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The Obsolete Cask Program: Initial Tests

L. B. Shappert J. H. Evans

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THE OBSOLETE CASK PROGRAM: INITIAL TESTS*

L. B. Shappert J. H. Evans**

*Research sponsored by the Division of Waste Management and Transportation, U.S. Atomic Energy Commission.

**General Engineering Division.

NOVEMBER 1974

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THE OBSOLETE CASK PROGRAM: INITIAL TESTS

L. B. Shappert J. H. Evans

ABSTRACT

Two casks were subjected to impact tests, which involved 30-ft drops onto a solid, essentially unyielding surface. The first cask, weighing about 6200 lb, was dropped on end, while the second, weighing about 6000 lb, was dropped twice on edge. Deformation to the casks was predicted before the tests, and the values obtained were compared with the test results. Both predicted cask deformations and accelerations agreed reasonably well with the measured values.

1. INTRODUCTION

The Obsolete Cask Program was initiated to study the behavior of casks under specified destructive test conditions and to establish the adequacy of the calculational techniques that are presently employed to predict cask damage. The test used to produce severe cask damage consists of a free fall by the cask from an elevation of 30 ft, impacting on an essentially unyielding surface in an orientation which would produce maximum damage. Other damage-producing tests involving puncture, fire, and submergence are described in the regulations.[1]

An advisory committee (see Appendix A), consisting of AEC and Contractor employees who are knowledgeable and experienced in cask testing and analytical damage prediction, was formed to provide guidance for the Program. At the initial committee meeting in Bethesda, Maryland, on June 14, 1973, a decision was made to place maximum testing effort on the 30-ft free-fall portion of the accident sequence. It was recognized that the other accident tests described in the regulations are important and should be investigated experimentally; however, present methods for predicting damage resulting from these other tests currently seem more satisfactory than for the 30-ft drop test. The effects of the 40-in.

free fall of a lead-shielded, steel-jacketed cask onto the 6-in. bar has been determined experimentally and reported.[2-4] The techniques presently employed in predicting the response of casks to the thermal exposure are based on sound theory and appear to be generally accepted.

The committee members suggested that, whenever experimental studies of temperature effects on casks were undertaken, three important areas should be investigated: (1) redistribution of melted lead after solidification; (2) local damage from melting lead, particularly at edges, as a function of time; and (3) damage from melting lead and thermal expansion in the vicinity of penetrations and abrupt changes of section. They also expressed the opinion that temperature distribution as a function of time should be experimentally verified.

A list was prepared of casks thought to be obsolete and available for testing. An effort was made to locate casks having geometries similar to spent fuel element shipping casks currently in use, that is, cylindrical lead-shielded casks having length/diameter ratios of 3 or greater. Some casks that were originally suggested were either unavailable or considered to be inadequate.

From this list, two ORNL casks (see Appendix B) were selected for the first tests because they had the desired geometry (length/diameter ratio of 3.08), were compatible with the capacity of the ORNL Drop Tower, were readily available, and had minimal contamination levels. Procedures and drawings illustrating modifications to the casks were prepared and circulated to the committee for comments. Subsequently, the procedures and modification drawings were revised to reflect these comments. These procedures and drawings are shown in Appendix C.

Several committee members expressed concern because, contrary to current practice in which most casks employ energy absorbers to minimize cask damage, the ORNL test models were unprotected. However, they felt that an understanding of the behavior of the basic cask was necessary prior to an investigation of energy absorbers and that energy absorbers can be evaluated most effectively by a model test program such as Davis[5] utilized in studying fins and Evans[6] employed in studying the tube in a tube energy absorber. Model tests should be used to establish the feasibility of the

various concepts and should be followed by full-scale tests of the better absorbers to verify results obtained with the test model.

2. CASK TESTS

The two ORNL casks used in the initial tests were actually lead-shielded, steel-jacketed sections of an original cask built in three sections; the original cask was intended for on-site use only (see Figs. 1 and 2). Cask 1, initially an end section, weighs 6200 lb, while Cask 2, initially the center section, weighs 6000 lb. Apparently, no effort had been made to metallurgically bond the lead shielding to the outer steel shell.

The cask sections were decontaminated prior to testing. Quarter-inch holes were drilled at intervals along the length of the cask to aid in evaluating the extent of lead displacement relative to the shell. Cask 1 was dropped directly on the end that had the closure plug bolted in place. Cask 2 was dropped twice, each time at an angle which allowed the center of gravity to be essentially directly above the point of impact. The closure plug was not included in the edge drops since it could not be readily removed from Cask 1 following the end drop.

3. TEST FACILITIES AND INSTRUMENTATION

The drop tests were performed at the existing ORNL Drop Tower (Fig. 3) and Drop Pad (Fig. 4). The casks were hoisted as illustrated in Fig. 5, and were subsequently released by a hydraulically actuated mechanism.

The instrumentation system, shown schematically in Fig. 6 and depicted in Figs. 7 and 8, was used to record acceleration-time responses of the cask and impact surface by attaching a piezoelectric accelerometer to the cask and feeding its output signal through a charge amplifier and a low-pass filter to the oscilloscope. With this instrumentation, an acceleration-time relationship was recorded for the impact. The filter was required because the high-frequency ringing experienced during the impacts completely obscured the effective acceleration trace produced by

ORNL DWG 74-8428 R1

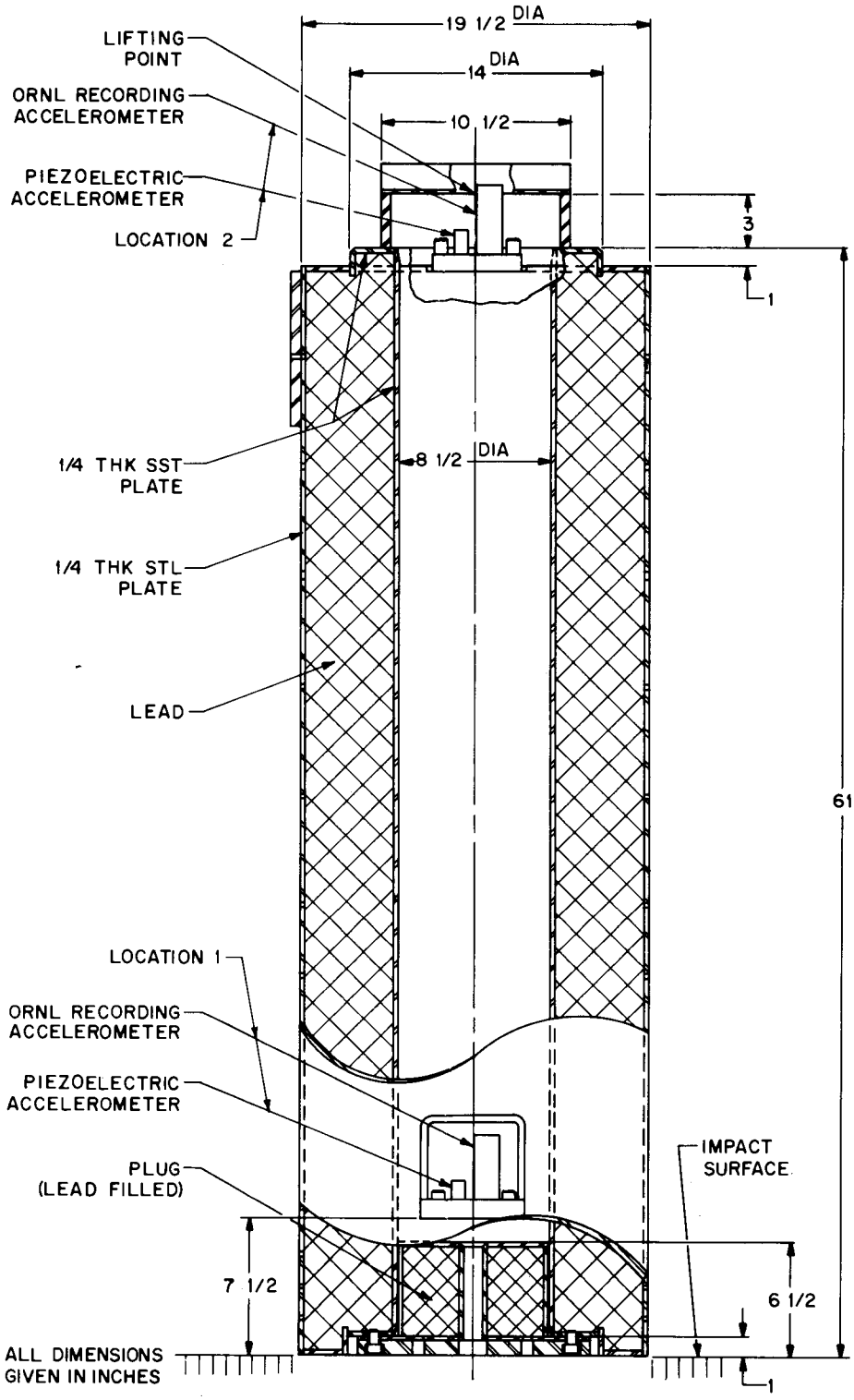

Fig. 1. Cask 1 for end drop.

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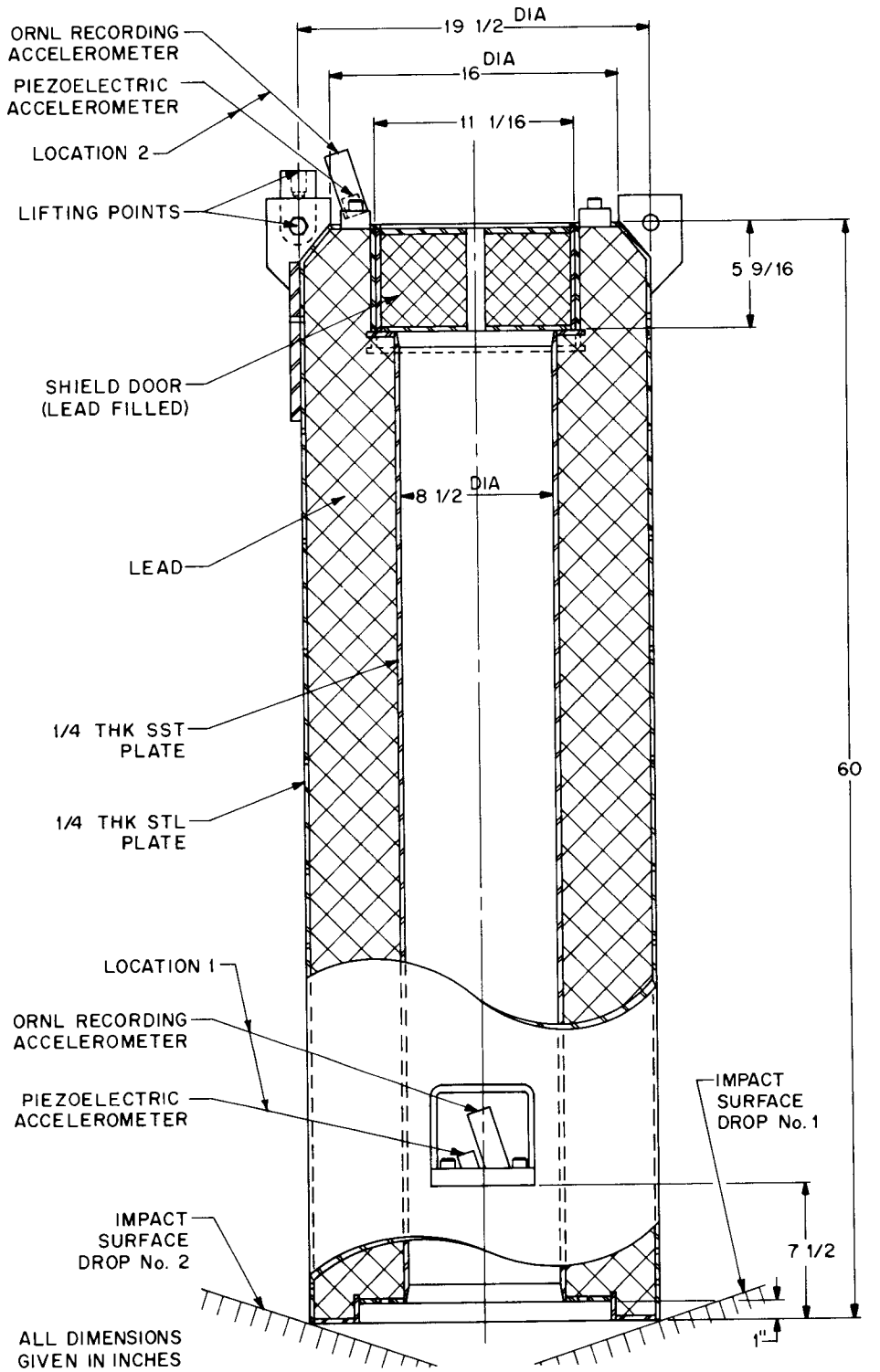

Fig. 2. Cask 2 for edge drop.

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Fig. 3. ORNL Drop Tower.

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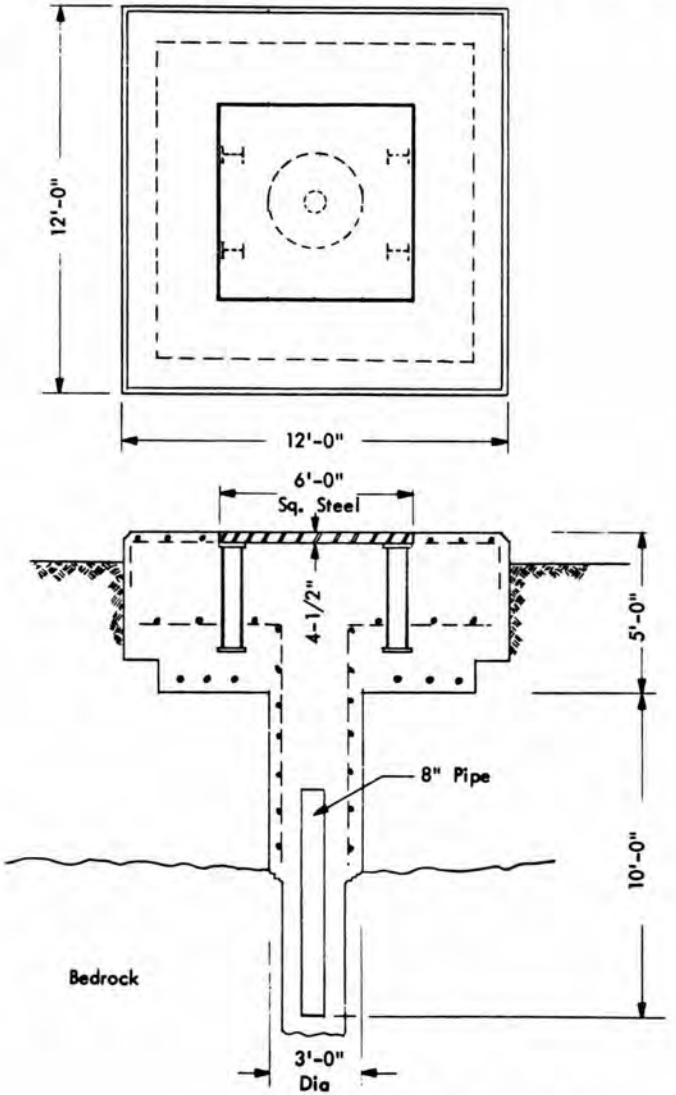

Fig. 4. ORNL Drop Pad.

