**SENTINEL**

TEST PLAN NO. 70

## TEST PLAN COVER SHEET

| | |
|---|---|
| TEST TITLE: MODEL 660 SERIES TYPE B TRANSPORT TESTS | |
| PRODUCT MODEL: 660 SERIES PROJECTORS | |
| ORIGINATED BY: S. Gr[illegible] | DATE: 17 SEPT 97 |
| **TEST PLAN REVIEW** | |
| ENGINEERING APPROVAL: [signature] | DATE: 17 Sept 97 |
| QUALITY ASSURANCE APPROVAL: | DATE: |
| REGULATORY AFFAIRS APPROVAL: C. Roughan | DATE: 17 Sep 97 |
| COMMENTS: | |
| **TEST RESULTS REVIEW** | |
| ENGINEERING APPROVAL: | DATE: |
| QUALITY ASSURANCE APPROVAL: | DATE: |
| REGULATORY AFFAIRS APPROVAL: | DATE: |

Amersham QSA

# SENTINEL

TEST PLAN NO. 70

| | |
|---|---|
| TEST TITLE: MODEL 660 SERIES TYPE B TRANSPORT TESTS | |
| PRODUCT MODEL: 660 SERIES PROJECTORS | |
| ORIGINATED BY: S. Gonsai | DATE: 17 SEPT 97 |
| ENGINEERING APPROVAL: | DATE: 17 Sept 97 |
| QUALITY ASSURANCE APPROVAL: | DATE: 17 Sept 97 |
| REGULATORY AFFAIRS APPROVAL: | DATE: |
| COMMENTS: | |
| ENGINEERING APPROVAL: | DATE: |
| QUALITY ASSURANCE APPROVAL: | DATE: |
| REGULATORY AFFAIRS APPROVAL: | DATE: |

Amersham QSA

PacTec
Packaging Technology, Inc.

4507-D Pacific Highway East
Tacoma, Washington 98424-2633
☎ (253) 922-1450 (253) 922-1445

September 17, 1997

*Document No. AMERgtc4.doc*
*File: 97012*
***[via Fax (617) 273-2216]***

Ms. Cathleen Roughan
Regulatory Affairs and Safety Manager
**Amersham Corporation**
40 North Avenue
Burlington, MA 01803

**SUBJECT:** Review of Amersham Test Plan #70, dated 9/17/97

**Reference:** Letter, Cathleen Roughan, Amersham Corporation, to Gary Clark, Packaging Technology, Inc., dated June 16, 1997.

Dear Ms. Roughan:

In accordance with the referenced letter, Packaging Technology has reviewed the subject test plan for the Model 660 package. Based on our independent review, we have determined that the test plan provides the required details to ensure that packaging testing performed in accordance with this test plan will comply with the requirements of Title 10, Code of Federal Regulations, Part 71 (10 CFR 71).

Very Truly Yours,

**Packaging Technology, Inc.**

G L Clark

Gary L. Clark, P.E.
Vice President

## Contents

## List of Figures and Tables

# Amersham Test Plan #70

This document describes the package design test plan for Sentinel Model 660 Series projectors to meet NRC requirements for Type B(U) packages (10 CFR 71.71 and 10 CFR 71.73). The test plan also covers the criteria stated in IAEA, Safety Series 6 (1985, as amended 1990). Quality Assurance will be involved in all aspects of this test plan and its execution.

The Model 660 Series includes the following models: 660, 660A, 660B, 660E, 660AE, and 660BE. Reference Certificate of Compliance 9033.

This document outlines the testing scenario, justifies the package orientations for the different test specimens, and provides test worksheets to record key steps in the testing sequence.

## 1.0 Transport Package Overview

The Model 660 Series projector consists of a source tube enclosed in a depleted-uranium shield, an end plate with a lock assembly, a second end plate with a storage plug assembly, four steel connecting rods, a sheet metal shell and foam packing material (Figure 1).

