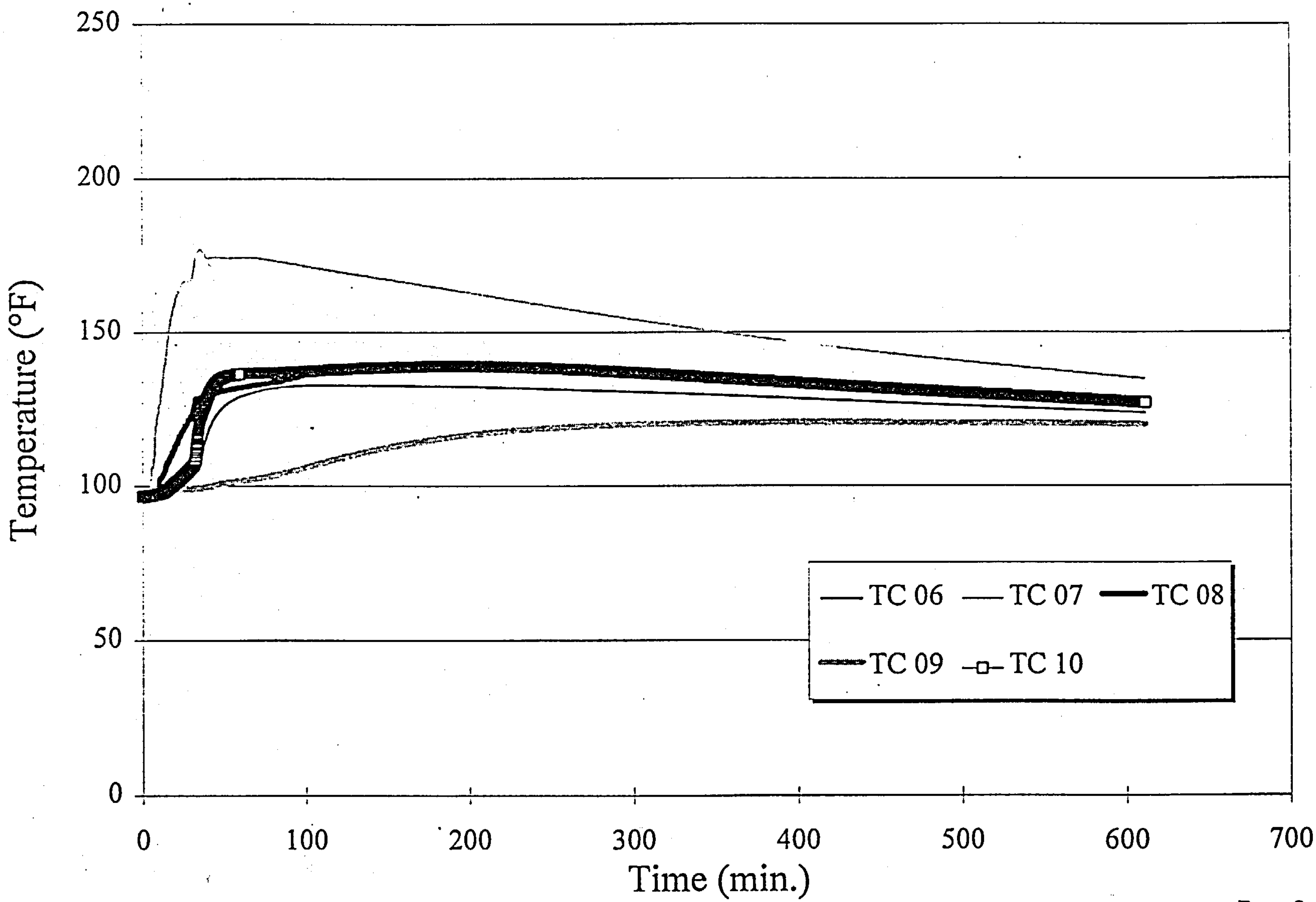


Figure 2.10.5-4
NCI-21PF-1 Package
Time vs Temperature Data (Thermocouples 11 to 15)
30B Cylinder

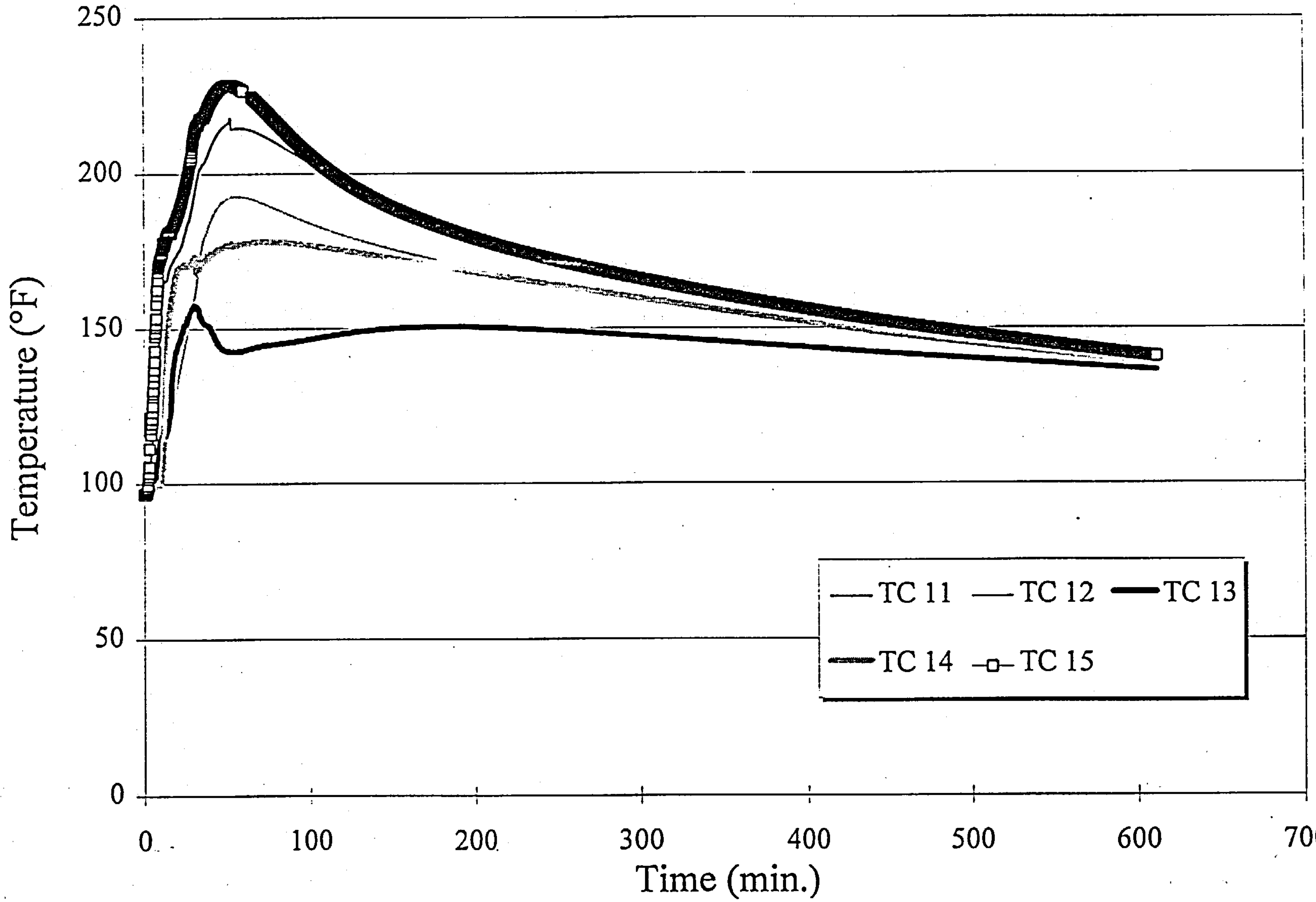


Figure 2.10.5-5
NCI-21PF-1 Package
Time vs Temperature Data (Thermocouples 16 to 21)
Fire Temperature

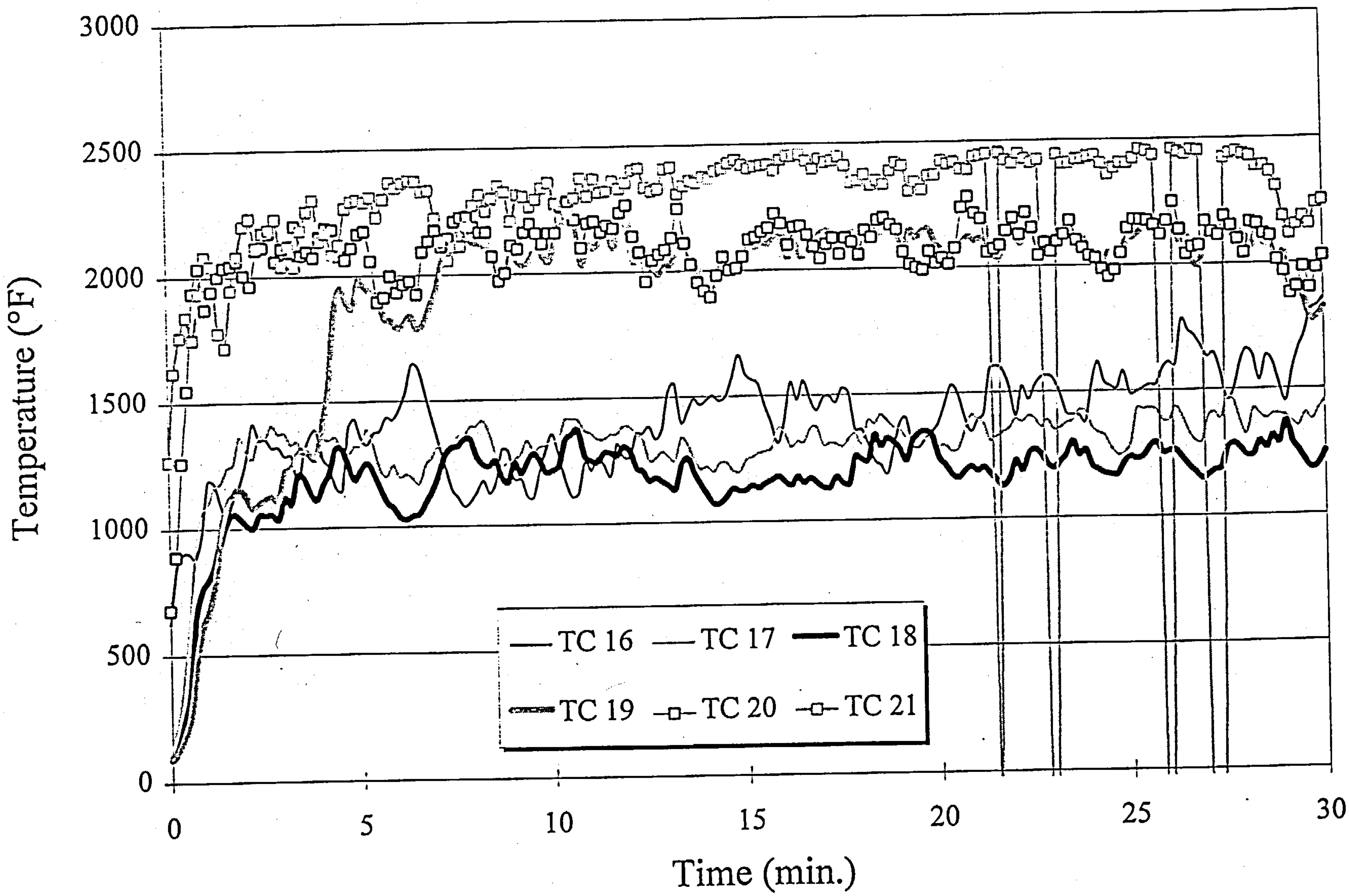


Photo 2.10.5-1
Drop Pad and Plywood Photographic Backdrop

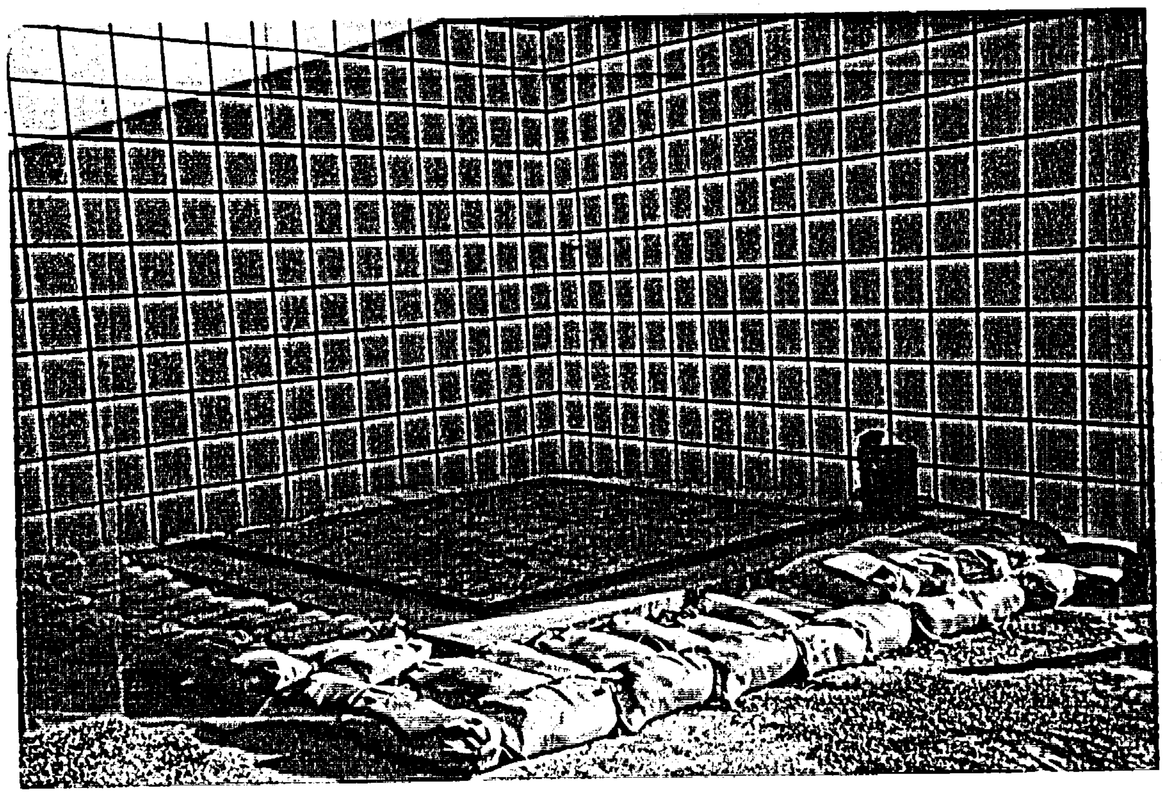


Photo 2.10.5-2
Punch

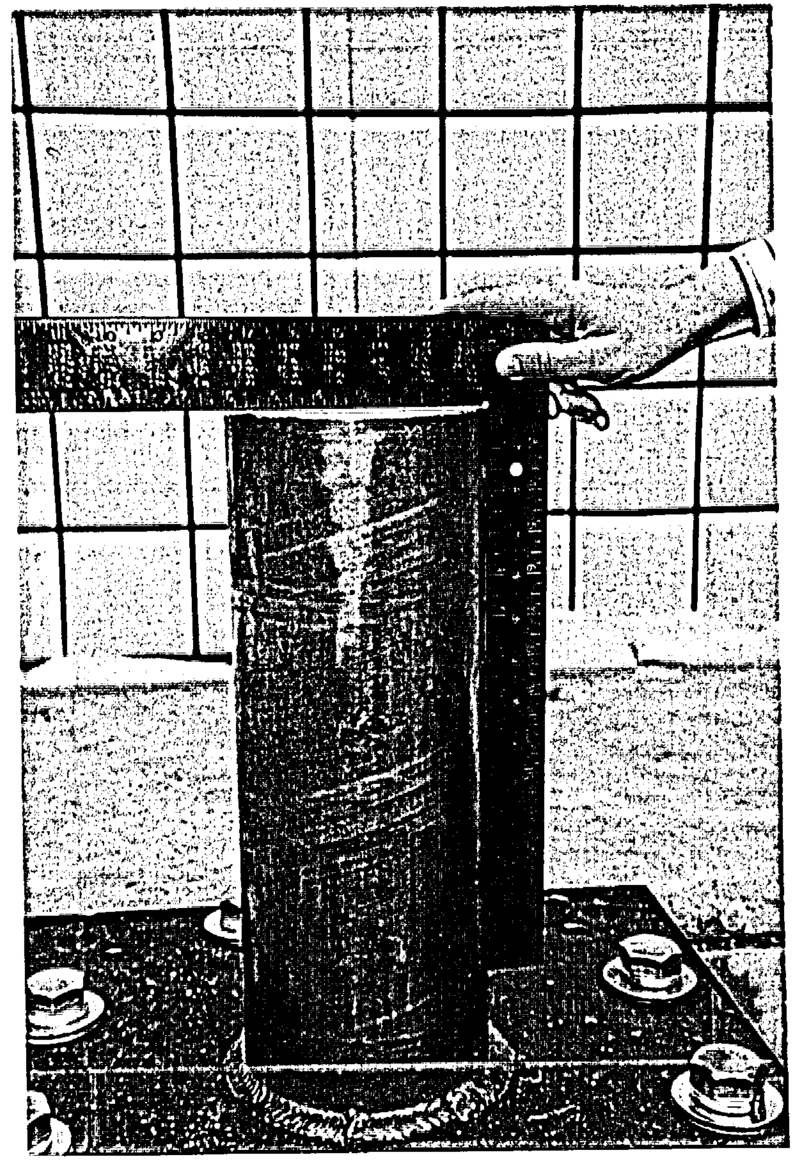
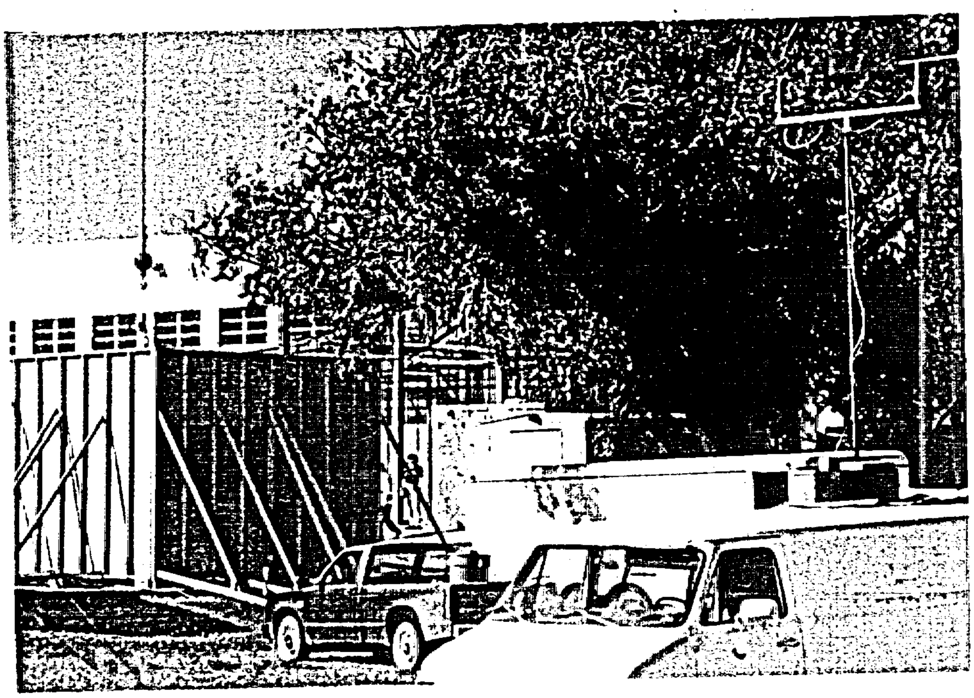
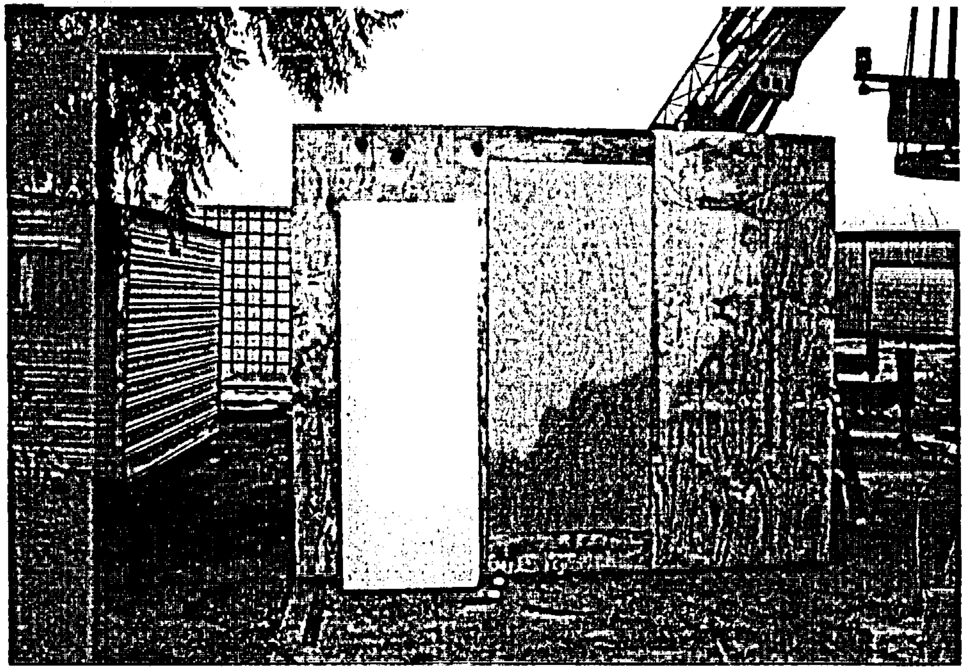