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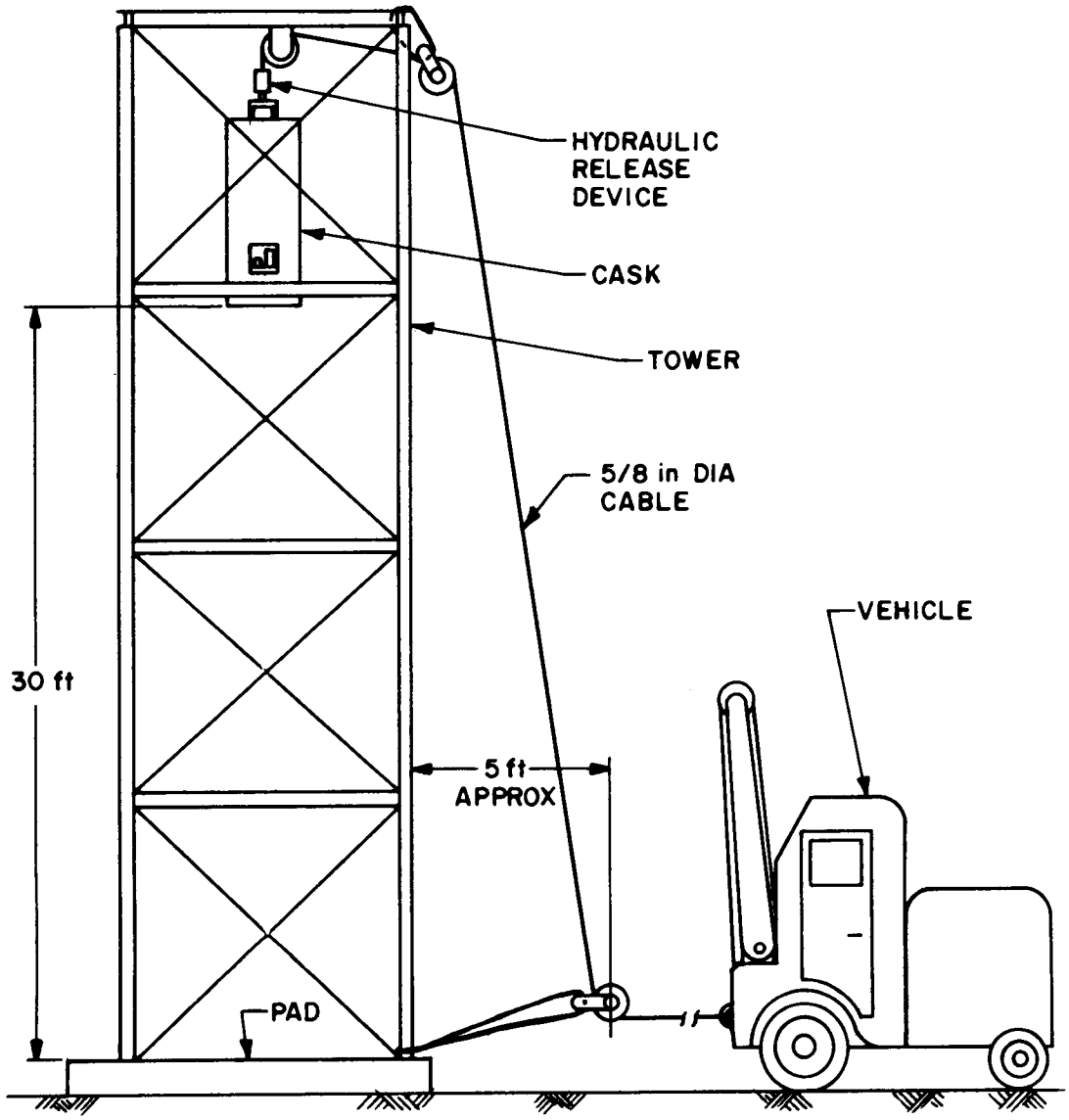

Fig. 5. Hoisting diagram.

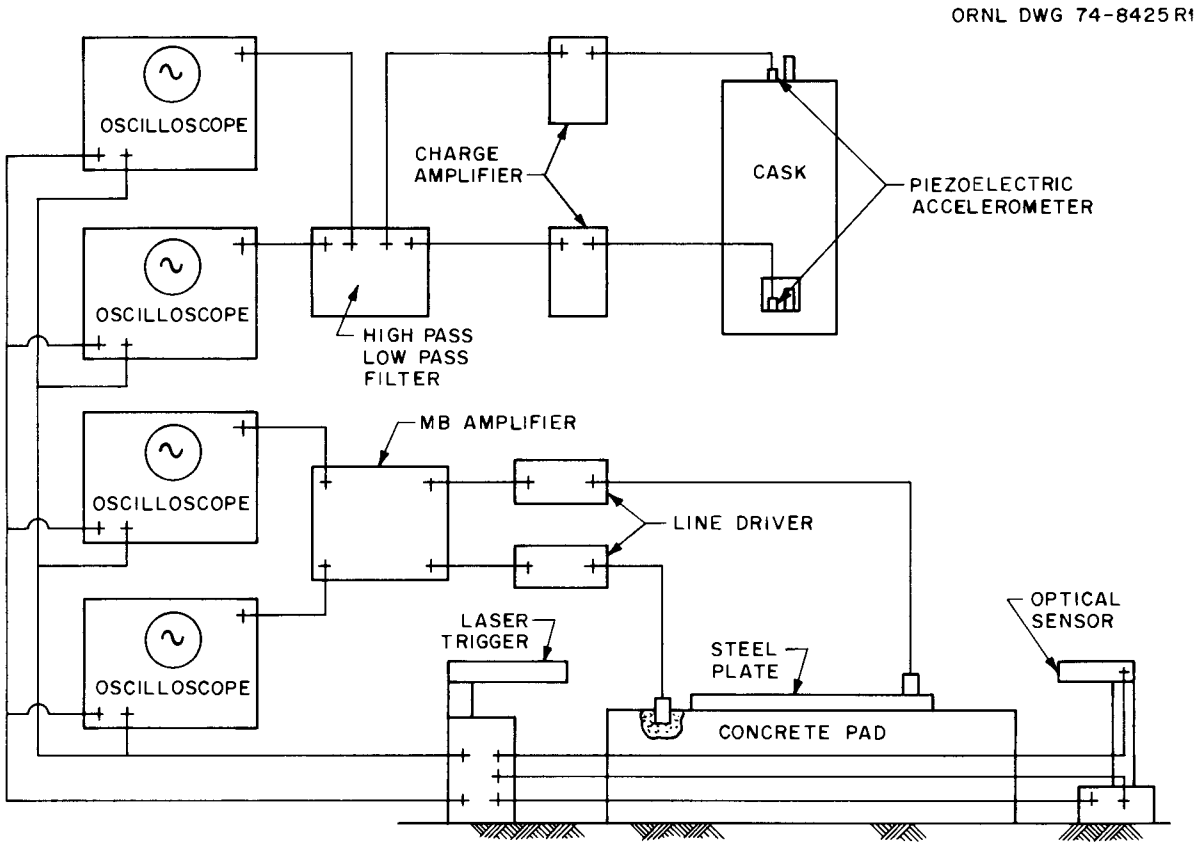

Fig. 6. Instrument schematic.

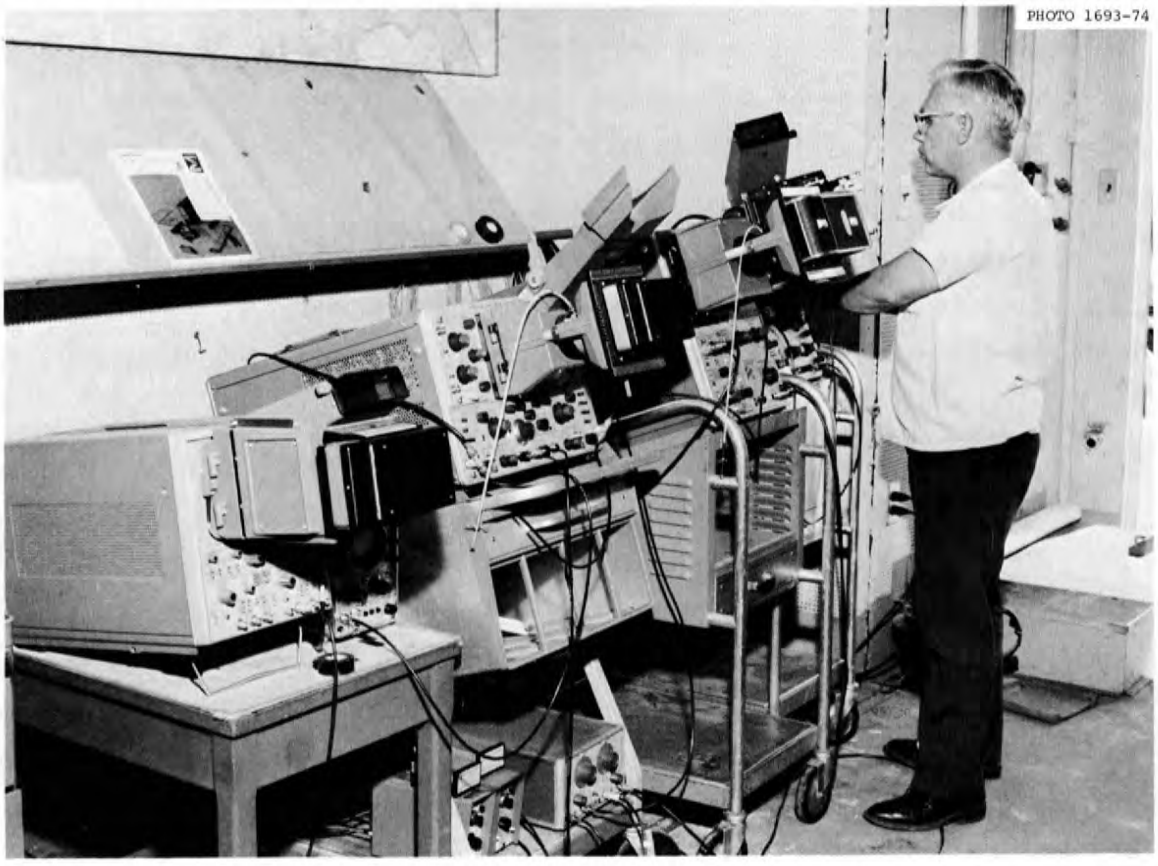

Fig. 7. Interior of trailer.

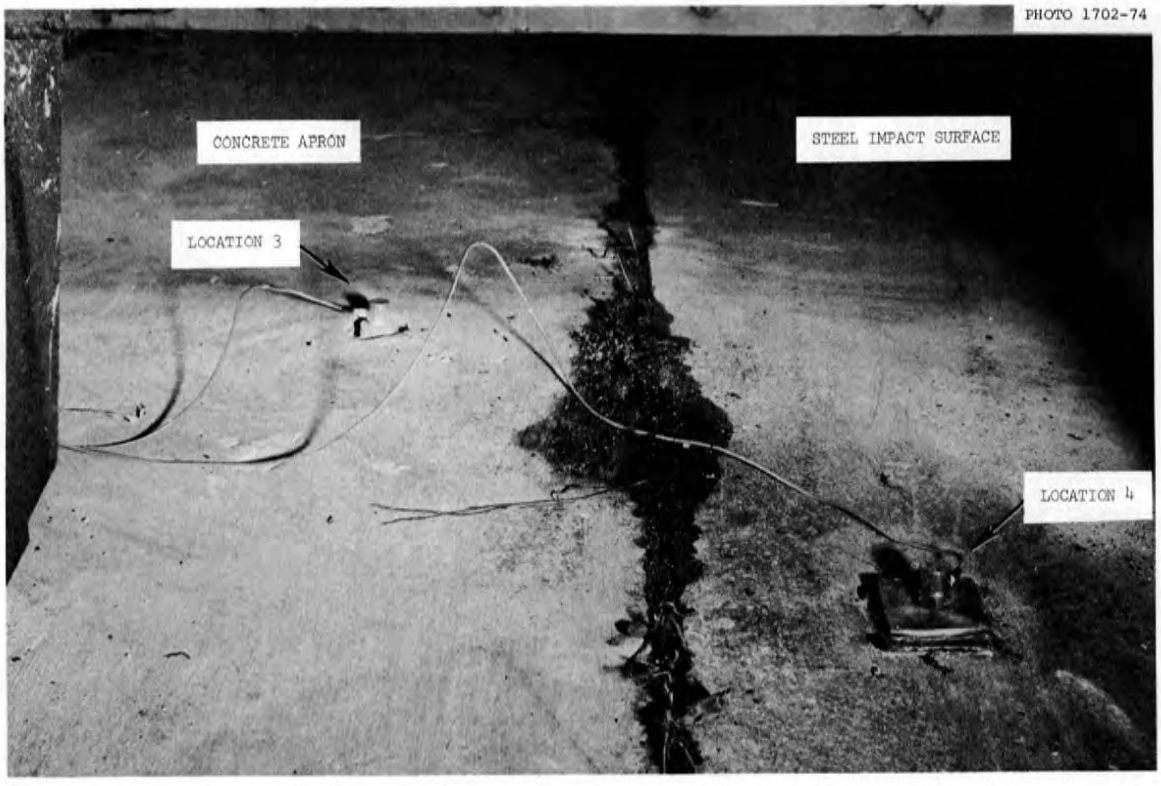

Fig. 8. Accelerometers on pad.

the accelerometer. The trace was recorded on film by using time-exposure photographic techniques and a Polaroid Land camera mounted on the oscilloscope. The laser system shown in Fig. 9 was used to trigger the oscilloscope.

Recording accelerometers, recently designed at ORNL (see Figs. 10 and 11), were used as a backup system to measure the peak or maximum effective acceleration at a given point. They were installed on the casks as shown in Figs. 1 and 2 for the two drops.

Three models of the recording accelerometer, designated as A, B, and C, have been designed and fabricated. Model A serves for a high range of accelerations, B for an intermediate range, and C for a lower range. Model A has been partially calibrated using dynamic data taken from a load cell in the manner described previously.[5,6] The calibration data compare favorably with the theoretical calibration curve derived from the dynamic properties of lead published by Evans.[7] The calibration data and the theoretical curve for the recording accelerometer model A are shown in Fig. 12.

Although no calibration data have been obtained for models B and C, the close agreement of the theoretical curve and data for model A indicates that use of the theoretical curves for the other models is appropriate until an experimental calibration curve is developed. Figure 13 shows the theoretical curves for the three models.

4. RESULTS

Cask 1, when released, fell as anticipated, impacting on end and coming to rest on its end. Malfunction of an undetermined nature occurred in three of the accelerometers (Nos. 1, 3, and 4) and prevented data from being acquired at these locations. An acceleration-time trace taken from accelerometer 2 is reproduced as Fig. 14. The recording accelerometers indicated peaks in acceleration of 275 g's at location 1 and 100 g's at location 2. The physical damage is illustrated dimensionally in Fig. 15 and shown photographically in Figs. 16-18. Failures occurred in the seam weld of the outer shell and in the weld joining the head and shell. Holes

Fig. 9. Photograph of the laser trigger system.

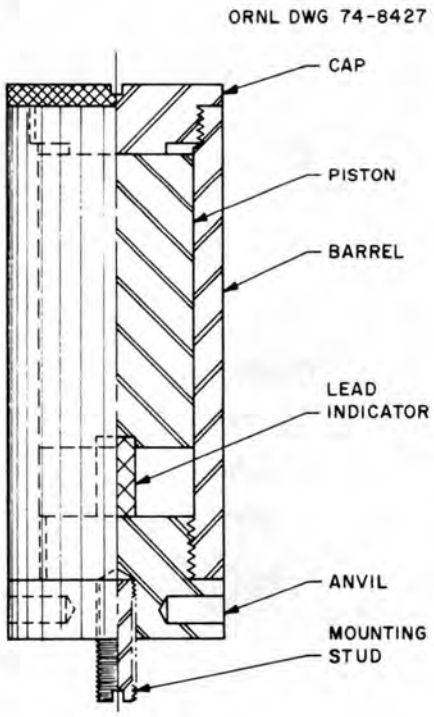

Fig. 10. Drawing of ORNL recording accelerometer.