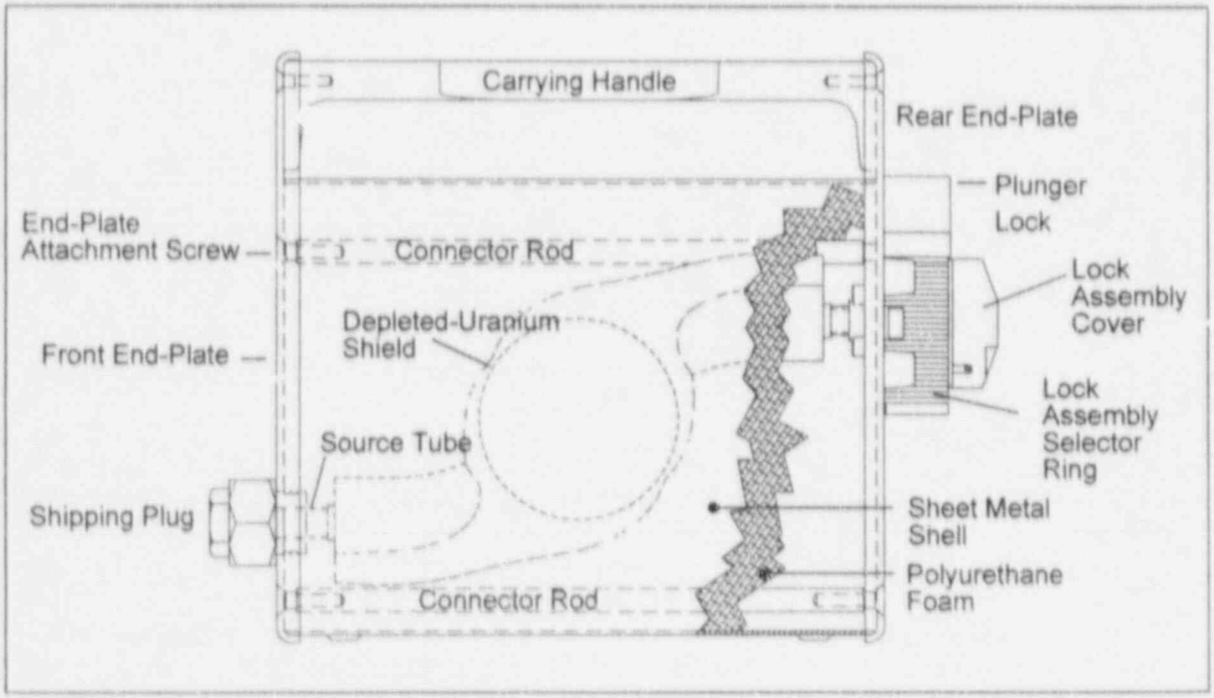



*Figure 1: Side View of a Model 660 Series Projector*

The shield consists of a 1/2-inch outside diameter source tube with its mid-section set in depleted uranium. One end of the source tube is inserted into a 1/2-inch deep hole of the lock assembly at the rear end-plate. The other end of the shield's source tube is inserted into another 1/2-inch deep hole of the shipping plug at the front end-plate. Both 1/2-inch deep holes allow enough radial clearance for a slip fitting attachment. There is approximately 1/8-inch axial clearance at the front end for assembly.

The source is contained in a special-form, encapsulated capsule assembly which is attached to the source wire assembly. This source wire assembly is secured in the package by the lock assembly. The lock assembly, in turn, is attached to the rear end-plate by four #10-32 U.N.C. stainless steel screws. There are two versions of the lock assembly used on the Model 660 series projectors. The size, material and location of the end-plate attachment screws are identical on both versions.

The shield, end plates and the sheet metal shell are connected by four 3/8-inch thick steel rods which are threaded at each end to accept 1/4-inch screws securing the end plates to the rods.

A polyurethane foam is used to fill the space around the shield and fill void within the sheet metal shell. The foam acts as an impact absorber.

The depleted-uranium shield provides the primary radiation protection for the Model 660 Series projector. The shield accomplishes this by limiting the transmission of gamma rays to a dose level at or below 200 mR/hr at the package surface and limiting the dose level at or below 10 mR/hr at one meter from the surface of the package. A fracture of the shield could compromise this protection.

The location of the source relative to its stored position in the shield is also an important safety element. A large displacement of the source relative to its stored position could elevate the dose at the surface of the package above regulatory limits.