Photo 2.10.5-3
Wind Speed and Direction Instrumentation





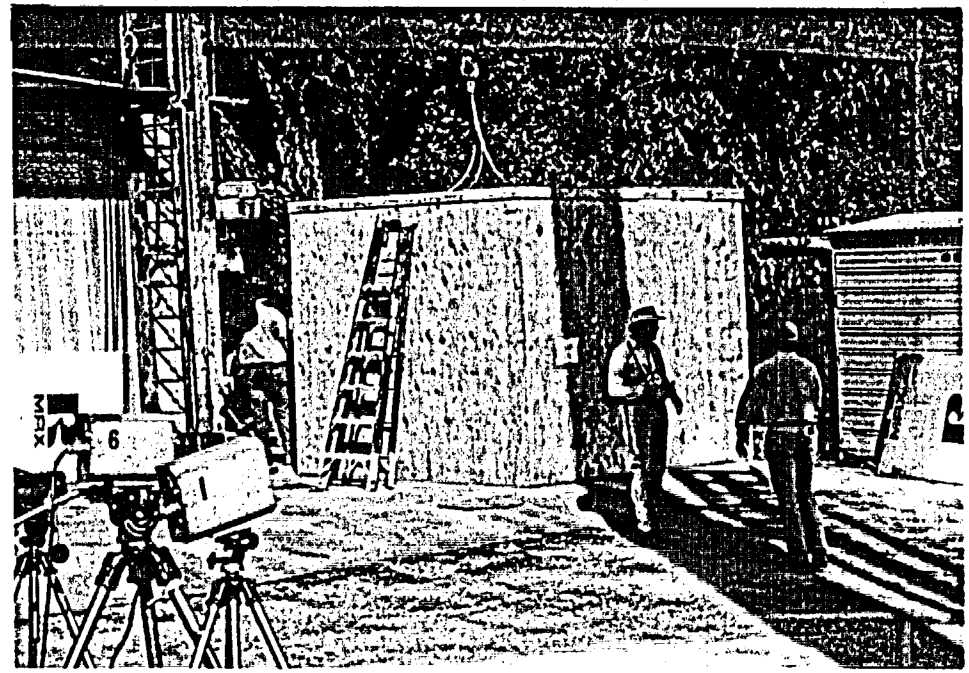


Photo 2.10.5-4
Cooling Chamber

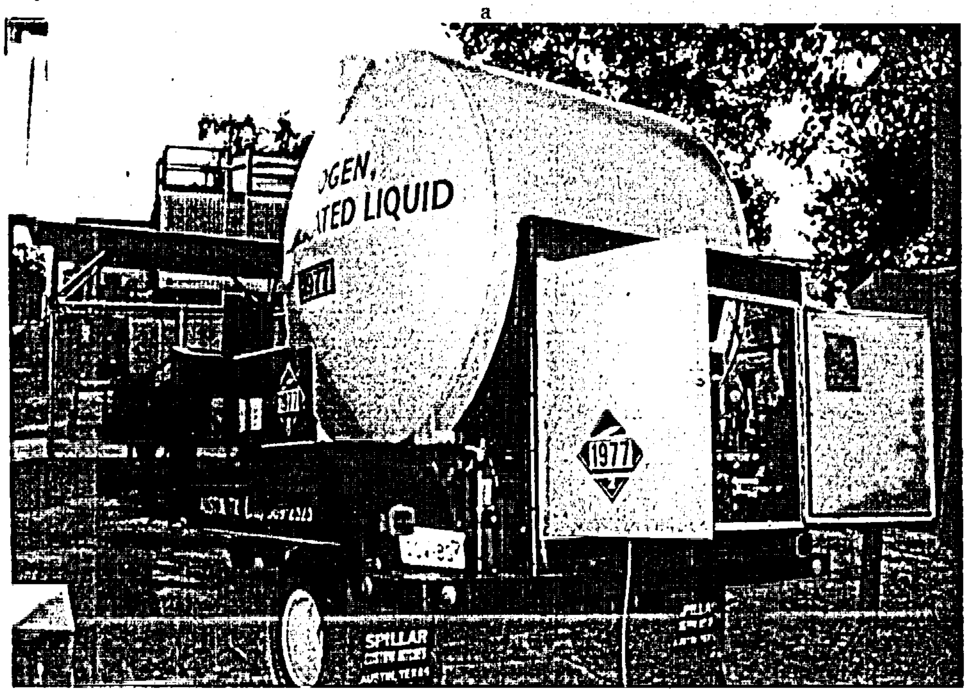


Photo 2.10.5-5
Crane

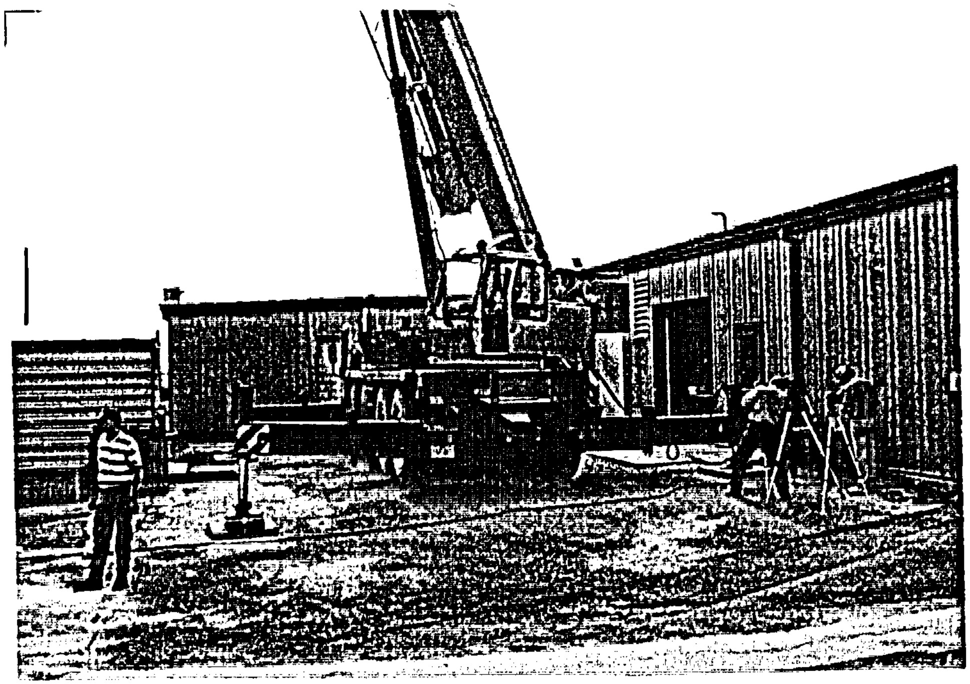


Photo 2.10.5-6
Test Article Release Mechanism

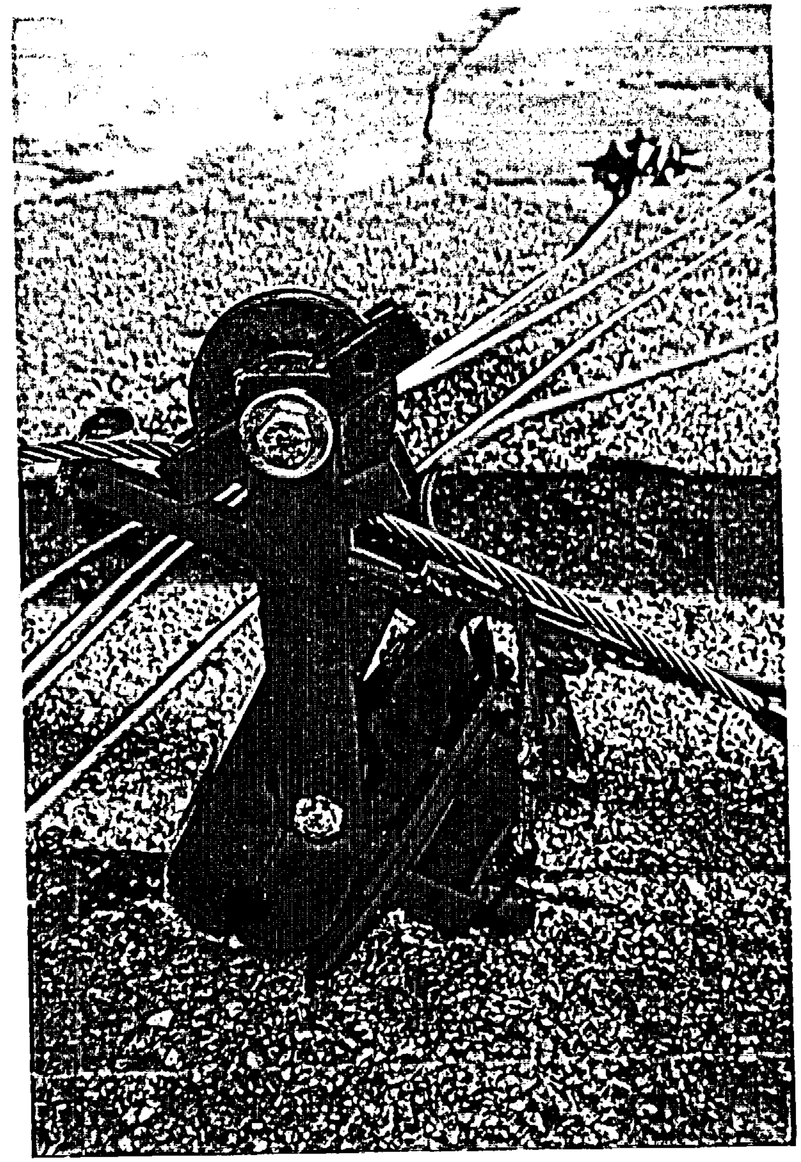


Photo 2.10.5-7
Video Equipment

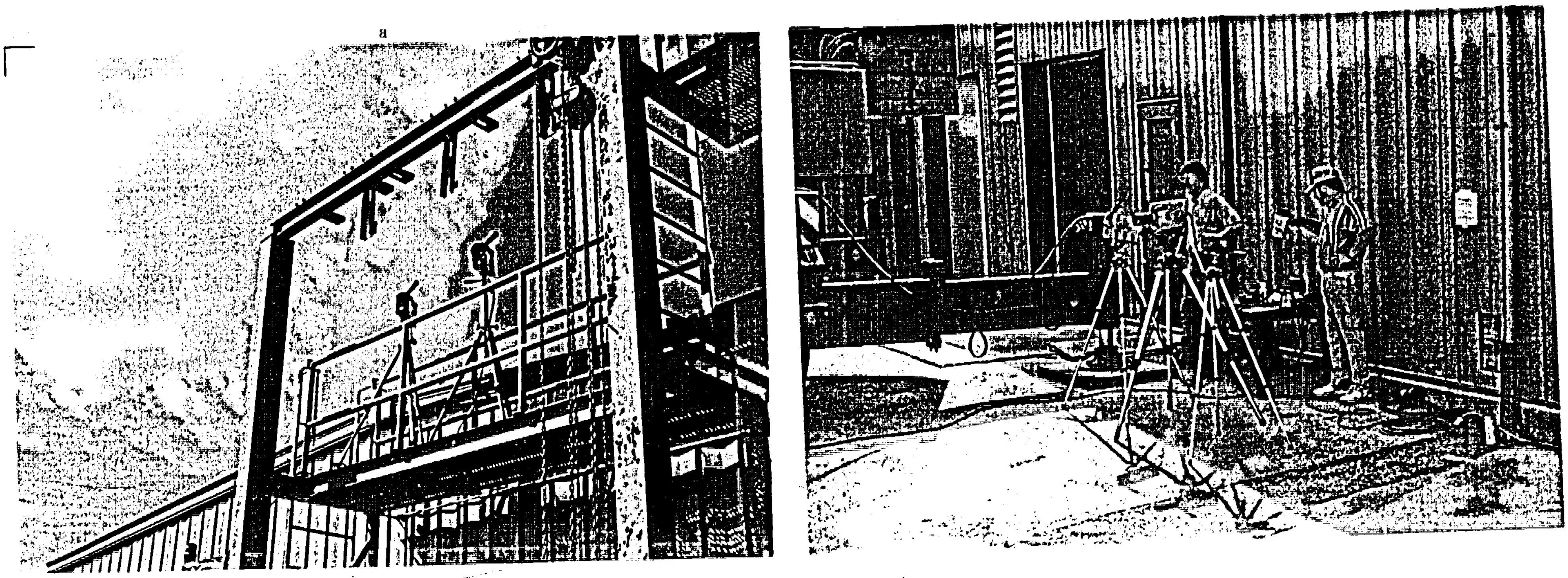


Photo 2.10.5-8
Fire Site and Test Stand

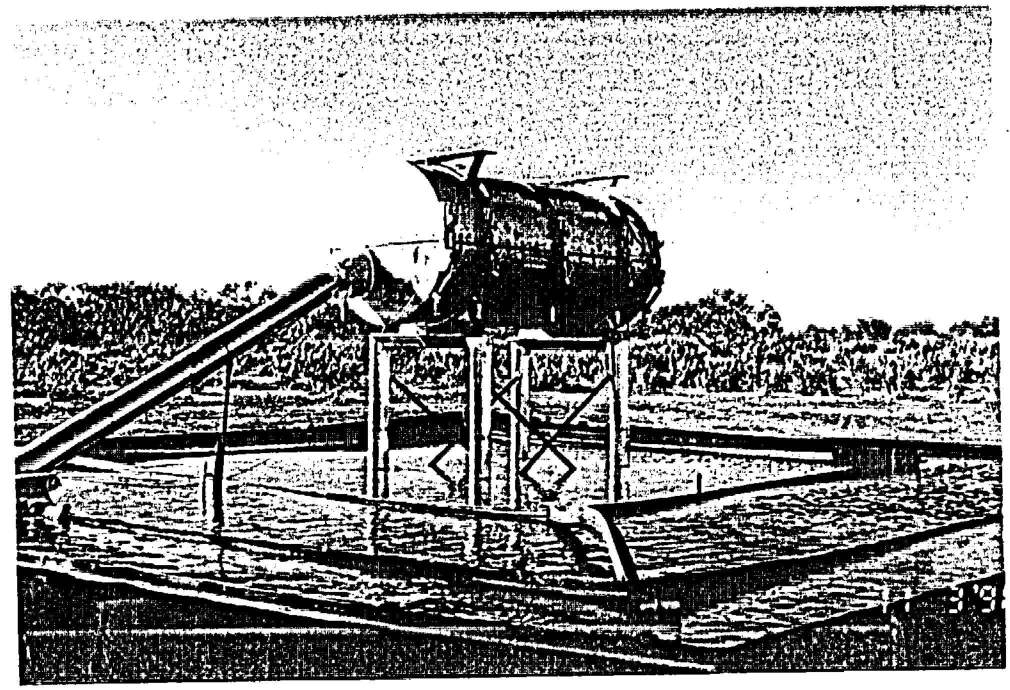


Photo 2.10.5-9
Leak Test Equipment, Calibrated Leak at Test Port

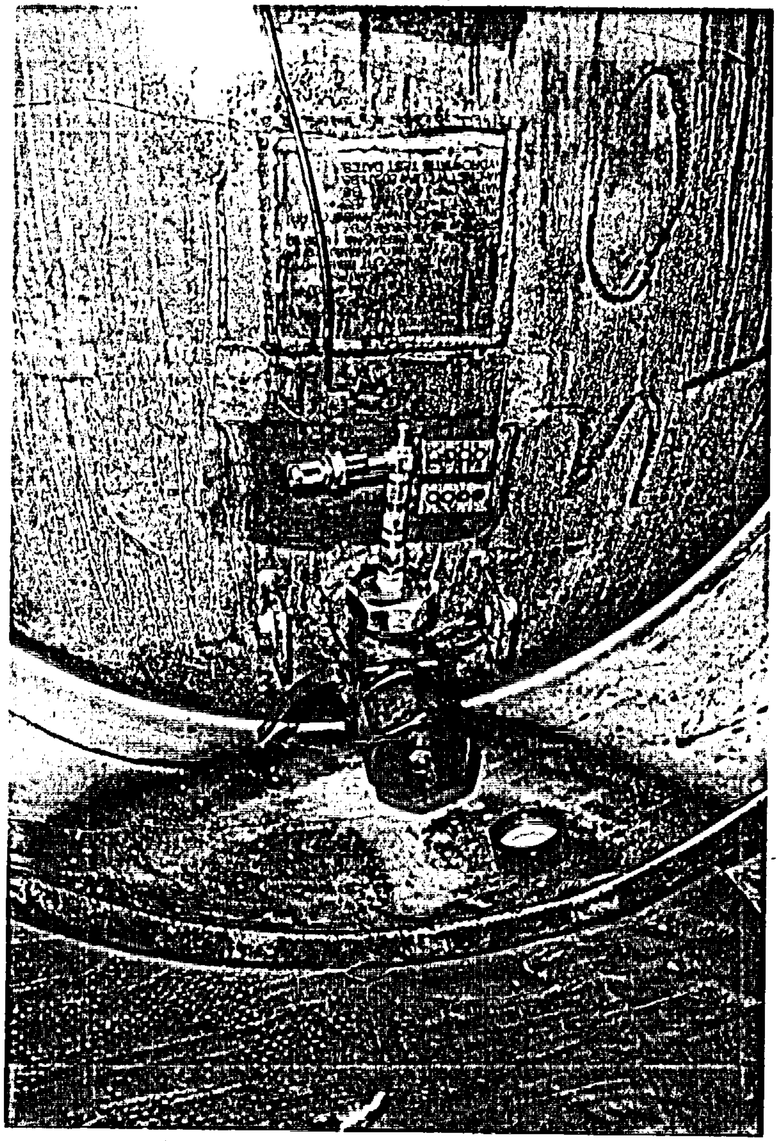


Photo 2.10.5-10
Leak Test Equipment, Calibrated Leak at Valve

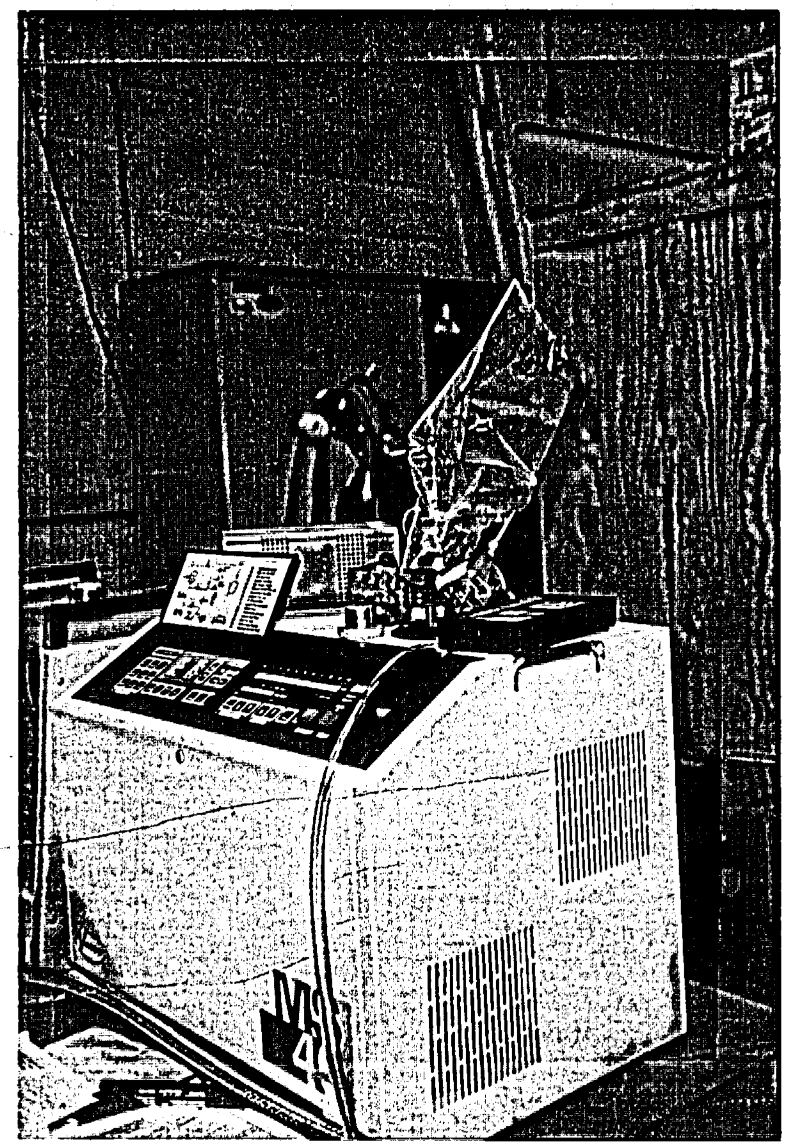


Photo 2.10.5-11
Bending the 30B Cylinder Skirt

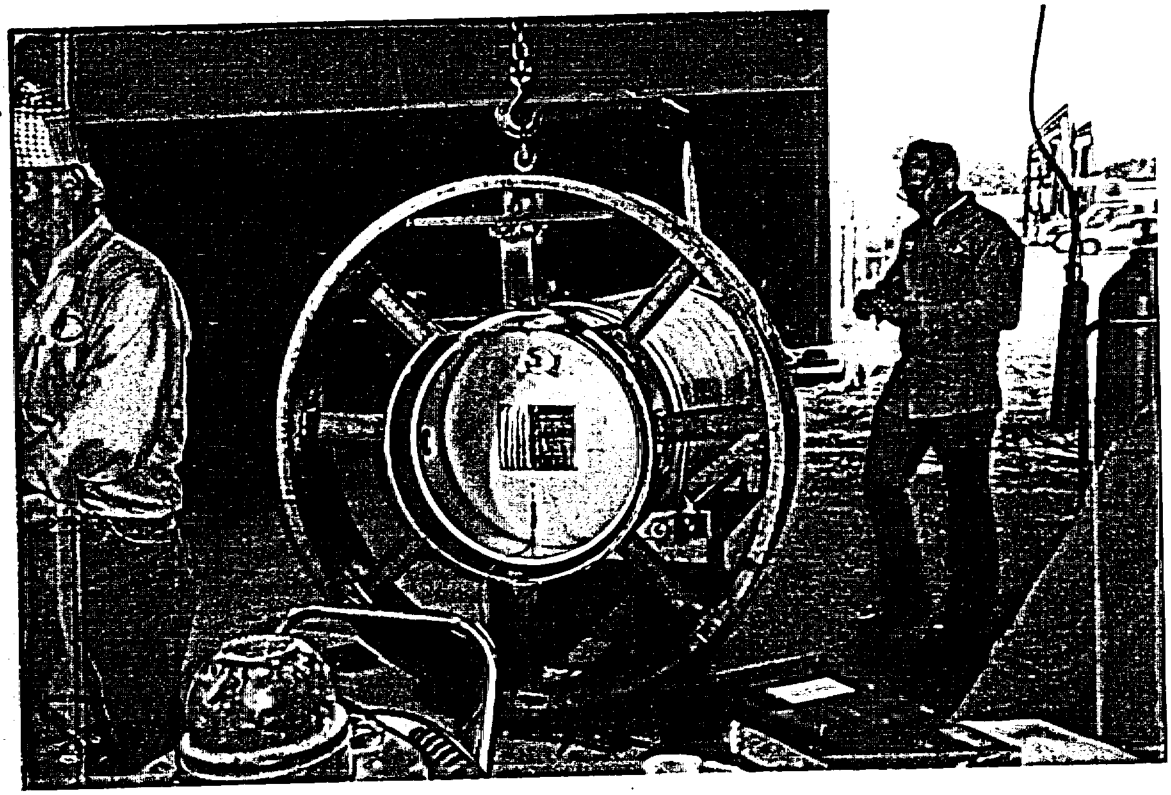


Photo 2.10.5-12
Repairing the 30B Cylinder Skirt

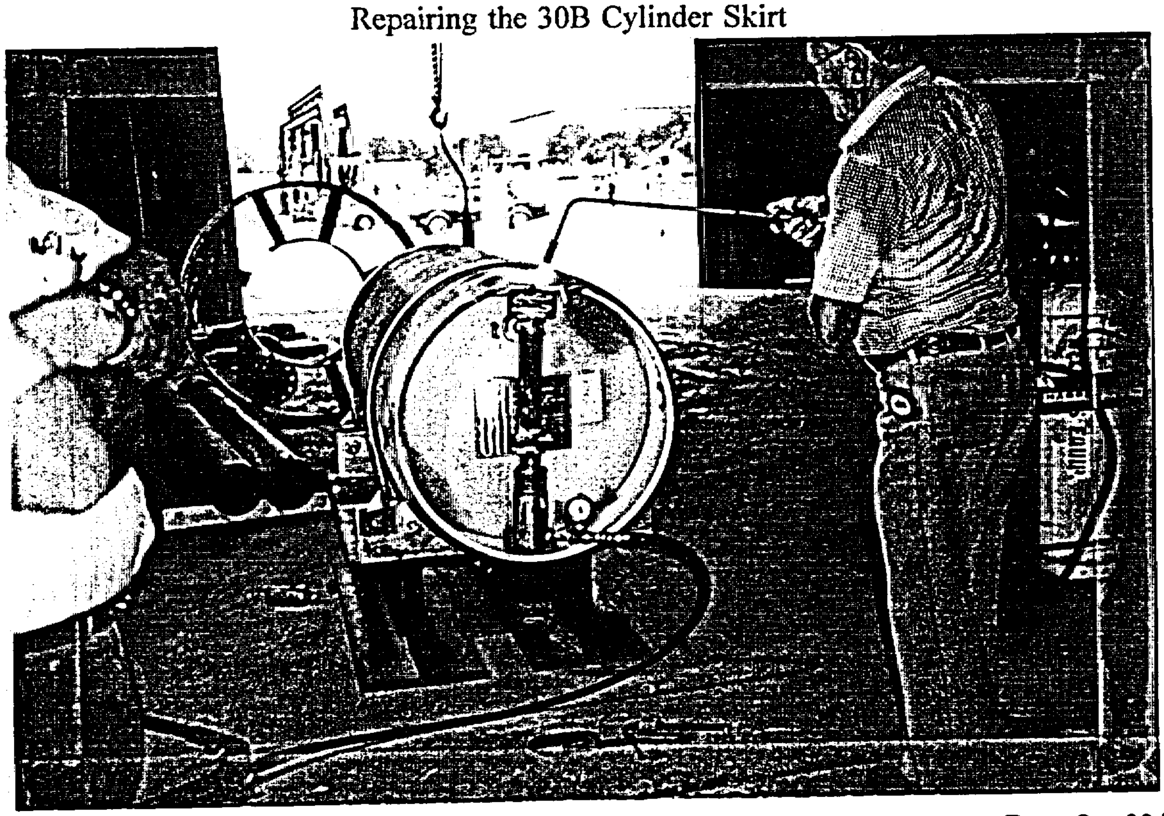


Photo 2.10.5-13
Damaged and Repaired 30B Cylinder Skirt

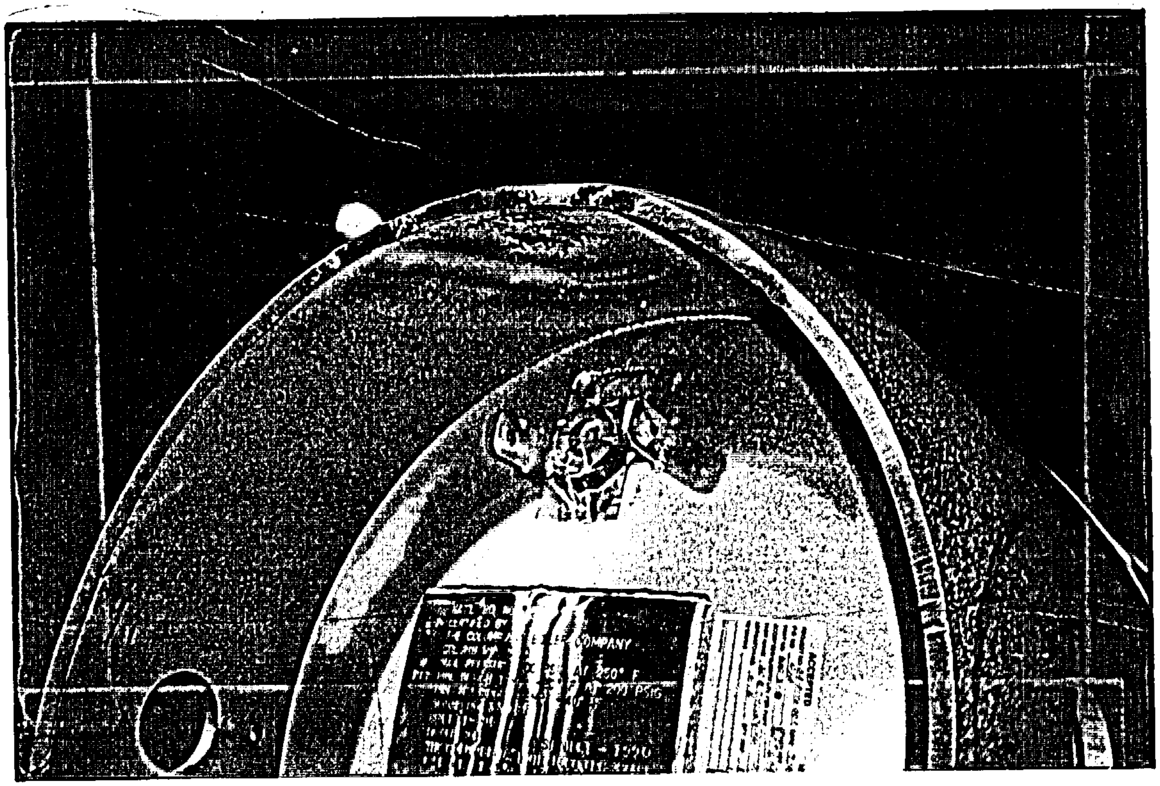


Photo 2.10.5-14
Valve Installation Tool

Photo 2.10.5-15
Valve Protection Device - Honeycomb Insert

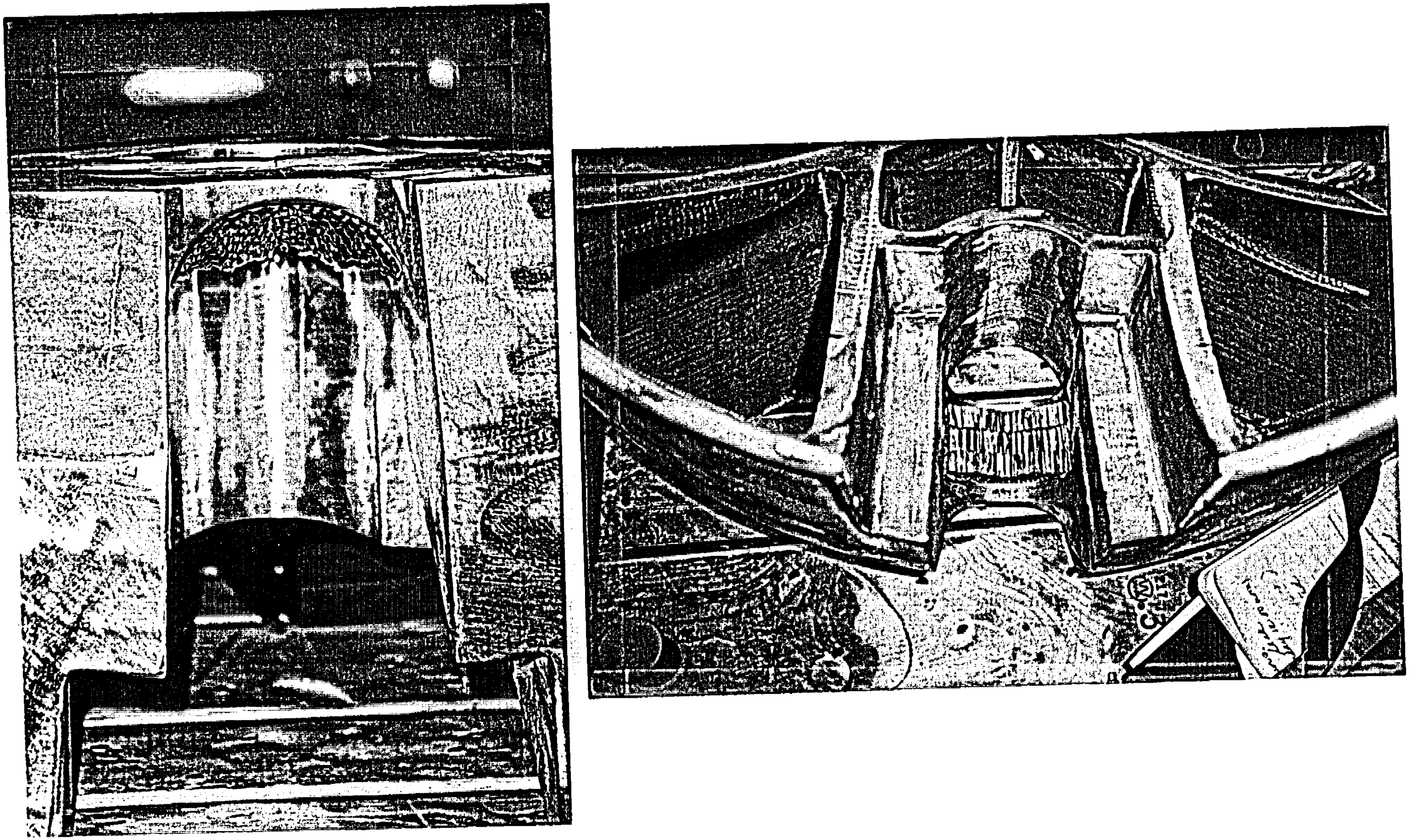


Photo 2.10.5-16
Typical - Checking Fit Between Valve and Honeycomb Insert

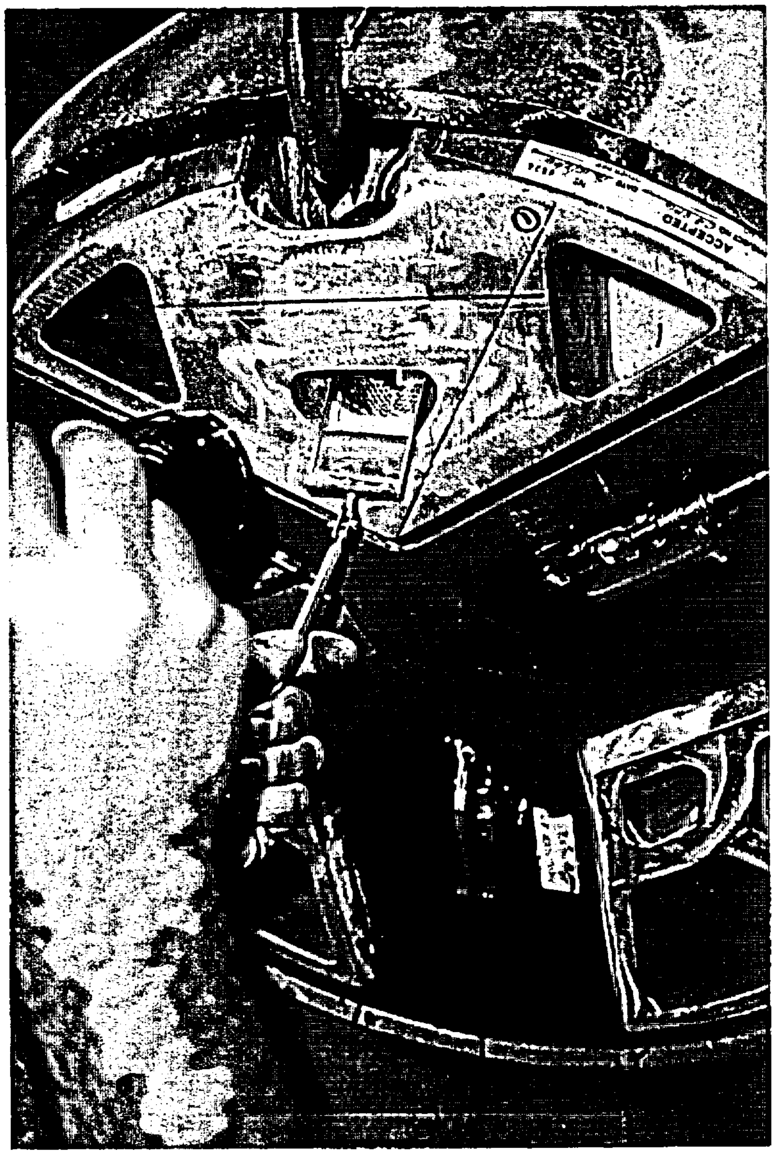


Photo 2.10.5-17
Valve Protection Device Installed in Cylinder Skirt

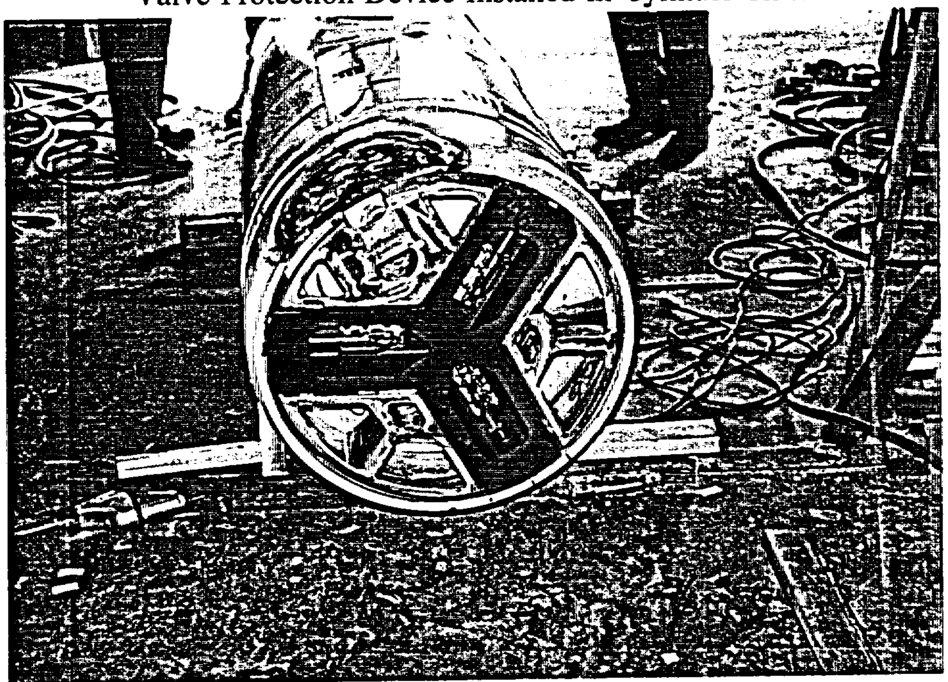


Photo 2.10.5-18
Cylinder with Temperature Indicating Instrumentation

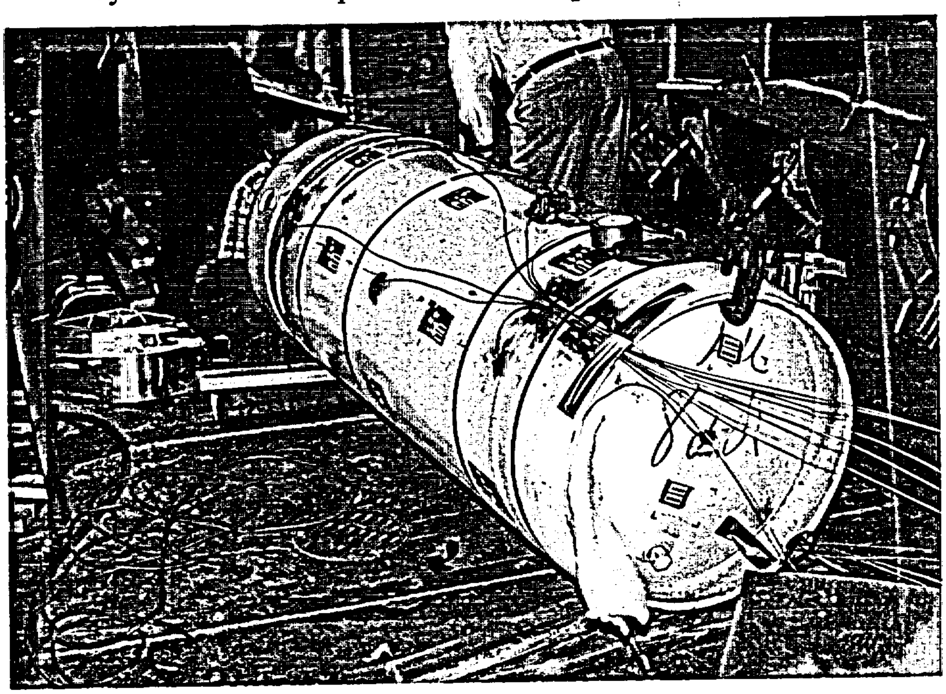


Photo 2.10.5-19
NCI-21PF-1 Overpack

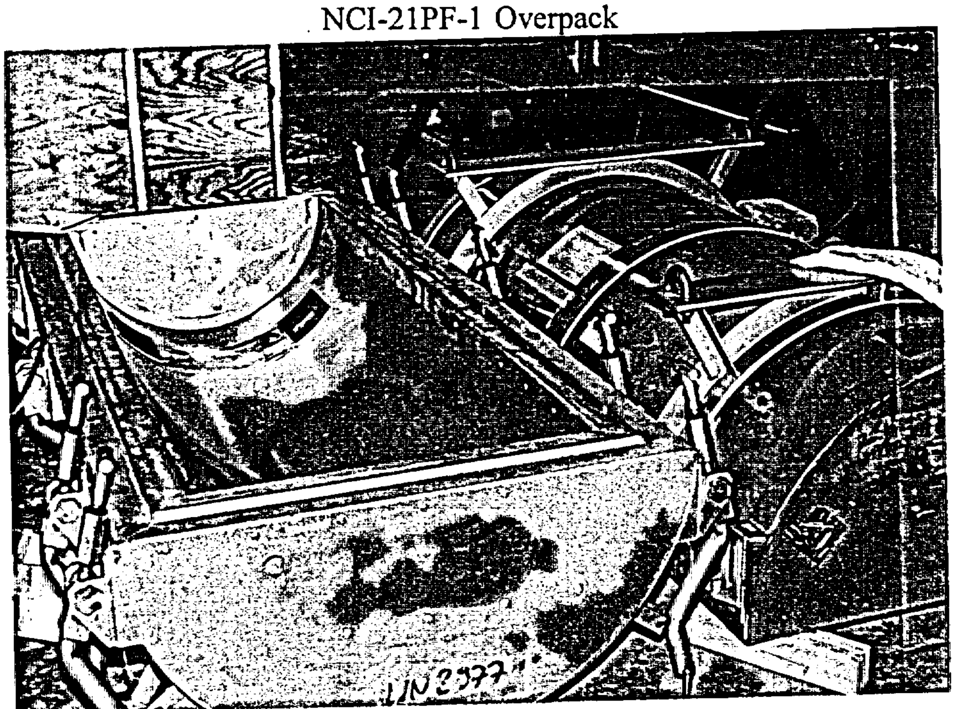


Photo 2.10.5-20
Loading 30B Cylinder with Valve Protection Device Installed into NCI-21PF-1 Overpack