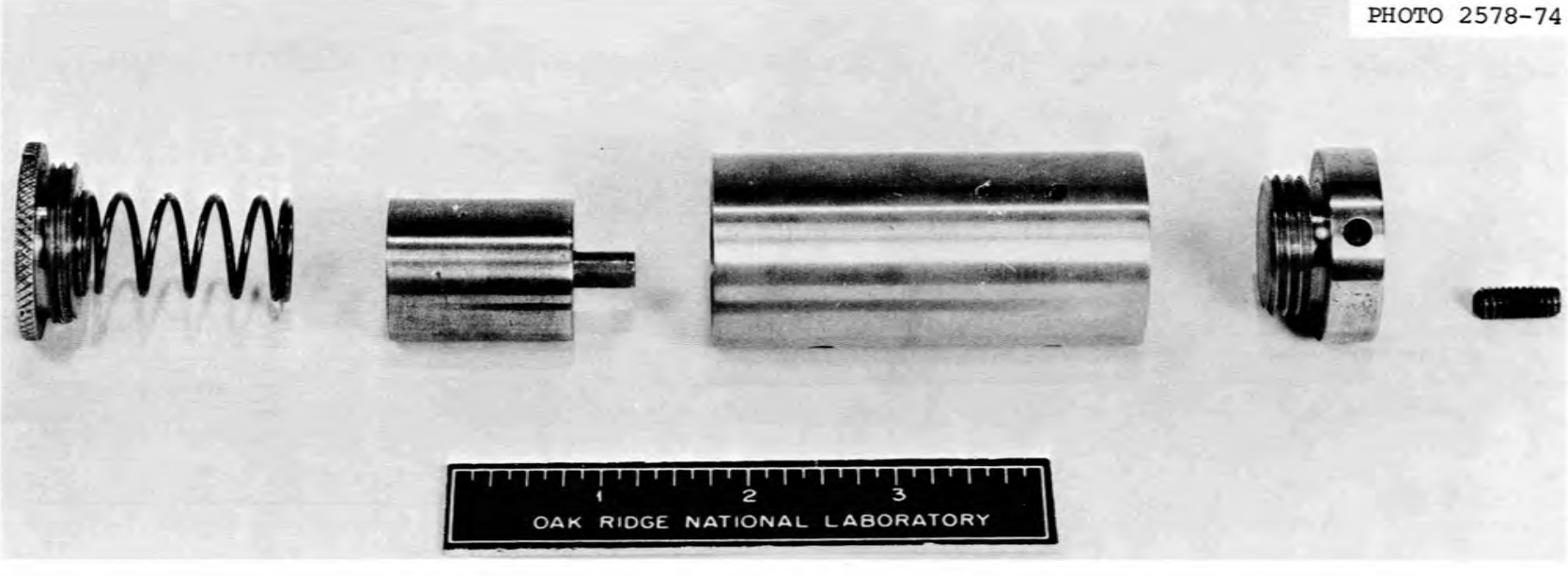

Fig. 11. Photograph of ORNL recording accelerometer.

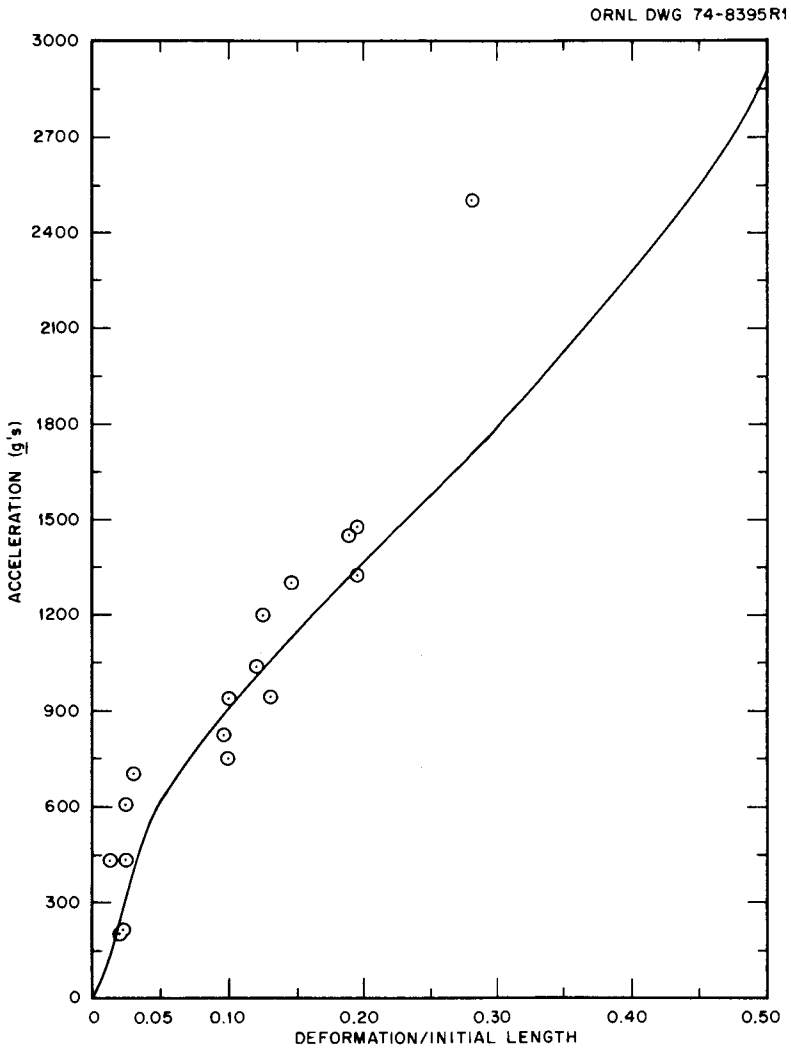

Fig. 12. Calibration curve for ORNL recording accelerometer, Model A.

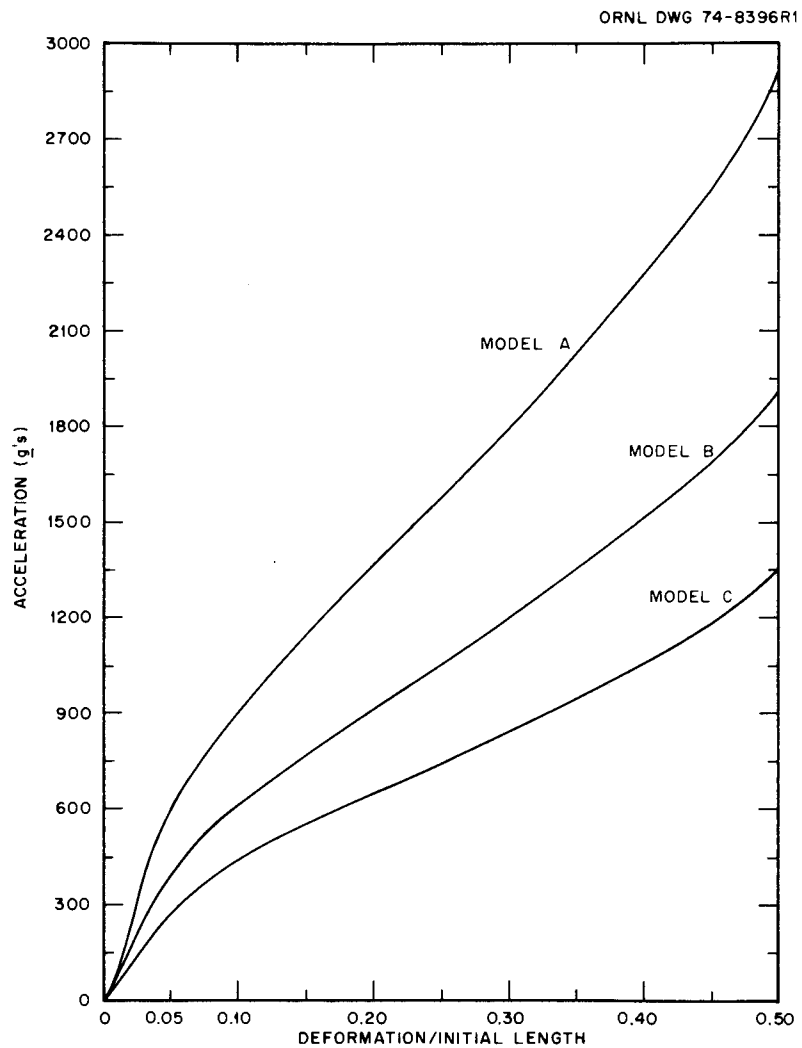

Fig. 13. Theoretical calibration curves for ORNL recording accelerometer, Models A, B, and C.

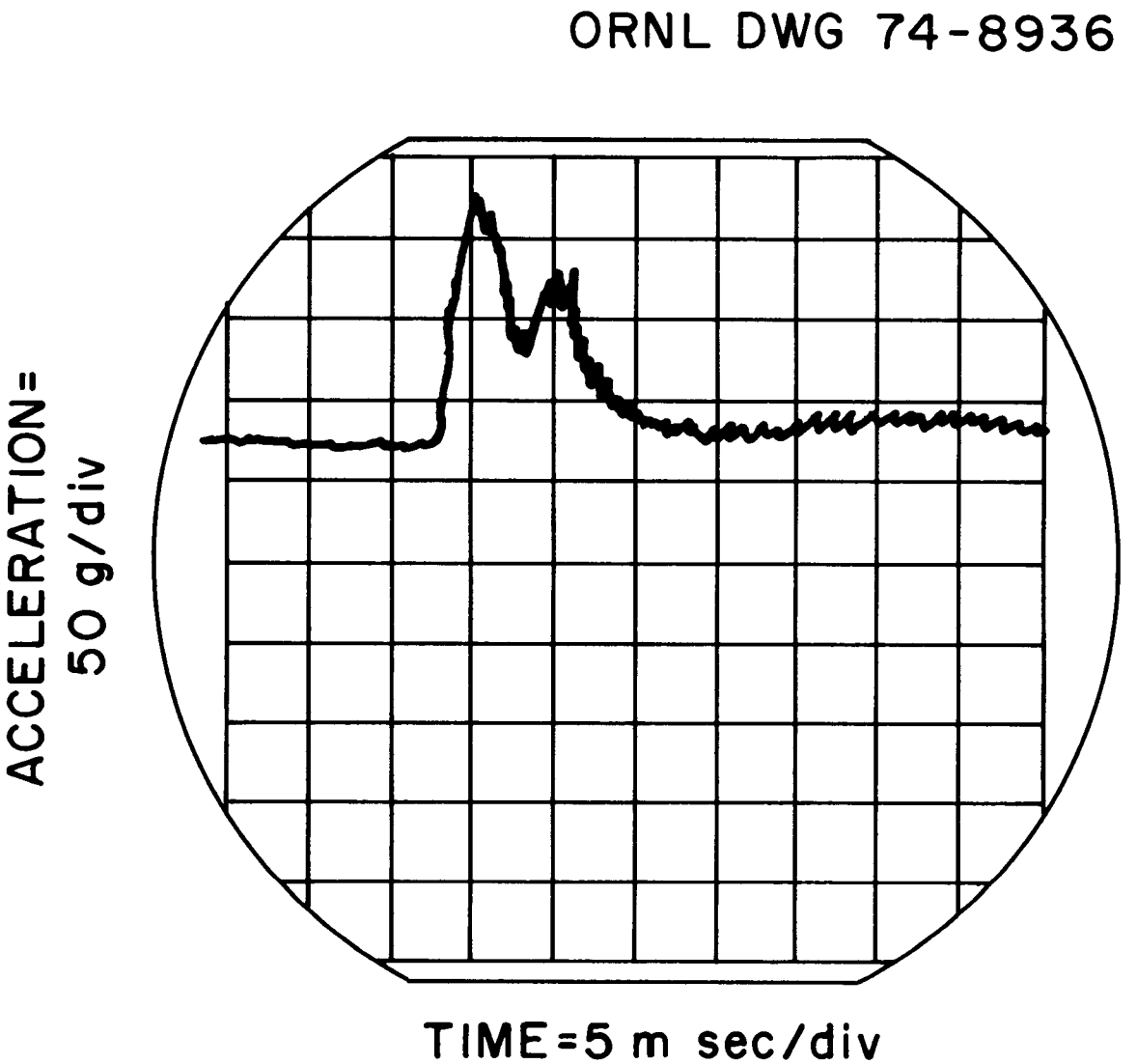

Fig. 14. Tracing of the acceleration-time trace for the end drop.

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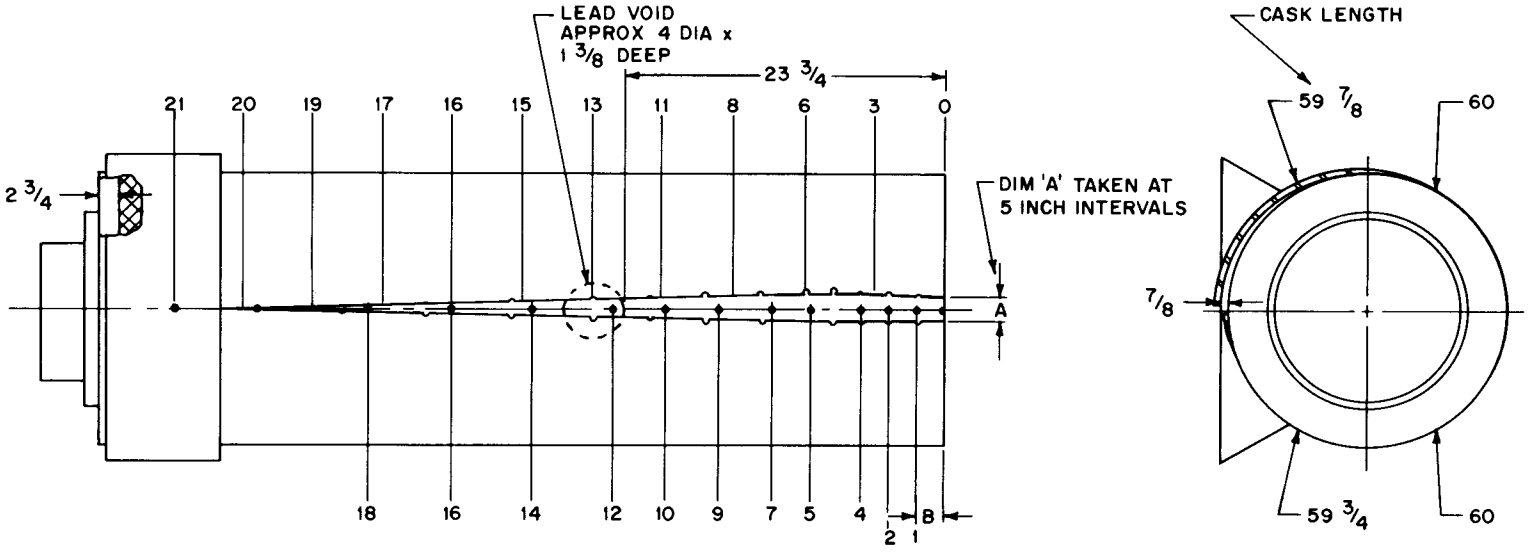

LOCATION	A	B	ORIG. B	LOCATION	A	B	ORIG. B
0	1 5/8	0	2	11	1 9/16		
1		2 3/16	4	12		23 11/16	25
2		4	6	13	1 3/8		
3	1 15/16			14		29 5/16	31
4		5 13/16	8	15	1		
5		9 1/2	10	16	3/4	35 1/16	37
6	1 15/16			17	1/2		
7		12 1/4	13	18		40 15/16	43
8	1 13/16			19	1/4		
9		16	17	20	1/16		
10		19 3/4	21	21			55

ALL DIMENSIONS
IN INCHES

Fig. 15. Drawing of cask damage sustained in end drop.

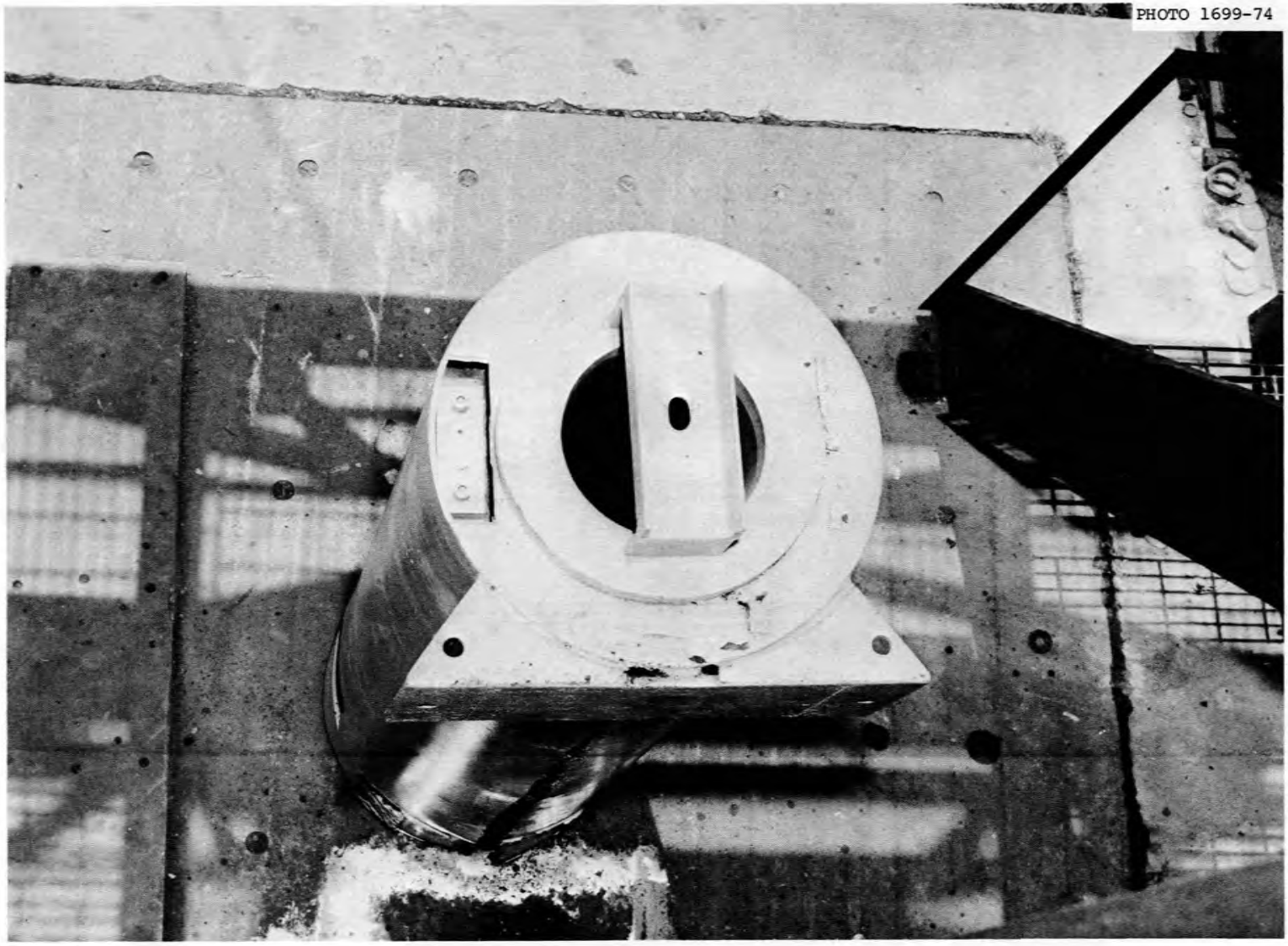

Fig. 16. Damage sustained in end drop - top view.