There are two possible scenarios to displace the source relative to its stored position:

- The shield could move away from the source if the source tubes were bent or fractured during testing.
- The source could move away from the shield if the lock assembly became loose or was removed from the end plate or if the end plates themselves became loose or were removed during testing.

The tests in this plan focus on damaging those components of the package which could cause the displacement of the source relative to its stored position within the shield and which affect the integrity of the shield itself.

## 2.0 Purpose

This purpose of this plan, which was developed in accordance with Amersham SOP-E005, is to ensure the Model 660 Series projectors meet the Type B transport package requirements of 10 CFR 71.

The series includes these models: 660, 660A, 660B, 660E, 660AE, and 660BE. Refer to Appendix A for descriptive drawings of these models.

The Normal Conditions of Transport tests (10 CFR 71.71) to be performed are the compression test, penetration test and four-foot free drop test.

The water spray preconditioning of the package is not performed as the Model 660 projectors are constructed of waterproof materials throughout. The water spray would not contribute to any degradation in structural integrity.

The Hypothetical Accident Tests (10 CFR 71.73) to be performed are the 30-foot free drop, puncture test, and thermal test.

The crush test (10 CFR 71.73(c)(2)) is not performed because the radioactive contents are special-form radioactive material.

The immersion test and all other conditions specified in 10 CFR 71 will be separately evaluated in accordance with Amersham Work Instruction WI-E08.

## 3.0 System Failures of Interest

The possible system failures which could occur during test conditions and affect package integrity:

## 3.1 Shield Movement or Fracture

Elevated dose levels and depleted uranium contamination may result if the shield were to move or break as a result of high shock loading.

## 3.2 Lock Assembly Screws

Elevated dose levels may result if the lock assembly with source assembly attached were to be removed or damaged as a result of high-impact loading.

Dispersal of special form contents is highly unlikely since the encapsulated source assembly meets the requirements of special form and is protected at the center of the shield.

## 3.3 Shipping Plug and Source Tube Connection

A direct impact on the shipping plug could deform the end plate in towards the shield. An impact could also damage the source tube connection allowing the shield to move.

## 3.4 End-Plate Attachment Screws

The loss of the rear end-plate would result in loss of the lock assembly as well and cause exposure of the source. The loss of the front plate may indicate that the loss of the rear plate is just as likely.

## 3.5 Other System Failures

Two other possible system failures were considered but rejected because damage to these components would not cause damage to safety-related components.

- **Plunger Lock**: The lock mount containing the plunger lock functions as a locking index plunger for the selector ring. It does not hold the source wire assembly. If it were to fail, the source would continue to be secured in the lock assembly. The selector ring can only be rotated during operation, that is, after removal of the shipping cap and depression of the anti-rotation lugs.
- **Carrying Handle**: The handle provides no safety features to the device. Its primary function is as a carrying or lifting feature.

## 4.0 Construction and Condition of Test Specimens

The test specimens will be Model 660B units constructed in accordance with Amersham Drawing D66010, Rev. C, modified per Drawing TP70, Rev. B. The units specified in Drawing TP70, Rev. B, are in accordance with the NRC-approved design.

Drawing TP70, Rev. B, specifies the Model 660 Series in its worst-case transport condition, that is, with supplemental lead added to the shield. The added weight induces higher loads during dynamic testing.

Except for the compression and thermal tests, the test temperature of the specimen must be below -40° C at the time of each test, a minimum temperature required by IAEA, Safety Series 6 (1985, as amended 1990). The low temperature represents the worst-case condition for the package because of the potential for brittle fracture of the shield and the end-plate attachment screws.

Four test specimens, built to Drawing TP70, Rev. B, and the Amersham Quality Assurance Program, are to be tested, one for each possible failure mode:

- Specimen A: Shield movement or fracture
- Specimen B: Failure of the lock assembly attachment screws
- Specimen C: Loss of the connection between the storage plug and the source tube
- Specimen D: Failure of the end-plate attachment screws

**NOTE:** *Because each test is designed to add to damage inflicted on a specific component or assembly in the preceding test, it is important that each specimen maintain its identity throughout the battery of tests and that the setup instructions specific to the specimen are strictly followed.*

Table 1 lists the differences between the test specimen and other 660 Series models.