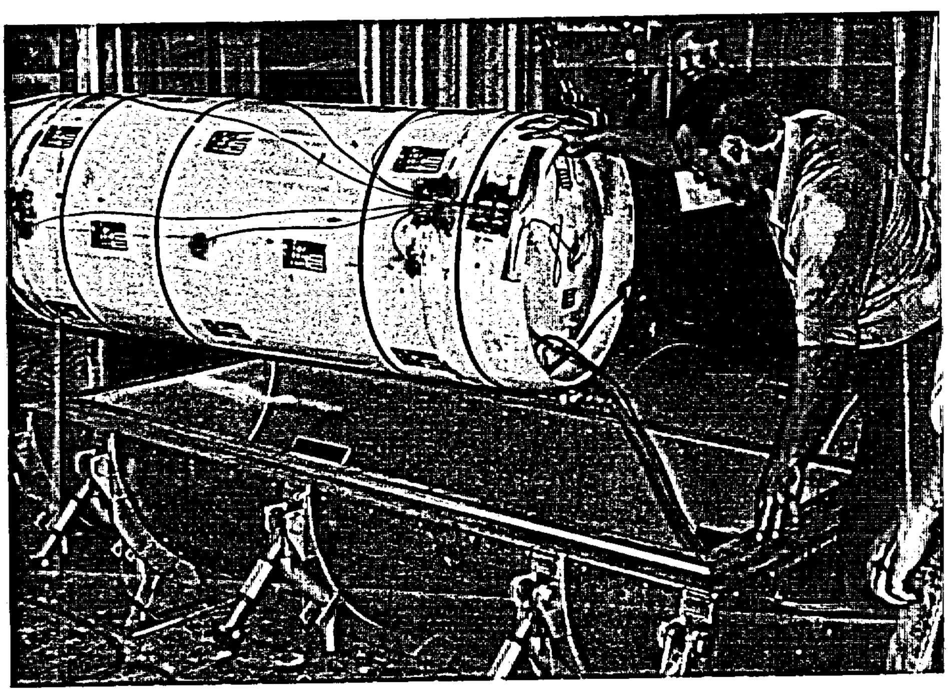


Photo 2.10.5-21
NCI-21PF-1 Package
30 Foot Free Drop

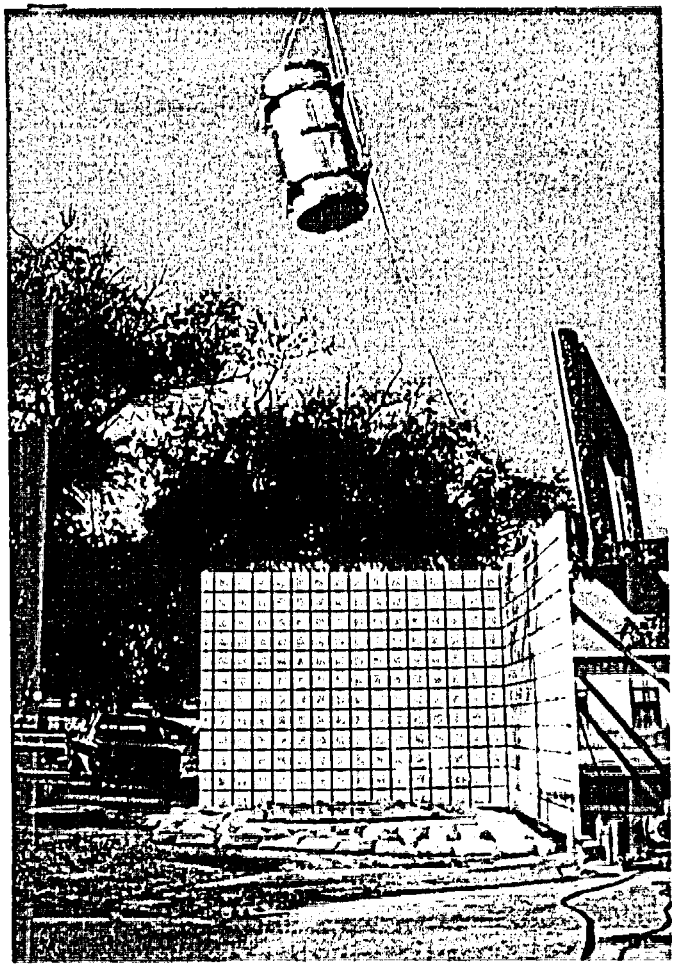


Photo 2.10.5-22
NCI-21PF-1 Package
Damage following 30 foot Drop

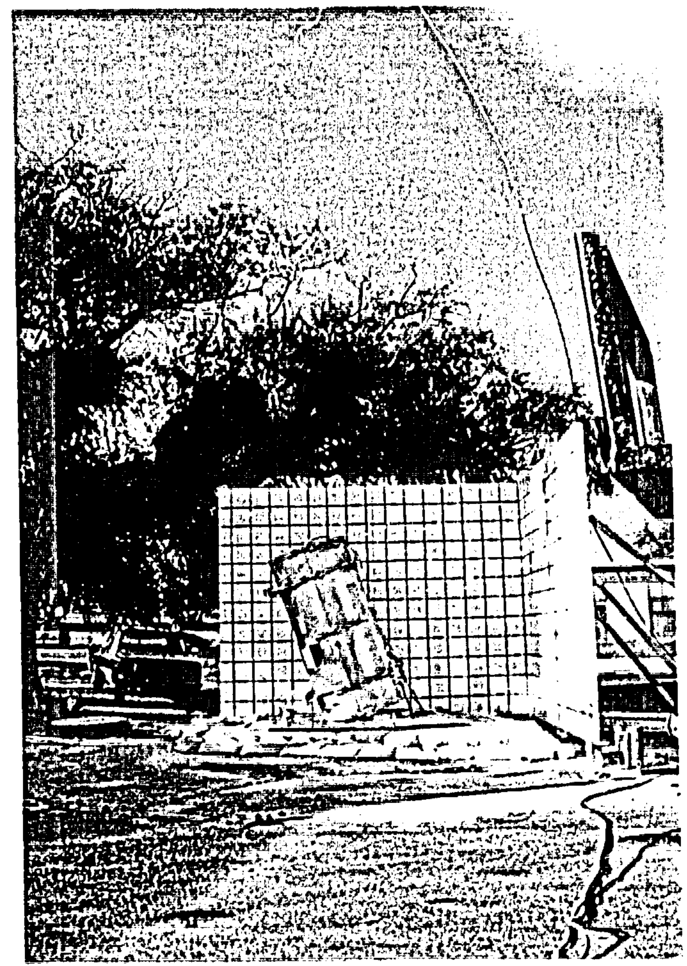


Photo 2.10.5-23
NCI-21PF-1 Package
40 inch Puncture

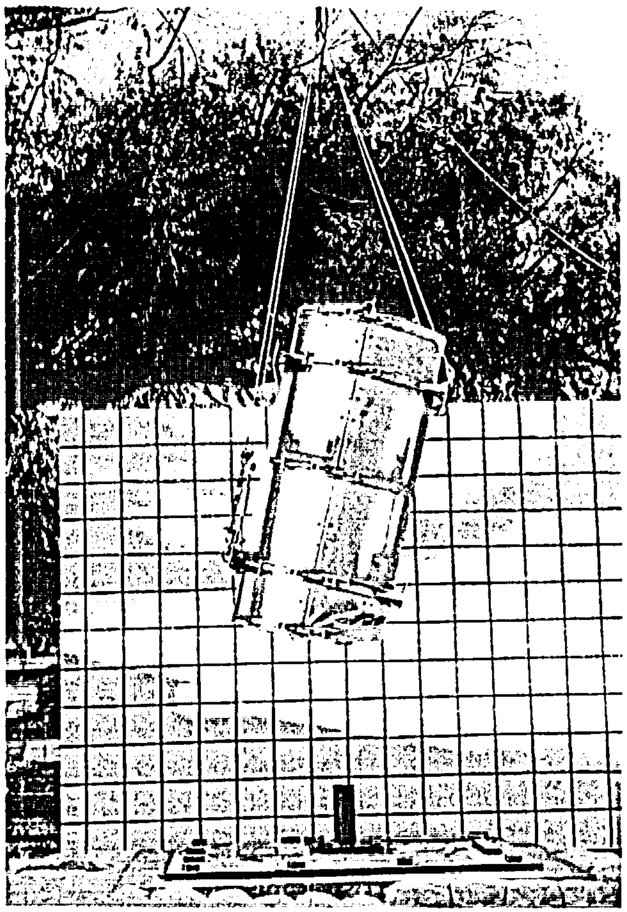


Photo 2.10.5-24
NCI-21PF-1 Package
Damage following 40 inch Puncture

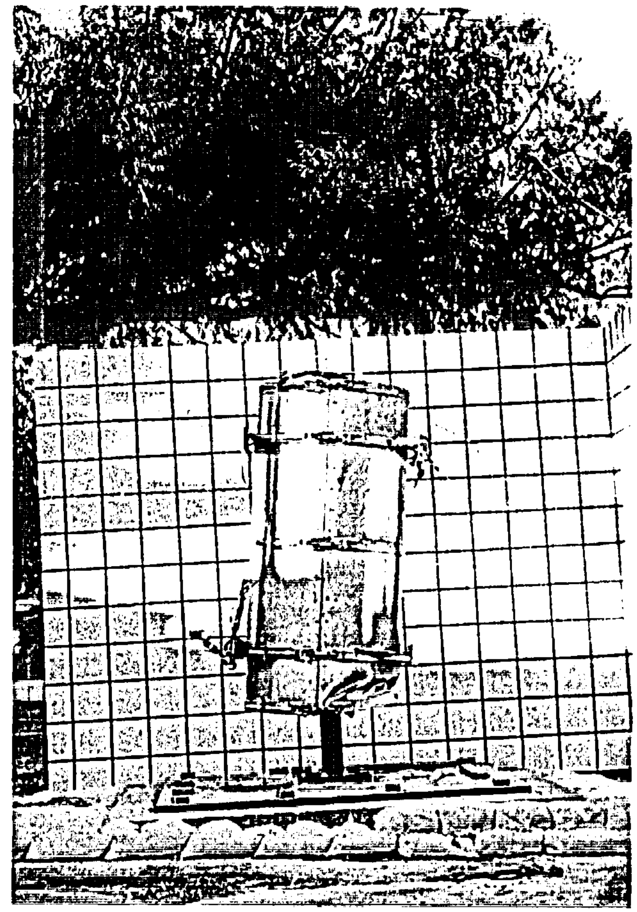


Photo 2.10.5-25
NCI-21PF-1 Package
Preparing for Fire Testing

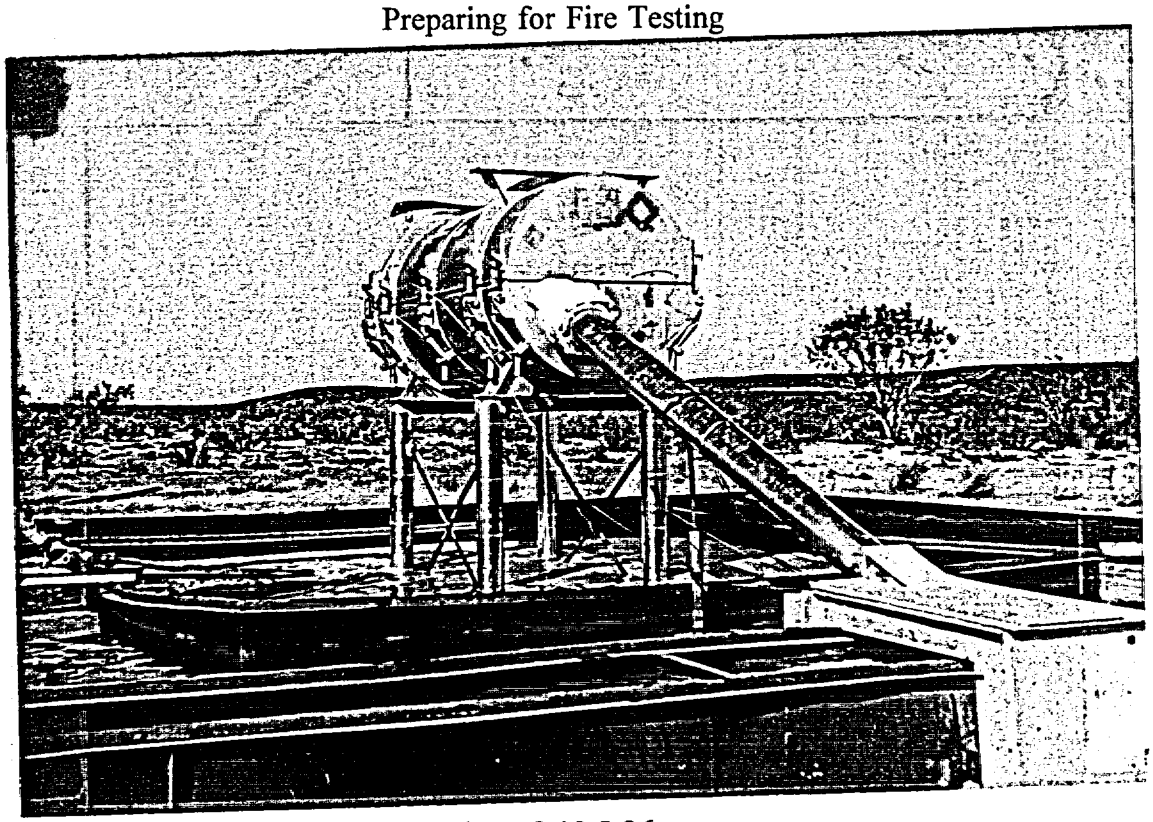


Photo 2.10.5-26
NCI-21PF-1 Package
Fully Engulfed

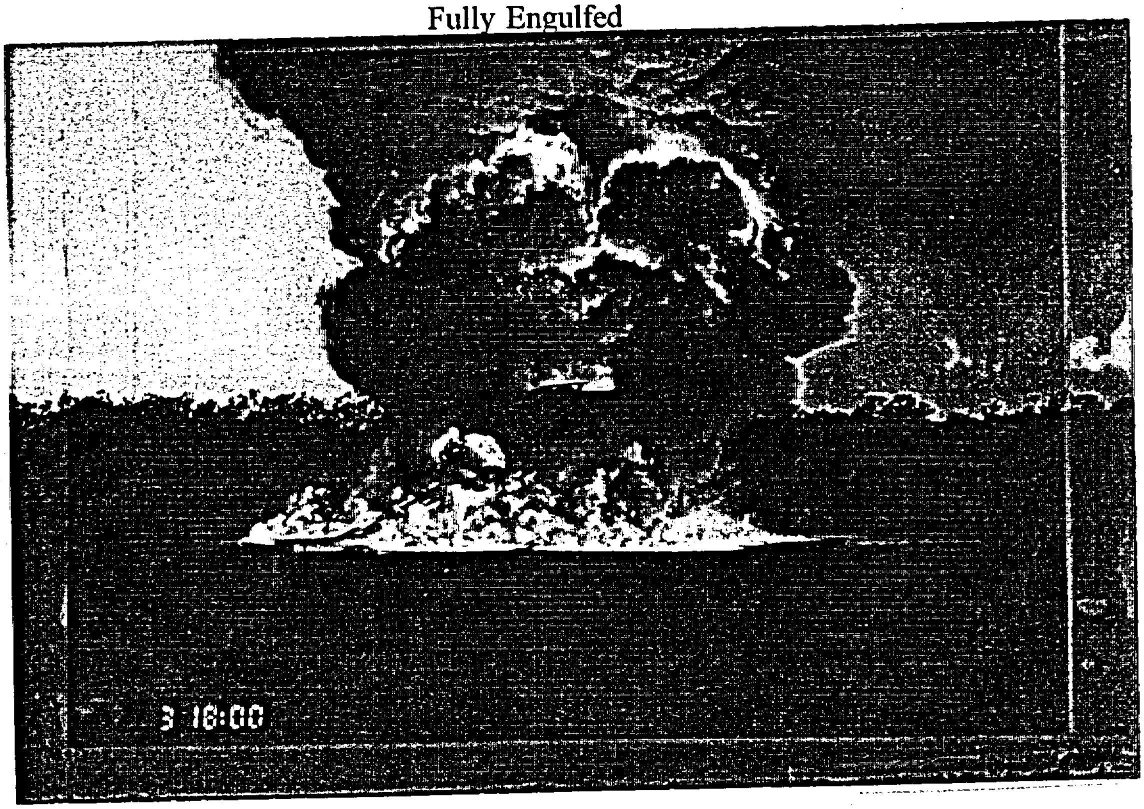


Photo 2.10.5-27
NCI-21PF-1 Package
Fire Complete

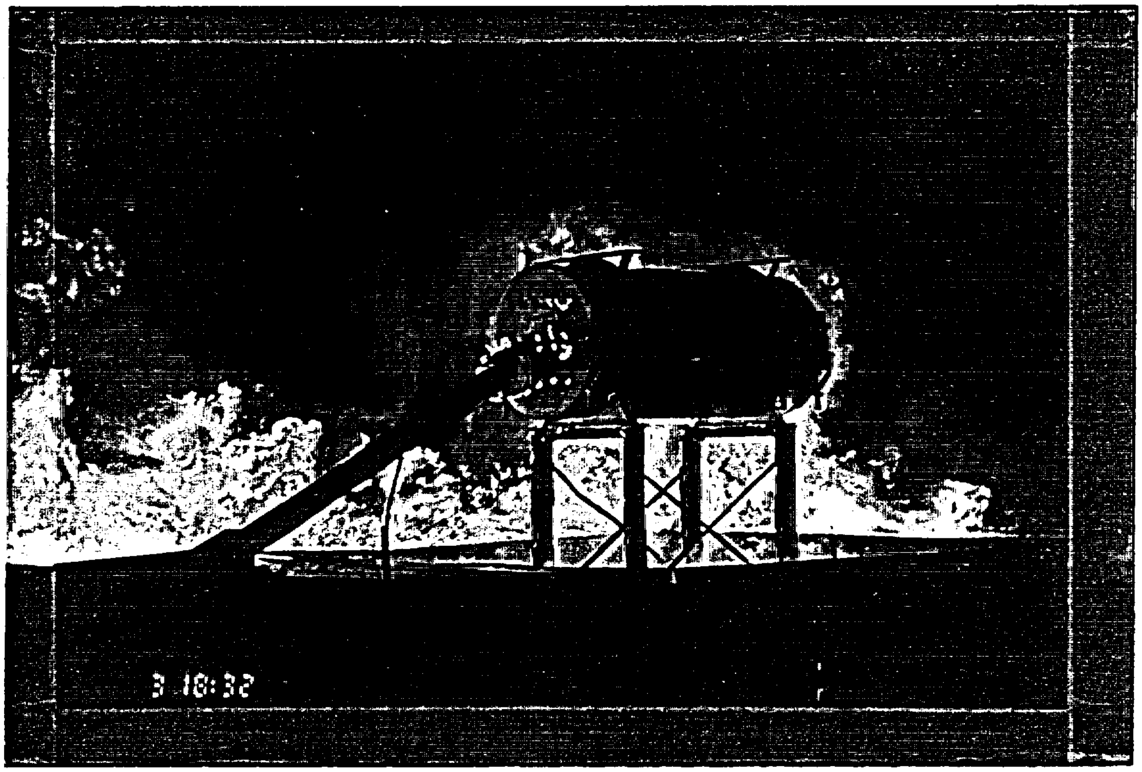


Photo 2.10.5-28
NCI-21PF-1 Package
Condition Following Cooldown

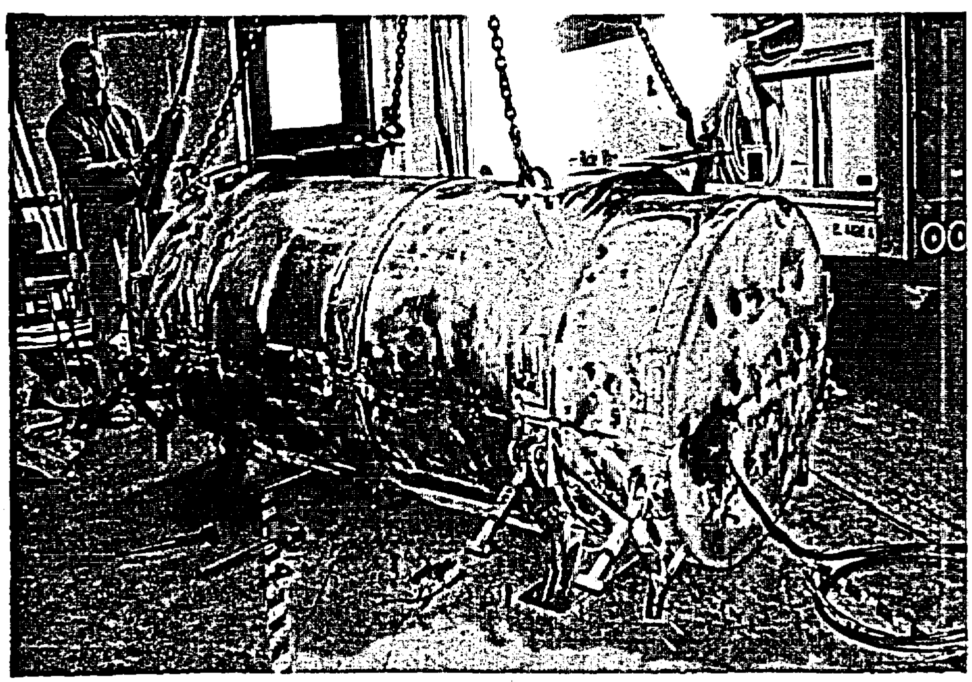


Photo 2.10.5-29
NCI-21PF-1 Package
Opening the Package after the Fire Test

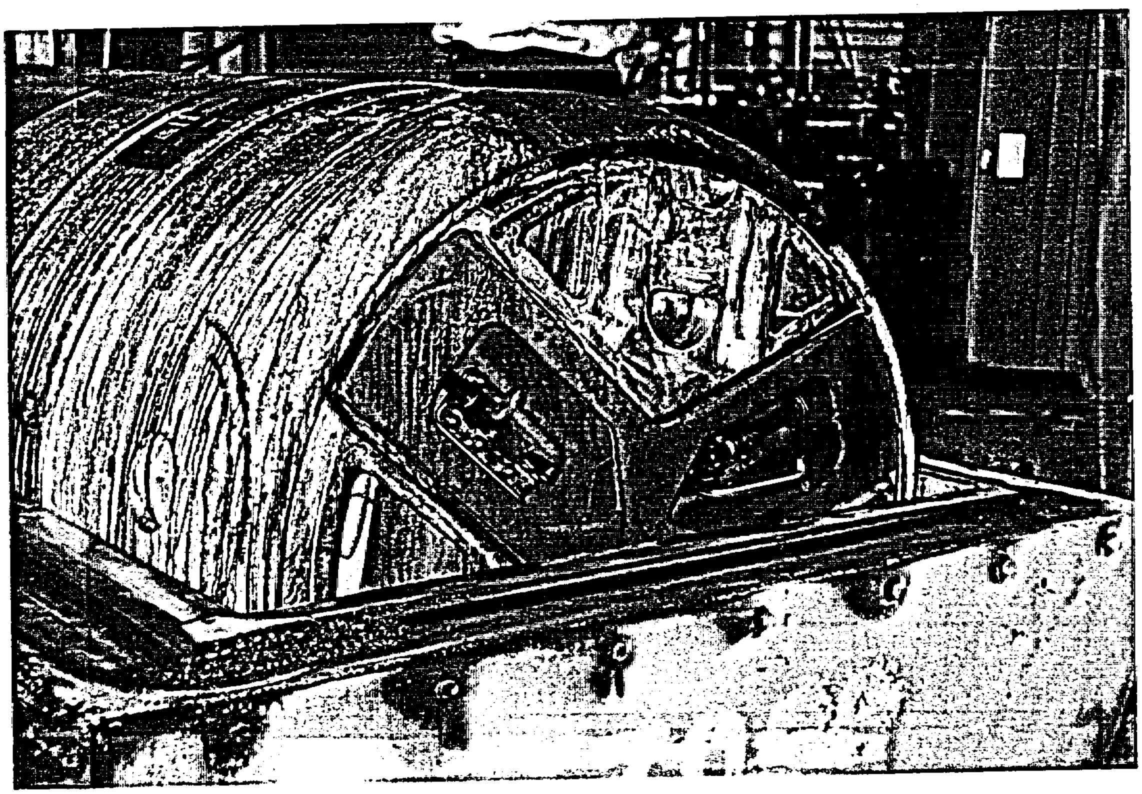


Photo 2.10.5-30
Aluminum Honeycomb Condition Following Testing
of the NCI-21PF-1 Package

APPENDIX 2.10.6
HISTORICAL TESTING AND VALVE PROTECTION DEVICE PERFORMANCE TESTING

TABLE OF CONTENTS

2.10.6.1 Introduction 2.10.6-1

2.10.6.2 Background 2.10.6-1

2.10.6.3 Overpack and Cylinder Testing History 2.10.6-2
- 2.10.6.3.1 Testing Conducted for Revision 0, SAR 2.10.6-2
- 2.10.6.3.2 Testing Conducted for Revision 1, SAR 2.10.6-3
- 2.10.6.3.3 Testing Conduced with pitted High Chloride Foam Overpacks, Transnucleaire, Paris 2.10.6-4
- 2.10.6.3.4 Testing Conducted with NCI-21PF-1 Overpacks with NCI-PF-1 Foam 2.10.6-4
- 2.10.6.3.5 Conclusion 2.10.6-5

2.10.6.4 Performance Testing of the Valve Protection Device 2.10.6-5
- 2.10.6.4.1 Test Purpose 2.10.6-5
- 2.10.6.4.2 Test Articles 2.10.6-5
- 2.10.6.4.3 Test Facility 2.10.6-6
- 2.10.6.4.4 Testing Equipment and Calibration 2.10.6-6
- 2.10.6.4.5 Testing Description 2.10.6-6
- 2.10.6.4.6 Summary and Results of Tests 2.10.6-9

2.10.6.5 Conclusions 2.10.6-12

2.10.6.6 References 2.10.6-12

LIST OF TABLES

2.10.6-1 ½ Scale Model Testing 2.10.6-13
2.10.6-2 COGEMA High Chloride (New) NCI-21PF-1 Testing 2.10.6-14
2.10.6-3 Transnucleaire High Chloride (Pitted) NCI-21PF-1 Testing 2.10.6-14
2.10.6-4 NCI-21PF-1 with NCI-PF-1 Foam Testing 2.10.6-15

LIST OF FIGURES

2.10.6-1 High Chloride NCI-21PF-1 Package with Valve Protection Device Performance Testing Program 2.10.6-16
2.10.6-2 Overpack Deformation following 13.5° from Vertical Free Drop . . . 2.10.6-19
2.10.6-3 Overpack Deformation following 13.5° from Vertical Puncture 2.10.6-19
2.10.6-4 Overpack Deformation following 30° from Vertical Free Drop 2.10.6-20
2.10.6-5 Overpack Deformation following 30° from Vertical Puncture 2.10.6-20
2.10.6-6 Valve Position Measurements on Cylinder Used for 13.5° and 30° from Vertical Drops 2.10.6-21
2.10.6-7 Valve Position Measurements with Valve Protection Device - Permanent Deformation 2.10.6-23

LIST OF PHOTOGRAPHS

2.10.6-1 High Chloride (Pitted) NCI-21PF-1 with no VPD, Transnucleaire Testing Results 2.10.6-24
2.10.6-2 High Chloride NCI-21PF-1 with VPD - Preparing for the 13.5°, 30 foot Free Drop 2.10.6-25
2.10.6-3 High Chloride NCI-21PF-1 with VPD - Damage Following the 13.5°, 30 foot Free Drop 2.10.6-25
2.10.6-4 High Chloride NCI-21PF-1 with VPD - Preparing for the 13.5°, 40 inch Puncture Drop 2.10.6-26
2.10.6-5 High Chloride NCI-21PF-1 with VPD - Damage Following the 13.5°, 40 inch Puncture Drop 2.10.6-26
2.10.6-6 High Chloride NCI-21PF-1 with VPD - Valve Protection Device Condition Following the 13.5° Drop Sequence 2.10.6-27
2.10.6-7 High Chloride NCI-21PF-1 with VPD - Preparing for the 30°, 30 foot Free Drop 2.10.6-28
2.10.6-8 High Chloride NCI-21PF-1 with VPD - Damage Following the 30°, 30 foot Free Drop 2.10.6-28
2.10.6-9 High Chloride NCI-21PF-1 with VPD - Preparing for the 30°, 40 inch Puncture Drop 2.10.6-29
2.10.6-10 High Chloride NCI-21PF-1 with VPD -Damage Following the 30°, 40 inch Puncture Drop 2.10.6-29
2.10.6-11 High Chloride NCI-21PF-1 with VPD - Valve Protection Device Condition Following the 30° Drop Sequence 2.10.6-30

APPENDIX 2.10.6
HISTORICAL TESTING AND VALVE PROTECTION DEVICE
PERFORMANCE TESTING

2.10.6.1 Introduction

The purpose of this appendix is to establish the "worst orientation" for hypothetical accident testing under the performance criteria of 10 CFR 71.73 based on past testing history. This appendix also summarizes the past testing history of the NCI-21PF-1 packaging, considering packages containing both high chloride and the current NCI-PF-1 foam formulations. This information is provided only as a basis for selection of the worst drop orientations. It is not intended to be used for validating the design of the overpacks.

It was concluded that the NCI-21PF-1 overpack with the valve protection device installed was expected to meet the requirements of 10 CFR 71. A 13.5° angle was chosen for full compliance testing.

2.10.6.2 Background

The NCI-21PF-1 overpack was designed to use the same SP-9 phenolic foam used in the DOT-21PF-1 overpacks prior to 1985. The major ingredient in the SP-9 foam was Union Carbide Phenolic Resin BRL-2760. Union Carbide discontinued producing Resin BRL-2760 in 1985. A substitute resin was obtained by Schenectady Chemical Company, HRJ-2590.

The overpacks (both DOT-21PF-1B and NCI-21PF-1 overpacks) fabricated by NCI from 1985 to 1991 used this modified HRJ-2590 resin foam formulation. In 1991, pitting was discovered on the inner and outer shells of the overpacks. This pitting was from chloride attack and was eventually attributed to the components in the phenolic foam. These overpacks were removed from service in the United States.

NCI performed an investigation and found that the foam made with the HRJ-2590 contained about 0.5% chloride content. The chloride was introduced to the resin during the hydrochloric acid neutralization step. The neutralization agent has been changed to oxalic acid. This resin produced a foam which was indistinguishable from the foam made with the original resin except that the chloride content in the foam dropped to under 200 ppm. This resin was designated HRJ-11825 by Schenectady Chemical Company.

As part of the verification of the new foam formulation, new testing was performed to demonstrate that the package performance meets the hypothetical accident conditions of 10 CFR 71. Testing was performed and reported to the NRC in 1995.

This testing resulted in elevated leak rates from the 30B cylinder when it was subjected to the drop and puncture tests in the 13.5° from vertical c.g. over valve orientation. The elevated leak rates identified in this testing program were attributed to the cylinder skirt collapsing thereby resulting in the overpack end wall moving to impact the cylinder valve. The cylinder skirt collapse was assumed to result from reusing a cylinder with a damaged (from previous drop tests) and repaired skirt for the testing program.

At the same time, COGEMA and Transnucleaire (France) were performing testing using the NCI-21PF-1 packaging containing the high chloride foam. This test was performed to arrange for special shipments using these overpacks within Europe. This package was dropped and puncture tested in the 30° from vertical orientation. This testing program also used a cylinder with a damaged (from previous drop tests) and repaired skirt. When the package was opened following drop testing, the cylinder skirt had bent and hit the cylinder valve. No leak testing was performed.

NCI concluded that cylinders with repaired skirts could not adequately protect the valve during the hypothetical drop accidents. NCI requested that cylinders with repaired skirts not be used in their overpacks. This posed a new problem since there is no industry documentation of cylinder skirt damage and repair. Without knowing which cylinders have undergone repair, another solution was needed.

The DOT-21PF specification overpacks were undergoing similar scrutiny. A solution was needed that would be applicable to both the NCI-21PF-1 and the DOT-21PF overpacks. A valve protection device was the proposed solution. Several different designs of the valve protection device were developed. It was determined that a valve protection device consisting of stiff aluminum inserts with a steel spider to hold them in place in the cylinder skirt would best protect the valve. A testing program was developed to evaluate the performance of this valve protection device in both the 13.5° and 30° from vertical orientations. This testing program was designed to simulate the free drop and puncture tests described in 10 CFR 71.73. The tests were performed on high chloride overpacks which had been removed from service. The results of these tests were also used to evaluate the "worst orientation" for future compliance testing on low chloride overpacks..

2.10.6.3 Overpack and Cylinder Testing History

2.10.6.3.1 Testing Conducted for Revision 0, SAR

In support of the Safety Analysis Report, Revision 0 (August, 1989), testing was conducted on a half scale model (leak testing was not performed). Basically, all dimensions, on the test article including thicknesses and tolerances were reduced by half. Wood and foam thicknesses were easily reduced to ½, but metal thicknesses are dependent on standard items available. The half scale model was built using metal thicknesses which were equal to or less than ½ their full-scale counterparts. All parts of the closure toggles were ½ the size of their full scale counterparts. Threaded parts, including those in the closure toggles were National Coarse threads and did not scale exactly. The minor thread diameters of the ½ scale threads were chosen to be equal to or less than half that of the full scale threads.

A one half scale dummy cylinder was fabricated with its shell made of ¼" (6.35 mm) thick steel plate and with flat end plates made of ½" thick steel plate instead of dished ends of ¼" thick steel.

In this testing sequence the package was subjected to a 30 foot free drop and 40 inch puncture with the package oriented such that the center of gravity was over the dummy valve. These drops were then followed by 30 foot side drops into the footings and into the closures. The testing ended with a 40 inch puncture test into the center closure. No damage was reported to the dummy cylinder valve. The test program that this package was subjected to and its results are presented in Table 2.10.6-1.

This testing program concluded that the NCI-21PF-1 package met the hypothetical accident criteria of 10 CFR 71.73.

2.10.6.3.2 Testing Conducted for Revision 1, SAR

In support of the Safety Analysis Report, Revision 1 (January, 1993), the results of the next testing program were included. In this case, testing was conducted by COGEMA on full scale high chloride foam models of the shipping package. The testing sequence and its results are summarized in Table 2.10.6-2.

In this testing sequence the package was subjected to a 30 foot drop followed by a 40 inch puncture test with the package in the 13.5° from vertical orientation. The first drop was performed with the valve cover box (defined in ANSI N14.1) in place. The package suffered leakage. The second sequence drop was performed without the valve cover box. The package had a post test indicated leakage of 5.7×10^{-3} atm cc/sec He which was less than the accident criteria of 1.4×10^{-1} atm cc/sec He.

Finally, in the third sequence the package was subjected to a 30 foot 30° from horizontal slapdown drop with secondary impact oriented into the valve. The 30 foot drop was followed by a 40 inch puncture test into a closure.

This testing program concluded that a new high chloride package, provided the valve cover box is removed, would meet the hypothetical accident criteria of 10 CFR 71.73.

Pitting was later discovered on the inner and outer shells of older high chloride DOT-21PF-1 and NCI-21PF-1 overpacks. The pitting was attributed to chloride attack and eventually attributed to components in the phenolic foam. The high chloride foam overpacks were removed from service and the NCI-PF-1 low chloride foam formulation was developed. The NRC requested additional testing of the NCI-21PF-1 (with NCI-PF-1 foam) packaging to demonstrate compliance with the hypothetical accident criteria of 10 CFR 71.73.