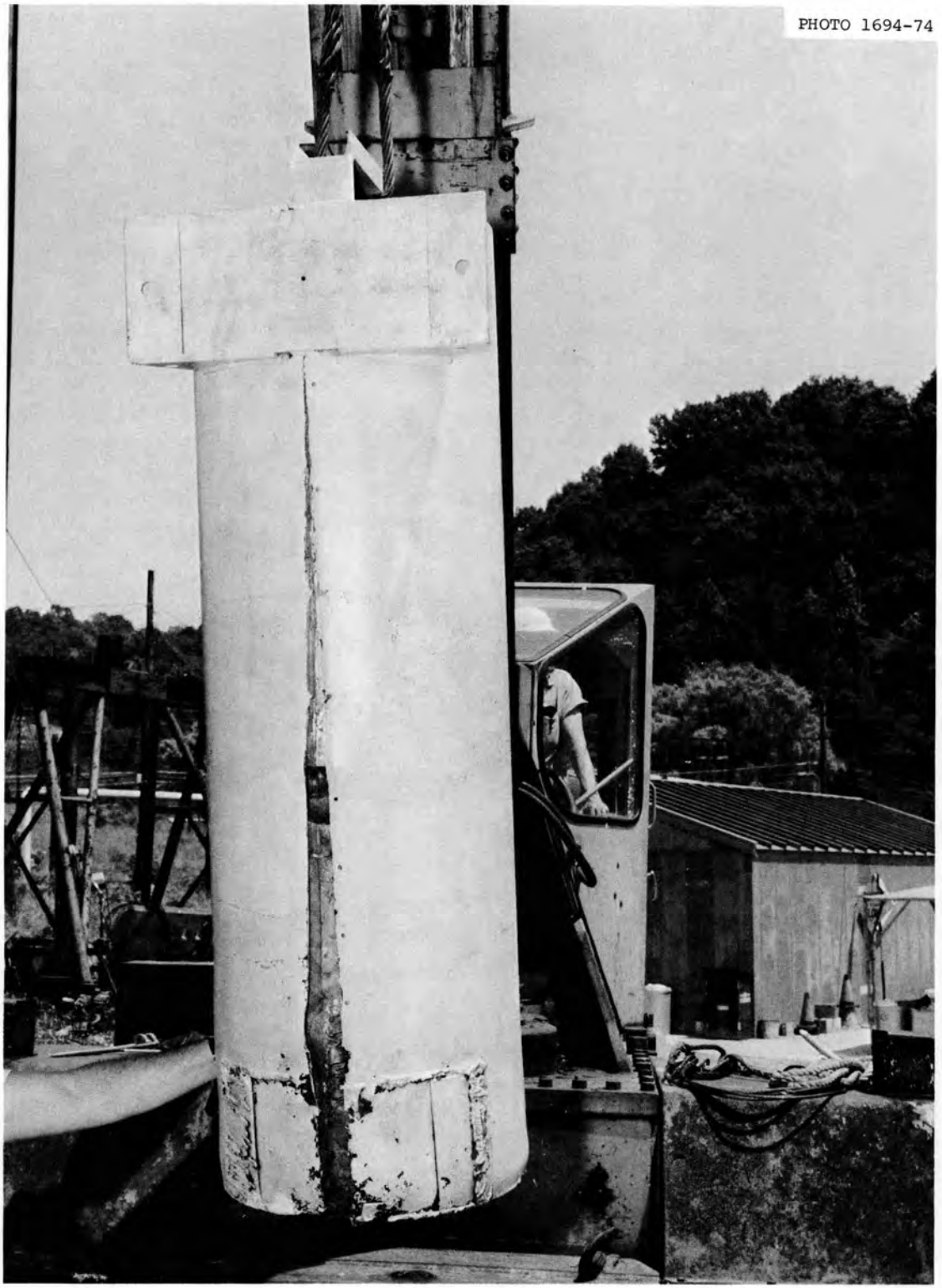

Fig. 17. Damage sustained in end drop - side view.

Fig. 18. Damage sustained in end drop - bottom view.

drilled in the outer shell of the cask may have contributed to the seam weld failure. Post-test examination of the failed welds indicated several spots in which the weld was only partially fused; in addition, there was an estimated 1/8-in. mismatch in the 1/4-in. shell at the seam weld in some locations.

There was a general settling of lead as a result of the impact, as indicated in Fig. 15. It was also discovered that a void of several cubic inches had occurred in the lead shield at the time of fabrication. The presence of this void should not have affected the test or be considered significant since the cask was apparently filled with lead with its axis horizontal in lieu of current practices of pouring lead with the axis vertical. The plug was jammed in the cavity and could not be removed using commonly available tools.

Cask 2 was dropped on an edge in such a manner that the center of gravity was directly above the point of impact. During free fall, the cask became fouled with the accelerometer cables, severing them before the impact occurred. However, the recording accelerometers indicated peak accelerations of 200 g's at location 1 and 120 g's at location 2 (see Fig. 2 for accelerometer location).

A second edge drop was made with Cask 2 turned 180° as opposed to the previous impact point. Acceleration-time traces for location 1 on the cask and location 3 (see Fig. 8) on the impact surface were acquired (see Figs. 19 and 20); the other accelerometer systems malfunctioned due to undetermined causes, and no data were obtained.

The recording accelerometers again indicated peak accelerations of 200 g's for location 1 and 120 g's for location 2. Figure 21 is a sketch of the observed physical damage to the cask as a result of the two edge drops. Photographic records of the damage are shown in Figs. 22-24.

The damage, which was primarily local in nature, did not extend to locations far removed from the impact area. The gap between the lead and the top head, originally very small prior to the drop, was found to be 1/16 in. after the drop (see Fig. 25). The weld joining the shell to the head failed in the area of contact. In addition, local failure

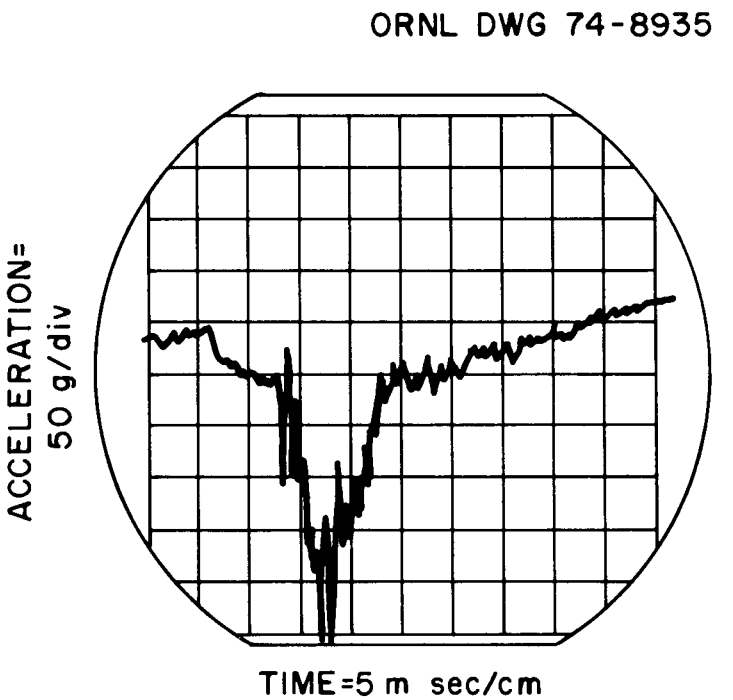

Fig. 19. Acceleration-time trace for cask — edge drop.

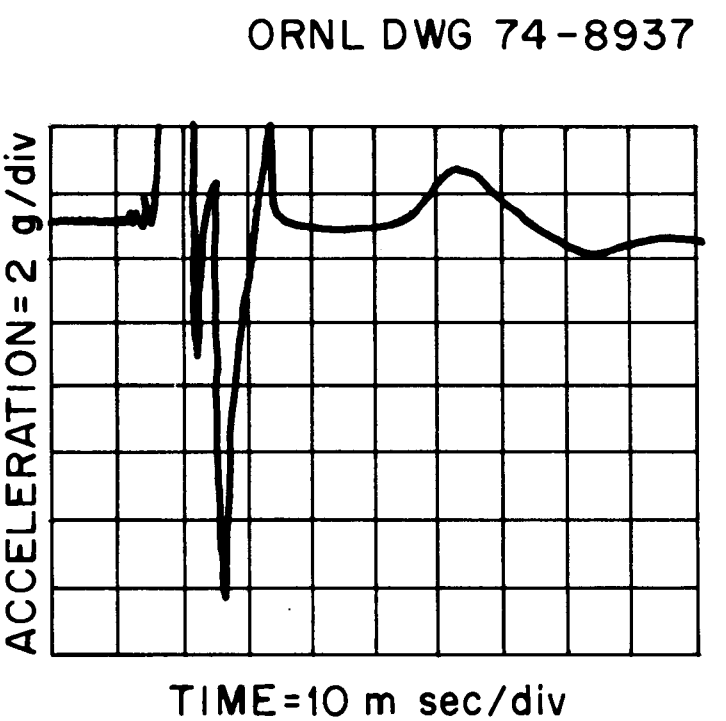

Fig. 20. Acceleration-time trace for the pad - edge drop.

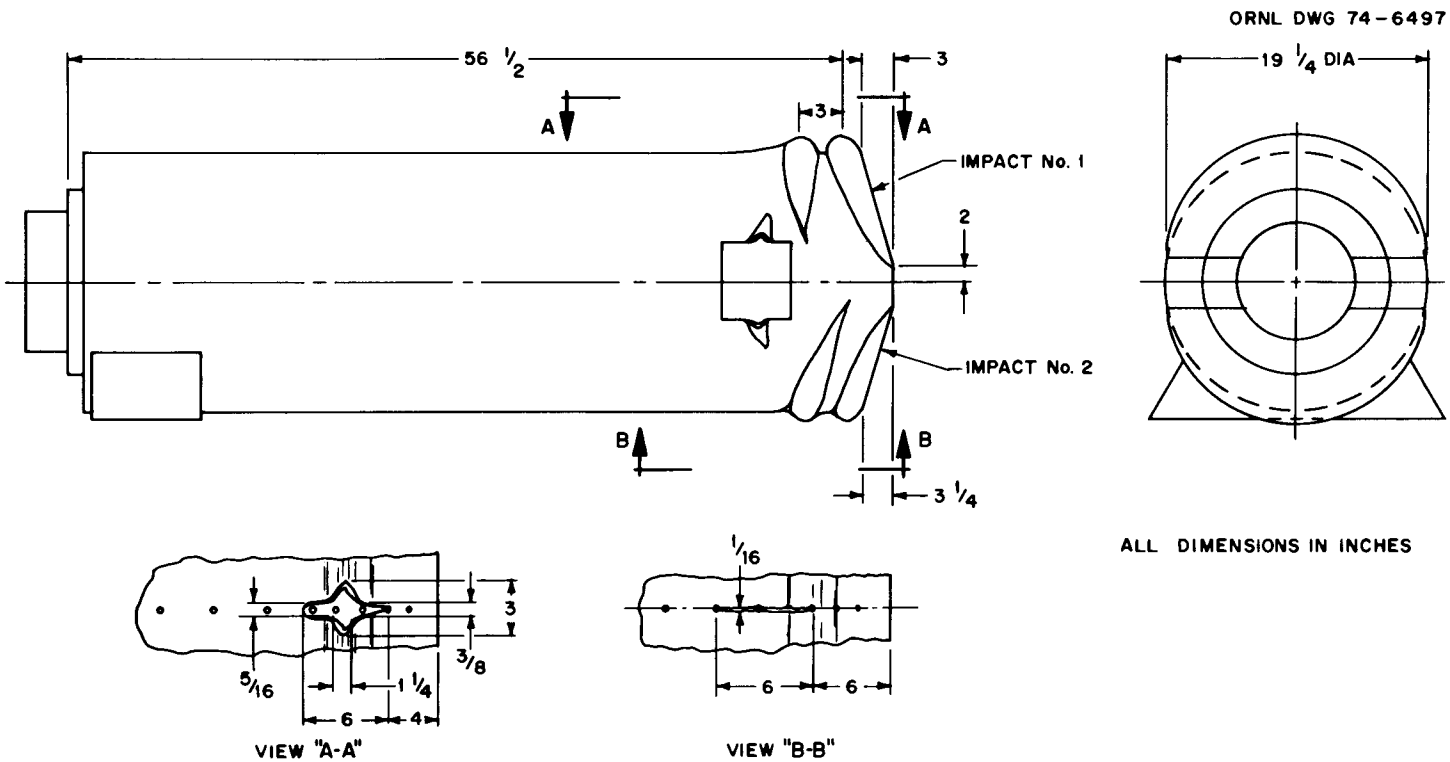

Fig. 21. Drawing of cask damage – two edge drops.

Fig. 22. Damage sustained in edge drop - end view.

Fig. 23. Damage sustained in edge drop - side view.

Fig. 24. Damage sustained in edge drop - end view.

Fig. 25. Damage sustained in edge drop.

occurred in the shell. The 1/4-in. holes that had been drilled through the shell to indicate lead movement probably contributed to the shell failure. The gross failure indicated in Fig. 21 was apparently the closure weld of the lead pour hole. Post-test visual examination of the failed welds indicated that inadequate weld penetration existed at the time of the drop test.

For each of the tests, the acceleration and time were scaled from the photographs of the oscilloscope traces and transferred to data cards. An existing computer program CIDR,[8] which numerically integrates the discrete force-time or acceleration-time data and obtains cask velocity and displacement as functions of time, was utilized to reduce the data.

Figure 26 is the computer plot of the acceleration-deformation data for the tests.

5. PREDICTIONS REGARDING DAMAGE

Prior to the tests, predictions of the damage to the casks were made using computer programs developed at ORNL. CEIR,[9] a program that predicts the deformation of a steel-jacketed, lead-shielded cask when dropped on end, was used to estimate the response of Cask 1. A movement or lead slump of 2.06 in. was predicted as a result of dropping the cask 30 ft onto a solid, essentially unyielding surface. A machine plot of the predicted acceleration-deformation curve is illustrated in Fig. 27.