2.10.6.3.3 Testing Conducted with pitted High Chloride Foam Overpacks, Transnucleaire, Paris

Transnucleaire, Paris, conducted a testing program using NCI-21PF-1 high chloride overpacks (March, 1995). These overpacks were pitted and the overpacks were being verified for their continued used under special arrangement with the French competent authority. Leak testing was not performed. Results were strictly based on the physical condition of the cylinder after the drop. (See Table 2.10.6-3 and Photo 2.10.6-1)

This testing program concluded that the 30° from vertical orientation could result in cylinder leakage due to impact of the cylinder skirt onto the valve.

2.10.6.3.4 Testing Conducted with NCI-21PF-1 Overpacks with NCI-PF-1 Foam

At the request of the NRC, to support the change in the foam formulation, NCI conducted an additional testing program to verify the adequacy of the foam (June, 1995). These tests were conducted on a full scale model of the shipping package. The cylinder used in testing had previously been used for other drop and puncture tests. The damage to the cylinder skirt had been repaired prior to testing. A description of the testing and its results are provided in Table 2.10.6-4.

The package was subjected to a 30 foot drop followed by a 40 inch puncture test with the package in the 13.5° from vertical orientation. The same package was subjected to a 30 foot 30° from horizontal slapdown drop with second impact into closure. The 30 foot drop was followed by a 40 inch puncture test into a closure. The same package was then fire tested. After the fire, the package had an indicated leak of 1.4 cc/sec. Skirt damage to the cylinder was also noted around the valve. The leak was attributed to the drop testing.

To protect the valve, a 1/2" thick plate was inserted in the valve end of the overpack. The 13.5° orientation 30 foot drop and 40 inch puncture test and the 30° horizontal slapdown and 40 inch puncture tests into a closure were repeated. After this second series of tests, the package was leak tested to a sensitivity of 10^{-1} cc/sec, and no leakage was indicated. Due to the low sensitivity of the leak test, it was not apparent that the 1/2" plate protected the valve during the test. In addition, the cylinder showed that damage had occurred when the valve stem came in contact with the end plate because the cylinder skirt had collapsed in the repaired area.

It was concluded that cylinders with damaged skirts should not be used for shipments. This testing program demonstrated that a 13.5° from vertical drop orientation could result in valve damage.

2.10.6.3.5 Conclusion

A review of the past testing history of the 30B cylinder indicates that the following two drop orientations have resulted in the most damage:

- 13.5° from vertical c.g. over valve with the package oriented so that the valve would be in the impact area. In this orientation, the overpack end wall could deform into the cylinder skirt and impact the valve.

- 30° from vertical with the package oriented so that the valve would be in the impact area. In this orientation, a previously damaged 30B cylinder skirt could collapse and impact the cylinder valve.

2.10.6.4 Performance Testing of the Valve Protection Device

2.10.6.4.1 Test Purpose

This testing was designed to evaluate the performance of the valve protection device in the 30 foot drop and the 40 inch puncture tests in both the 13.5° and 30° from vertical orientations, and to determine the worst drop orientation for full scale compliance testing

2.10.6.4.2 Test Articles

Each test article consisted of a UF6 30B cylinder, a valve protection device, and a high chloride NCI-21PF-1 overpack (which had been removed from service). The high chloride overpacks were used for the following reasons:

- NCI-21PF-1 overpacks with the current foam formulation were not readily available for testing.

- The overpack wood and metal dimensions are identical to the currently licensed configuration. The 13.5° and 30° from vertical drops are close to end drops where the wood and steel are present. The high chloride overpacks were considered representative for determining worst orientations only.

Additional description on each test article are provided below.

30B Cylinder

Two full size 30B cylinders were used for the testing program. These were representative cylinders. The cylinder used for the 13.5° from vertical drop testing had never been used in drop and puncture testing (the skirt was bent and repaired). The cylinder used for the 30° from vertical drop testing was re-used from a previous drop test using a DOT-21PF-1B overpack with valve protection device (this cylinder also had a skirt that had been bent and repaired).

Valve Protection Device

Same as used in Section 2.10.5.2.

High Chloride NCI-21PF-1 Overpack

The overpacks used for testing were high chloride NCI-21PF-1 overpacks which had been removed from service in 1994. The overpacks were visually inspected prior to the drop testing, and no significant damage was identified. The shells showed the pitting typical of overpacks with high chloride foam. The overpack toggle bolts were torqued to a value of 110 ft-lb prior to testing.

2.10.6.4.3 Test Facility

See Section 2.10.5.3.

2.10.6.4.4 Test Equipment and Calibration

See Section 2.10.5.4.

2.10.6.4.5 Test Description

The testing program is described below. A flow chart of the testing program is provided in Figure 2.10.6-1.

Removing the 30B Cylinder Valve

The valves were removed from the cylinder.

Bending of 30B Cylinder Skirt

The cylinder skirts were bent as described in Section 2.10.5.5.

Filling the 30B Cylinder and Replacing the 30B Cylinder Valve

See Section 2.10.5.5.

Normal Conditions Leak Testing

See Section 2.10.5.5.

Preparation of the 30B Cylinder and the High Chloride NCI-21PF-1 Overpack

30B Cylinder: The location of the valve protection device with respect to the valve and the cylinder was recorded. Aluminum honeycomb was epoxied to the inside of the aluminum casting around the valve area to record the minimum clearance between the valve and the valve protection device during the drop testing (typical photos are provided in Appendix 2.10.5). A thermocouple was attached to the cylinder skirt to determine cylinder temperature prior to drop and puncture testing.

High Chloride NCI-21PF-1 Overpack: The cylinder was placed horizontally into the bottom half of the overpack. The seals were inspected to ensure that no debris was present. The toggle bolts were torqued to 110 ft-lbs prior to testing. A hole was drilled in the end wall of the overpack (opposite from the valve location) for the thermocouple that was attached to the cylinder skirt.

Loading Cylinder into Overpack and Cooling of Overpack

The 30B cylinder with valve protection device was loaded into the overpack with the valve in the 12 o'clock position.

The test article was installed in the cooling chamber for a period of at least 38 hours prior to testing. The cylinder, valve protection device and overpack halves were all cooled. The top portion of the overpack was separated from the bottom of the overpack by wood blocks to enhance cooling.

Remove Overpack from Storage and Close Overpack

The test article was removed from the cooling chamber and the toggles were closed immediately prior to testing. The toggles were closed according to standard procedure. The location of the valve was marked on the external surface of the overpack. The temperature of the test article was measured using the thermocouple attached to the cylinder skirt.

Perform 30 ft Free Drops and Record Damages

The first test article was positioned at an orientation of 13.5±1° from vertical with the package center of gravity over the valve. The temperature of the test article, the wind speed, and the ambient temperatures were recorded prior to the drop.

The package was lifted to a height of 30 ft using a crane. The release of the test item was by a pneumatically-actuated quick release mechanism. No guidance of the test item was provided during the drop.

Deformation data of the overpack was measured and recorded. High speed video were taken of the drop event. Color photographs of the extent of damage were taken. The overpack was not opened, it was placed into the cooling chamber until the 40 inch puncture test could be performed.

This sequence was repeated using the second test article but the package was oriented 30±1° from vertical with the impact into the valve location.

Perform 40 inch Puncture Tests and Record Damages

The first test article was positioned at an orientation of 13.5±1° from vertical with the location of the valve positioned directly above the puncture bar. The temperature of the test article, the wind speed, and the ambient temperatures were recorded prior to the drop.

The package was lifted to a height of 40 inches using a crane. The release of the test item was by the pneumatically-actuated quick release mechanism. Again, no guidance of the test item was provided during the drop.

Deformation data of the overpack was measured and recorded. High speed video was taken of the drop event. Color photographs of the extent of damage were taken. The overpack was opened and the cylinder and valve protection device were inspected.

This sequence was repeated using the second test article but the package was oriented 30±1° from vertical with the impact into the valve location.

Leak Testing

Once the package was opened, the cylinder was removed from the overpack and the valve protection device was removed from the cylinder skirt. The following leak tests were performed on the 30B cylinder after drop and puncture testing:

- A bubble leak test was performed on the valve cap, valve stem, valve packing nut and the valve seat with a cylinder internal pressure of 100 psig nitrogen (due to the cold temperature of the cylinders we did not want the moisture in air to freeze in the cylinder). The internal pressure was held for a period of 15 minutes. Any indication of bubbles were noted.

- A helium mass spectrometer test was performed by evacuating the cylinder and introducing helium around the valve cap, valve stem, valve packing nut and the valve seat for a period of at least 2 minutes. If no leakage was indicated then this leak test was ended. If leakage was indicated, the valve was bagged and continuously sprayed with helium. The helium leak indicator would be monitored until the readings stabilized. Both the indicated leak rate and the time to stabilization were recorded.

- If the helium leak test indicated leakage then a 19 psig hydrostatic test was performed on the cylinder. The cylinder with the valve in the 6 o'clock position was filled with tap water and a blue dying agent. The pressure in the cylinder was increased to 19 psig and held for a minimum of eight hours. Periodically the valve cap, valve stem, valve packing nut and the valve seat were checked for any indication of water leakage from the cylinder.

2.10.6.4.6 Summary and Results of Tests

Testing was conducted at Southwest Research Institute (SwRI), San Antonio, Texas in accordance with written procedures.

The ambient temperature was about 90°F during the drop sequences. The wind speed was 3 to 3.5 mph.

13.5° from Vertical Center of Gravity over Valve Orientation

The first test article was positioned at an orientation of 13° from vertical, and raised 30 feet as measured from the lowest position on the overpack. The overpack was rotated so that the impact would be into the valve location (Photo 2.10.6-2). The temperature of the test article prior to the drop was -10°F. The overpack deformed at the impact area as shown in Figure 2.10.6-2. All closures remained intact. Buckling of the overpack outer skin extended to the first reinforcement ring. A maximum gap of 1/4 inch between the two halves of the overpack was visible at the center of the impact end. The remainder of the overpack seam was snug (Photo 2.10.6-3). The package was not opened. It was returned to the cooling chamber until the puncture test could be performed.

The test article was then positioned at an orientation of 13.5° from vertical with the location of the valve positioned directly above the puncture bar, and raised 40 inches above the bar (Photo 2.10.6-4). The temperature of the test article prior to the drop was not recorded due to thermocouple damage from the 30 ft drop. The overpack deformed at the impact area as shown in Figure 2.10.6-3 (Photo 2.10.6-5).

The test articles were opened at the completion of all testing. There was no internal tearing of the overpacks, and only slight deformation of the skirt and valve protection device. In neither case did any part of the cylinder, overpack, or valve protection device hit the valve itself. The clearance between the valve protection device and the valve stem tip was about 3 mm. The pre and post test measurements are provided in Figures 2.10.6-6 and 2.10.6-7. (See Photo 2.10.6-6.)

After inspections were completed, a soap film bubble test was made on both cylinders. The temperature of the cylinder was quite cold, so the area at the base of the valve was heated with a hot air gun to prevent the soap film from freezing. The cylinder was pressurized with nitrogen to 100 psig. The soap film was applied to the valve threads, stem, packing nut, and cap. A leak was evident at the threads. No other leaks were visible.

The cylinder was then evacuated overnight for helium leak testing. Immediately prior to introducing helium to the outside of the valve of the cylinder from test 1, the leak rate background was 3.5×10^{-7} std cc/sec. A short burst of helium was applied to the valve, and an increase in the leak rate signal to the 10^{-6} range occurred within a few seconds.

The valve was then bagged and the bag was continuously sprayed with helium. After 2.3 hours, the leak rate was judged stable when there was no signal change over a five minute period. The reading was 3.9×10^{-4} std cc/sec. Helium was sprayed on the vacuum manifold and the connection to the cylinder to verify that there were no leaks there.

Following the helium leak test, the 100 psig soap bubble test was reperformed to see when a leak was first evident. Easily visible bubbles appeared at or before 1 psig.

The cylinder underwent hydrostatic testing at a pressure of 19 psig. This test was performed to verify that there would be no water inleakage due to the immersion test specified in 10 CFR 71.73(c)(5). There was no indication of water leakage.

30° from Vertical Orientation

The second test article was positioned at an orientation of 29° from vertical with the impact into the valve location, and raised 30 feet as measured from the lowest position of the overpack (Photo 2.10.6-7). The temperature at the 30B cylinder skirt prior to the drop was 0°F. The overpack deformed at the impact area as shown in Figure 2.10.6-4. All closures remained intact (Photo 2.10.6-8). The package was not opened. It was placed in the cooling chamber until the puncture test could be performed.

The test article was then positioned at an orientation of 30° from vertical with the valve location positioned directly above the puncture bar, and raised 40 inches above the bar (Photo 2.10.6-9). The temperature of the test article prior to the drop was -2°. The overpack deformed at the impact area as shown in Figure 2.10.6-5 (Photo 2.10.6-10).

The test articles were opened at the completion of all testing. There was no internal tearing of the overpack, and only slight deformation of the skirt and valve protection device. No part of the cylinder, overpack, or valve protection device hit the valve itself. The pre and post test measurements are provided in Figures 2.10.6-6 and 2.10.6-7. (See Photo 2.10.6-11.)

The cylinder was pressurized with nitrogen to 100 psig and bubble tested for 15 minutes. No bubbles appeared.

The cylinder was then evacuated overnight for helium leak testing. The cylinder from test article two was tested first. Immediately prior to introducing helium to the outside of the valve, the leak rate background was 3.1×10^{-8} std cc/sec. No leak was found after spraying the outside of the valve for several minutes.

After helium leak testing, the 100 psig soap film tests were repeated with the same results as were found earlier. The cylinder did not undergo hydrostatic testing since there was no leakage indicated during the soap bubble test or the helium mass spectrometer test.

2.10.6.5 Conclusion

It has been concluded that the NCI-21PF-1 overpack with the valve protection device installed is expected to meet the requirements of 10 CFR 71. The 13.5° angle was chosen for full compliance testing. Specific results noted from each drop sequence are provided below:

13.5° from Vertical Test Sequence

- The maximum damage occurred to the valve protection device in the 13.5° from vertical drop and puncture orientation (Figure 2.10.6-7). The bridge of the valve protection device deformed 0.128 inches overall. A leak 3.9×10^{-4} std cc/sec was measured at the cylinder valve following this drop series. A subsequent hydrostatic test simulating the 3 foot immersion test showed no water leakage.

- Some deflection of the cylinder skirt was evident as shown in the Pre-Test and Post-Test measurements shown in Figures 2.10.6-6.

30° from Vertical Test Sequence

- The valve protection device satisfactorily protected the valve during the 30° drop test series, with no resulting leakage.

- Some deflection of the cylinder skirt was evident as shown in the Pre-Test and Post-Test measurements shown in Figures 2.10.6-6.

- The valve protection device deformed 0.048 inches due to the drop tests as shown in Figure 2.10.6-7.

2.10.6.6 Reference Documents

2.10.6.6-1 "Safety Analysis Report for a Type B Certificate of Compliance for the NCI-21PF-1 Protective Shipping Package," Nuclear Container, Inc., Revision 1, January 11, 1993.

2.10.6.6-2 "Test Report - Regulation Drop Tests on 30B Cylindrical Container + 21PF 1 Overpack," Cogema, Reprocessing Division, May 1992.

2.10.6.6-3 Transnucleaire Test Report, 1995.

2.10.6.6-4 NCI Test Report, 1995.

Table 2.10.6-1
½ Scale Model Testing*
NCI-21PF-1 with no Valve Protection Device

Test	Result
30 foot (9 m) free drop: Center of gravity over dummy cylinder valve and impact into the dummy cylinder valve. (approximately 13.5° from vertical)	External Inspection: No tears or rips in either overpack skin nor welds. Closures on deformed end bent but operable, other closures intact and operable. About 0.5 cm gap, developed between package halves on impact end. Internal Inspection: Inner liner bulged inward toward cylinder valve leaving a gap between the end of the valve and deformed end plate of about 0.6 cm. No damage to dummy valve.
40 inch (1 m) puncture: Center of gravity over dummy cylinder valve and impact into damaged area from previous 30 foot drop.	External Inspection: 3 inch diameter dent and about 0.7 cm deep was in area of impact. End plate not penetrated and no broken welds or tears. One tie-down base was bent. Closures unchanged from 30 foot drop. Internal Inspection: Gap between cylinder valve and inner end slightly reduced to about 0.5 cm, no further damage found.
30 foot (9 m) free drop: No repairs were made to the ½ scale model prior to this drop. Horizontal position, impact flat into tie-downs.	External Inspection: Tie down bases were deformed and package bottom flattened slightly. Narrow rip in outer skin near valve end in area in previously damaged area. Rip about 4.5 cm long with max opening less than 1 cm wide. No broken welds. Closures intact; no gaps between package halves.
30 foot (9 m) free drop: No repairs were made to the ½ scale model prior to this drop. Horizontal position, impact flat into closures.	External Inspection: Closures remained intact, however gaps between the cover and bottom portions of package developed at closure plane on impact side. Gaps opened to maximum width of about 1.5 cm at surface and closed to nearly nothing at step joint. Tie down bases and stacking frames deformed but no further rips or tears in outer skin. No broken welds
40 inch (1 m) puncture: No repairs were made to the ½ scale model prior to this drop. Horizontal position, impact into center closure on undamaged side.	External Inspection: Closure coupling nut and swing bolts pushed into the side of package. No other damage resulted from this drop.

*This information is provided to justify worst drop orientation for compliance testing only.

Table 2.10.6-2
COGEMA High Chloride (New) NCI-21PF-1 Testing*
No Valve Protection Device

Test	Result
30 foot (9 m) free drop, 13.8° from vertical, c,g. over valve, impact into valve (Valve cover box in place) 40 inch (1 m) puncture, 15.2° from vertical, impact into previously damaged area (Valve cover box in place)	Before Leak Test: 3.03×10^{-9} atm cc/sec He Post Leak Test: $> 1.4 \times 10^{-1}$ atm cc/sec He External Damage: No closures broken.
30 foot (9 m) free drop, 13.3° from vertical, c.g. over valve, impact into valve (No valve cover box) 40 inch (1 m) puncture, 13.2° from vertical, c.g. over valve, impact into previously damaged area from 30 ft drop (No valve cover box)	Before Leak Test : 4.9×10^{-9} atm cc/sec He Post Leak Test: 5.7×10^{-3} atm cc/sec He External Damage: Two closures broken
30 foot (9 m) free drop 31° from horizontal, secondary impact into valve (No valve cover box) 40 inch (1 m) puncture Horizontal impact into center toggle closure (No valve cover box)	Before Leak Test: 8.7×10^{-9} atm cc/sec He Post Leak Test: 6.6×10^{-9} atm cc/sec He External Damage: One closure broke after 30 foot drop. After puncture, closure that impacted the punch was broken. No damage indicated to the valve.

*This information is provided to justify worst drop orientation for compliance testing only.

Table 2.10.6-3
Transnucleaire High Chloride (Pitted) NCI-21PF-1 Testing Results*
No Valve Protection Device

Test	Results
30 foot (9 m) free drop: 26.7° from vertical 40 inch (1 m) puncture: 29.9° from vertical, impact into side skin of overpack	External Damage: From the puncture a semi-elliptical rip that was 20 cm x 30 cm resulted. Depth of rip was 5.8 cm. The crush depth from the 30 foot drop was 6 inches. Internal Inspection: cylinder skirt impacted valve. Cylinder wall was dented 1 inch where punch impacted. No tears in cylinder wall.

*This information is provided to justify worst drop orientation for compliance testing only.

Table 2.10.6-4
NCI-21PF-1 (with NCI-PF-1 Foam) Test Results*
No Valve Protection Device

Test	Result
30 foot (9 m) free drop, 13° from vertical, c.g. over valve, impact into valve. 40 inch (1 m) puncture, 13° from vertical, c.g. over valve, impact into previously damaged area from 30 ft drop. 30 foot (9 m) free drop 30° from horizontal, impact into closures. 40 inch (1 m) puncture Horizontal impact into side of overpack. 30 minute fire test: following drops, a 31 minute fully engulfing fire test was conducted.	Prior to testing, cylinder pressurized with 19.5 psig of helium. Helium sniffer probe detected no leaks. Test sensitive to 1.0 x 10^{-5} std cc/sec. First 30' free drop, outer shell buckled. Crush depth of 3" measured. No closures broken. After 40" puncture, dent of 8"x 8"x ¾" deep was measured. No closures broken. Second 30' free drop, additional buckling noted. 3" long tear was observed in one weld on lower toggle bracket. Second 40" puncture, dent of 8" 8" x 3" deep was measured on side of overpack. No closures broken. Following fire test, package was opened and skirt damage was noted. Leak detection indicated leak rate of 1.4 cc/sec.
30 foot (9 m) free drop, 13° from vertical, c.g. over valve, impact into valve. 40 inch (1 m) puncture, 13° from vertical, c.g. over valve, impact into previously damaged area from 30 ft drop. 30 foot (9 m) free drop 30° from horizontal, impact into closures. 40 inch (1 m) puncture Horizontal impact into side of overpack.	¼" steel plate added to valve end of overpack. Prior to testing, cylinder pressurized with 20 psig of helium. Helium sniffer probe detected no leaks. Test sensitive to 1.0 x 10^{-5} std cc/sec. After first 30 ft free drop, outer shell buckled. Crush depth of 4" measured. No closures broken. After 40" puncture, dent of 8"x 8"x ½" deep was measured. No closures broken. Second 30 ft free drop, additional buckling noted. 5" long tear along bottom of end plate, and a 1/16" x 3¾" tear in top of end plate. Pivot nut on first toggle sheared. Second 40" puncture, a dent of 24" x 23" x 4" deep measured on side of overpack. No additional closures broken. Leak detector indicated no leaks. Test sensitivity was 1 x 10^{-1} atm cc/sec.

*This information is provided to justify worst drop orientation for compliance testing only.

Figure 2.10.6-1
High Chloride NCI-21PF-1 Package with Valve Protection Device
Performance Testing Program

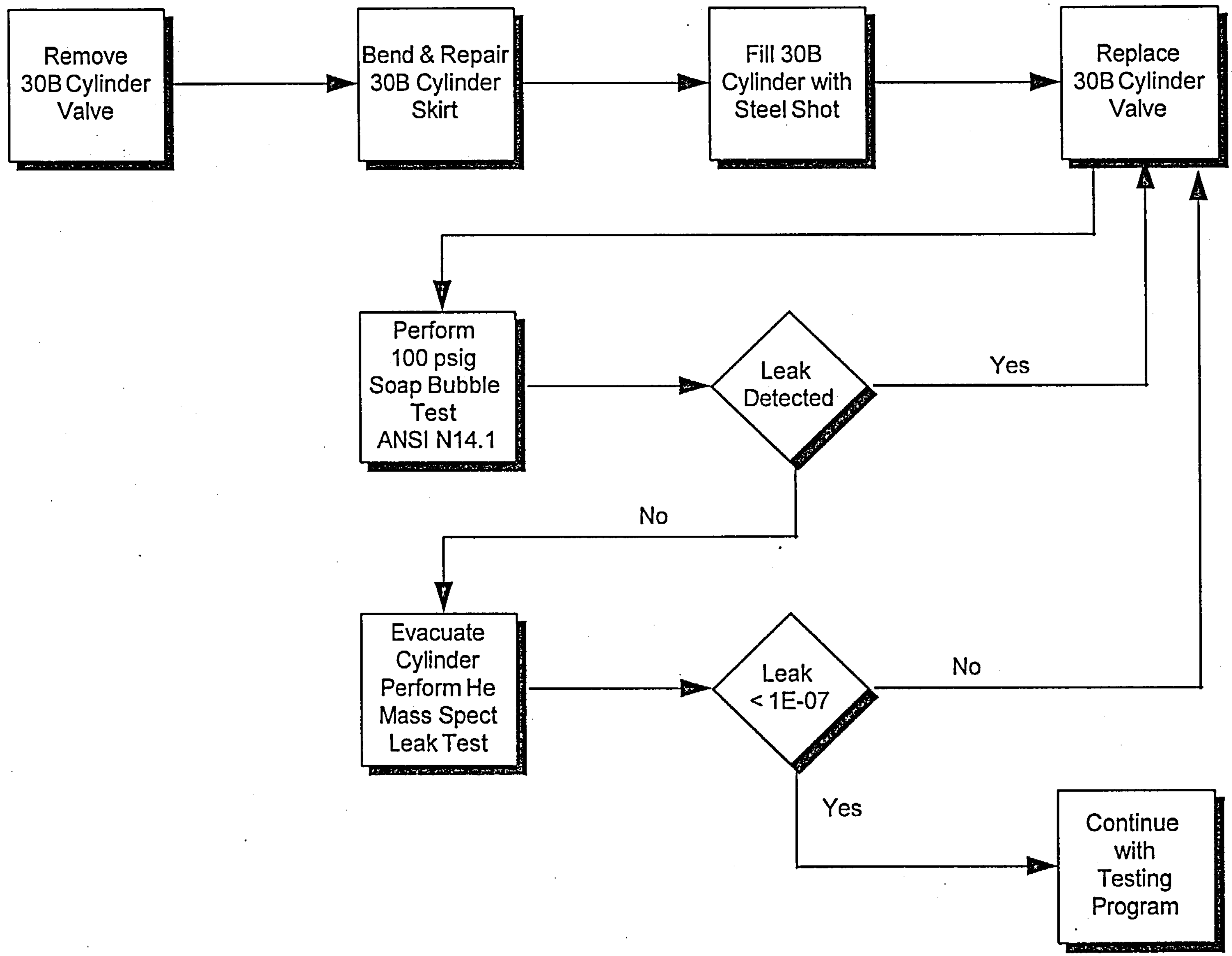


Figure 2.10.6-1
High Chloride NCI-21PF-1 Package with Valve Protection Device
Performance Testing Program
(continued)

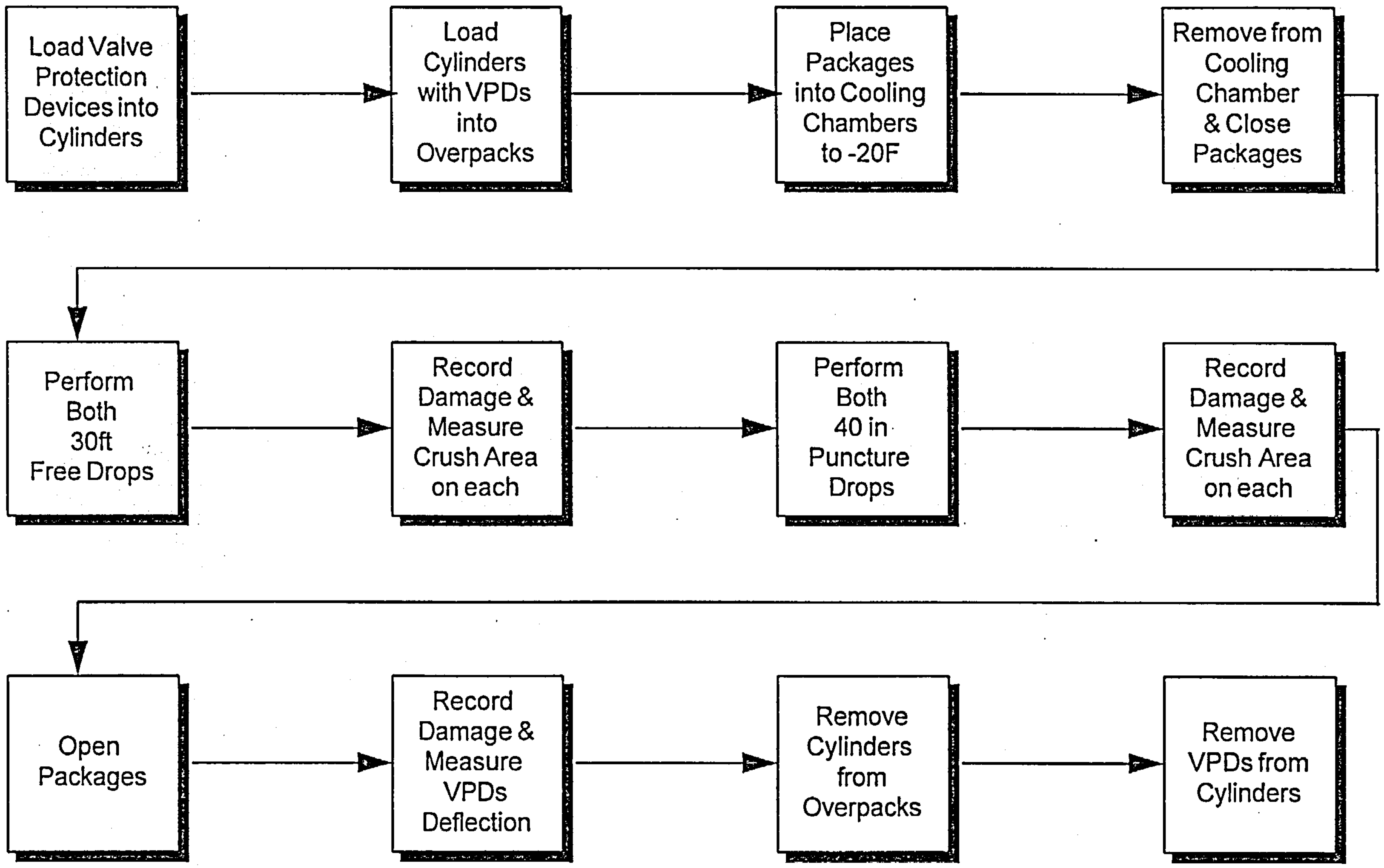


Figure 2.10.6-1
High Chloride NCI-21PF-1 Package with Valve Protection Device
Performance Testing Program
(continued)

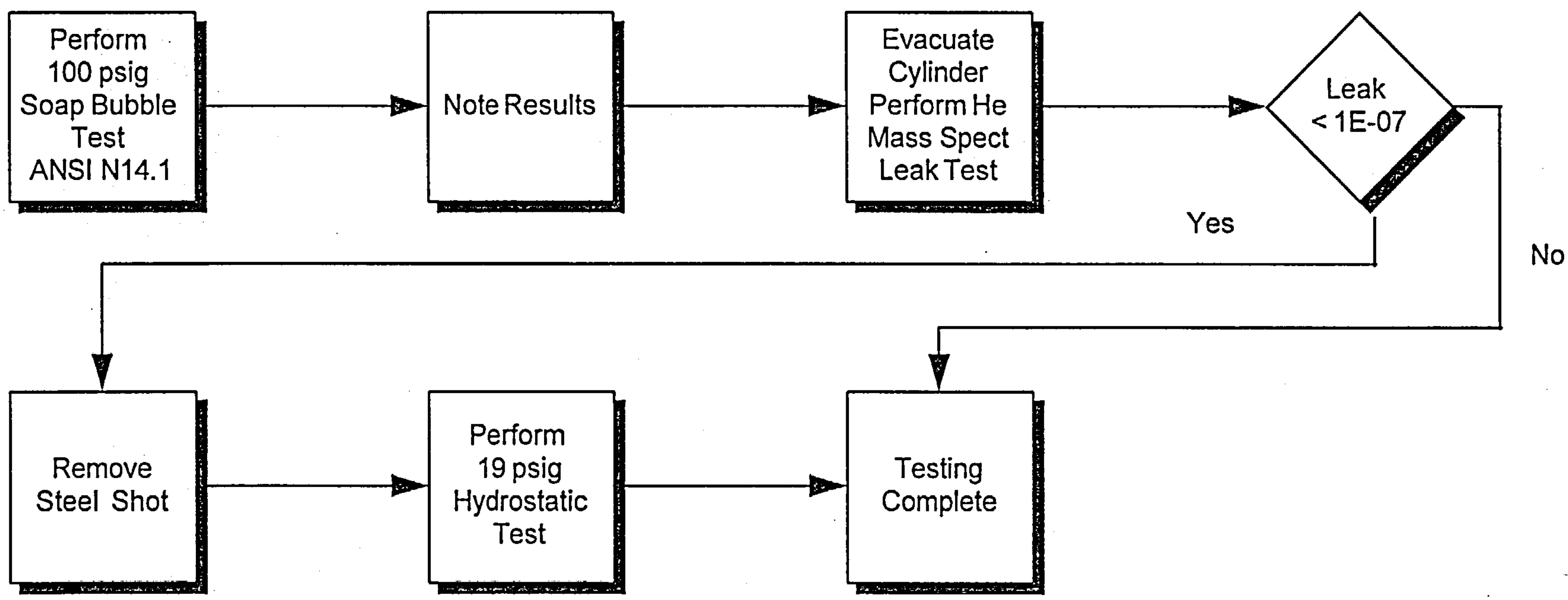


Figure 2.10.6-2
High Chloride NCI-21PF-1 Package with Valve Protection Device
Deformation following 13.5° from Vertical Free Drop