Two programs, given in Appendix D and denoted as CCI-1 and CCI-2, were used to predict the response of Cask 2 in an edge impact. Analysis methods used in CCI-1 are based on the assumption that the cask is built of lead having a specific energy of 8000 in.-lb/in.^{3} This approximate value of the specific energy (sometimes called the dynamic flow pressure) has been observed in impacts of lead-shielded, steel-jacketed casks. Analysis methods used in CCI-2 are based on the assumption that energy deforming the steel head, the steel outer shell, and the lead shielding can be separated. The specific energy of the confined lead in this case was assumed to be 6000 in.-lb/in.^{3} Estimates of the energy required to bend the flat head and buckle the outer steel shell are based on limited

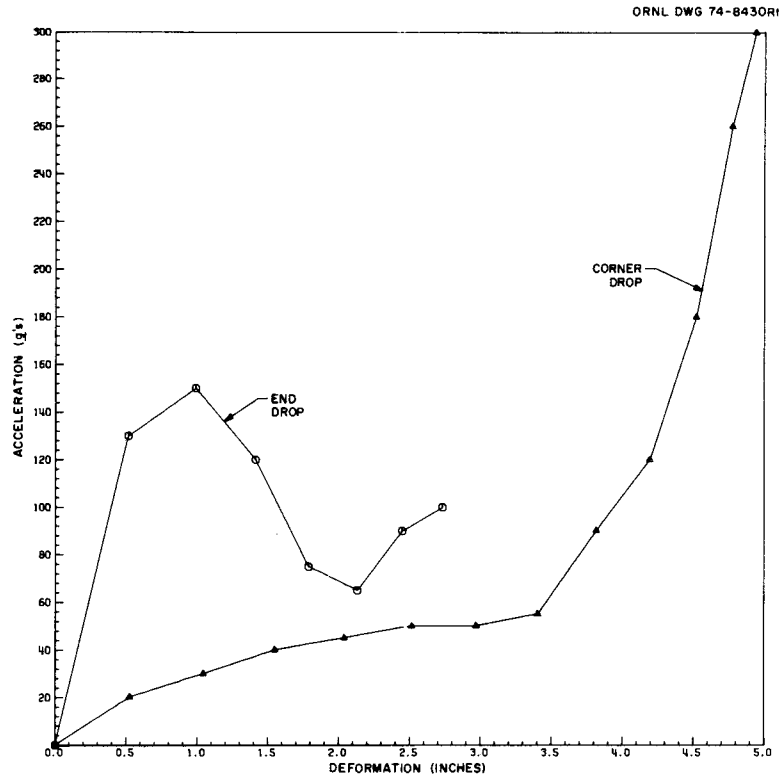

Fig. 26. Computer plot of acceleration-deformation data for end and edge drops.

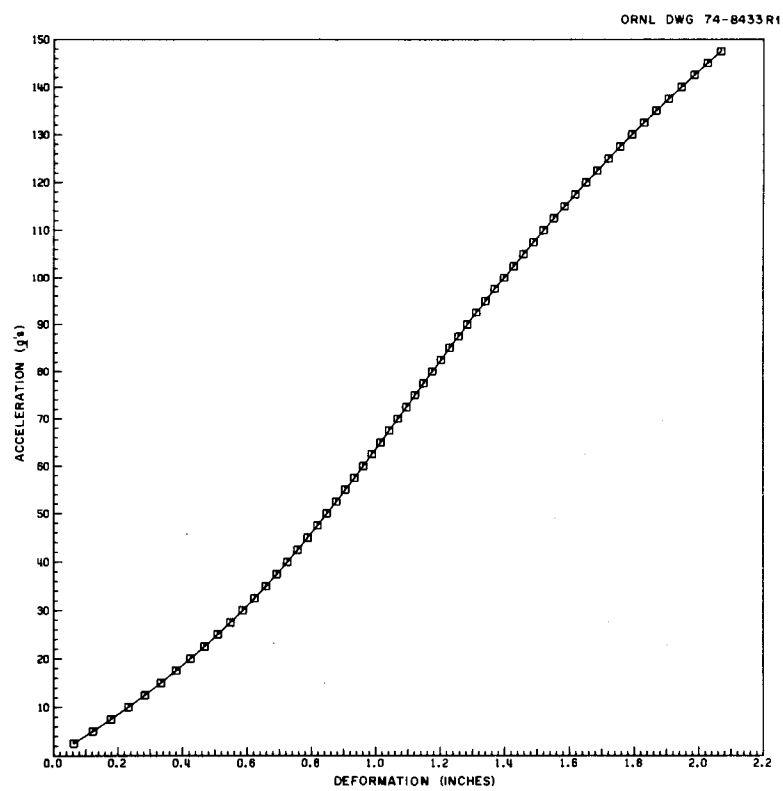

Fig. 27. Computer plot of acceleration vs deformation as predicted by CEIR for Cask 1 dropped on end.

available dynamic data. The two programs (CCI-1 and CCI-2) predicted deformations of 3.4 in. and 4.0 in., respectively. The acceleration-deformation responses of the cask are shown in Figs. 28 and 29 for the two drops.

It was also predicted that significant weld failures would occur in the impact area, particularly the shell-to-head weld. Previous tests[10] on similar welds in ASTM A-516 grade 55 low-alloy base metal had resulted in failure.

6. COMPARISON OF EXPERIMENTAL DATA AND CALCULATED VALUES

The calculated values and the experimental data were found to correlate reasonably well. For the end drop, a lead settlement of 2.06 in. was calculated using CEIR.[9] The actual settlement (see Fig. 15) was measured to be 2.75 in. A discrepancy such as this should be expected since the calculated value was based on the assumption that the outer steel shell would remain intact in the impact, dissipating some of the kinetic energy of the lead in circumferential tension. In fact, the outer shell failed. The calculated and experimental acceleration-deformation curves are reproduced for comparison in Fig. 30. Note that there is considerable difference in the shapes of the curves, as well as a significant numerical variation in the coordinates, although the predicted and measured accelerations are of the same order of magnitude. Some of the difference in the shapes of the curves can be attributed to the failure of the outer shell of the cask. Examination of the experimental data curve indicates that shell failure occurred quite early in the impact -- in the neighborhood of acceleration and deformation coordinates of (150 g's, 1 in.).

Deformation values of 3.4 in. and 4.0 in. were calculated for the edge drop, using the CCI-1 and CCI-2 codes respectively. Measured deformations for the two essentially identical edge drops (see Fig. 21) were 3 in. (first drop) and 3.25 in. (second drop). The curves of experimentally determined and computed acceleration-deformation data are reproduced in Fig. 31 for comparison. The curves have the same general shape,

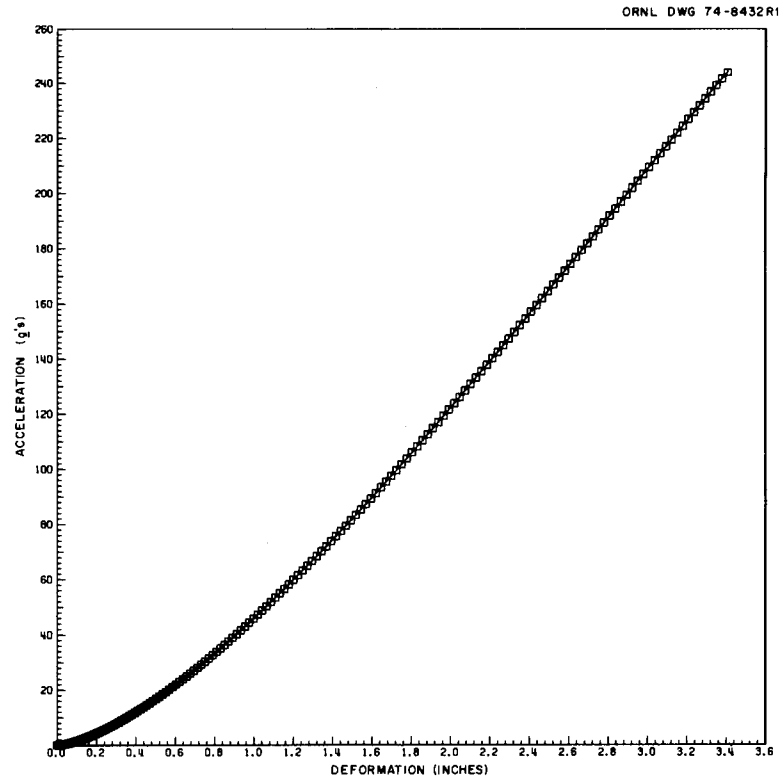

Fig. 28. Computer plot of acceleration vs deformation as predicted by CCI-1 for Cask 2 dropped on edge.

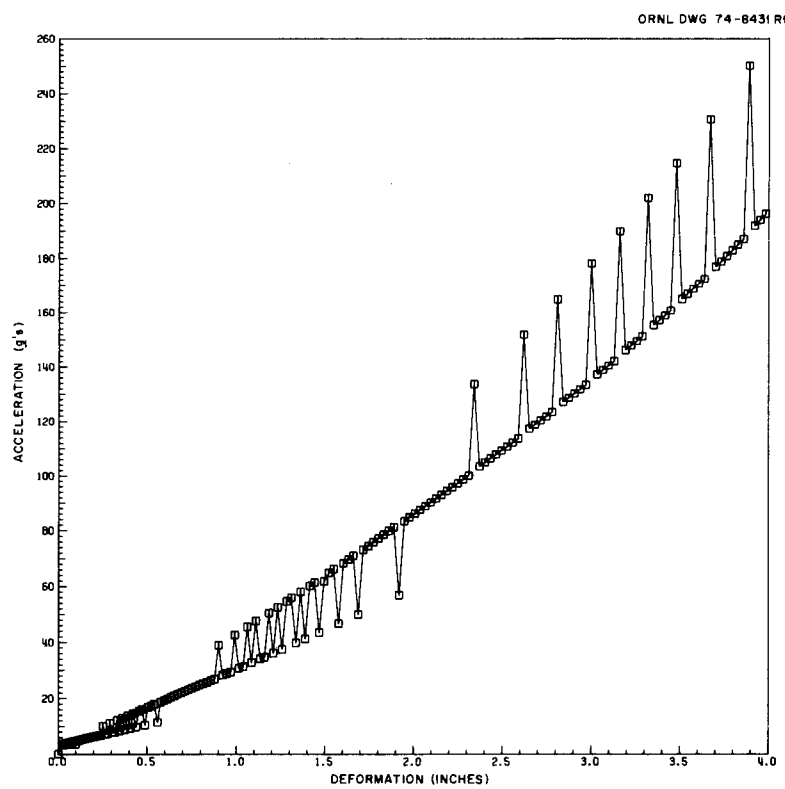

Fig. 29. Computer plot of acceleration vs deformation as predicted by CCI-2 for Cask 2 dropped on edge.

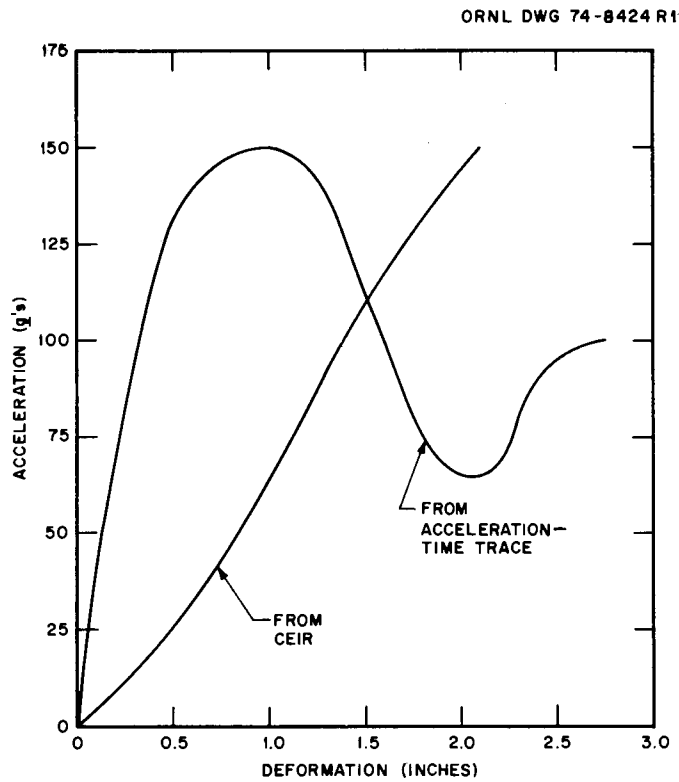

Fig. 30. Acceleration-deformation plots for end drop.

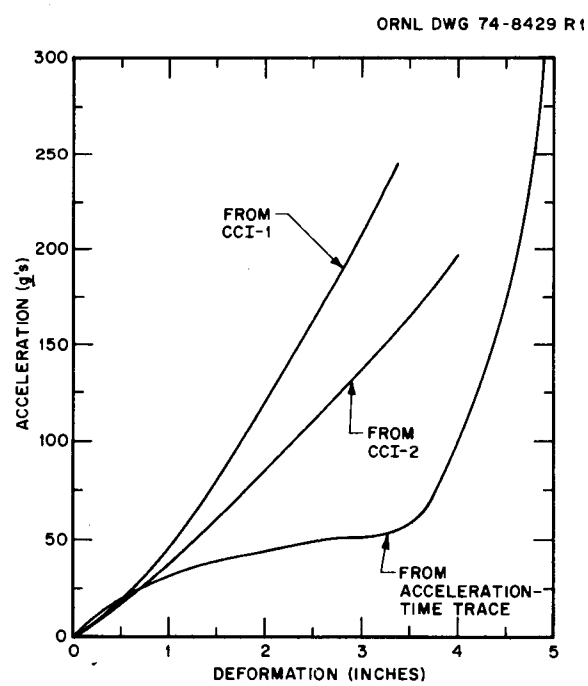

Fig. 31. Acceleration-deformation plots for edge drop.

although significant variations in values are evident. Note, however, that the computed values are of the same magnitude as the measured values.

7. CONCLUSIONS

The experimentally determined and calculated responses of the test casks were in sufficient agreement to warrant continued use of the basic calculational methods employed. It should be noted that current predictions are not always conservative; consequently, there may be a need to add a small margin of safety to them. Certainly, improvements in present analysis methods can be made as a result of a better understanding of the modes in which large casks might fail. It is apparent that welds need to be of high quality if they are to withstand, without rupture, the severe impact required by the regulations. Improvements need to be made in the data acquisition system for future tests.

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6. J. H. Evans, Structural Analysis of Shipping Casks. X. Experimental and Analytical Evaluation of the Tubes in Pipe Energy Absorber, ORNL-TM-1312, Vol. 10 (July 1971).

7. J. H. Evans, Structural Analysis of Shipping Casks. VIII. An Experimental and Analytical Study of the Stress-Strain Properties of Lead Under Specified Impact Conditions, ORNL-TM-1312, Vol. 8 (August 1970).

8. J. H. Evans, "Impact Testing of Chemical Lead, Cask Models, and an Energy Absorbing Device," Proceedings of the Third International Symposium on the Packaging and Transportation of Radioactive Materials, Richland, Washington, August 16-20, 1971 (CONF-710801), Vol. 2.

9. J. H. Evans, Structural Analysis of Shipping Casks. XIII. CEIR: A FORTRAN Program for Estimation of the Response of Cylindrical Lead-Shielded Cask to End Impacts, ORNL-TM-1312, Vol. 13 (June 1974).

10. J. H. Evans, H. A. Nelms, and W. C. Stoddart, "Experimental and Analytical Developments at Oak Ridge National Laboratory for Demonstrating Compliance with Federal Regulations," Proceedings of the Second International Symposium on Packaging and Transportation of Radioactive Material, Gatlinburg, Tenn., Oct. 14-18, 1968 (CONF-681001).

APPENDIX A:

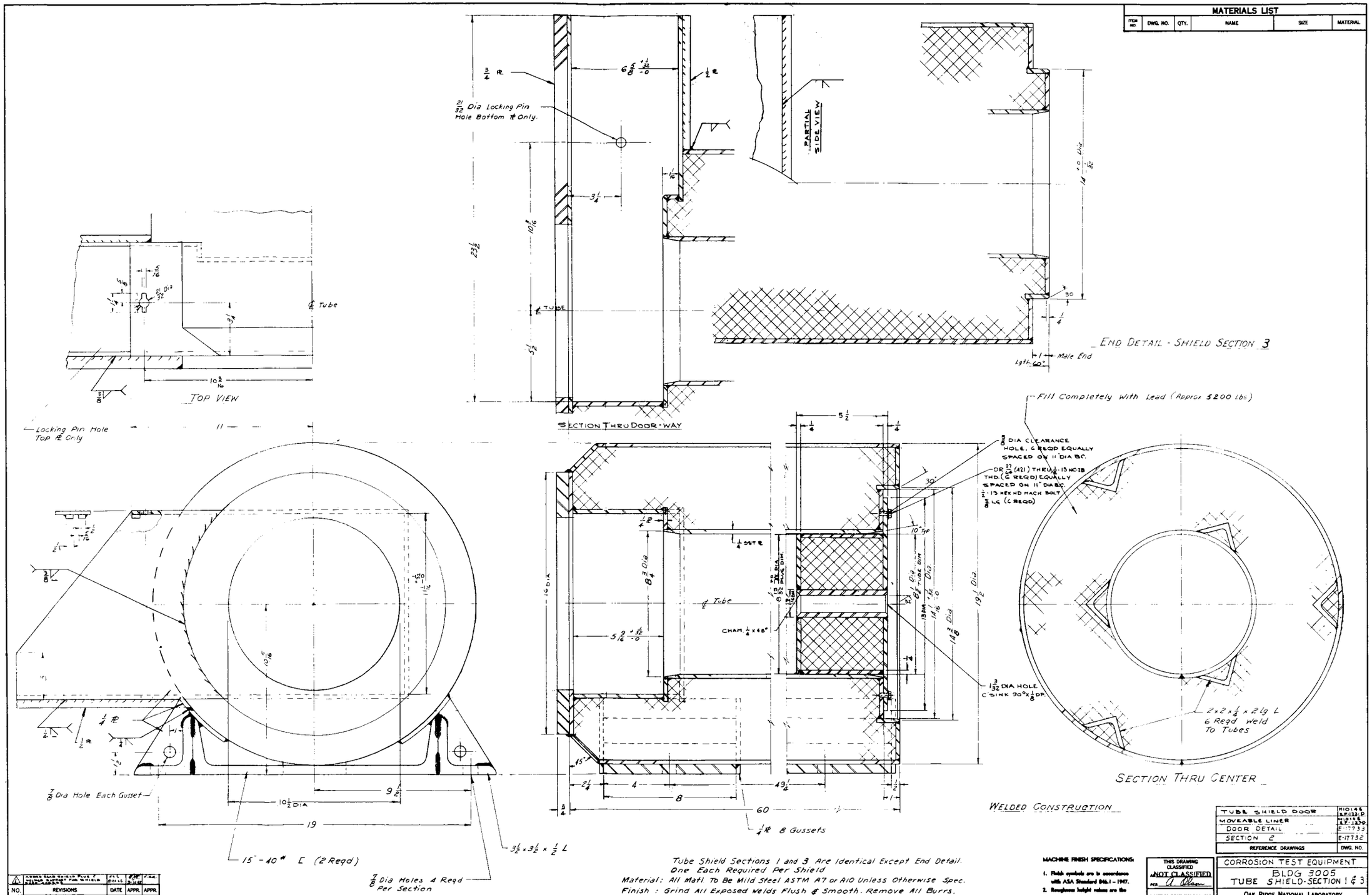
ADVISORY COMMITTEE

Name	Company	Address
D. R. Alvord	Aerojet Nuclear	Idaho Falls, Idaho
Robert L. Chandler	AEC/SROO	Aiken, S. C.
C. L. Brown	Battelle Northwest	Richland, Wash.
Ross Chappell	AEC/REG	Bethesda, Md.
Bob Donham	LASL	Los Alamos, N. M.
John Evans	ORNL	Oak Ridge, Tenn.
Robert I. Elder	AEC/CH	Argonne, Ill.
Louis Fuka	LASL	Los Alamos, N. M.
John W. Langhaar	DuPont Company - AED	Wilmington, Delaware
Elmer Lusk	Battelle Columbus Lab.	Columbus, Ohio
C. E. MacDonald	AEC/REG	Washington, D. C.
W. C. McCluggage	AEC/DOS	Washington, D. C.
L. B. Shappert	ORNL	Oak Ridge, Tenn.
James A. Sisler	AEC/WMT	Washington, D. C.
David R. Smith	LASL	Los Alamos, N. M.
Soung-Nan Liu	Battelle Northwest	Richland, Wash.
William J. Stone	AEC/ALO	Albuquerque, N. M.

APPENDIX B:

ORIGINAL ENGINEERING DRAWINGS OF CASKS

MATERIALS LIST					
ITEM NO.	DWG. NO.	QTY.	NAME	SIZE	MATERIAL



Tube Shield Sections 1 and 3 Are Identical Except End Detail.
One Each Required Per Shield
Material: All Matl. To Be Mild Steel ASTM A7 or A10 Unless Otherwise Spec.
Finish : Grind All Exposed Welds Flush & Smooth. Remove All Burrs.
Paint Mild Steel Surfaces With Gray Amercoat #33 Per Mfg's Spec.
Weight : Stamp Approx Wt "6200 Lbs" On Top Side

MACHINE FINISH SPECIFICATIONS:

1. Finish symbols are in accordance with ASA Standard B46.1 - 1947.
2. Roughness height values are the maximum arithmetical average deviation from the mean surface, expressed in microinches.
3. For surfaces not otherwise indicated, roughness height shall not exceed √.

THIS DRAWING CLASSIFIED	
NOT CLASSIFIED	
PER	
LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED	
FRACTIONS: ± 1/16	
DECIMALS: ±	
ANGLES: ± 1°	
SCALE: 1/2 = 1	

TUBE SHIELD DOOR		H10148	
MOVEABLE LINER		H10148	E-17230
DOOR DETAIL		E-17733	
SECTION 2		E-17732	
REFERENCE DRAWINGS		DWG. NO.	

CORROSION TEST EQUIPMENT
BLDG 3005
TUBE SHIELD-SECTION 1 & 3

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
CARBIDE AND CARBON CHEMICALS COMPANY
A DIVISION OF UNION CARBIDE AND CARBON CORPORATION
OAK RIDGE, TENNESSEE

SUBMITTED: J. Ramey — ACCEPTED: A. Olson — APPROVED: H. W. West

34351-29
WO-A-3409

E-17731 REV. 1

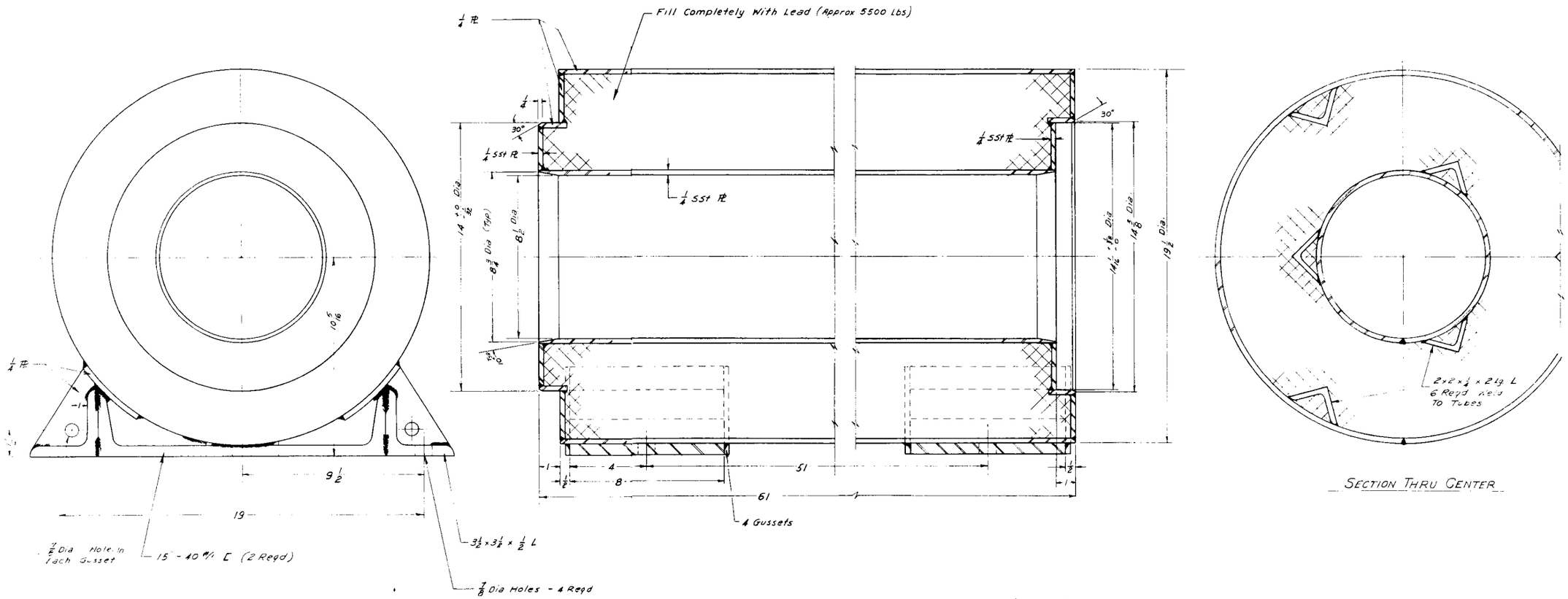
NO.	REVISIONS	DATE	APPR.	APPR.
1	ADDED REAR SHIELD PLATE & REVISED GUSSET FOR SHIELD	8-15-55		

DRAWING NO. E-

DRAWN	DATE	CHECKED	DATE	APPROVED	DATE
E F M	8-18-55	A. Olson	9-25-55		
DESIGNED	DATE	SUBMITTED	DATE	APPROVED	DATE
Marguerat		W A P	9-25-55		

HEALTH PHYSICS	MEDICAL	OPERATIONS	SAFETY
FIRE PROTECTION	RESEARCH SHOP	MAINTENANCE	

MATERIALS LIST					
ITEM NO.	DWG. NO.	QTY.	NAME	SIZE	MATERIAL



Material:
All Material To Be Mild Steel ASTM A7 or A10 Unless Otherwise Specified.

Finish:
Grind All Exposed Welds Flush & Smooth. Remove All Burrs
Paint Mild Steel Surfaces With Gray Amercoat #33 Per Mfg's Specs.

Weight:
Stamp Approx Wt. "6000 Lbs" On Top Side

NO.	REVISIONS	DATE	APPR.	APPR.

DRAWING NO. E-

DRAWN	DATE	CHECKED	DATE	APPROVED	DATE
E E W	9-18-59	A. Olson	9-25-59		
DESIGNED	DATE	SUBMITTED	DATE	APPROVED	DATE
Wargsberg		H A P	5-16-63		
HEALTH PHYSICS	MEDICAL	OPERATIONS	SAFETY		
FIRE PROTECTION	RESEARCH SHOP	MAINTENANCE			

MACHINE FINISH SPECIFICATIONS:

1. Finish symbols are in accordance with ASA Standard B46.1 - 1947.
2. Roughness height values are the maximum arithmetical average deviation from the mean surface, expressed in microinches.
3. For surfaces not otherwise indicated, roughness height shall not exceed √.

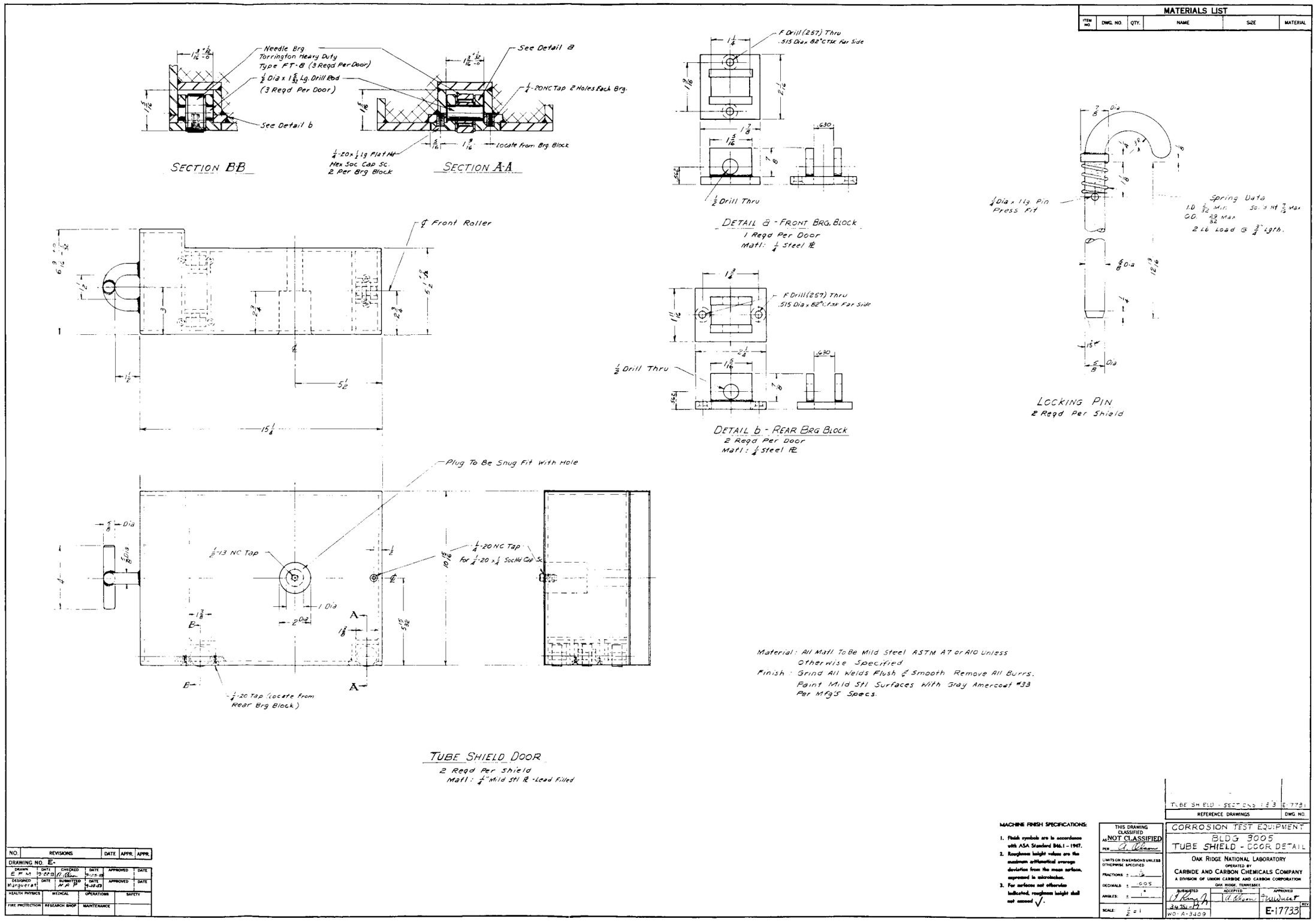
THIS DRAWING CLASSIFIED
AS NOT CLASSIFIED
PER A. Olson
LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
FRACTIONS: ± 1/16
DECIMALS: ±
ANGLES: ± 1°
SCALE: 1/2 = 1

CARRIAGE	E-17734
SECTION 1 & 3	E-17731
REFERENCE DRAWINGS	DWG. NO.