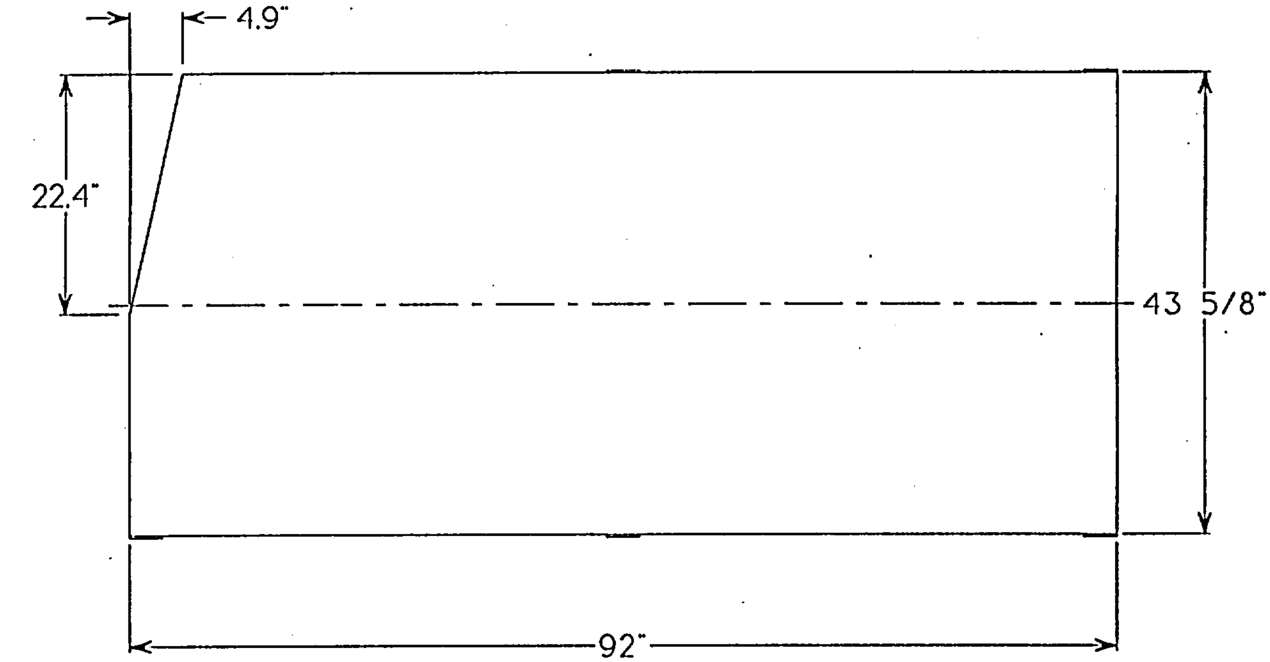


Figure 2.10.6-3
High Chloride NCI-21PF-1 Package with Valve Protection Device
Deformation following 13.5° from Vertical Puncture

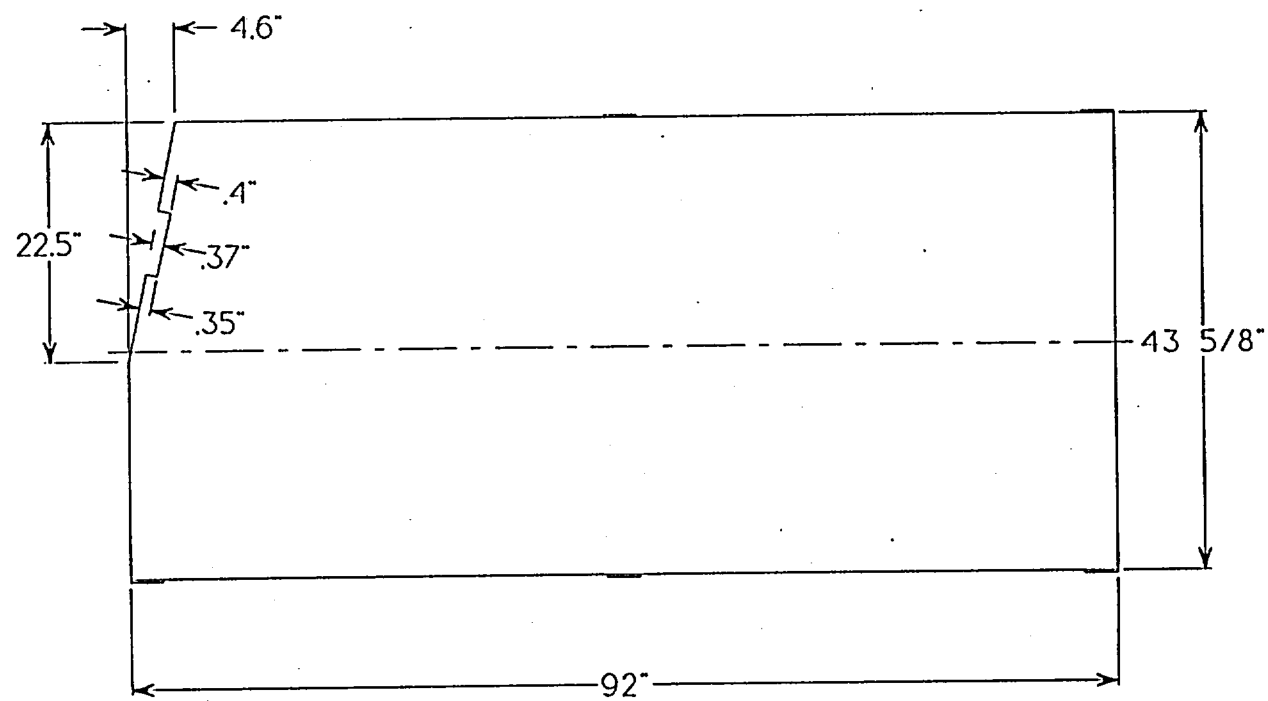


Figure 2.10.6-4
High Chloride NCI-21PF-1 Package with Valve Protection Device
Deformation following 30° from Vertical Free Drop

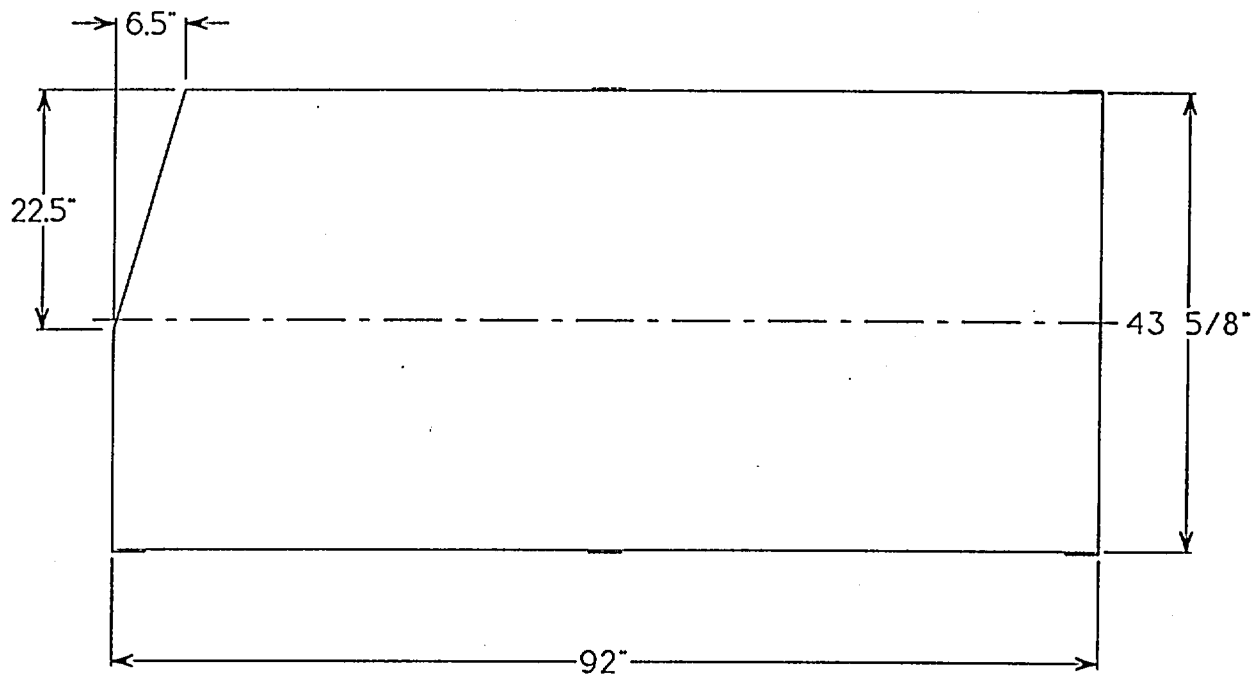


Figure 2.10.6-5
High Chloride NCI-21PF-1 Package with Valve Protection Device
Deformation following 30° from Vertical Puncture

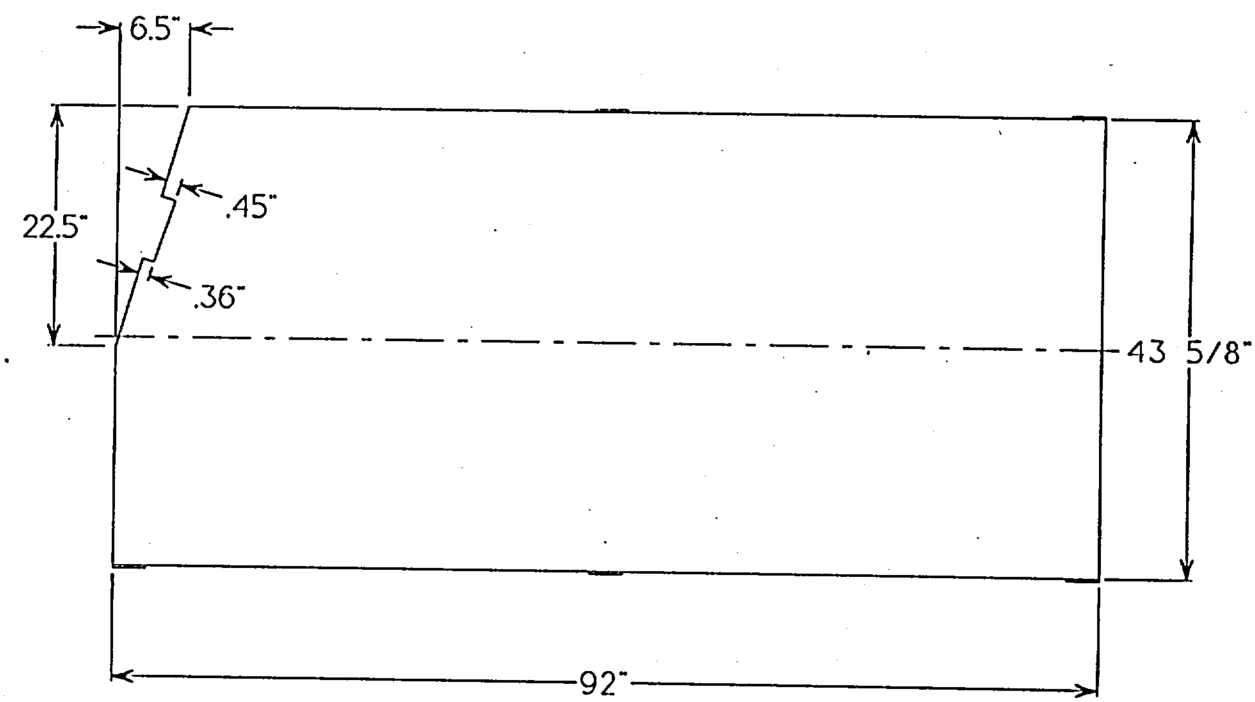


Figure 2.10.6-6
High Chloride NCI-21PF-1 Package with Valve Protection Device
Valve Position Measurements on
Cylinder Used for 13.5° and 30° from Vertical Drops

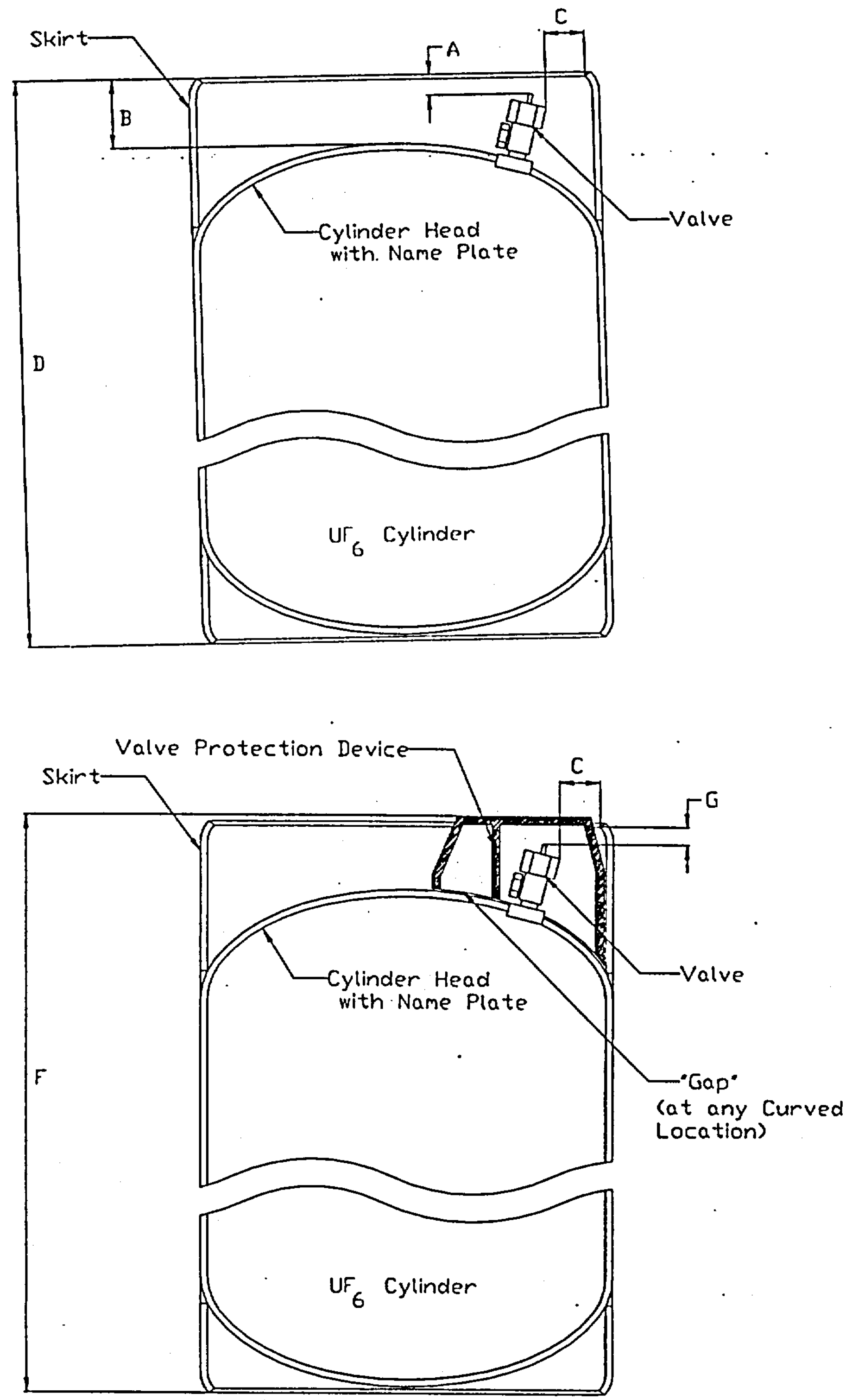
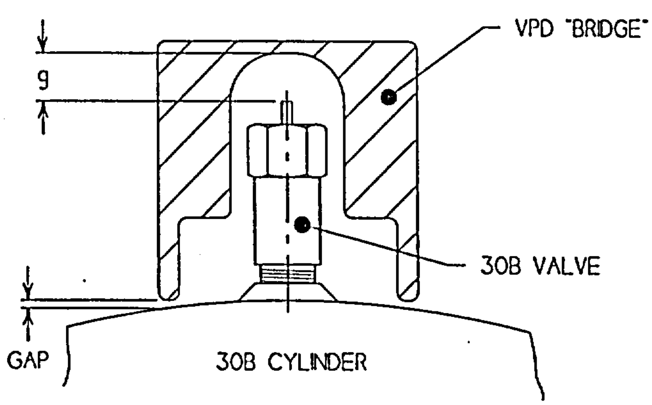


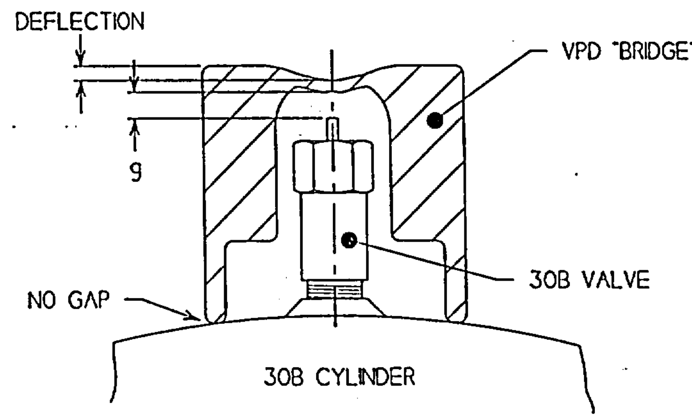
Figure 2.10.6-6
High Chloride NCI-21PF-1 Package with Valve Protection Device
Valve Position Measurements on
Cylinder Used for 13.5° and 30° from Vertical Drops
(continued)

View of "bridge" over valve location:

Pre-Test:



Post-Test:



13.5° from Vertical Orientation

Location	Pre-Test (inches)	Post Test (inches)
A	0.69	0.55
B	4.95	4.91
C	2.50	21.4
D	81.4	81.4
g	0.667	0.15
Gap	0.127	0.0

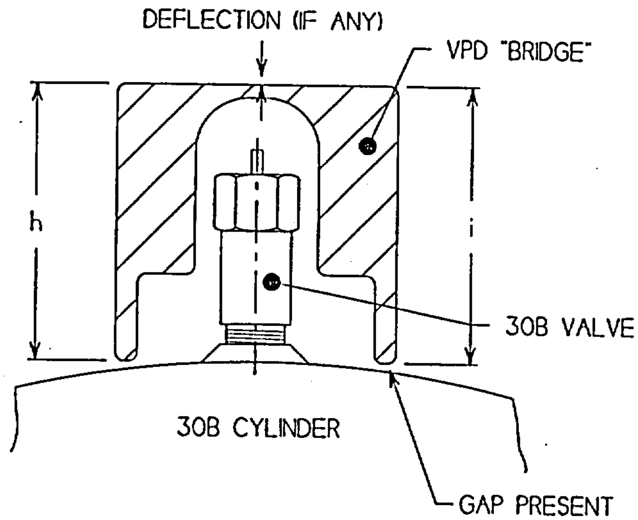
30° from Vertical Orientation

Location	Pre Test (inches)	Post-Test (inches)
A	1.25	0.89
B	5.38	5.30
C	2.50	1.38
D	81.4	81.5
g	0.774	0.4
Gap	0.128	0.138

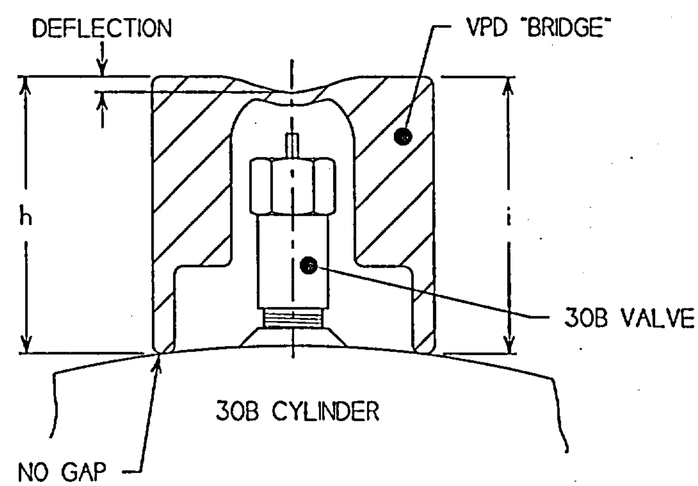
* Gap was measured at "any curved location", the gap between the underside of the valve protection device and the cylinder head is not uniform. This value is not representative of the gap at the valve location.

Figure 2.10.6-7
High Chloride NCI-21PF-1 Package with Valve Protection Device
Valve Protection Device Permanent Deformation

Pre-Test:



Post-Test:



13.5° from Vertical Orientation

Location	Pre-Test (inches)	Post Test (inches)
h	7.13	7.08
i	7.14	7.14
deflection	0.017	0.120
height at bridge*	7.118	6.99
permanent deformation of VPD**	0.128	

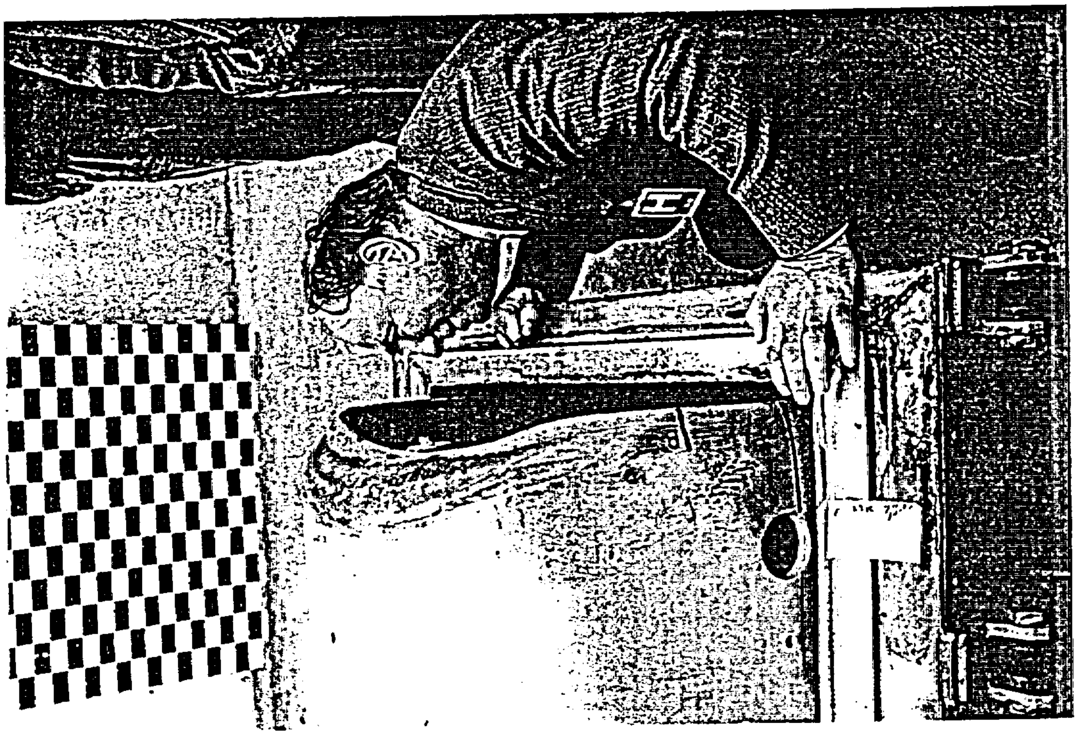
30° from Vertical Orientation

Location	Pre Test (inches)	Post-Test (inches)
h	6.88	6.88
i	6.95	6.95
deflection	0.0	0.048
height at bridge*	6.915	6.867
permanent deformation of VPD**	0.048	

* height at bridge is calculated by: {½ (h - i) - deflection}

** permanent deformation is calculated by: (Height at Bridge)$_{Pre\text{-}test}$ - (Height at Bridge)$_{Post\text{-}test}$

Photo 2.10.6-1
High Chloride (Pitted) NCI-21PF-1 with No Valve Protection Device
Results of Testing Performed by Transnucleaire (Paris)



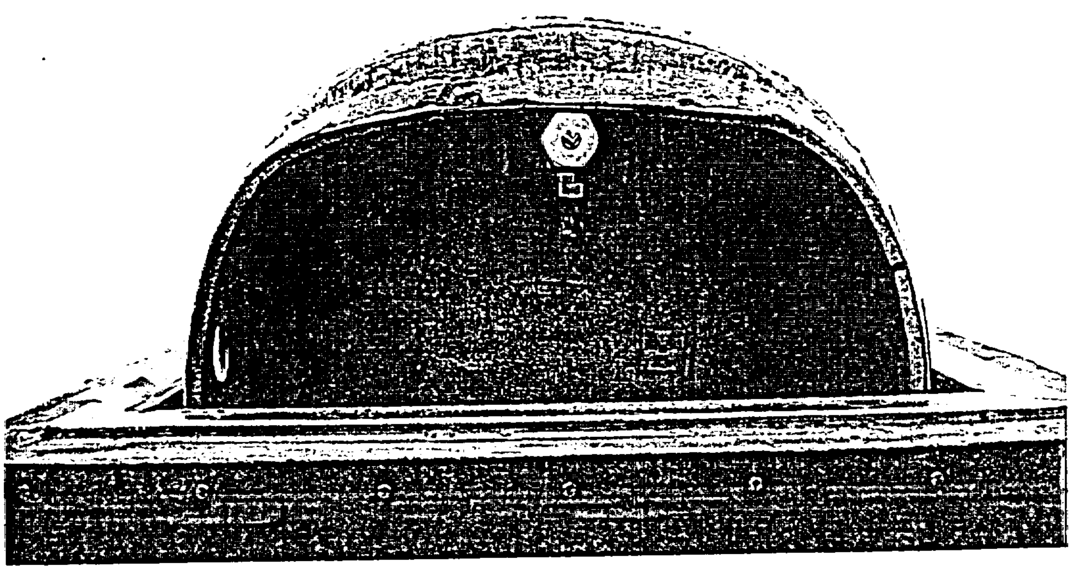


Photo 2.10.6-2
High Chloride NCI-21PF-1 with Valve Protection Device
Preparing for the 13.5°, 30 foot Free Drop

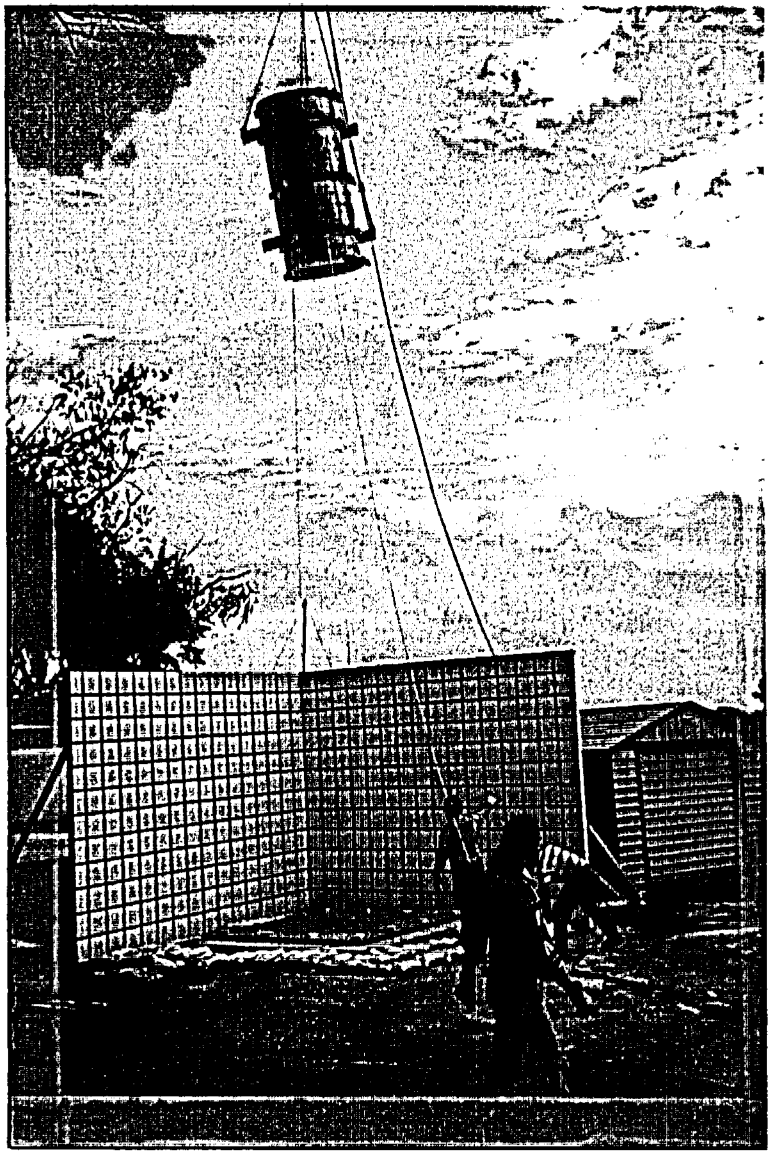


Photo 2.10.6-3
High Chloride NCI-21PF-1 with Valve Protection Device
Damage following 13.5°, 30 Foot Free Drop

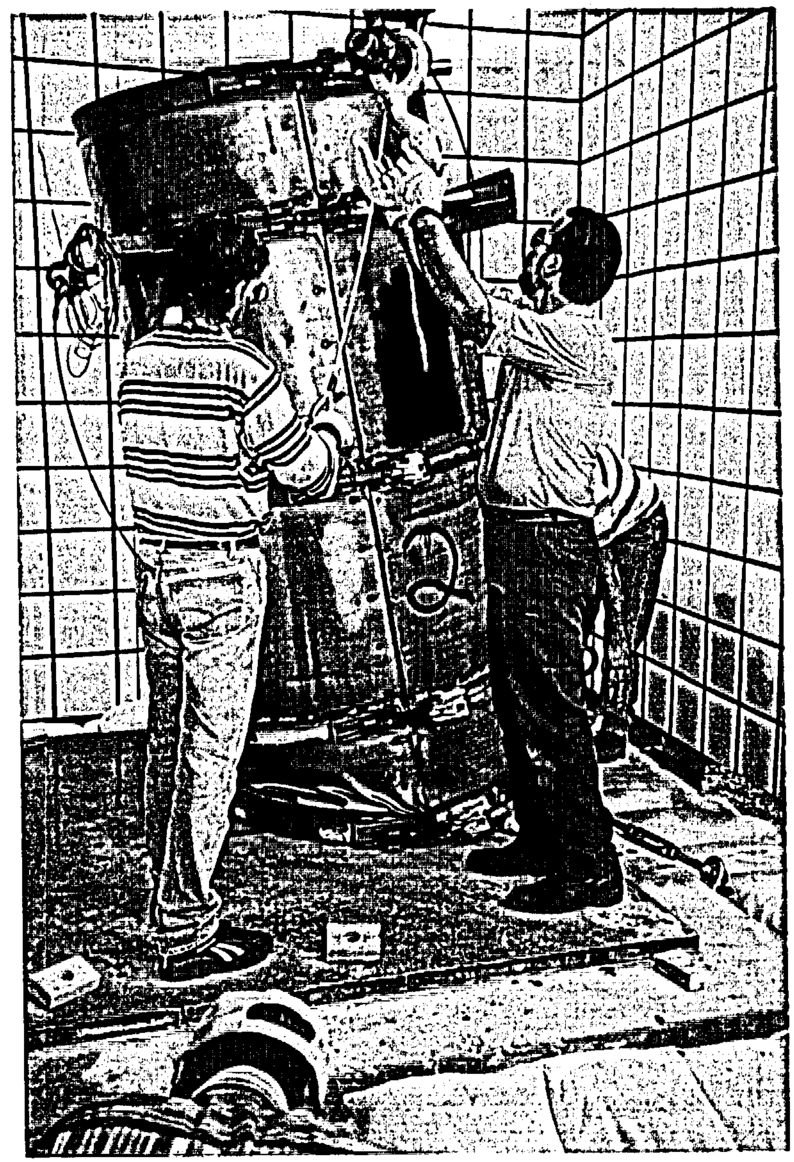


Photo 2.10.6-4
High Chloride NCI-21PF-1 with Valve Protection Device
Preparing for the 13.5°, 40 inch Puncture

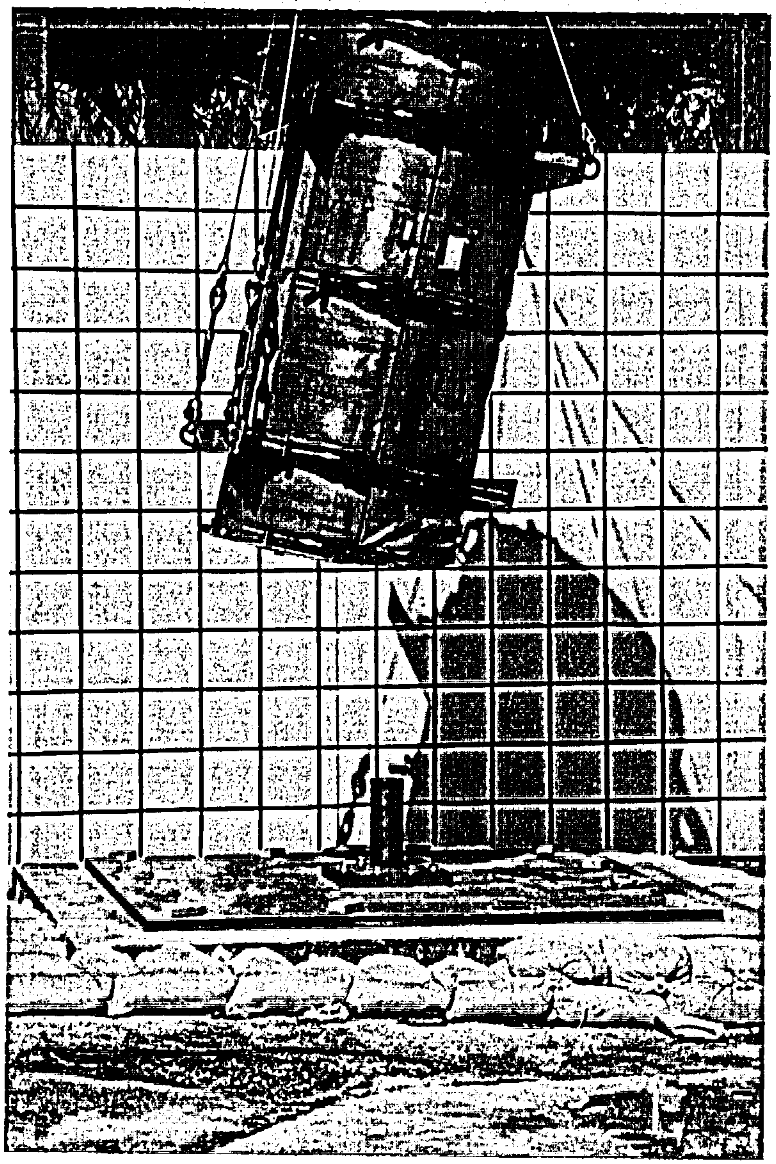


Photo 2.10.6-5
High Chloride NCI-21PF-1 with Valve Protection Device
Damage following 13.5°, 40 inch Puncture