CORROSION TEST EQUIPMENT
BLDG 3005
TUBE SHIELD - SECTION 2

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
CARBIDE AND CARBON CHEMICALS COMPANY
A DIVISION OF UNION CARBIDE AND CARBON CORPORATION
OAK RIDGE, TENNESSEE

SUBMITTED	ACCEPTED	APPROVED
R. Ring Jr.	A. Olson	F W Wurst
3-6-61-14		
WO - A-3409		E-17732 REV


MATERIALS LIST
ITEM NO. | DWG. NO. | QTY. | NAME | SIZE | MATERIAL
Needle Brg. Torrington Heavy Duty Type FT-8 (3 Reqd Per Door)
1/2 Dia x 1 5/32 Lg. Drill Rod (3 Reqd Per Door)
See Detail b
SECTION B-B
See Detail a
1/4-20NC Tap 2 Holes Each Brg.
1/4-20 x 1/2 Lg Flat Hd Hex Soc Cap Sc. 2 Per Brg Block
Locate From Brg. Block
SECTION A-A
F Drill (.257) Thru .515 Dia x 82° CTSK Far Side
1/2 Drill Thru
DETAIL a - FRONT BRG. BLOCK
1 Reqd Per Door
Matl: 1/4 Steel PL
F Drill (.257) Thru .515 Dia x 82° CTSK Far Side
1/2 Drill Thru
DETAIL b - REAR BRG BLOCK
2 Reqd Per Door
Matl: 1/4 Steel PL
1/4 Dia x 1 Lg. Pin Press Fit
Spring Data
I.D. 3/32 Min. Sol. Ht 7/16 Max
O.D. 29/32 Max
2 Lb Load @ 3/4" Lgth.
LOCKING PIN
2 Reqd Per Shield
℄ Front Roller
Plug To Be Snug Fit With Hole
1/2-13 NC Tap
1/4-20 NC Tap For 1/4-20 x 1/4 SocHd Cap Sc.
1 Dia
1/4-20 Tap (Locate From Rear Brg Block)
TUBE SHIELD DOOR
2 Reqd Per Shield
Matl: 1/4" Mild Stl PL - Lead Filled
Material: All Matl. To Be Mild Steel ASTM A7 or A10 Unless Otherwise Specified
Finish: Grind All Welds Flush & Smooth Remove All Burrs. Paint Mild Stl Surfaces With Gray Amercoat #33 Per Mfg'S Specs.
TUBE SHIELD - SECTIONS 1 & 3 | E-17731
REFERENCE DRAWINGS | DWG. NO.
MACHINE FINISH SPECIFICATIONS:
1. Finish symbols are in accordance with ASA Standard B46.1 - 1947.
2. Roughness height values are the maximum arithmetical average deviation from the mean surface, expressed in microinches.
3. For surfaces not otherwise indicated, roughness height shall not exceed √.
THIS DRAWING CLASSIFIED AS NOT CLASSIFIED PER A. Olson
LIMITS ON DIMENSIONS UNLESS OTHERWISE SPECIFIED
FRACTIONS ± 1/16
DECIMALS ± .005
ANGLES ± 1°
SCALE: 1/2 = 1
CORROSION TEST EQUIPMENT
BLDG 3005
TUBE SHIELD - DOOR DETAIL
OAK RIDGE NATIONAL LABORATORY
OPERATED BY
CARBIDE AND CARBON CHEMICALS COMPANY
A DIVISION OF UNION CARBIDE AND CARBON CORPORATION
OAK RIDGE, TENNESSEE
SUBMITTED | ACCEPTED | APPROVED
34751-A
WO-A-3409
E-17733
NO. | REVISIONS | DATE | APPR. | APPR.
DRAWING NO. E-
DRAWN E F M | DATE 9-22-53 | CHECKED A. Olson | DATE 9-25-53 | APPROVED | DATE
DESIGNED Marguerat | DATE | SUBMITTED N A P | DATE 9-28-53 | APPROVED | DATE
HEALTH PHYSICS | MEDICAL | OPERATIONS | SAFETY
FIRE PROTECTION | RESEARCH SHOP | MAINTENANCE

APPENDIX C:

OBSOLETE CASK TESTING PROGRAM

Impact Test Description No. 73-4

Purpose – The tests outlined in subsequent paragraphs are the first of a sequence of tests which will be conducted to investigate and, hopefully confirm, the validity of certain calculational techniques currently employed to predict the behavior of casks when exposed to the impact specified in the regulations. Secondary goals of these tests are to establish or confirm material properties, to verify the adequacy of current data acquisition techniques and equipment, to develop additional data acquisition techniques as necessary, and to develop information on the cost of preparing for and conducting tests.

Cask Description – The first two casks we propose to test weigh 6200 and 6000 pounds and are an end and the center sections of the ORNL Tube Shield Cask, which was originally built in three sections. The end section is identified as Cask No. 1 and the center section as Cask No. 2. The cask was fabricated from ORNL drawings E-17731, E-17732, and E-17733. It is identified by ORNL number 5S-18-141. The salient features of the casks and the modifications to be effected for this test are illustrated on ORNL drawings M-11577-EM-001-E for Cask No. 1 and M-11577-EM-002-E for Cask No. 2.

Pre-Test Preparation – The casks will be disassembled by ORNL P&E Division personnel and surveyed for contamination by ORNL Health Physics. If contaminated, the cask will be decontaminated to green tag limits.* All painted surfaces will be sandblasted to bare metal. Lead cavities will be checked for moisture and contamination via pipe taps installed for this purpose. The lead cavities will be leak checked and leaks repaired. The modifications shown on drawings M-11577-EM-001-E and M-11577-EM-002-E will be made and a dimensional inspection of the complete test cask performed and the results recorded. The modified casks will be weighed.

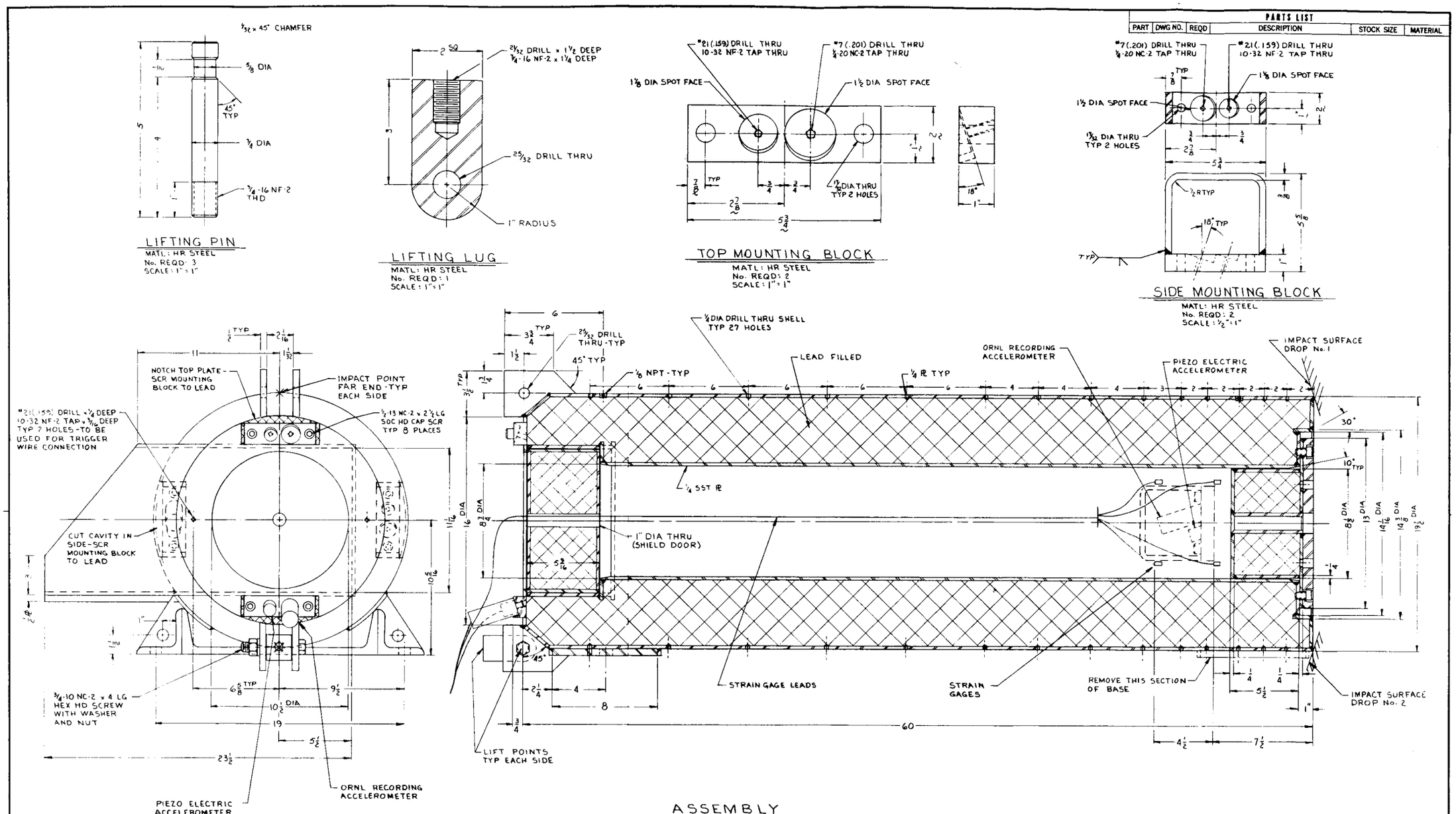
Test Philosophy – Cask No. 1 will be dropped twice on edge in an orientation such that the center of gravity of the cask and the point of impact are in the same vertical plane. The intended impact points are identified on drawing -001. Piezoelectric accelerometers and "peak" recording accelerometers will be mounted in the location shown on the drawing for these tests. The instrumentation system shown in Fig. 1 will be used to measure and record the acceleration with respect to time for each test. Post yielding strain gages will be mounted on the cask in those locations shown on the drawing. Readings will be taken before and after each test. A graphical map of the damaged area will be produced by applying a grid to the impact area before dropping and measuring after impact.

---

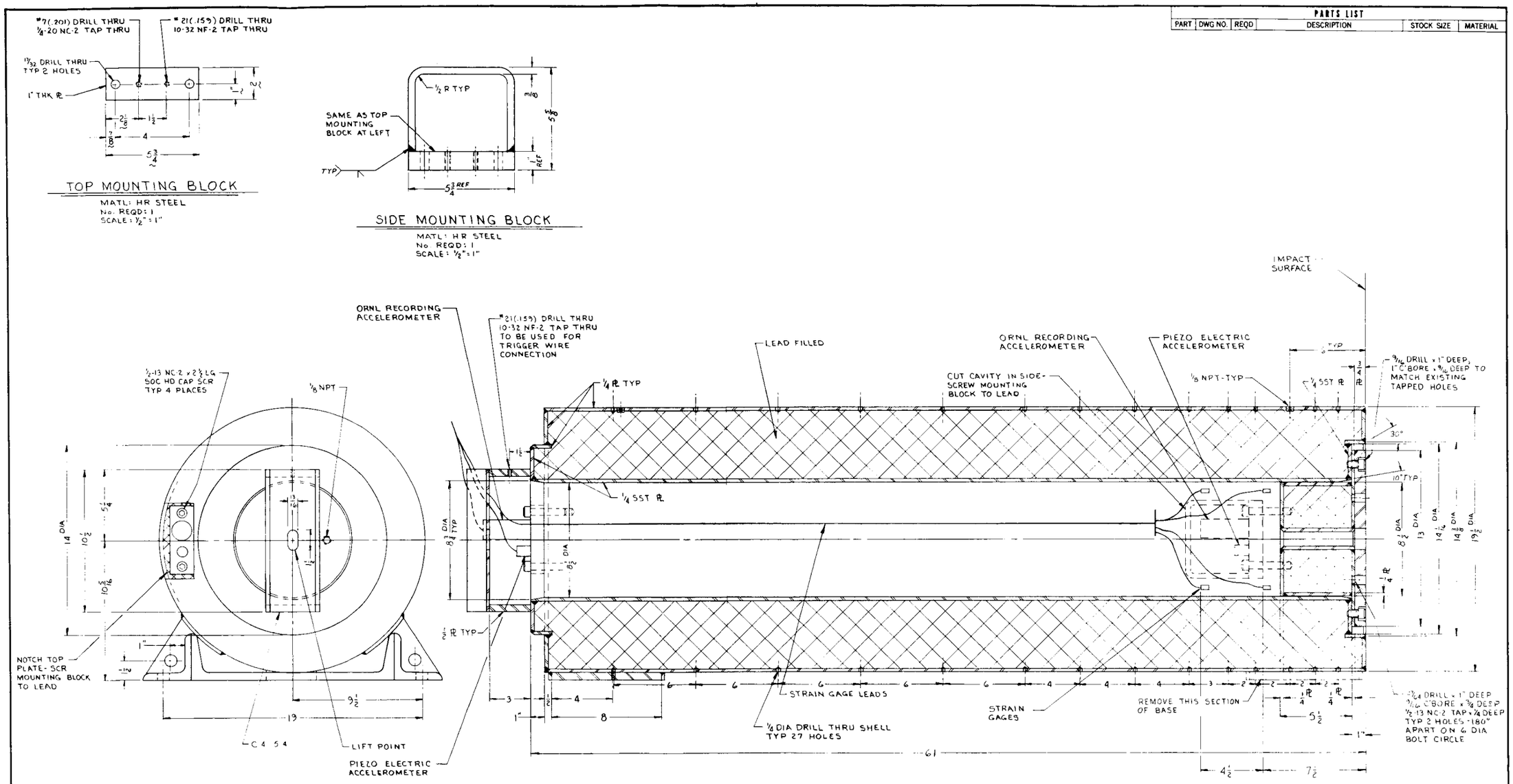
*Green tag limits restrict direct survey readings to $<300\ \alpha$ dpm/100 cm^2 and <0.05 mrad/hr β, transferable contamination to $<30\ \alpha$ dpm/100 cm^2 and $<200\ \beta$, dpm/100 cm^2.

Cask No. 2 will be dropped on its end as identified on the drawing. Piezoelectric and peak recording accelerometers will be mounted as indicated on the drawing. As before, post yielding strain gages will be mounted on the cask in the locations shown and "before" and "after" readings will be taken. A graphical map of the damaged area will also be made.

We will consider applying "Stresscoat" to selected areas where it will not interfere with the above. After the edge and end drops the container may be dropped on the 6-in.-diam bar from 40 in. if the damage from the 30 ft drop is such that it seems practical. The cask will be photographed extensively before and after each test, and each test will be photographed by both normal and high-speed movies.


PARTS LIST
PART | DWG NO. | REQD | DESCRIPTION | STOCK SIZE | MATERIAL
LIFTING PIN
MATL: HR STEEL
No. REQD: 3
SCALE: 1" = 1"
LIFTING LUG
MATL: HR STEEL
No. REQD: 1
SCALE: 1" = 1"
TOP MOUNTING BLOCK
MATL: HR STEEL
No. REQD: 2
SCALE: 1" = 1"
SIDE MOUNTING BLOCK
MATL: HR STEEL
No. REQD: 2
SCALE: 1/2" = 1"
ASSEMBLY
SCALE: 3/8" = 1"
APPROX. WEIGHT - 6200 LBS
SEE ORNL TEST DESCRIPTION 73-4
NOTCH TOP PLATE - SCR MOUNTING BLOCK TO LEAD
IMPACT POINT FAR END - TYP EACH SIDE
CUT CAVITY IN SIDE - SCR MOUNTING BLOCK TO LEAD
PIEZO ELECTRIC ACCELEROMETER
ORNL RECORDING ACCELEROMETER
LEAD FILLED
STRAIN GAGE LEADS
STRAIN GAGES
REMOVE THIS SECTION OF BASE
IMPACT SURFACE DROP No. 1
IMPACT SURFACE DROP No. 2
LIFT POINTS TYP EACH SIDE
1" DIA THRU (SHIELD DOOR)
TUBE SHIELD
E-17731
REFERENCE DRAWINGS
NUMBER
OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE
TESTING OF OBSOLETE CASKS
CORNER DROP
TEST No. 1 & 2
M 11577 EM 001

PARTS LIST					
PART	DWG NO.	REQD	DESCRIPTION	STOCK SIZE	MATERIAL



ASSEMBLY

SCALE: 3/8" = 1"

APPROX. WEIGHT - 6000 LBS.

SEE ORNL TEST DESCRIPTION 73-4

NO REPRESENTATION OR WARRANTY, EXPRESSED OR IMPLIED, IS MADE THAT THE USE OR DISCLOSURE OF ANY INFORMATION, APPARATUS, METHOD OR PROCESS DISCLOSED IN THESE DRAWINGS MAY NOT INFRINGE PRIVATE RIGHTS OF OTHERS. NO LIABILITY IS ASSUMED WITH RESPECT TO THE USE OF, OR FOR DAMAGES RESULTING FROM THE USE OF, ANY INFORMATION, APPARATUS, METHOD OR PROCESS DISCLOSED IN THESE DRAWINGS. THE DRAWINGS ARE BEING MADE AVAILABLE FOR INFORMATION TO BIDDER AND ARE NOT TO BE USED FOR OTHER PURPOSES AND ARE TO BE RETURNED UPON REQUEST OF THE FORWARDING CONTRACTOR.

GENERAL SPECIFICATIONS

UNLESS OTHERWISE SPECIFIED:
1. BREAK ALL SHARP EDGES
2. TYPE, GRADE, OR FINISH OF MATERIAL MAY BE CHOSEN BY FABRICATOR.
3. MACHINED SURFACE FINISH SHALL NOT EXCEED: (ASA B46.1-1962) ✓

TOLERANCES UNLESS OTHERWISE SPECIFIED:
FRACTIONS ± 1/16
DECIMALS ±
ANGLES ± 1°
SCALE: NOTED

NO.	REVISIONS	DATE	APPD	APPD

DRAWN	DATE	SUBMITTED	DATE	APPROVED	DATE
N. ROBERTS	10-5-73			BYE	3/26/74
DESIGNED	DATE	APPROVED	DATE	APPROVED	DATE
J. EVANS	10-3-73				
CHECKED	DATE	APPROVED	DATE	APPROVED	DATE

TUBE SHIELD — E-17732

REFERENCE DRAWINGS — NUMBER

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

TESTING OF OBSOLETE CASKS — BLDG. NO.

END DROP
TEST No. 3

DESIGNED — ACCEPTED — APPROVED

M 11577 EM 002 E REV.