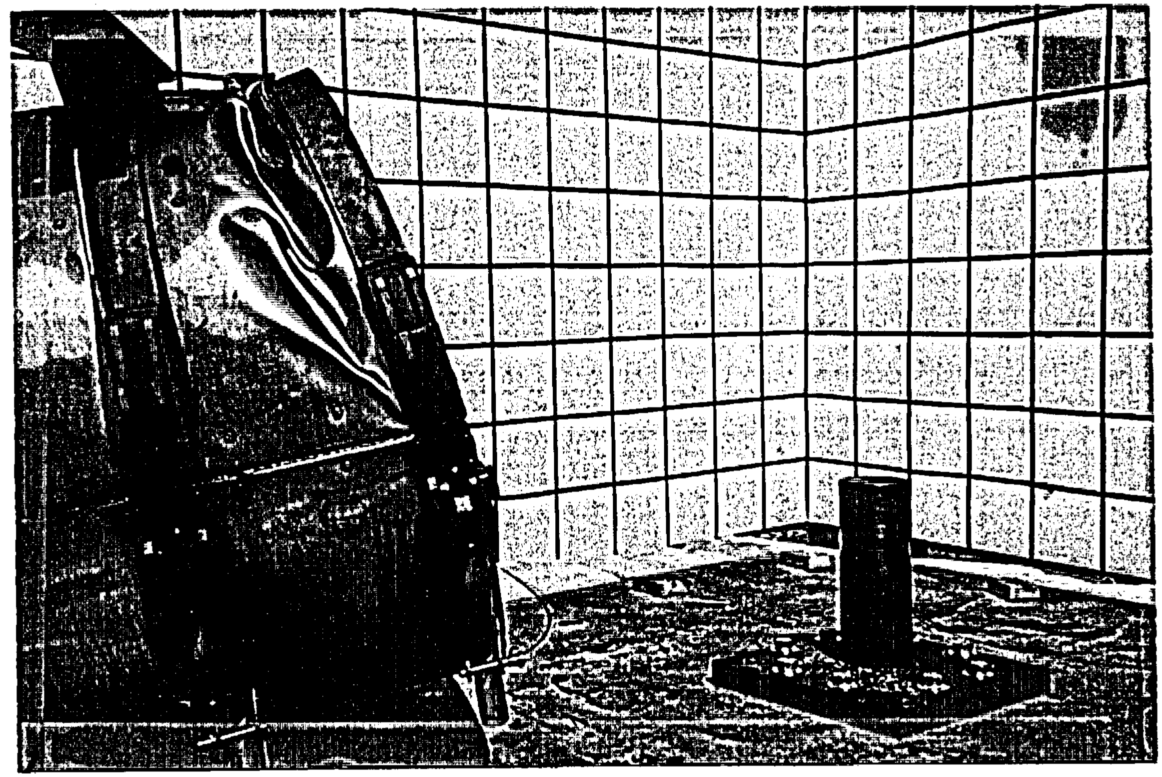
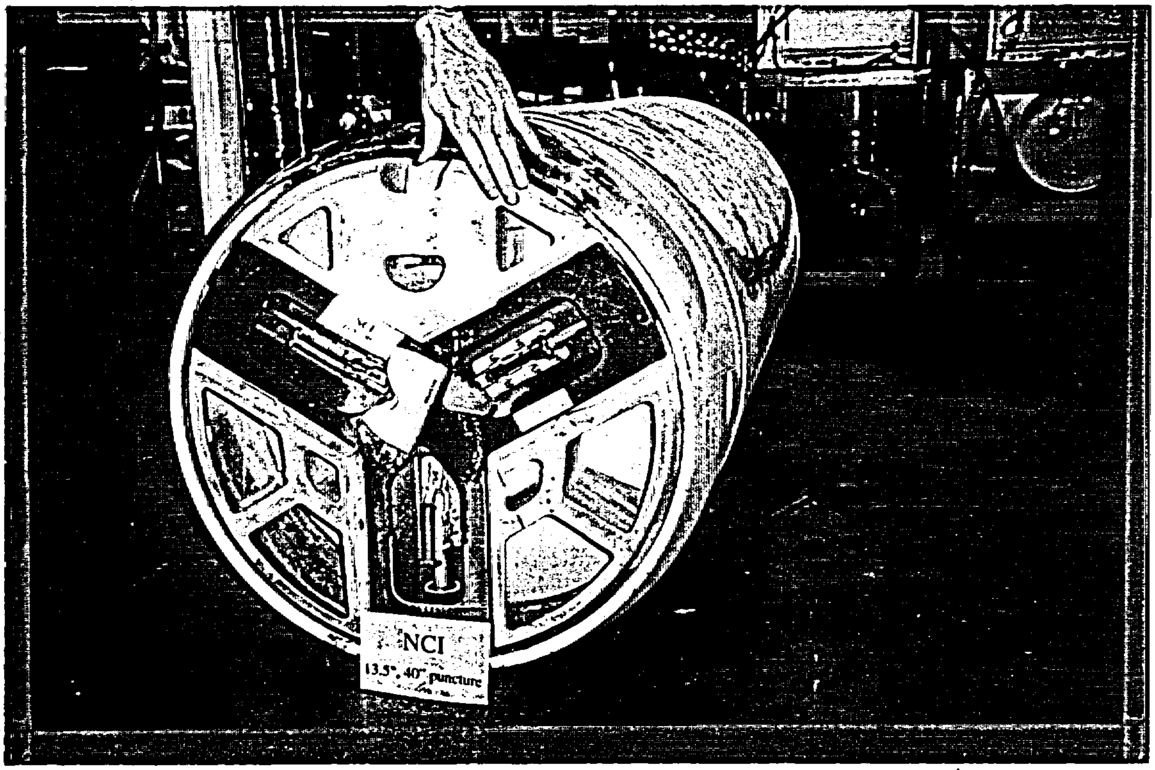


Photo 2.10.6-6
High Chloride NCI-21PF-1 with Valve Protection Device
Valve Protection Device Condition following 13.5° Drop Sequence



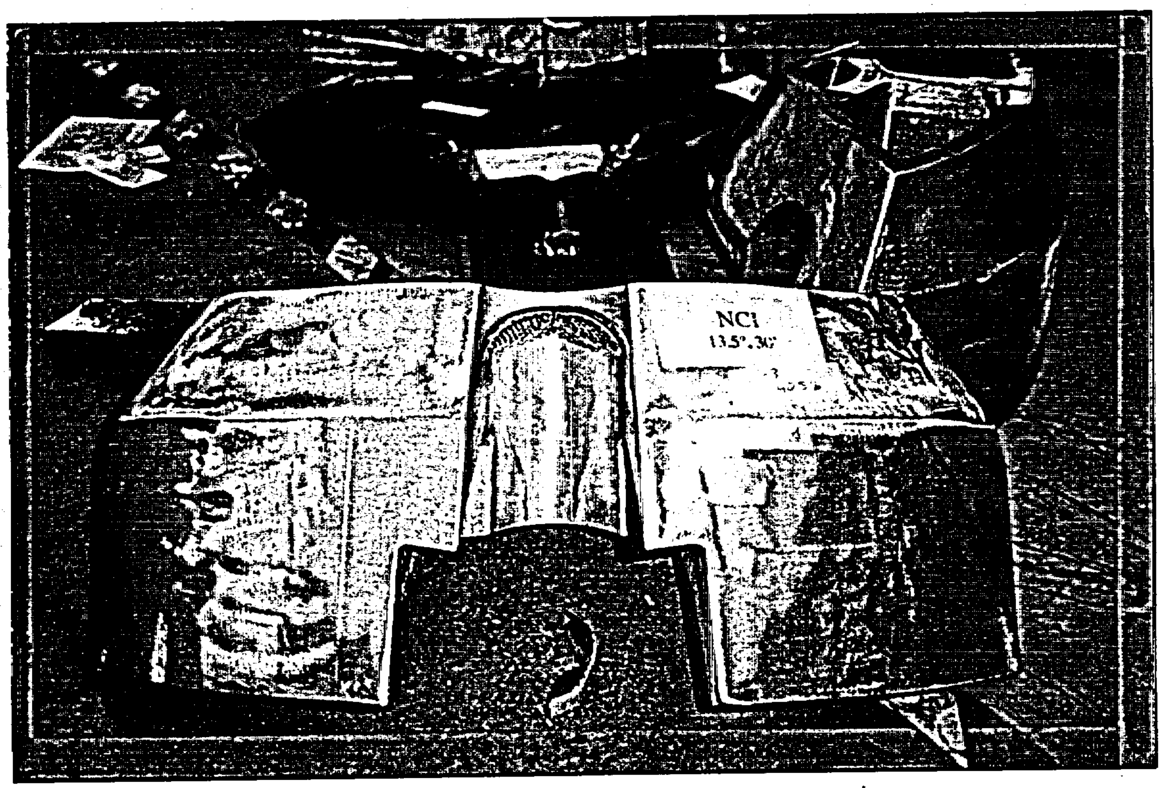


Photo 2.10.6-7
High Chloride NCI-21PF-1 with Valve Protection Device
Preparing for the 30°, 30 foot Free Drop

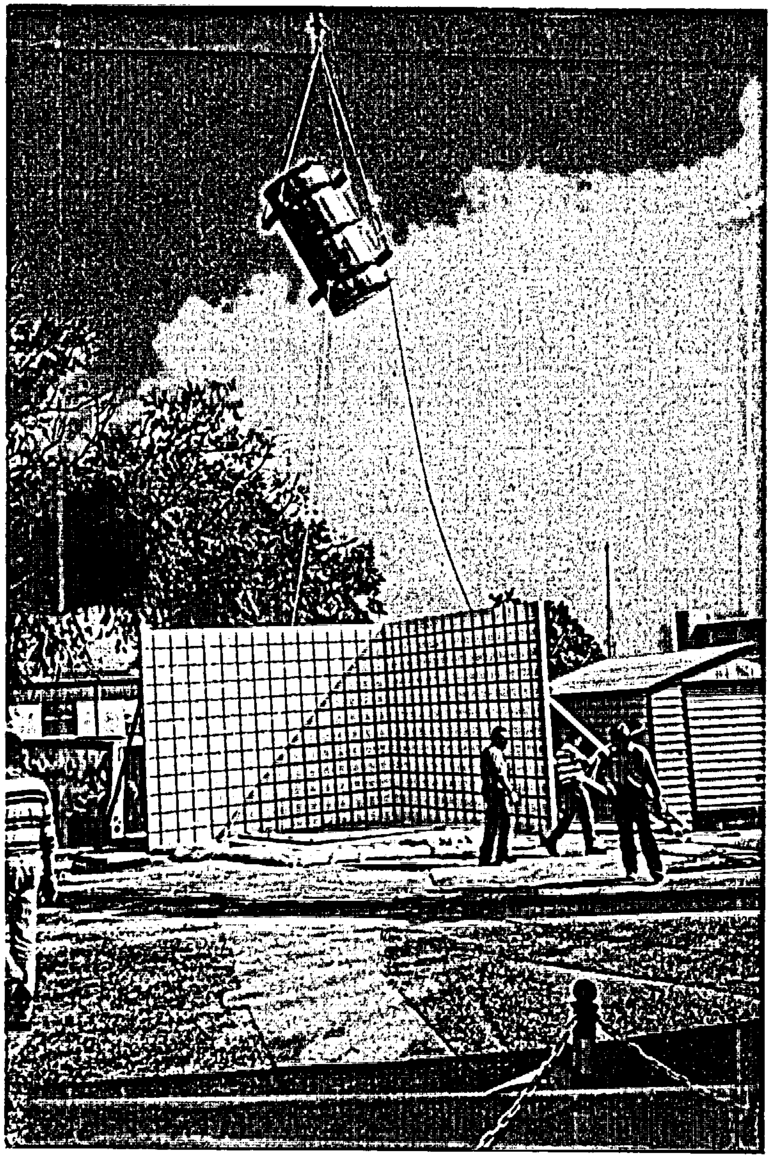


Photo 2.10.6-8
High Chloride NCI-21PF-1 with Valve Protection Device
Damage following 30°, 30 Foot Free Drop

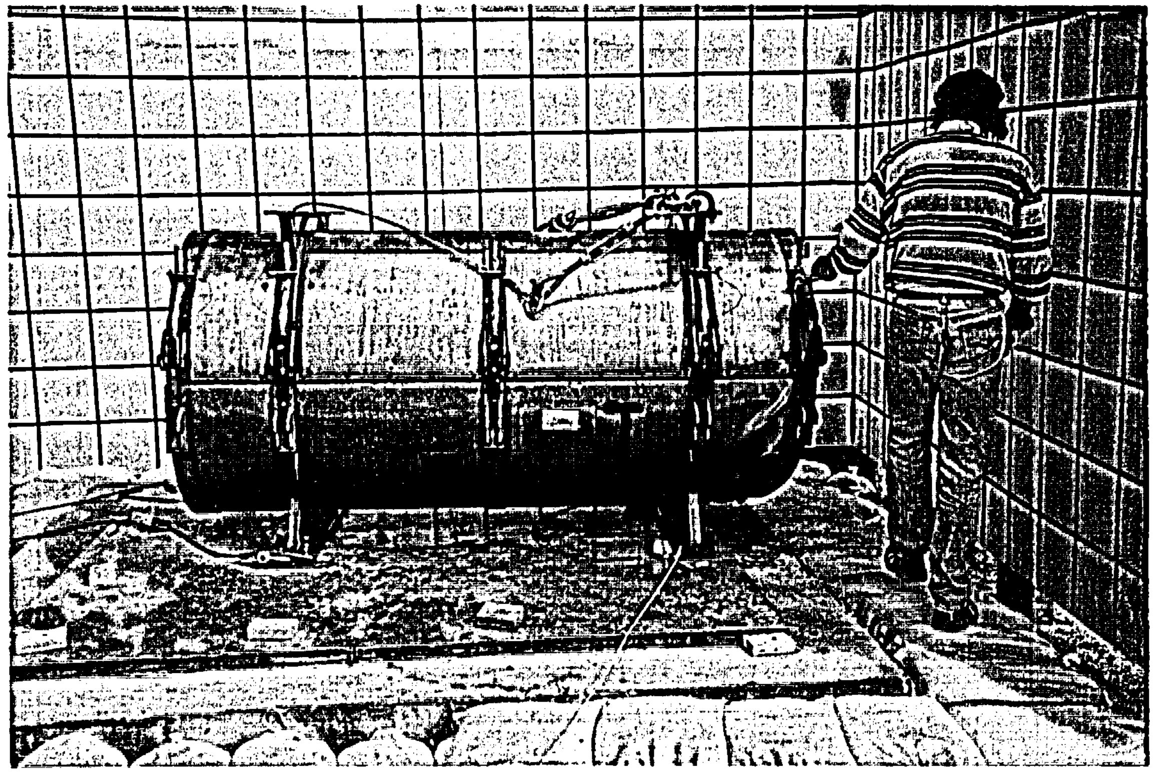


Photo 2.10.6-9
High Chloride NCI-21PF-1 with Valve Protection Device
Preparing for the 30°, 40 inch Puncture

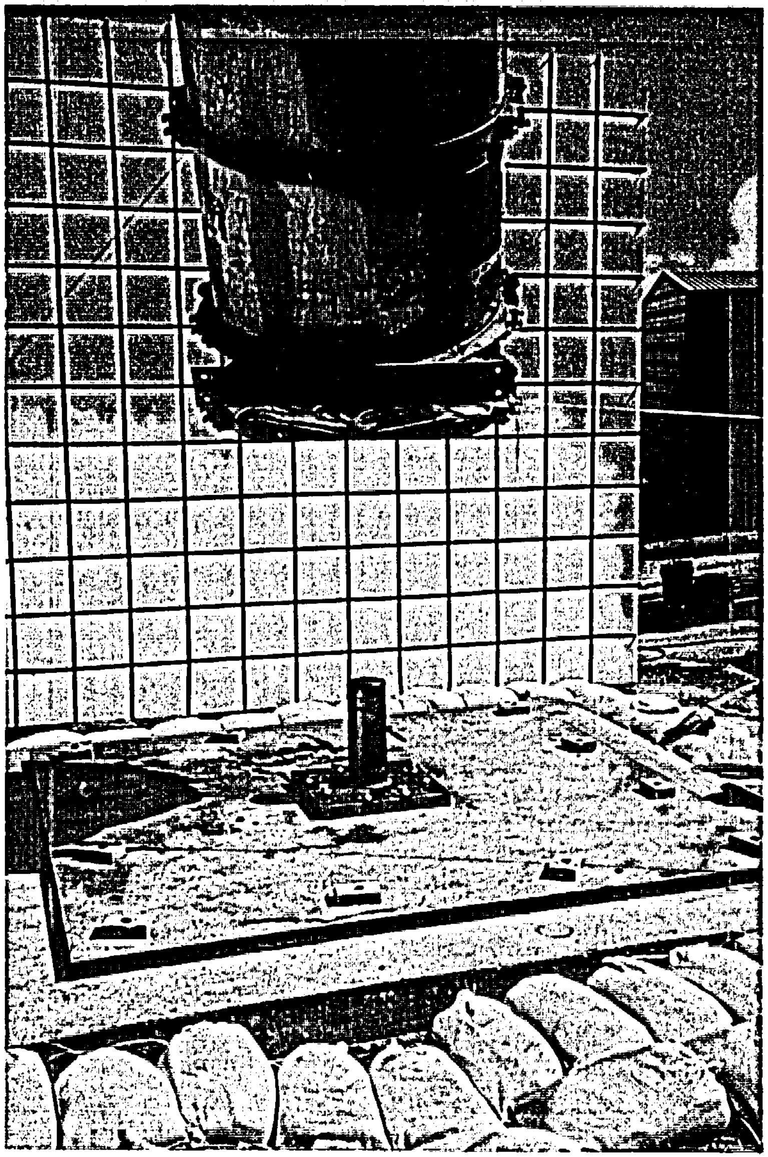


Photo 2.10.6-10
High Chloride NCI-21PF-1 with Valve Protection Device
Damage following 30°, 40 inch Puncture

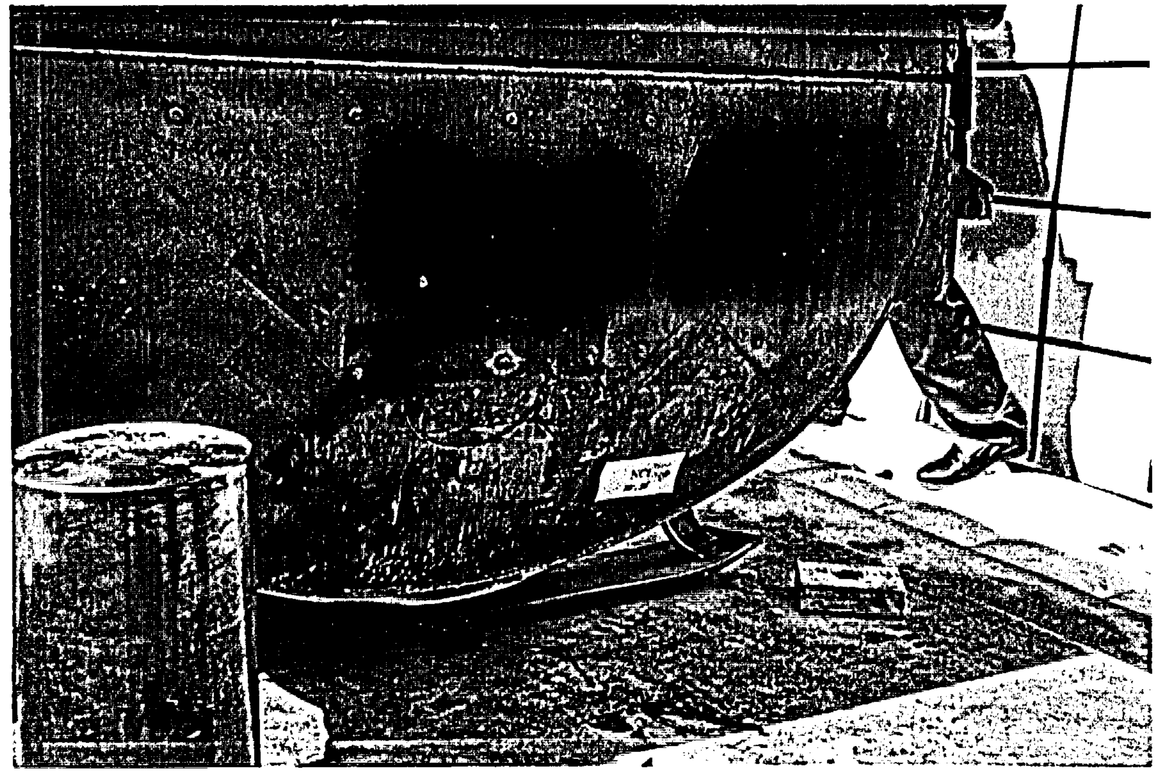
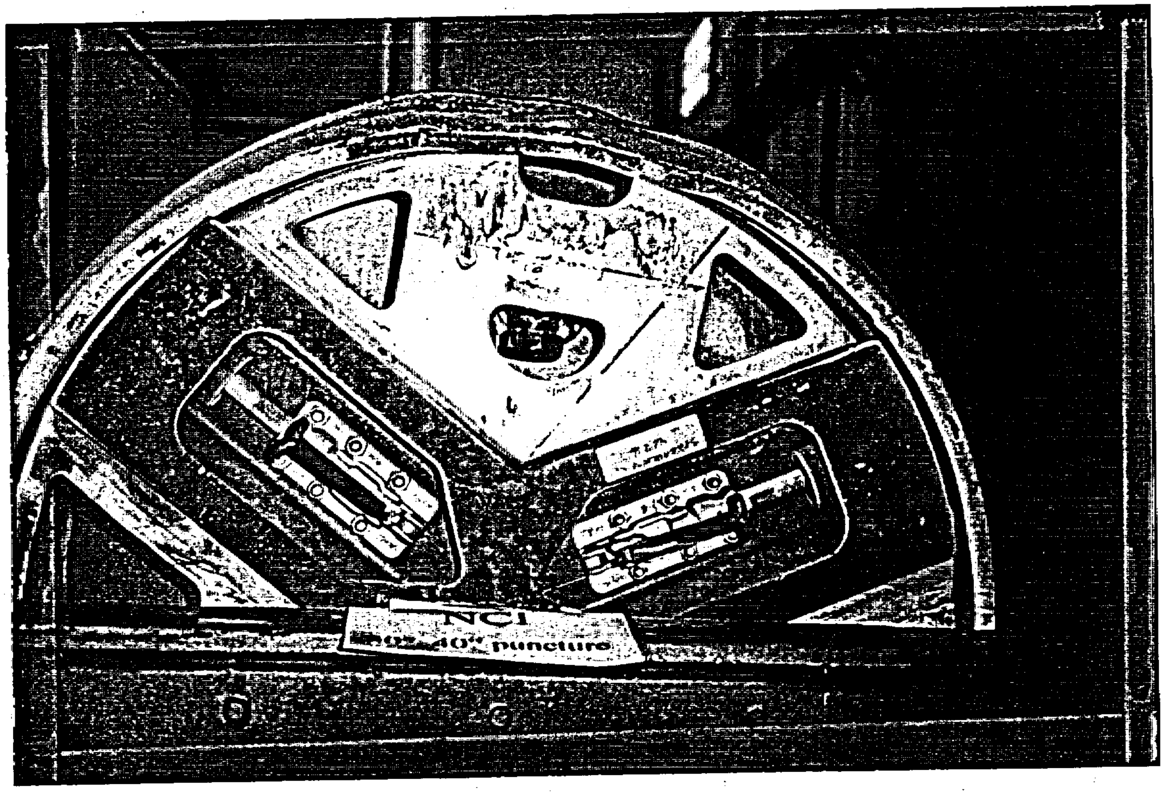
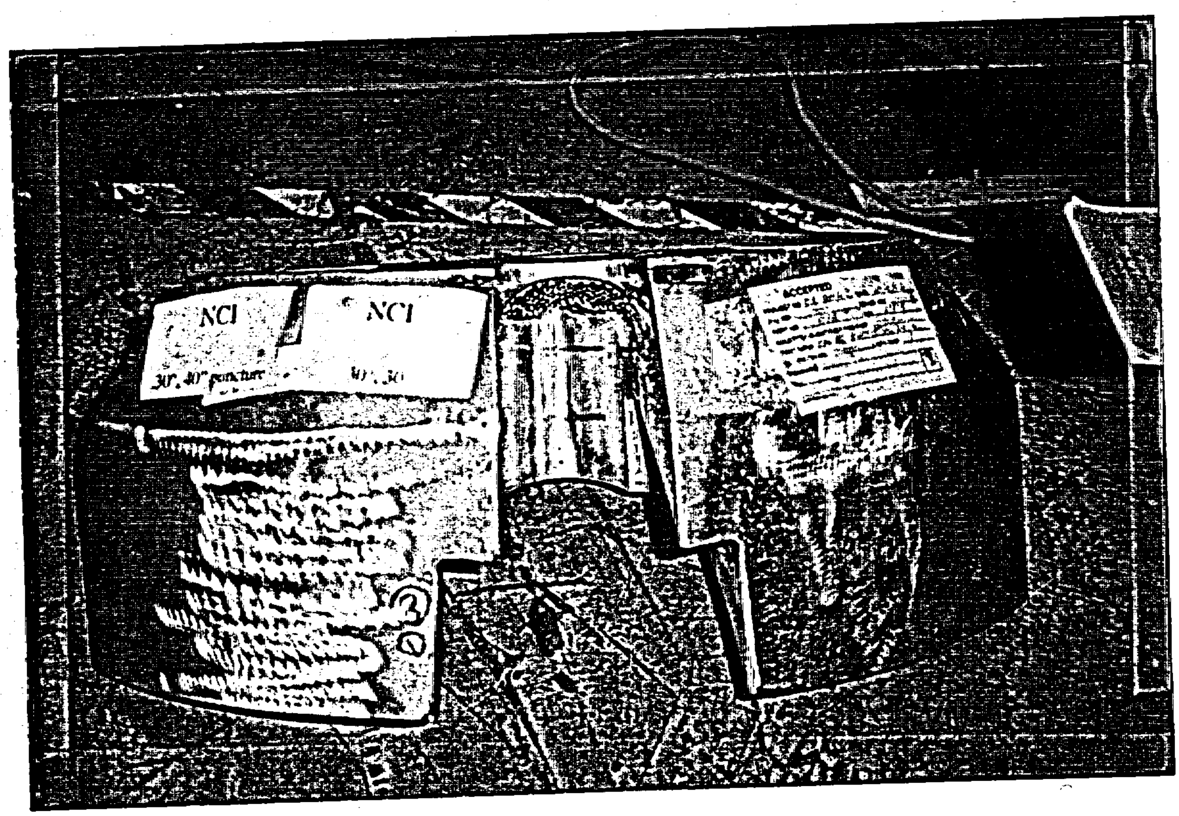


Photo 2.10.6-11
High Chloride NCI-21PF-1 with Valve Protection Device
Valve Protection Device Condition following 30° Drop Sequence





CHAPTER THREE
THERMAL EVALUATION

TABLE OF CONTENTS

3.1 DISCUSSION 3-1
- 3.1.1 Thermal Source Specification 3-1
- 3.1.2 Thermal Acceptance Criteria 3-1

3.2 SUMMARY OF THERMAL PROPERTIES OF MATERIALS 3-4

3.3 TECHNICAL SPECIFICATION OF COMPONENTS 3-5

3.4 THERMAL EVALUATION FOR NORMAL CONDITIONS OF TRANSPORT 3-5
- 3.4.1 Conditions Evaluated 3-5
- 3.4.2 Acceptance Criteria for Normal Conditions of Transport 3-5
- 3.4.3 Thermal Model 3-6
- 3.4.4 Maximum Temperatures 3-8
- 3.4.5 Minimum Temperatures 3-8
- 3.4.6 Maximum Pressure 3-8

3.5. THERMAL EVALUATION FOR HYPOTHETICAL ACCIDENT CONDITIONS 3-8
- 3.5.1 Conditions Evaluated 3-8
- 3.5.2 Acceptance Criteria for Hypothetical Accident Conditions 3-9
- 3.5.3 Thermal Model 3-9
- 3.5.4 Package Conditions and Environment 3-9
- 3.5.5 Package Temperatures 3-10
- 3.5.6 Analysis of Test Data 3-10
- 3.5.7 Minimum 30B Cylinder Load 3-15
- 3.5.8 Maximum Temperatures 3-17
- 3.5.9 Minimum Temperatures 3-17
- 3.5.10 Maximum Pressure 3-17

3.6. THERMAL EVALUATION AND CONCLUSIONS 3-17

3.7 REFERENCES 3-18

LIST OF FIGURES

3.5-1 Measured Fire Temperature - Time History 3-11
3.5-2 Measured Cylinder Temperature - Time History 3-12
3.5-3 Energy Absorbed between 100°F and 250°F 3-13
3.5-4 Cylinder Temperature - Time History 3-16

CHAPTER THREE
THERMAL EVALUATION

3.1 DISCUSSION

The NCI-21PF-1 overpack with valve protection device is designed to maintain the temperatures and pressures of the 30B cylinder within specified limits during normal transportation and hypothetical accident conditions. An evaluation of the thermal performance of the packaging is presented in this chapter. Objectives of the thermal tests and analyses performed for this evaluation include:

- Determination of the package's thermal limits;

- Determination of the maximum and minimum temperatures of the uranium hexafluoride within a loaded 30B cylinder;

- Determination of the maximum and minimum pressures of the uranium hexafluoride within a loaded 30B cylinder;

- Determination of the minimum load of uranium hexafluoride the 30B cylinder can carry such that its maximum temperatures and pressures remain below the thermal acceptance criteria listed below.

3.1.1 Thermal Source Specification

The decay heat generated by 5020 lb. of uranium hexafluoride (enriched 5% or less) is less than 3W. It is considered insignificant in the thermal evaluation of the overpack. The heat dissipation from the thermal source is therefore neglected.

3.1.2 Thermal Acceptance Criteria

The thermal design criteria are associated with maintaining containment of the 30B cylinder during normal conditions of transport and the hypothetical accident conditions. In general, the thermal design criteria are limits on the temperature of the uranium hexafluoride within the 30B cylinder. The function of the overpack is to limit the temperature excursions of the contents of the 30B cylinder to the range specified below.

3.1.2.1 Minimum Temperature Limit

The 30B cylinder is manufactured in accordance with ANSI N14.1 (Reference 3.7.1). ANSI N14.1 lists the design temperature range for the 30B cylinder as -20 °F to 250 °F, with a minimum transport temperature of -40 °F (6.10.1 Design Conditions). All 30B Cylinders are fabricated in accordance with Section VIII, Division 1, of the ANSI/ASME Code, are ASME

Code stamped, and certified in writing by the manufacturer to comply with ANSI N14.1. Therefore, the minimum temperature limit for the 30B cylinder is -40 °F.

3.1.2.2 Maximum Pressure Limit

Section 6.10.4 (Testing) of ANSI N14.1 states that the cylinder shall be hydrostatically tested to 400 psig. Following the cleaning operation and valve installation, an air test at 100 psig shall be carried out, and all connections and fittings (including the valve seat and packing) shall be leak tested using Carbona soapless lather or an approved equivalent. No leakage shall be permitted. When the cylinder is purchased without valves, this test shall be carried out by the purchaser. Therefore, the maximum pressure limit is conservatively taken to be 100 psig ≈ 115 psia.

The 30B cylinder is filled (up to the maximum amount allowed by ANSI N14.1) with uranium hexafluoride. Tight controls are followed to ensure that the cylinder contains only uranium hexafluoride. The vapor pressure of uranium hexafluoride at 250 °F is 100 psia (Ref. 3.7.2, Figure 3, UF_6 Phase Diagram). Thus, the maximum pressure limit of 115 psia is approximately equivalent to a temperature limit of 250 °F.

3.1.2.3 Maximum Temperature Limit

The maximum temperature limit for the uranium hexafluoride is based on preventing hydraulic rupture of the 30B cylinder due to the volumetric increase of the uranium hexafluoride at elevated temperatures. In order to establish this limit, some background information on the manner in which the fill limit for the 30B cylinder was determined is presented below.

All cylinder volumes are verified by measuring the weight of water at 60 °F which fills the cylinder. The water weight is required to be accurate to ±0.1% (Ref. 3.7.1, Section 6.10.9 Certification). This weight, when divided by the density of water at 60 °F (62.37 lb/ ft^3) determines the actual volume of the cylinder in cubic feet. It shall not be less than the minimum of 26 ft^3, (Ref. 3.7.1, Section 6.10). This ensures that every 30B cylinder has more capacity than the minimum, so that fill calculations based on the certified minimum are conservative. Reference 3.7.3, Maximum Cylinder Fill Limit Evaluation, contains additional background information.

Uranium hexafluoride is unusual in that it exhibits a significant expansion when undergoing the phase change from solid to liquid. Its coefficient of expansion in the liquid phase is also unusually high. The expansion factor from a solid at 68 °F to a liquid at 250 °F is approximately 1.56, a 56 % increase in volume (Reference 3.7.2).

The safe fill limit is determined such that the volume of uranium hexafluoride at 250 °F, plus a 5% allowance for ullage, is less than the certified minimum volume of the 30B cylinder.

(Ullage is defined as the gas volume above a liquid in a container.) The safe fill limit is calculated as follows:

Density of uranium hexafluoride at 250 °F:	203.3 lb/ ft^3 (Ref. 3.7.2)
Certified Minimum 30B cylinder volume:	26 ft^3 (Ref. 3.7.1)
Allowance for ullage:	5 %
Usable volume:	0.95 x 26 ft^3 = 24.7 ft^3
Safe fill limit:	203.3 lb/ ft^3 x 24.7 ft^3 = 5022 lb.

The weight is rounded down to a published value of 5020 lb. (Ref. 3.7.2, Appendix. UF_6 Cylinder Data Summary).

Based on the design temperature range of the 30B cylinder of -20 °F to 250 °F (Ref. 3.7.1, Section 6.10.1 Design Conditions), and the safe fill limit of the cylinder, the maximum temperature criteria for the 30B cylinder under hypothetical accident conditions is 250 °F. Note that this temperature limit is the same as that derived in Section 3.1.2.2.

These maximum pressure and temperature criteria have several significant conservative assumptions built in. The largest source of conservatism is the assumption that the 30B cylinder will rupture hydraulically at 250 °F, when the volume of the UF_6 is equal to 95% of the volume of the cylinder. In fact, hydraulic rupture will be delayed until the pressure of the uranium hexafluoride reaches the rupture pressure of the cylinder at temperature. In Ref. 3.7.3, Investigation of UF_6 Behavior in a Fire, pg. 17-24, the authors concluded that the 30B cylinder would fail at an internal pressure of 800 psia and a final UF_6 temperature of 367 °F.

Uranium hexafluoride cylinders are liquefied at up to 225 °F at USEC facilities, and other UF_6 facilities routinely approach 235 °F to attain required flow rates during cylinder unloading (Ref. 3.7.3, Maximum Cylinder Fill Limit Evaluation, p. 116). Therefore, the maximum temperature criteria under hypothetical accident conditions is only 15 °F greater than the temperature the cylinders routinely reach during unloading.

3.1.2.4 Thermal Acceptance Criteria Summary

Minimum Temperature Limit:	-40 °F
Maximum Pressure Limit:	115 psia
Maximum Temperature Limit:	250 °F

3.2 SUMMARY OF THERMAL PROPERTIES OF MATERIALS

The thermal properties of materials used in the thermal analyses are listed below. The values are listed as given in the corresponding references.

a. Uranium hexafluoride (Ref. 3.7.2 and Ref. 3.7.3, p. 3)
Used for: contents of 30B cylinder under normal transport and hypothetical accident conditions calculations.

Temperature (°F)	Phase	Specific Heat Btu/lbm-°F	Heat of Fusion Btu/lbm
<147	solid	0.114	
147	melting		23.5
>147	liquid	0.130	

b. Steel Shot - Plain carbon steel (Ref. 3.7.4, Table TDC, p. 650 and Table NF-2, p. 670)
Used for: contents of 30B cylinder during fire test evaluation.

Temperature (°F)	Specific Heat Btu/lbm-°F
70	0.105
100	0.107
150	0.110
200	0.114
250	0.117
300	0.119

c. Phenolic Foam (Appendix 2.10.2)
Used for: foam in overpack during normal conditions of transport calculations.

Reported Conductivity: 0.021 Btu/hr-ft-°F < k < 0.025 Btu/hr-ft-°F.
Analysis used: k = 0.10 Btu/hr-ft-°F.

d. White Oak Wood (Ref. 3.7.5)
Used for: wood in overpack during normal conditions of transport calculations.

Reported Conductivity: k = 0.05 Btu/hr-ft-°F.
Analysis used: k = 0.10 Btu/hr-ft-°F.

e. Overpack Surface (Ref. 3.7.6, Table 5-2, Emittance of Various Surfaces)
Used for: solar absorptivity and emissivity of typical weathered surfaces during normal conditions of transport calculation.

Analysis used: emissivity = absorptivity = 0.85

3.3 TECHNICAL SPECIFICATIONS OF COMPONENTS

There are no additional thermal technical specifications for any of the overpack components.

3.4 THERMAL EVALUATION FOR NORMAL CONDITIONS OF TRANSPORT

3.4.1 Conditions Evaluated

Section 71.71 of 10 CFR Part 71 defines the normal conditions of transport. Three different conditions are evaluated. The relevant thermal conditions from §71.71(c) are listed below:

(1) *Heat.* An ambient temperature of 38 °C (100 °F) in still air, and insolation according to the following table:

INSOLATION DATA

Form and location of surface	Total insolation for a 12-hour period (g cal/cm^2)
Flat surfaces transported horizontally: Base	None
Flat surfaces transported horizontally: Other surfaces	800
Flat surfaces not transported horizontally	200
Curved surfaces	400

(2) *Cold.* An ambient temperature of -40 °C (-40 °F) in still air and shade.

The relevant thermal conditions from §71.43(g) are listed below:

(3) A package must be designed and constructed, and prepared for transport so that in still air at 38 °C (100 °F) and in the shade, no accessible surface of a package would have a temperature exceeding 50 °C (122 °F) in a nonexclusive use shipment, or 85 °C (185 °F) in an exclusive use shipment.

3.4.2 Acceptance Criteria for Normal Conditions of Transport

In general, the thermal design criteria are limits on the temperature of the uranium hexafluoride within the 30B cylinder. The overpack must not degrade substantially during normal transport conditions so as to prevent it from protecting the cylinder in the event of a thermal accident.

The materials of construction of the overpack (essentially stainless steel, wood, and phenolic foam) are not particularly temperature sensitive. The overpack materials do not degrade at temperatures within the range of -40 °F to 185 °F. The overpack is not air-tight, and is therefore not effected by changes in pressure.

Therefore, the acceptance criteria for the entire packaging under normal conditions of transport are as given below:

	30B Cylinder / UF_6	Overpack
Minimum Temperature Limit	-40 °F	-40 °F
Maximum Pressure Limit	115 psia	not applicable
Maximum Temperature Limit	250 °F	185 °F

3.4.3 Thermal Model

3.4.3.1 Analytical Model

The maximum and minimum temperatures of the package were determined with hand calculations. The calculations assumed that the overpack and 30B cylinder and could be conservatively modeled as an infinitely long cylinder lying horizontally.

(1) *Heat.* The calculations assumed zero decay heat load and a solar insolation load of 400 cal/12-hr-cm^2, or 122.9 Btu/hr-ft^2 for twelve hours, followed by zero solar heat load for 12 hours, repeated indefinitely, on the surface of the infinitely long cylinder. The solar absorptivity of the surface of the cylinder is conservatively estimated as 0.85. Ambient temperature is assumed to remain constant at 100 °F. The solar heat load is calculated as:

$$q_{solar} = 122.9 \text{ Btu/hr-ft}^2 \times 0.85 = 104 \text{ Btu/hr-ft}^2 \quad \text{for twelve hours, and}$$
$$q_{solar} = 0 \quad \text{for twelve hours}$$

Heat is passively rejected to the environment through a combination of natural convection and radiation. The emissivity of the surface of the cylinder is taken to be 0.85.

$$h_{total} = h_{conv} + h_{rad}$$

$$h_{conv} = 0.18 \, (T_s - T_{amb})^{1/3} \qquad \text{(Ref. 3.7.6, Eqn. 7-26)}$$

$$q_{rad} = \sigma_b \, e \, [\, T_s^4 - T_{amb}^4 \,] \qquad \text{(with T in °R)}$$

The total energy into the overpack surface must equal the total energy out at steady-state. In the case of constant insolation, this reduces to:

$$q_{solar} = h_{conv} \Delta T + q_{rad}$$

The solution of this equation is T_s = 156 °F when the insolation is equal to 104 Btu/hr-ft^2. The solution to this equation is T_s = 100 °F when the insolation is equal to zero. The average surface temperature is therefore (100+156)/2 = 128 °F, and the peak surface temperature is 156 °F.

Due to the low conductivity of the foam and wood, and the extremely large thermal inertia of uranium hexafluoride, it can be shown that the thermal response of the uranium hexafluoride is so slow that it never exceeds the average surface temperature by more than 8 °F. Thus, the peak uranium hexafluoride temperature is 136 °F. This is shown below:

At quasi-steady state, the maximum difference in temperature between the overpack outer shell and the uranium hexafluoride is 156 °F - 128 °F = 28 °F.

If this gradient were constantly maintained, the heat flow to the UF_6 would be:

$$q = [\ 2\pi\ k\ L\ /\ \ln(\ r_o/r_i\ )\ ]\ \Delta T \qquad \text{(Ref. 3.7.6, Eqn. 2-6)}$$

The solution of this equation, assuming that r_o = 21", r_i = 15", L = 90", and k = 0.10 Btu/hr-ft-°F = 0.00833 Btu/hr-in-°F, is:

$$q = 400 \text{ Btu/hr}$$

The rate at which the temperature of the uranium hexafluoride is changing is given by:

$$dT_{UF6}/dt = q/mc_p = 400 \text{ Btu/hr} / (5020 \text{ lb} \times 0.114 \text{ Btu/lb-°F}) = 0.7 \text{ °F/hr}$$

This temperature rise can occur for a maximum of 12 hours. The maximum deviation from the average temperature that the UF_6 will experience is equal to 12hr x 0.7 °F/hr = 8.4 °F. Therefore, the maximum temperature of the uranium hexafluoride is 128 °F + 8 °F = 136 °F.

(2) *Cold.* An ambient temperature of -40 °F with no insolation and no decay heat, results in a package with a uniform temperature of -40 °F.

(3) Section 71.43(g). An ambient temperature of 100 °F with no insolation and no decay heat, results in a package with a uniform temperature of 100 °F.

3.4.3.2 Test Model

The evaluation above, together with the large body of experience the users community has in transporting this package without any degradation of the overpack from temperature excursions, precludes the necessity to perform additional thermal testing.

3.4.4 Maximum Temperatures

The maximum overpack surface temperature is 156 °F. The maximum uranium hexafluoride temperature is 136 °F. These temperature are well below the limits specified in Section 3.4.2.

3.4.5 Minimum Temperatures

The minimum temperature is -40 °F. This is also the minimum acceptable temperature.

3.4.6 Maximum Pressure

The maximum pressure occurs when the uranium hexafluoride reaches its peak temperature of 136 °F. Thus, the maximum pressure of UF_6 is less than 22 psia (Ref. 3.7.2, Figure 3, UF_6 Phase Diagram). This pressure is less than the acceptable pressure of 250 psia.

3.5 THERMAL EVALUATION FOR HYPOTHETICAL ACCIDENT CONDITIONS

3.5.1 Conditions Evaluated

Section 71.73 of 10 CFR Part 71 defines the hypothetical accident conditions. The relevant thermal conditions are taken from §71.73(c) and are listed below:

> (4) *Thermal.* Exposure of the specimen fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent, and in sufficiently quiescent ambient conditions, to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 800 °C (1475 °F) for a period of 30 minutes, or any other thermal test that provides the equivalent total heat input to the package and which provides a time averaged environmental temperature of 800 °C. The fuel source must extend horizontally at least 1 m (40 in), but may not extend more than 3 m (10 ft), beyond any external surface of the specimen, and the specimen must be positioned 1 m (40 in) above the surface of the fuel source. [...] Artificial cooling may not be applied after cessation of external heat input, and any combustion of materials of construction, must be allowed to proceed until it terminates naturally.

Section 71.73 requires that the package be subjected to "Free Drop" and "Puncture" tests prior to the thermal testing. The initial temperature of the packaging is that value between -29 °C (-20°F) and 38 °C (100 °F) which is most unfavorable to the feature under consideration. For this packaging, 100 °F is the most unfavorable starting point for the fire test.

3.5.2 Acceptance Criteria for Hypothetical Accident Conditions

In general, the thermal design criteria are limits on the temperature of the uranium hexafluoride within the 30B cylinder. The function of the overpack is to limit the temperature excursions of the contents of the 30B cylinder to the range specified below. The overpack is not required to survive the thermal accident.

Therefore, the acceptance criteria for the uranium hexafluoride within the 30B cylinder under hypothetical accident conditions are as given below:

	Uranium Hexafluoride
Minimum Temperature Limit	-40 °F
Maximum Pressure Limit	115 psia
Maximum Temperature Limit	250 °F

3.5.3 Thermal Model

3.5.3.1 Analytical Model

The licensing basis for the overpack, with respect to hypothetical thermal accident conditions, is the full scale package testing that was performed. This testing program is described in more detail in Appendix 2.10.5, and in the following section. This test program precludes the need for an analytical model of the packaging during the hypothetical thermal accident conditions.

3.5.3.2 Test Model

The hypothetical accident conditions given above in Section 3.5.1 were investigated by performing the specified tests on the actual packaging, where 5020 lb. of steel shot were substituted for the uranium hexafluoride.

3.5.4 Package Conditions and Environment

The package was damaged as a result of the drop testing. See Appendix 2.10.5 for a complete description of packaging condition prior to and following the thermal test.

The measured ambient temperature during testing was approximately 64 °F. The average wind speed during the first hour of testing was 3.5 mph.

The fire was fully engulfing. The package was spaced 40 inches above the surface of the fuel, and no artificial cooling was applied to the package following the fire. The package rested upon a simple support system that was incapable of shielding the package from the fire or cooling the package in any significant way. In order to obtain a fully engulfing fire, the fuel source extended beyond the package between 2 m and 4 m, which exceeds the 10 CFR

71.73 requirements of 1 m to 3 m, but results in a more severe thermal environment. The duration of the fire was 31 minutes, and the average measured flame temperature was 1681 °F.

In summary, the thermal environment to which the packaging was subjected during the test was more severe than the environment required by 10 CFR Part 71, §73.73. For the purpose of calculations, it is assumed that the thermal environment created during the tests performed was identical to the environment required. This introduces conservatism into the analysis.

The data from the six thermocouples that were used to measure the fire temperature have been averaged and are shown in Figure 3.5-1.

3.5.5 Package Temperatures

Measured temperature data from the twelve thermocouples attached to the 30B cylinder are presented in Appendix 2.10.5. The average temperature-time history is shown in Figure 3.5-2. Note that the maximum average temperature occurs 60 minutes after the fire test began.

The initial starting temperature of the packaging was 97 °F, as opposed to the desired 100 °F. This difference is considered to be insignificant.

The average temperature at discrete times is tabulated below:

Time (min)	0	5	10	15	20	25	30	35	40	45	50	55	60
Temp. (°F)	96.8	100.5	113.5	123.7	131.6	137.0	142.1	147.4	151.0	153.2	154.4	154.7	155.0

3.5.6 Analysis of Test Data

The purpose of this section is to determine the temperature of a uranium hexafluoride filled cylinder from the data collected on the steel shot filled cylinder.

The heat required to bring steel shot and uranium hexafluoride from 100 °F to a given temperature is shown in Figure 3.5-3. This demonstrates the large margin of safety uranium hexafluoride possesses relative to steel shot. The heat of fusion (23.5 Btu/lbm) accounts for approximately one half of the energy the uranium hexafluoride will absorb between 100 °F and 250 °F (42.25 Btu/lbm total).

Using 5020 pounds of steel shot, the average temperature at a particular time can be used to calculate the amount of heat that has been absorbed by the steel shot, and the rate at which heat is being absorbed. Implicit in this calculation are the assumptions that, (i) the average temperature of the steel shot is at all times equivalent to the

Figure 3.5-1
Measured Fire Temperature-Time History

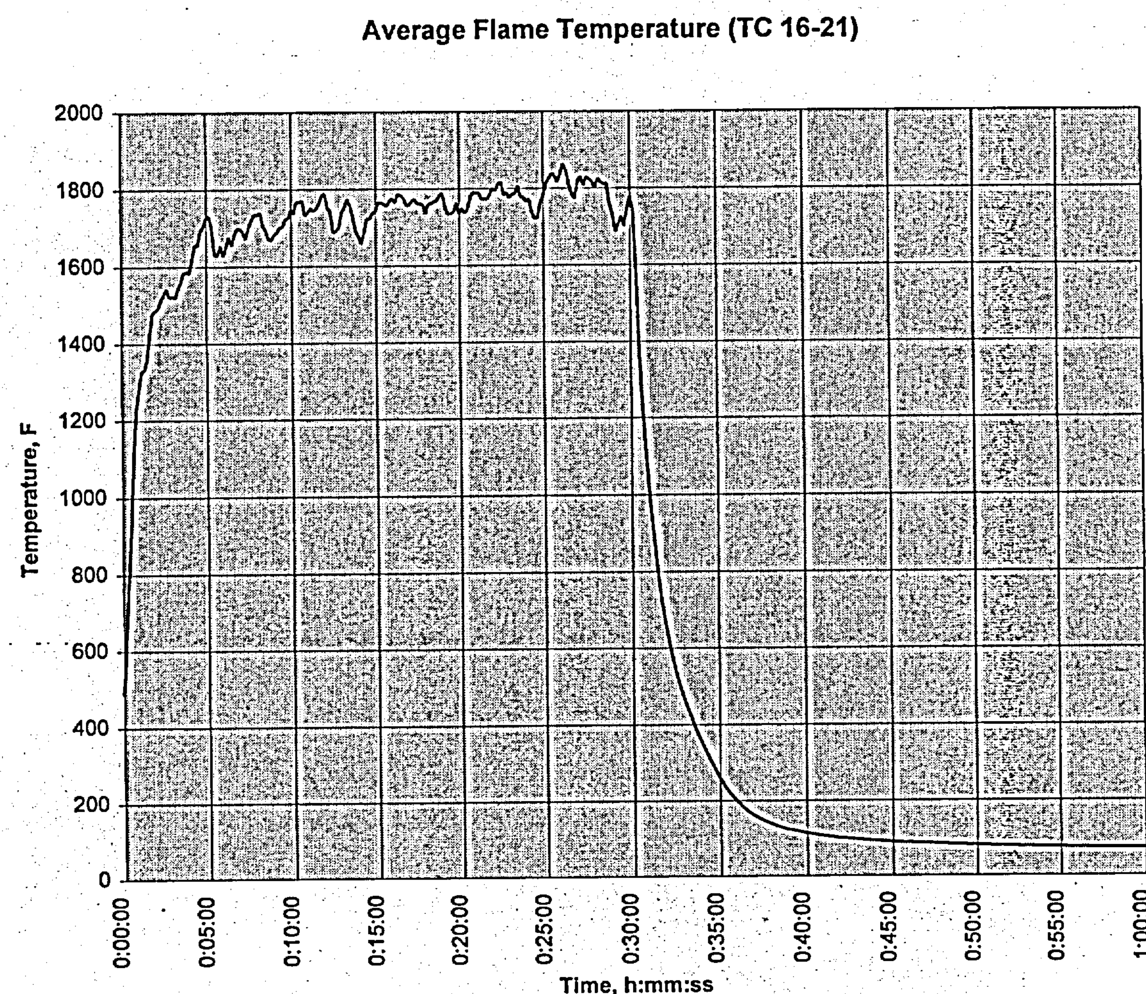


Figure 3.5-2
Measured Cylinder Temperature-Time History

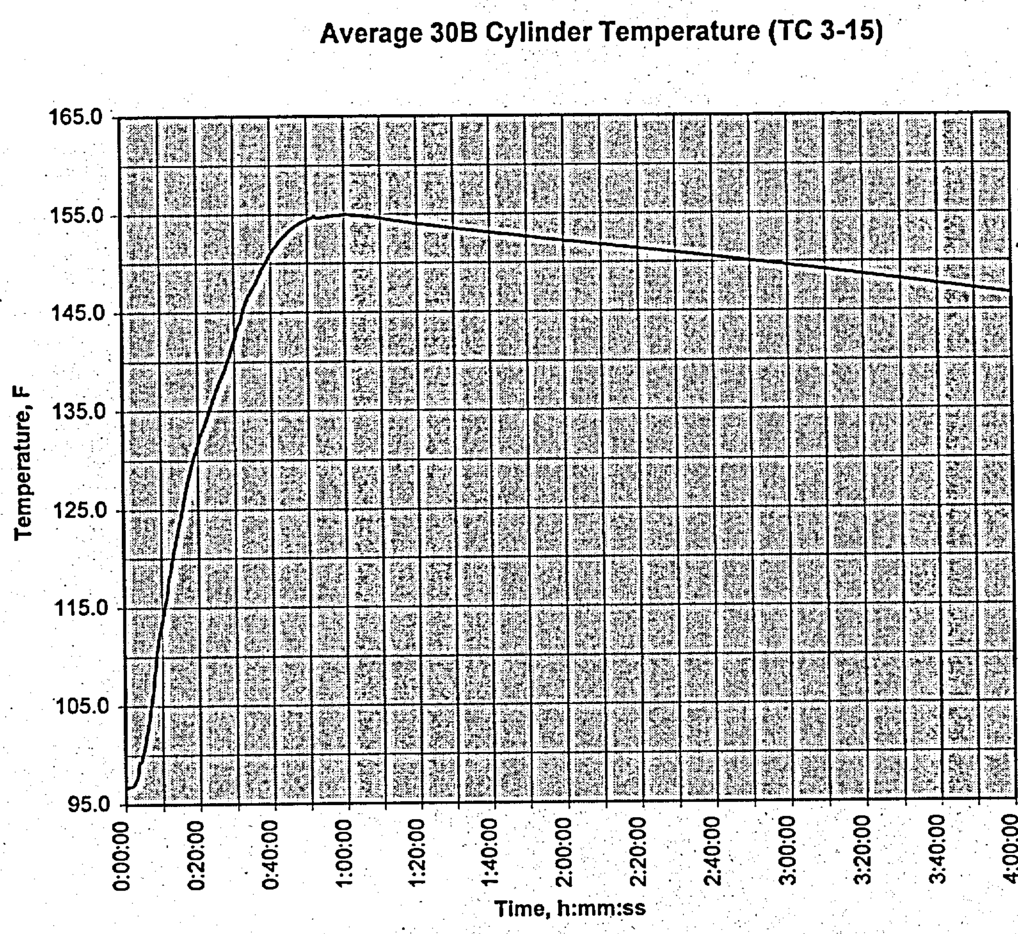
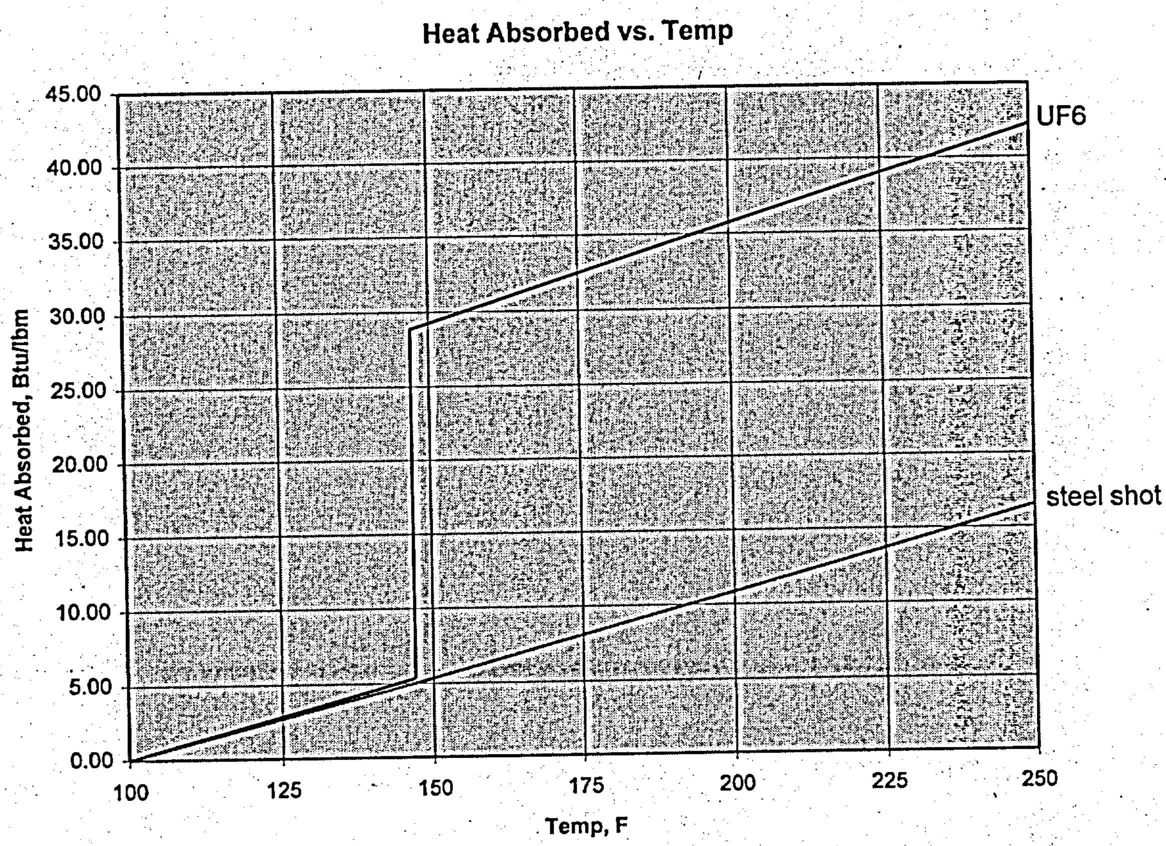


Figure 3.5-3
Energy Absorbed between 100 °F and 250 °F



average temperature of the 30B cylinder wall, and (ii) that the temperatures listed above fairly represent the average temperature of the cylinder. Assumption (ii) is reasonable based upon the physical location of the thermocouples. See Appendix 2.10.5 for additional information.

Assumption (i) is conservative, because there will be a temperature drop between the cylinder wall and the center of the cylinder's contents while the cylinder temperature is increasing. In addition, the top of the cylinder is hotter than the bottom of the cylinder, which is in contact with the steel shot. A more physically reasonable average temperature is the average temperature of that portion of the cylinder that is in contact with the shot. For these reasons, the calculation below conservatively overstates the rate at which heat is entering the steel shot.

Heat In = (heat capacity of steel shot) x (temperature change) x (5,020 lb. steel shot)
Heat Rate = (increment heat) ÷ (duration of increment in hours)

Time (min)	0	5	10	15	20	25	30	35	40	45	50	55	60
Heat In (Btu)	0	1,983	6,820	5,401	4,148	2,834	2,708	2,773	1,910	1,156	673	134	154
Rate (Btu/hr)	0	23,792	81,838	64,809	49,774	34,010	32,502	33,280	22,917	13,867	8,077	1,606	1,849

The total amount of heat the steel shot receives is the sum of the "Heat In" row, or 30,693 Btu.

Uranium hexafluoride melts at 147 °F. A cylinder filled with UF_6 will remain at 147°F until all of the UF_6 melts. The rate at which heat enters the cylinder is proportional to the temperature drop between the cylinder wall and the overpack inner wall. Thus, the UF_6 will absorb heat from the overpack at the same rate as long as it remains at 147 °F, or until the overpack begins to cool significantly.

The steel shot filled cylinder reaches 147 °F between 30 and 35 minutes. Therefore, it is assumed that for the times between 30 and 60 minutes, a UF_6 filled cylinder's temperature will be (approximately) 147 °F, and it will absorb heat at a constant rate. The rate at which heat is absorbed by the UF_6 filled cylinder for times between 30 and 60 minutes is equal to the rate at which the steel shot filled cylinder absorbs heat between 30 and 35 minutes, or 33,280 Btu/hr.

The maximum average measured temperature for the 30B cylinder filled with steel shot is 155.0 °F. The cylinder reaches this temperature 60 minutes after the fire starts (30 minutes after the fire ends). The cylinder loses heat after this point in time. Therefore, this analysis assumes that a cylinder filled with uranium hexafluoride will also begin to lose heat 60 minutes after the beginning of the fire.

The rate at which heat enters the uranium hexafluoride filled cylinder based on the test results for the steel shot filled cylinder is given below.

Time (min)	0	5	10	15	20	25	30	35	40	45	50	55	60
Rate (Btu/hr)	0	23,792	81,838	64,809	49,774	34,010	32,502	33,280	33,280	33,280	33,280	33,280	33,280

The uranium hexafluoride temperatures are:

Time (min)	0	5	10	15	20	25	30	35	40	45	50	55	60
Temp. (°F)	97	100	112	122	129	134	139	143	147	147	147	147	147
Liquid (%)	0	0	0	0	0	0	0	0	0.6	2.9	5.3	7.6	10.0

The maximum UF_6 temperature is 147 °F. The maximum pressure is 22 psia at the triple-point temperature of 147 °F (Ref. 3.7.2, Figure 3, UF_6 Phase Diagram). The temperature-time history for both the steel shot filled and the uranium hexafluoride filled cylinders is shown in Figure 3.5-4.

3.5.7 Minimum 30B Cylinder Load

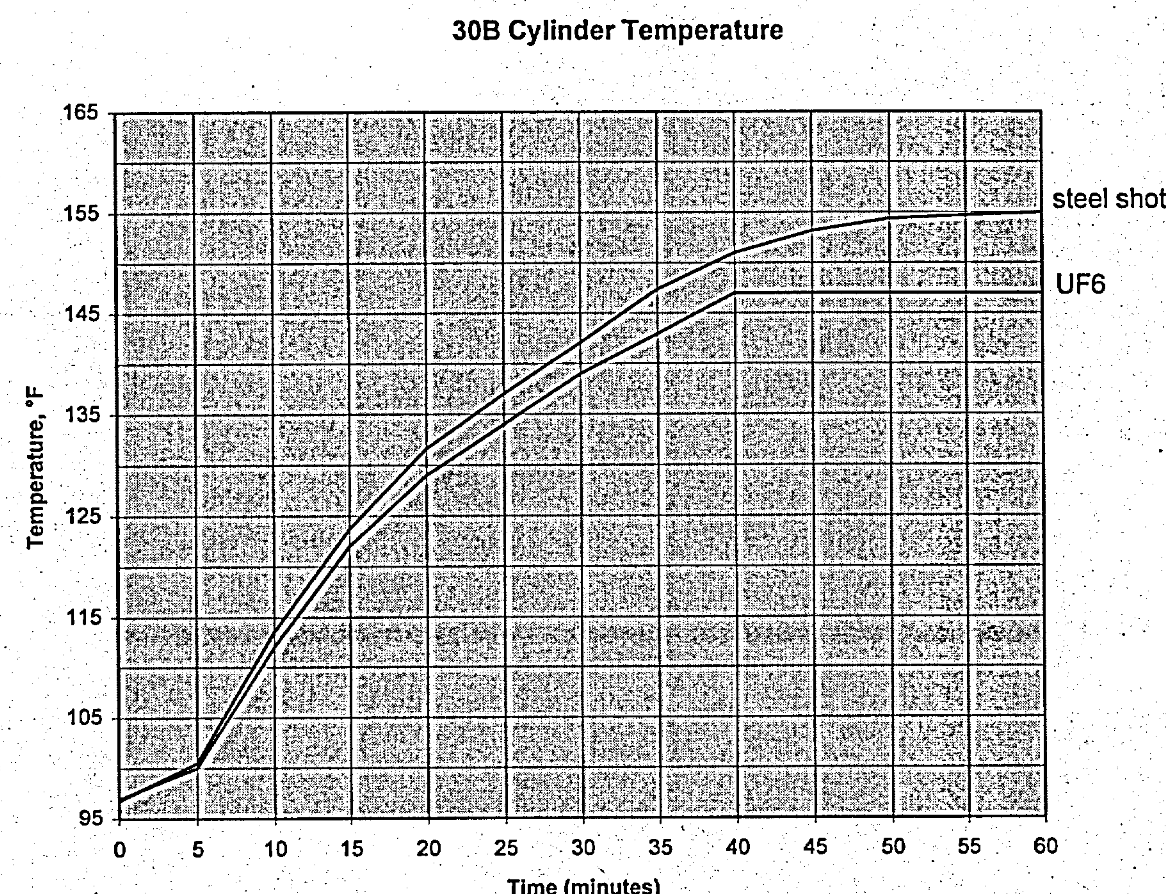
The heat required to bring UF_6 from 100 °F to 250 °F is equal to 42.25 Btu/lbm. A partially loaded cylinder will heat up more quickly than a fully loaded cylinder because it has less thermal mass. As the rate at which heat enters the cylinder is proportional to the temperature drop between the cylinder wall and the overpack inner wall, the cylinder will absorb less total heat because at all times this temperature drop will be less than or equal to the temperature drop in the fully loaded cylinder. However, the analysis will conservatively assume that the partially loaded cylinder absorbs the same amount of heat as the fully loaded cylinder. On this basis, the minimum load of UF_6 can be calculated as follows:

Total Heat In = $M\ c_p\ \Delta T$ + (% melted) M (heat of fusion)
= 5020 lbm x 0.114 Btu/lbm-°F x (147°F - 97°F) + 0.10 x 5020 lbm x 23.5 Btu/lbm
= 40,411 Btu

Minimum Load = (Total Heat In)÷ (Heat for 1 lb. UF_6, 100-250 °F)
= 40,411 Btu ÷ 42.25 Btu/lbm
= 956 lbm

Minimum Load, % = (956 lbm ÷ 5020 lbm) x 100 %
= 19 %

Figure 3.5-4
Cylinder Temperature-Time History



3.5.8 Maximum Temperatures

The maximum temperature of 250 °F occurs 60 minutes after the fire begins when the 30B cylinder contains the minimum load of uranium hexafluoride (956 lb.). This temperature is equal to the maximum acceptable uranium hexafluoride temperature.