APPENDIX D:

LISTINGS FOR PROGRAMS CCI-1 AND CCI-2

CCI-1 PROGRAM

```
**FTN,L,E,G.
C              PROGRAM NUMBER  1001-CASK
C  MADE OF A HOMOGENEOUS MATERIAL / AN IDEAL STRESS-STRAIN RELATIONSHIP
C  IMPACTING AN UNYIELDING SURFACE. THE CASK IMPACTS ON ITS CORNER
C  THIS PROGRAM COMPUTES THE RESPONSE OF A CASK HAVING RIGHT CYLINDRICAL
C  GEOMETRY.
C   BY JOHN EVANS P.E., GENERAL ENGINEERING DIVISION, OAK RIDGE NATIONAL LAB.
C
C                       GLOSSARY OF NOTATION
C            R=RADIUS OF CASK
C            C=CASK LENGTH
C            S=YIELD STRESS OR FLOW PRESSURE
C            W=CASK WEIGHT
C            H=DROP HEIGHT
C            O=ANGLE AT WHICH CASK IMPACTS
C            U=ENERGY
C            F=FORCE
C            T=TIME
C            AG=ACCELERATION
C            UT=TOTAL ENERGY
C            V=VELOCITY
C            X=DEFORMATION
C            AN=ANGLE IN CONTACT / THE SURFACE
C
      DIMENSION V(1000),AR(1000),F(1000),U(1000),T(1000),AN(1000),
     1 X(1000),AG(1000)
      S=0.0
      ANA = 0.0
C  INPUT MATERIAL CONSTANT
C  INPUT CASK GEOMETRY
      R=9.5
      C=60.
      W=6000.
      O=ATAN(2.*R/C)
C  INPUT TEST CONDITION
      H=360.
C  INPUT ANGLE INCREMENTS
   30 BB=.01
      AA=.01
      S=8000.
      WRITE (51,1002)
      WRITE (51,1002)
      WRITE (51,1010)
 1010 FORMAT(1H ,30X,'TESTING OF OBSOLETE CASKS, TEST 1')
      WRITE (51,1002)
      WRITE (51,1002)
C  ZERO SUBSCRIPTED VARIABLES
      DO 14 I=1,1000
      AN(I)=0.0
      AG(I)=0.0
      V(I)=0.0
      X(I)=0.0
      T(I)=0.0
      F(I)=0.0
      U(I)=0.0
      AR(I)=0.0
   14 CONTINUE
```

```
C  ZERO NONSUBSCRIPTED VARIABLES
      TA=0.0
      AE=0.0
      A=0.0
      AR=0.0
      TX=0.0
      U=0.0
      XX=0.0
      XA=0.0
      UT=W*H
      VV=SQRT((64.*H)/12.)
      DO 1 I=1,1000
      AR=0.0
C  INCREMENT ANGLE A
    9 A=A+AA
      CA=COS(A)
      B=0.0
      AE=0.0
      SUMU=0.0
   10 DO 2 J=1,1000
C  INCREMENT ANGLE B
      B=B+BB
      CB=COS(B)
C  CALCULATE VOLUME DISPLACED
   11 CC=(CB-CA)
      BY=TAN(O)*R*CC
      BX=R*CC
   12 DZ=R*CB*BB
      DU=BY*BX*DZ*S
C  CALCULATE ENERGY ABSORBED
      SUMU=SUMU+DU
C  CALCULATE AREA
   13 DA=2.*BX*DZ/COS(O)
      AE=AE+DA
      IF(B.GE.A) GO TO 3
    2 CONTINUE
    3 U(I)=SUMU
      IF(U(I).GE.UT) GO TO 4
      AR(I)=AE
C  CALCULATE FORCE
      F(I)=AR(I)*S
C  CALCULATE VELOCITY
    5 VA  =SQRT((64./(12.*W))*(UT-U(I)))
C CALCULATE ACCELERATION
      AG(I)=F(I)/W
C CALCULATE DEFORMATION
      XA  =(TAN(O)*COS(O)*R*(1.-CA))
      X(I)=XA
C CALCULATE TIME
      TX=(XA-XX)/((VV+VA)*6.)
    7 TA=TA+TX
      T(I)=TA*1000.
      XX=XA
    6 V(I)=VA
    8 VV=VA
      AN(I)=A*57.3
      IF(U(I).GE.UT) GO TO 4
```

```
    1 CONTINUE
    4 CONTINUE
C     OUTPUT-WRITE LOOP
      K=I-1
      WRITE (51,1002)
      WRITE(51,1004)
 1004 FORMAT (1H, 9X,37HCASK GEOMETRY AND MATERIAL PROPERTIES)                1
      WRITE (51,1002)
      WRITE(51,1005)
 1005 FORMAT (1H, 4X,6HRADIUS,8X,6HLENGTH,10X,6HWEIGHT,6X,                    3
     1        15HSPECIFIC ENERGY)
      WRITE(51,1006)
 1006 FORMAT (1H, 4X,6HINCHES,8X,6HINCHES,10X,6HPOUNDS,8X
     1        13HLB-IN/CU. IN.)
      WRITE(51,1002)
 1002 FORMAT(1H0)
      WRITE(51,1007) R,C,W,S
 1007 FORMAT (F11.3,F14.3,F16.1,F18.1)
      WRITE(51,1002)
      WRITE(51,1000)
 1000 FORMAT (1H.,4X,11HDEFORMATION,4X,8HVELOCITY,7X,4HTIME,13X,5HFORCE,      13
     1        10X,6HENERGY,5X,12HACCELERATION)
      WRITE(51,1001)
 1001 FORMAT (1H, 6X,6HINCHES,7X,8HFT./SEC.,4X,12HMILLISECONDS,8X,            16
     1        6HPOUNDS,10X,6HLB-IN.,10X,3HX G)
      WRITE(51,1002)
      DO 15 I=1,K
      WRITE(51,1003) X(I),V(I),T(I),F(I),U(I),AG(I)
 1003 FORMAT(1H ,F14.4,F13.2,F16.5,F15.2,F16.2,F12.2)
   15 CONTINUE
      CALL QWIKPL(X,AG,K,'LINEAR','J.H.EVANS$')
   20 CONTINUE
      STOP
      END
```

CCI-2 PROGRAM

```
**FTN,L,E,G.
C                    PROGRAM NUMBER 1007-CASK
C
C
C   THIS PROGRAM ANALYZES THE IMPACT OF A CLAD LEAD SHIELDED CASK HAVING RIGHT
C   CYLINDRICAL GEOMETRY, IMPACTING WITH ITS AXIS INCLINED AT AN ANGLE
C  CODED BY JOHN H. EVANS P. E. OAK RIDGE NATIONAL LABROTORY AUG. 1973
C
C              TESTING OF OBSOLETE CASKS
C
C
C                         GLOSSARY OF NOTATION
C
C                   X=DEFLECTION(INCHES)
C                   U=ENERGY(LB-INCHES)
C                   P=FORCE(POUNDS)
C                   T=TIME(MILISECONDS)
C                   AG=ACCELERATION(G'S)
C                   B=ANGLE SUBTENDED BY THE DEFORMED AREA(DEGREES)
C                   V=VELOCITY(FT/SEC)
C                   W=WEIGHT OF THE CASK(POUNDS)
C                   H=DROP HEIGHT(INCHES)
C                   C=CASK LENGTH(INCHES)
C                   R=CASK RADIUS(INCHES)
C                   O=ANGLE SUBTENDED BY THE DEFORMED AREA(RADIANS)
C                   UT=TOTAL POTENTIAL ENERGY OF THE CASK (LB-INCHES)
C                   T=SHELL THICKNESS (IN.)
C                   TH=HEAD THICKNESS,PLUG END (IN.)
C                   TAH=HEAD THICKNESS,BOTTOM END (IN.)
C                   W=CASK WEIGHT (POUNDS)
C                   SL=SPECIFIC ENERGY OF SHIELDING MATERIAL  (IN-LB/CU.IN)
C                   ST=SPECIFIC ENERGY OF CLADDING IN TENSION (IN-LB/CU IN)
C                   SC=SPECIFIC ENERGY OF CLADDING IN COMPRESSION (IN-LB/CU IN)
C                   SB=SPECIFIC ENERGY OF CLADDING IN BENDING (IN-LB/CU IN)
C                   OO=INCREMENT OF ANGLE O
C                   TM=TIME (SEC.)
C                   G=ACCELERATION (FT/SEC/SEC)
C                   B=O IN DEGREES
C                   VL=VOLUME OF SHIELDING DISPLACED (CU.IN.)
C                   A=ANGLE OF SHELL BENDING (RADIANS)
C                   US=ENERGY DISSIPATED IN STREACHING THE SHELL (IN.LB.)
C                   UH=ENERGY DISSIPATED IN DEFORMING THE HEADS  (IN.LB.)
C                   UL=ENERGY DISSIPATED IN DISPLACING SHIELDING (IN.LB.)
C                   UB=ENERGY DISSIPATED IN BENDING THE SHELL (IN.LB.)
C
C
      DIMENSION U(1000),X(1000),P(1000),G(1000),AG(1000),TM(1000)
     1,AP(1000),V(1000)
     2,UL(1000),UH(1000),US(1000),ULL(1000)
C  INPUT CASK GEOMETRY
      R=9.75
      CL=59.5
      T=.250
      TH=.250
      W=6000.
C  INPUT MATL. PROPERTIES
      EM=29000000.
```

```
      PR=.3
      SL=6000.
      ST=65000.
      SC=120000.
      SB=(ST+SC)/2.
C  INPUT CONSTANTS
      CP=2.094
      CPP=3.1416/2.
C  INPUT TEST CONDITION
      H=360.
C    CALCULATE CASK POTENTIAL ENERGY
      UT=W*H
C    INPUT INCREMENT OF ANGLE,O
      OO=.01
      DZ=.01
      AA=.002
C    ZERO SUBSCRIPTED VARIABLES
      DO 1  I=1,1000
      UL(I)=0.0
      ULL(I)=0.0
      UH(I)=0.0
      US(I)=0.0
      X(I)=0.0
      U(I)=0.0
      P(I)=0.0
      TM(I)=0.0
      G(I)=0.0
      AG(I)=0.0
      AP(I)=0.0
      V(I)=0.0
    1 CONTINUE
C    ZERO NONSUBSCRIPTED VARIABLES
      A=0.0
      B=0.0
      DT=0.0
      TS=0.0
      PU=0.0
      VV=0.0
      UU=0.0
      XX=0.0
      O=.1
      XO=.005
      ULL=0.0
      OLO=3.141593
      SUMX=0.0
      B=ATAN(R*2./CL)
      BB=SIN(B)
      CB=COS(B)
      TB=BB/CB
      FK=EM/(SQRT(3.*(1.-PR*PR)))
      FS=((FK*T*T)/R)
      DO 2 I=1,1000
      IF(O.GT.OLO)  GO TO 31
      IF(I.NE.1) GO TO 12
      V(I)= SQRT((64.*H)/12.)
   12 CONTINUE
      IF(I.EQ.1) GO TO 5
```

```
      CC=OO
      O=O+OO
      SO=SIN(O)
      SOO=SIN(2.*O)/2.
      CO=COS(O)
      STO=((SIN(2.*O))/2.)
C  SOLVE EQUATION 4 BY TRIAL AND ERROR
      C=0.
      DO 20 K=1,2000
      C=C+CC
      YC=R*TB*(COS(C)-CO)
      DELU= FS*YC*R*CC
      UCS=UCS+DELU
      IF(C.GE.O) GO TO 21
   20 CONTINUE
   21 CONTINUE
      US(I)=UCS
C  EQUATION 5
      US(I)=((T*T*C*SB*R*O)/2.)
      A=0.0
      Z=0.0
      VL=0.0
      DO 22,J=1,1000
      Z=Z+DZ
      A=ARCOS(1.-(Z/(R*TB)))
      IF(A.GT.O) GO TO 23
      SSA=(SIN(2.*A))
      SA=SIN(A)
      CA=COS(A)
C  EQUATION 1
      AREA=(((R*R)/2.)*(2.*A-SSA))
      DV=AREA*DZ
      VL=VL+DV
   22 CONTINUE
   23 CONTINUE
      UL(I)=VL*SL
      UH(I)=((.1194*SB*TH*TH*R*R*B)*(O-STO))
C  EQUATION  2
C  COMPUTE DEFORMATION
      X(I)=(R*(1.-CO)*TB)
      DEFO=X(I)
      IF(O.LE.OLO)  GO TO 32
   31 CONTINUE
      SUMX=SUMX+XO
      VLL=(3.141593*R*R*SUMX)
      ULL(I)=SL*VLL
      X(I)=DEFO+SUMX
   32 CONTINUE
      U(I)=UL(I)+UH(I)+US(I)+ULL(I)
C    COMPUTE APPLIED FORCE
      P(I)=(U(I)-UU)/(X(I)-XX)
C    COMPUTE ACCELERATION
      G(I)=(P(I)*32.)/W
      AG(I)=P(I)/W
      IF(U(I).GT.UT) GO TO  7
C    COMPUTE VELOCITY
    8 V(I)= SQRT((UT-U(I))*(64./(W*12.)))
```

```
    7 CONTINUE
C     COMPUTE LAPSED TIME
      DT=(VV-V(I))/G(I)
      TS=TS+DT
      TM(I)=TS*1000.
C     COMPUTE PERCENTAGE ENERGY STORED
      PU=U(I)/UT
    5 XX=X(I)
      UU=U(I)
      VV=V(I)
      IF(U(I).GE.UT) GO TO 4
    2 CONTINUE
    4 CONTINUE
      J=I
      WRITE(51,1010)
C     OUTPUT-WRITE LOOP
      WRITE(51,1002)
      WRITE(51,1010)
      WRITE(51,1010)
      WRITE(51,1002)
      WRITE(51,1008)
      WRITE(51,1002)
      WRITE(51,1010)
      WRITE(51,1002)
      WRITE(51,1004)
      WRITE(51,1005)
      WRITE(51,1006)
      WRITE(51,1002)
      WRITE(51,1007) R,CL,T,TH,THH,W
      WRITE(51,1002)
      WRITE(51,1000)
      WRITE(51,1001)
      WRITE(51,1002)
      DO 11 I=1,1000
      WRITE(51,1003) X(I),V(I),TM(I),P(I),U(I),AG(I)
      IF(I.EQ.J) GO TO 10
   11 CONTINUE
   10 CONTINUE
      WRITE(51,1002)
      WRITE(51,1010)
      WRITE(51,1010)
      WRITE(51,1002)
      WRITE(51,1011)
      WRITE(51,1002)
      WRITE(51,1012)
      WRITE(51,1002)
      DO 24 I=1,1000
      WRITE (51,1009)UL(I), US(I),UH(I),ULL(I)
      IF(I.EQ.J) GO TO 25
   24 CONTINUE
   25 CONTINUE
      WRITE(51,1002)
      WRITE(51,1010)
      WRITE(51,1010)
      CALL QWIKPL(X,AG,J,'LINEAR','J.H.EVANS$')
 1000 FORMAT (1H.,4X,11HDEFORMATION,4X,8HVELOCITY,7X,4HTIME,13X,5HFORCE,      13
     1        10X,6HENERGY,5X,12HACCELERATION)
```

```
1001 FORMAT (1H, 6X,6HINCHES,7X,8HFT./SEC.,4X,11HMILISECONDS,8X,
    1         6HPOUNDS,10X,6HLB-IN.,10X,3HX G)
1002 FORMAT(1H0)
1003 FORMAT (F12.4,F13.2,F15.4,F18.2,F16.2,F12.2)
1004 FORMAT (1H,30X,13HCASK GEOMETRY)
1005 FORMAT (1H, 4X,6HRADIUS,9X,6HLENGTH,8X,10HSHELL THK.,5X,
    1         9HHEAD THK.,5X,9HHEAD THK.,7X,6HWEIGHT)
1006 FORMAT (1H, 4X,6HINCHES,9X,6HINCHES,9X,6HINCHES,9X,6HINCHES,
    1         9X,6HINCHES,9X,6HPOUNDS)
1007 FORMAT (F10.3,4F15.3,F15.1)
1008 FORMAT(1H,5X,34HTESTING OF OBSOLETE CASKS TEST # 1)
1009 FORMAT (4F20.1)
1010 FORMAT(1H, X,49H*************************************************,
    1       55H*********************************************************,
    2       14H**************)
1011 FORMAT(1H,15X,26HCOMPONENTS OF TOTAL ENERGY)
1012 FORMAT(1H,13X,5HUL(I),15X,5HUS(I),15X,5HUH(I),14X,6HULL(I))
     STOP
     END
```

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