3.5.9 Minimum Temperatures

The minimum temperature during hypothetical accident conditions is the initial temperature of the packaging, or 100 °F.

3.5.10 Maximum Pressure

The maximum pressure occurs when the minimum load of uranium hexafluoride reaches 250 °F 60 minutes after the fire begins. This pressure is 100 psia. This is less than the 115 psia pressure limit.

3.6 THERMAL EVALUATION AND CONCLUSIONS

The packaging's performance during normal transport conditions is acceptable. The maximum overpack temperature is 156 °F. The maximum uranium hexafluoride temperature is 136 °F. The minimum temperature is -40 °F. The maximum pressure is less than 22 psia. These results all lie within the acceptable ranges.

Based on analysis of full scale package testing results, only 10 % of the UF_6 in a fully loaded 30B cylinder melts during the hypothetical thermal accident. This is based on an analysis where 40,411 Btu were applied to the UF_6, as opposed to the 30,693 Btu the steel shot absorbed during the test fire, an increase of 32 %. The maximum UF_6 temperature is 147 °F. This is less than the temperature limit of 250 °F. The maximum pressure is 22 psia at the triple-point temperature of 147 °F. This pressure is less than the 115 psia pressure limit. This demonstrates the large safety margin a fully loaded 30B cylinder possesses relative to the hypothetical thermal accident condition.

The minimum load the overpack and 30B cylinder can carry and still meet the thermal limits under hypothetical thermal accident conditions is 956 lb. of UF_6, or 19 % of the 5020 lb. rated load.

3.7 REFERENCES

3.7.1 ANSI N14.1, Uranium Hexafluoride - Packaging for Transport, American National Standards Institute (ANSI).

3.7.2 USEC-651, Uranium Hexafluoride: A Manual of Good Handling Practices, United States Enrichment Corporation (USEC).

3.7.3 Uranium Hexafluoride - Safe Handling, Processing, and Transporting, Conference Proceedings, Oak Ridge, Tennessee, May 24-26, 1988.

3.7.4 1992 ASME B&PV Code, Section II, Part D - Properties, with 1994 Addenda.

3.7.5 Wood Handbook: Wood as an Engineering Material, Forest Products Laboratory, US Department of Agriculture, 1987.

3.7.6 Frank Kreith, Principles of Heat Transfer, 3rd Edition, 1973.

CHAPTER FOUR
CONTAINMENT

TABLE OF CONTENTS

4.1 CONTAINMENT BOUNDARY 4-1
4.1.1 Containment Vessel 4-1
4.1.2 Containment Penetrations 4-1
4.1.3 Seals and Welds 4-1
4.1.4 Closure 4-1

4.2 REQUIREMENTS FOR NORMAL CONDITIONS OF TRANSPORT 4-2
4.2.1 Containment of Radioactive Material 4-2
4.2.2 Pressurization of Containment Vessel 4-2
4.2.3 Containment Criterion 4-2

4.3 CONTAINMENT REQUIREMENTS FOR HYPOTHETICAL ACCIDENT CONDITIONS 4-3
4.3.1 Fission Gas Products 4-3
4.3.2 Containment of Radioactive Material 4-3
4.3.3 Containment Criterion 4-3

4.4 APPENDICES
4.4.1 Calculation of Permissible Leak Rate for Normal Conditions 4.4.1-1
4.4.2 Calculation of Permissible Leak Rate for Accident Conditions 4.4.2-1

CHAPTER FOUR
CONTAINMENT

4.1 CONTAINMENT BOUNDARY

Containment for the NCI-21PF-1 protective shipping package is maintained by the Model 30B cylinder. Appendix 1.3 (from ANSI N14.1) illustrates the 30B Cylinder.

4.1.1 Containment Vessel

The containment boundary for the NCI-21PF-1 Shipping Package is the 30B cylinder. Containment is maintained as long as there is no structural damage to the cylinder or its valve and as long as the cylinder is not over-heated or over-pressurized. ANSI N14.1 lists the following design requirements for the 30B Cylinder:

Design Pressure: 22 psig external
200 psig internal

Design Temperature: -40°F to 250°F

4.1.2 Containment Penetrations

The 30B cylinder has two penetrations: the fill valve in one end and the drain plug in the other end. The plug and valve meet the performance requirements specified in ANSI N14.1.

4.1.3 Seals and Welds

The Model 30B cylinder is fabricated, inspected, tested, and maintained in accordance with United States Enrichment Corporation Report USEC-651 and ANSI N14.1. As required by ANSI N14.1, the cylinder is fabricated in accordance with Section VIII, Division 1, of the ASME Boiler and Pressure Vessel Code.

4.1.4 Closure

The 30B cylinder is closed by means of a threaded plug fitting on one end and on the other end by a special 1" gas valve which is fabricated, inspected, tested, and maintained in accordance with USEC-651 and ANSI N14.1 section 6.15. ANSI N14.1 states that the valve and plug inlet threads will be tinned; 7-12 threads will be engaged on the valve using between 200-400 ft-lb of torque; and 5-8 threads will be engaged on the plug using between 150-600 ft-lb of torque.

4.2 REQUIREMENTS FOR NORMAL CONDITIONS OF TRANSPORT

4.2.1 Containment of Radioactive Material

The only radioactive materials in fresh UF_6 are isotopes of uranium, primarily U235 and U238 which have unlimited A_2 values. Reprocessed UF_6 contains traces of fission products, transuranics, and increased amounts of U234. The allowable leak rate for Type B shipments based upon the content limit of $1150A_2$ / 1540 kg (see section 1.3) is $1.35x10^{-4}$ std cm^3/s. The calculation of this leak rate is provided in Appendix 4.4.1. The test results reported in Chapter 2 verify that the cylinder is leak tight (leak rate less than 10^{-7} std cm^3/s) under normal conditions.

4.2.2 Pressurization of Containment Vessel

During filling of the 30B cylinder with liquid UF_6, the maximum temperature inside the 30B cylinder is 180°F (USEC-651). This temperature would result in an internal UF_6 gas pressure of 60 psia. As stated in USEC-651, UF_6 is cooled and solidified and the internal pressure of a filled 30B cylinder is below atmospheric prior to shipment. At maximum normal temperature of UF_6, 136°F, the vapor pressure is less than 22 psia (Sections 3.4.4 and 3.4.6). At maximum temperature of UF_6 in a fire accident, 250°F, the vapor pressure would be 100 psia (Sections 3.5.8 and 3.5.10). All these are below the ANSI N14.1 internal design pressure of 200 psig.

4.2.3 Containment Criterion

A 100 psig air pressure soap bubble leak test is performed at assembly and during 5 year periodic inspection on the valve and plug threads, seat, cap, packing nut and stem of the 30B cylinder. This method is in accordance with new cylinder and periodic inspection requirements listed in ANSI N14.1.

During 10 CFR 71 compliance testing, following the soap bubble test, a helium mass spectrometer was used to verify that the leak rate was less than 10^{-7} std cm^3/sec for normal conditions. The test is described in Appendix 2.10.5.

4.3 CONTAINMENT REQUIREMENTS FOR HYPOTHETICAL ACCIDENT CONDITIONS

4.3.1 Fission Gas Products

Neither fresh nor recycled UF_6 contains fission gas products.

4.3.2 Containment of Radioactive Material

Using the methodology of ANSI N14.5, the maximum permissible accident leak rate for a Type B shipment of UF_6 in a 30 B cylinder is 1.45×10^{-2} std cm^3/sec. Appendix 4.4.2 provides this calculation.

4.3.3 Containment Criterion

Full scale compliance testing was performed on the NCI-21PF-1 package. This testing is fully described in Sections 2.10.5 and 3.5. Upon completion of tests, two leak tests were performed. A 100 psig air pressure soap bubble leak test was performed on the valve threads, seat, cap, packing nut and stem of the 30B cylinder. This method is in accordance with new cylinder and periodic inspection requirements listed in ANSI N14.1. No bubbles were found.

Following the soap bubble test, a helium mass spectrometer was used to quantify the leak rate. The test results showed that the package before and after testing had a leak rate less than 10^{-7} std cc/s.

APPENDIX 4.4.1
CALCULATION OF
PERMISSIBLE LEAK RATE FOR NORMAL CONDITIONS

TABLE OF CONTENTS

4.4.1 Calculation of Permissible Leak Rate for Normal Conditions 4.4.1-1

APPENDIX 4.4.1
CALCULATION OF
PERMISSIBLE LEAK RATE FOR NORMAL CONDITIONS

The contents as defined in Appendix 1.3, $1150A_2/1540$ kg = 0.75 A_2/kg, are assumed releasable in the form of UF_6 vapor at the maximum content temperature. The maximum allowable release rate determined in that calculation will be converted to an air equivalent at standard conditions in accordance with ANSI N14.5 -1987. The leak path is assumed to be 1 cm long.

The maximum temperature of the UF_6 under normal conditions is 134°F. The vapor pressure at that temperature is 18 psia per USEC-651, Figure 3.

The mass density of the UF_6 vapor is, according to the ideal gas law pV=mRT.

$p= 18\ \text{lbf/in}^2 = 2592\ \text{lbf/ft}^2$
T= 594°R
$R=R_u$/molecular weight = 1545.33/352 =4.39 ft-lbf/lbm-°R

$$m/V = p/RT = 2592/(4.39*594) = 0.99\ \text{lbm/ft}^3 = 0.016\ \text{g/cm}^3$$

Using the methodology and nomenclature of ANSI N14.5:

$$C_N = (0.016\ \text{g/cm}^3)\ (0.75\ A_2/1000\ \text{g}) = 1.19\text{x}10^{-5}\ A_2/\text{cm}^3$$
$$R_N = 10^{-6} A_2/\text{hr} * 1\ \text{hr}/3600\ \text{s} = 2.778\text{x}10^{-10}\ A_2/\text{s}$$
$$L_N = R_N/C_N = 2.78\text{x}10^{-10}/1.19\text{x}10^{-5} = 2.33\text{x}10^{-5}\ \text{cm}^3/\text{s}\ UF_6 \text{ at } 134°\text{F, 18 psia}$$

Conversion to standard leak rate

Given the relatively low flow rate and the pressure ratio P_d/P_u = 14.7/18 = 0.82, the equations for continuum flow are appropriate. The correlation to standard conditions will be done according to ANSI N14.5, Equation B12.

Using the viscosity for UF_6 vapor at 134°C, μ = 0.0206 cP, L = $2.33\text{x}10^{-5}$ cm^3/s, a = 1 cm, M = 352, T = 330 K, P_u = 18 psia = 1.22 atm abs, P_d = 1 atm abs, and P_a = 1.11 atm abs, first use equation B2 to determine the hole diameter D, and the values for F_c and F_m:

$$2.33\text{x}10^{-5} = [2.49\text{x}10^6 D^4/0.0206 + 3.81\text{x}10^3 D^3 (330/352)^{0.5}/1.11](1.22 - 1)$$
$$D = 9.61\text{x}10^{-4}\ \text{cm},\ F_c = 1.03\text{x}10^{-4},\ \text{and}\ F_m = 2.95\text{x}10^{-6}.$$

Using equation B12:

$$L_R = 0.99\{1.03\text{x}10^{-4}(0.0206/0.0185) + 2.95\text{x}10^{-6}[(298/330)(352/29)]^{0.5}(1.11/0.505)\}$$
$$= 1.35\text{x}10^{-4}\ \text{std cm}^3/\text{s}$$

APPENDIX 4.4.2
CALCULATION OF
PERMISSIBLE LEAK RATE FOR ACCIDENT CONDITIONS

TABLE OF CONTENTS

4.4.2 Calculation of Permissible Leak Rate for Accident Conditions 4.4.2-1

APPENDIX 4.4.2
CALCULATION OF
PERMISSIBLE LEAK RATE FOR ACCIDENT CONDITIONS

The contents as defined in Appendix 1.3, $1150A_2/1540$ kg = 0.75 A_2/kg, are assumed releasable in the form of UF_6 vapor at the maximum content temperature. The maximum allowable release rate determined in that calculation will be converted to an air equivalent at standard conditions in accordance with ANSI N14.5 -1987.

The maximum temperature of the UF_6 in a fire accident is 250°F. The vapor pressure at that temperature is 100 psia per USEC-651, Figure 3.

The mass density of the UF_6 vapor is, according to the ideal gas law, pV=mRT.

$p = 100\ \text{lbf/in}^2 = 14400\ \text{lbf/ft}^2$

T= 710°R

$R = R_u/\text{molecular weight} = 1545.33/352 = 4.39$ ft-lbf/lbm-°R

$$m/V = p/RT = 14400/(4.39*710) = 4.62\ \text{lbm/ft}^3 = 0.074\ \text{g/cm}^3$$

Using the methodology and nomenclature of ANSI N14.5:

$$C_A = (0.074\ \text{g/cm}^3)\ (0.75\ A_2/1000\ \text{g}) = 5.55\text{x}10^{-5}\ A_2/\text{cm}^3$$

$$R_A = A_2/\text{week} = 1.65\text{x}10^{-6}\ A_2/\text{s}$$

$$L_A = R_A/C_A = 1.65\text{x}10^{-6}/5.55\text{x}10^{-5} = 2.97\text{x}10^{-2}\ \text{cm}^3/\text{s}\ UF_6 \text{ at } 250°\text{F, } 100 \text{ psia}$$

Given the relatively large flow rate and the pressure ratio $P_d/P_u = 14.7/100 = 0.15$, we can safely assume the flow is choked. The correlation to standard conditions will be done according to ANSI N14.5, Equation B13.

Using the specific heat ratio for UF_6 vapor at 200°C, k = 1.15, L= $2.97\text{x}10^{-2}$ cm^3/s, M= 352, T=250°F = 394 K, and P_u=100 psia = 6.8 atm abs,

$$L_R = 2.97\text{x}10^{-2}\{[0.583/(1.15/2.15)][352/29][298/394]\}^{0.5}[1/6.8][0.634/(2/2.15)^{1/0.15}]$$
$$= 1.45\text{x}10^{-2}\ \text{std cm}^3/\text{s}.$$

CHAPTER FIVE
SHIELDING EVALUATION

TABLE OF CONTENTS

5.0 SHIELDING EVALUATION 5-1

CHAPTER FIVE
SHIELDING EVALUATION

Gamma and neutron shielding are not required for cylinders of UF_6 because the 0.5 inch thick cylinder walls provide more than adequate shielding for low enriched uranium, both fresh and recycled. However, it is the responsibility of the shipper to assure compliance with 10 CFR 71.47 regarding radiation standards for each shipment.

CHAPTER SIX
CRITICALITY EVALUATION

TABLE OF CONTENTS

6.1 DISCUSSION AND RESULTS 6-1

6.2 PACKAGE LOADING 6-1

6.3 MODEL SPECIFICATION 6-3

6.4 CRITICALITY CALCULATION 6-3

6.5 CRITICALITY BENCHMARK EXPERIMENTS 6-3

6.6 REFERENCES 6-3

LIST OF TABLES

6-1 Summary of Criticality Evaluation 6-2

CHAPTER SIX
CRITICALITY EVALUATION

6.1 DISCUSSION AND RESULTS

For criticality control, the NCI-21PF-1 relies upon:

- specification of maximum H/U ratio, or equivalently, minimum UF_6 purity,
- impact absorption by the protective overpack, which prevents damage to the 30B cylinder sufficient to cause water in-leakage or reduction of package volume under normal and accident conditions, and
- thermal protection of the cylinder by the overpack, which prevents damage to the cylinder which could cause the contents to leak out or water to leak in.

Purity control is provided according to ASTM C787 and C996 (References 6.6.1 and 6.6.2, respectively), which require minimum 99.5% purity. The maximum H/U atomic ratio of 0.088 allowed according to 49 CFR 173.417, Table 6, corresponds to 0.5% impurity, with all the impurity being hydrogen flouride (HF). Drop, puncture, and fire testing described in Chapter 2.7 demonstrate that water will not leak in, nor will the contents leak out under accident conditions. The testing also demonstrates that the overall dimensions of the overpack will remain essentially the same, so that the spacing assumed in modeling an array of packages is valid for both normal and accident conditions.

A criticality evaluation is provided in ORNL/TM-11947 (Reference 6.6.3). This evaluation is directly applicable to this packaging. The report evaluates k_{eff} using the SCALE4 computer code system for an infinite array of packages with optimum interspersed moderation, and finds the worst case to be $k_{eff} = 0.817 \pm 0.003$. The worst case calculation is summarized in Table 6-1. An infinite array of damaged or undamaged packages remaining subcritical corresponds to a transport index for criticality control of zero. However, the transport index of 5 is retained from earlier revisions of the Certificate of Compliance for the NCI-21PF-1, and from the similar DOT-21PF-1 as specified in 49 CFR 173.417, Table 6.

6.2 PACKAGE LOADING

The NCI-21PF-1 package contents may be either fresh or recycled UF_6. The loading is

Cylinder Type:	Model 30B
Maximum Weight of UF_6:	5,020 lb
Maximum U-235 Enrichment:	5 wt%
Minimum UF_6 purity	99.5 wt%
Transport Index for criticality control:	5.0

Because the contents are loaded as a liquid which solidifies upon cooling before shipment, the geometric configuration of the contents can vary somewhat. The form of the contents is the same for both normal and accident conditions, except for variation of density with temperature. Several possible geometric configurations of the solid UF_6 and the variation of density with temperature are evaluated in the ORNL criticality calculation.

Hydrostatic testing has verified that water will not leak into the 30B cylinder after accident testing. The only moderation internal to the 30B cylinder is provided by the impurities, which may include HF, and which are limited as noted above. For the purpose of the criticality calculation, the maximum H/U ratio, 0.088, is assumed.

Table 6-1
Summary of Criticality Evaluation

Model conditions	normal and accident, same model
Number of packages in contact	infinite
$k_{eff} \pm \sigma$	0.817 ± 0.003
Optimum interspersed moderation	water, specific gravity = 0.015
Close reflection by water	Not applicable to infinite array
Package size, including overpack	54.81 cm radius, 231.14 cm height
Internal size of 30B cylinder	36.83 cm radius, 172.78 cm height
Overpack material	water, same as interspersed
Package contents	UF_6, 5% enriched, 99.5% pure, 5.1 g/cm^3, 5030 lb
Temperature	20 °C
Contents geometry	Solid UF_6 cylinder with central cylindrical void
Internal moderation	No water; 0.5 % impurity entirely HF; H/U=0.088

6.3 MODEL SPECIFICATION

The model is described in Section 3.1 of ORNL/TM-11947 (Reference 6.6.3). Although the model is based upon the DOT-21PF-1 overpack, most of the calculations, including the worst case, used the outer dimensions of the overpack to maintain the spacing between packages, but replaced the actual overpack materials by water at the density of the interspersed moderator. This materials substitution is conservative, and makes the model applicable to the NCI-21PF-1 packaging despite any material differences between the overpacks. The diameter and length of the NCI-21PF-1 are 55.40 and 233.68 cm respectively. The dimensions used in the model are both slightly smaller, resulting in closer, and therefore conservative, spacing between packages in the model array.

6.4 CRITICALITY CALCULATION

The calculations described in Reference 6.6.3 were performed using the CSAS25 sequence from the SCALE4 computer code system with the SCALE 27 group ENDF/B-IV cross sections. The calculations first assume an internal geometric configuration of the contents, an infinite square lattice array, and a temperature of 20 °C, and vary the water density to find the optimum interspersed moderation. At and near that water density, sensitivity studies are performed varying contents configuration, temperature and corresponding UF_6 density, and closer package spacing to simulate triangular pitch arrays.

The results are summarized in Table 4 of the report, and the worst case is summarized in Table 6-1 above.

6.5 CRITICALITY BENCHMARK EXPERIMENTS

The validation of the computer code and cross sections against 51 critical experiment benchmarks is described in Sections 2.2 and 3.2.5 of Reference 6.6.3..

6.6 REFERENCES

6.6.1 ASTM Standard C787, "Standard Specification for Uranium Hexaflouride for Enrichment."

6.6.2 ASTM Standard C996, "Standard Specification for Uranium Hexaflouride Enriched to Less Than 5% ^{235}U."

6.6.3 ORNL/TM-11947, Criticality Safety Review of 2 1/2-, 10-, and 14-Ton UF_6 Cylinders, B.L. Broadhead, Martin Marietta Energy Systems, Oak Ridge National Laboratory, October, 1991.

CHAPTER SEVEN
OPERATING PROCEDURES

TABLE OF CONTENTS

7.1 PROCEDURES FOR LOADING PACKAGE 7-1
7.1.1 Receipt and Filling of 30B Cylinder 7-1
7.1.2 Final Cylinder Inspection 7-1
7.1.3 Overpack and Valve Protection Device Inspection 7-1
7.1.4 Procedure for Loading the NCI-21PF-1 Overpack 7-2

7.2 PROCEDURES FOR UNLOADING PACKAGE 7-3

7.3 PREPARATION OF EMPTY PACKAGE FOR TRANSPORT 7-4

CHAPTER SEVEN
OPERATING PROCEDURES

The NCI-21PF-1 overpack is loaded and unloaded and the 30B UF_6 cylinder is filled, tested, and handled in accordance with standard, in-plant, operating procedures at various enrichment plants and at various nuclear fuel facilities. These procedures are described in USEC-651 and ANSI Standard N14.1. As a minimum, the specific procedures include steps described in the subsequent sections.

7.1 PROCEDURES FOR LOADING PACKAGE

7.1.1 Receipt and Filling of 30B Cylinder

Receipt and filling of the 30B cylinder shall be performed in accordance with USEC-651 and ANSI N14.1.

7.1.2 Final Cylinder Inspection

Complete the inspection of UF_6 cylinder prior to insertion into overpack per USEC-651 and ANSI N14.1.

7.1.3 Overpack and Valve Protection Device Inspection

The user shall inspect the NCI-21PF-1 overpack and valve protection device in accordance with written procedures prior to every outgoing shipment and upon receipt of every incoming shipment to assure the following:

7.1.3.1 NCI-21PF-1 Overpack:

a. Overpack base and supports are sound with no broken welds or components.
b. Overpack inner and outer shells are intact with no broken welds and no holes, tears, or cracks greater than 1/2 inch.
c. Inner liner is free of debris and standing water and is intact and are not in a deteriorated or damaged condition.
d. Gaskets and cylinder support pads are in place and intact and are not in a deteriorated or damaged condition.
e. Wood cover plates and welds are sound and undamaged.
f. Overpack halves fit together properly with no gaps.
g. Closure clamps are properly adjusted for tight closure and the coupling/adjusting nuts are properly locked; Verify that the torque adjustment on the closures has occurred within the last year.
h. All vent seals/plugs are securely in place.

7.1.3.2 Valve protection device:

a. Verify that the spider is sound with no broken welds.
b. Verify that the spider clamps operate properly and verify that the bolts located on the tips are locked in place.
c. Verify that the neoprene bolt protectors are in place and not deteriorated (replace if damaged).

7.1.4 <u>Procedure for Loading the NCI-21PF-1 Overpack</u>

7.1.4.1 Complete the inspection report verifying that the following overpack components are free from damage and are in working order:

a. Inner and outer shells
b. Cylinder support pads
c. Gasket and gasket surfaces; verify that gaskets have been replaced within past 3 years.
d. Vent seals/plugs.
e. Tie-down and lifting/stacking supports.
f. Lifting U-bolts.
g. Toggle closures and toggle handle ball-lock-pins.
h. Security seal lugs.

7.1.4.2 Remove the temporary valve protector cover, if present.

7.1.4.3 The cylinder (horizontal) shall be oriented with the valve in the twelve o'clock position.

7.1.4.4 One secondary aluminum insert shall be placed into the cylinder skirt.

7.1.4.5 The next secondary aluminum insert shall be placed into the cylinder skirt.

7.1.4.6 Once the two pieces have been placed inside of the cylinder skirt, a two to three inch space should exist between the two pieces. A steel spacer shall be placed between the two pieces. (See Appendix 1.3 for illustration)

7.1.4.7 The aluminum (primary) insert shall be placed over the valve.

7.1.4.8 Install the metal spider of the valve protection device among the inserts. Verify that the bridge of valve location insert covers the cylinder valve.

7.1.4.9 Clamp the metal spider of the valve protection device in place. (See Appendix 1.3 for illustration)

7.1.4.10 Carefully load the UF_6 cylinder into bottom half of the overpack with the cylinder valve positioned up (at 12:00 o'clock position).

7.1.4.11 Carefully place lid on overpack.

7.1.4.12 Engage all toggle clamps, then close all toggle clamps alternating first corner-to-corner (4 closures) followed by side-to-side (6 closures).

7.1.4.13 Secure the handles with the ball-lock-pins.

7.1.4.14 Install security seals and record their numbers.

7.1.4.15 Complete inspection report.

7.1.4.16 Complete radiation survey and assign Transport Index.

7.1.4.17 Remove old labels and re-label per applicable regulations.

7.2 PROCEDURES FOR UNLOADING PACKAGE

7.2.1 Complete receiving report.

7.2.2 Remove and record the overpack seal.

7.2.3 Remove the ball-lock-pins and open all toggles before disengaging from upper brackets.

7.2.4 Remove the lid of the overpack.

7.2.5 Remove the 30B cylinder from the overpack.

7.2.6 Unclamp the metal spider of the valve protection device.

7.2.7 Remove the metal spider from among the inserts.

7.2.8 Remove the metal spacer from among the inserts.

7.2.9 Carefully remove the main valve location (primary) insert from the cylinder skirt.

7.2.10 Remove the secondary location inserts from the cylinder skirt.

7.2.11 Clean any loose debris from NCI-21PF-1 overpack interior and valve protection device.

7.2.12 Close the overpack prior to storage.

7.3 PREPARATION OF EMPTY PACKAGE FOR TRANSPORT

Empty cylinders may be shipped without protective overpacks and valve protection devices provided the residual heel does not exceed 25 lbs of UF_6 and 5% maximum U-235 enrichment.

Preparation of an empty overpack for shipment:

7.3.1 Close the overpack.

7.3.2 Complete radiation survey.

7.3.3 Remove old labels and re-label per applicable regulations.

CHAPTER EIGHT
ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

TABLE OF CONTENTS

8.1 ACCEPTANCE TESTS 8-1
8.1.1 Acceptance Tests for the NCI-21PF-1 Overpack 8-1
8.1.2 Acceptance Tests for the Valve Protection Device 8-2
8.1.3 Acceptance Tests for the 30B Cylinder 8-2

8.2 MAINTENANCE PROGRAMS 8-2
8.2.1 Maintenance Programs for the NCI-21PF-1 Overpack 8-2
8.2.2 Maintenance Programs for the Valve Protection Device 8-5
8.2.3 Maintenance Programs for the 30B Cylinder 8-5

CHAPTER EIGHT
ACCEPTANCE AND MAINTENANCE PROGRAMS

This chapter describes the activities to be performed in compliance with Subpart G of 10 CFR 71 to assure that the NCI-21PF-1 package conforms to the requirements of this Safety Analysis Report and remains in conformance following loading.

8.1 ACCEPTANCE TESTS

8.1.1 Acceptance Tests for the NCI-21PF-1 Overpack

Each completed overpack shall be inspected to document compliance with the following drawing requirements:

(a) Final dimensions as described below:
- Inner cylinder cavity dimensions.
- Outer shell dimensions.
- Toggle clamp locations.
- Bolt center locations and hole diameters in tie down supports and in lifting/stacking frames.
- Flatness of gasket surface.

(b) Installation of gaskets and cylinder support pads.

(c) Lid to body fit.

(d) Toggle clamp adjustments and locking of adjustment nuts.

(e) Installation of lifting eye-bolts and security seal pads.

(f) Actual weights of lid and bottom halves.

(g) Final assembled weights.

(h) Proper permanent marking and nameplates per 10 CFR 71.85(c), 49 CFR 1178,121-5, and ANSI N14.1 (latest revision).

8.1.2 Acceptance Tests for the Valve Protection Device

Each completed valve protection device shall be inspected to document compliance with the following drawing requirements:

(a) As-built dimensions.

(b) Clamp adjustments

(c) Actual weights of steel spider, steel space, primary insert and each secondary insert.

(d) Final weight of entire valve protection device.

(e) Proper permanent marking of each component per drawing VPD-0001.

8.1.3 Acceptance Tests for the 30B Cylinder

Acceptance tests for the 30B cylinder shall be in accordance with ANSI N14.1. In addition, the fitup of the Valve Protection Device to the cylinder shall be performed as specified below.

Prior to first use of each cylinder with a valve protection device, a fit up test will be performed to verify that the valve protection device fits properly in the cylinder. This fit up test will verify the clearances in two locations:

- g, clearance between the valve and the underside of the bridge; and
- Gap, clearance between the underside of the valve protection device and the cylinder head.

The (g - Gap) value as specified on Figure 2.7-8 shall be at least 3/16" (5 mm).

Reports, certifications, and records of the 30B cylinder shall be in accordance with ANSI N14.1. and are summarized below.

8.2 MAINTENANCE PROGRAMS

8.2.1 Maintenance Programs for the NCI-21PF-1 Overpack

The user shall establish written procedures for the periodic maintenance and inspection of each Model NCI-21PF-1 overpack requiring the following as a minimum:

8.2.1.1 Annually

(a) Check that the lifting/stacking frames, lifting eyebolts, closure clamps, and tie-down supports are sound and free from weld cracks, damage and deterioration.

(b) Check that the closure clamps properly adjust and lock. Check torque on the overpack closures using the following method:

- Loosen set-screws in collar bolts.
- Adjust toggle closures to securely close overpack.
- Engage toggle clamps and close toggles, alternating first corner to corner (4 closures) followed by side to side (6 closures).
- Torque closures to 110±10 foot-pounds.
- Tighten set screws.

(c) Check that all vents are properly sealed.

(d) Check that the inner and outer shells are free of holes, cracks, tears, and broken welds, and the inner shells are free of debris and standing water.

(e) Check that the wood cover plates are sound and undamaged, and gasket sealing surfaces meet drawing requirements.

(f) Individually weigh each half (lid and bottom) of each packaging to verify that neither half has gained more than 25 pounds. Weight gain must be assumed to be water. If either half exhibits a gain of more than 25 pounds, the packaging must be removed from service and dried to within 10 pounds of its original nameplate weight. New weights of each packaging half must be established after any modifications, refurbishment, or repainting. After drying each packaging must be inspected, as above.

(g) Check that gaskets are in place, intact, and not damaged or deteriorated.

8.2.1.2 Every Three Years

(a) Perform all annual inspections as listed above.

(b) Replace and inspect gaskets.

8.2.1.3 Every Five Years

The owners are responsible for recertifying the NCI-21PF-1 overpack every five years to meet original design specifications. The following inspections shall be performed:

(a) Perform all routine inspections stated in Chapter 7 and all annual inspections stated above. (If it is time to replace the gasket, this shall be performed as well).

(b) Full visual inspection of all welds for the presence of cracks. Any questionable condition of a weld shall be subject to further examination to assure that no cracks are present. Weld defects shall be repaired.

(c) Check the base and lid for warpage and/or distortion which could prevent tight closure. Check that the gasket sealing surfaces meet design specifications.

(d) Probe all base vent and lid vent holes to ascertain the rigidity and presence of insulation. Assure that vent holes are properly sealed.

(e) Verify that inner and outer shells are free of corrosion, pitting, cracks, broken welds and pinholes.

(f) Assure that security seal holes are functional and capable of maintaining their integrity when seals are used.

(g) Permanently mark the exterior nameplate listing the date of recertification, the individual base and lid weights, and the name of the recertifying company.

(h) The overpack shall receive a full visual inspection for rusting and the presence of corrosion. This inspection shall include assurance that corrosion has not reduced the skin wall thickness by 10% of the nominal thickness. When visual inspection cannot assure sufficient wall thickness, other examinations shall be utilized, such as ultrasonic testing, to assure acceptability.

(i) All repairs shall be performed by competent sources. All repairs that require welding shall be made by welders who are qualified in accordance with Section IX of the ANSI/ASME Boiler and Pressure Vessel Code or Section 5 of ANSI/AWS D1.1. The repair shop shall provide certification of weld procedures and welder qualifications.

8.2.2 Maintenance Programs for the Valve Protection Device

In addition to routine operational inspections, the valve protection device shall be inspected every five years to verify compliance with original design criteria. As a minimum this maintenance and inspection shall include:

(a) Perform all routine inspections outlined in Chapter 7.

(b) Perform full visual inspection of all welds for the presence of cracks. Any questionable condition of a weld shall be subject to further examination to assure that no cracks are present. Weld defects shall be repaired.

(c) All repairs shall be performed by competent sources. All repairs that require welding shall be made by welders who are qualified in accordance with Section IX of the ANSI/ASME Boiler and Pressure Vessel Code or Section 5 of ANSI/AWS D1.1. The repair shop shall provide certification of weld procedures and welder qualifications.

(d) Perform full visual inspection of painted surfaces; any discontinuity in paint coverage shall be corrected.

8.2.3 Maintenance Program for the 30B Cylinder

Maintenance of the 30B Cylinders shall be performed in accordance with ANSI N14.1.