**Table 1: Model 660 Series Variations**

| Feature | Test Specimen per Drawing TP70, Rev. B | 660 Series Models |
|---|---|---|
| Shell Material | Stainless steel | The Models 660, 660A, 660AE and 660E can have either a carbon steel shell or a stainless steel shell.<br>All other models in the series use stainless steel. |
| Lock Assembly | Posilok™ | The Model 660 and 660E use a non Posilok lock assembly.<br>All other models feature the Posilok lock assembly. |
| Actuator Wires and Connectors | No actuator wires and connectors | Models 660AE, 660BE and 660E have wires and connectors attached to ends plates for automatic actuation.<br>Models 660, 660A and 660B do not have actuator wires and connectors. |
| Shield Capacity | 140 Curie | The following models have 120-Curie capacity shields: 660, 660A, 660AE and 660E.<br>The following models have 140-Curie capacity shields: 660B and 660BE. |
| Body Width | Standard width (5 1/4 inches) | Some Model 660s and Model 660Es have a narrow-body design (4 3/4 inches wide).<br>All other models only use the standard-width body (5 1/4 inches). |
| Source Tube Material | Titanium | Prior to 1980, the Models 660, 660A, 660AE and 660E were manufactured with zircaloy source tubes.<br>All other units have titanium source tubes. |
| Use of Lead | Supplemental lead added | Prior to June 1992, some units in the Model 660 Series had lead added to supplement the shielding. The maximum amount of lead added was 3 pounds. The amount was also limited by a maximum shield weight of 40 pounds and a maximum package weight of 56 pounds. |
| Weight | 54 pounds minimum | Over the last five years, the average package weight has been approximately 50 pounds. Earlier in the product history, the average weight was approximately 53 pounds. |

The differences listed in Table 1 do not affect the radiological safety of the projector for the following reasons:

- **Shell Materials**: The shell thickness is 1/16-inch for the carbon steel and stainless steel versions. The likelihood of a crack or brittle flaw increases with the thickness of the section and is a problem in sections greater than 1/8-inch. Additionally, the temperature for transition from ductile to brittle is lower for the thinner sections. The thicker carbon steel end plates will reach the ductile to brittle transition temperature long before the shell does. The end plates are structural members, while the shell is not structurally significant.

- **Lock Style**: Damage to the Posilok lock assembly used on the test specimen would represent damage to any Model 660 Series lock assembly, including the non Posilok style assemblies used on the Model 660 and the Model 660E.

  The internal components of both lock assemblies are protected by the same lock assembly cover and practically the same selector ring. The cover and selector ring must be significantly damaged before an impact can disrupt the internal components' securement of the source. Because of the strength of the cover and the selector ring, damage to the source securement is more likely to occur from the failure of the lock assembly attachment screws. All models use the same type and size attachment screws in the same locations.

- **Actuator Wires and Connectors:** The additional parts used for automatic actuation provide no structural support.

- **Shield Capacity:** The lower-capacity shields are either lighter than or the same weight as the shield used on the Model 660B, making the 660B the worst case for shield failures of interest in these tests.

- **Body Width:** The end plates and shells of the narrow-body versions of the Model 660 and the Model 660E would provide smaller impact surfaces than the standard-width plates and shell used in the test specimen. The smaller impact surfaces would result in greater surface deformation and less deceleration on impact. As a result there would be less transfer of impact forces that could affect the integrity of the source securement.

- **Source Tube Material:** The Model 660 Series projectors have been manufactured with titanium source tubes exclusively since 1980. Because this represents our current manufacturing methods and because the majority of Model 660 Series units currently in use have titanium source tubes, the test specimens will be manufactured with titanium source tubes. Based on an evaluation of the damage caused by the tests, we will assess the implications for previously fabricated packages which utilized zircaloy.

  Note that although listed on the descriptive drawings, stainless steel source tubes have never been used in the fabrication of Model 660 Series units, nor do we intend to use them in future fabrication.

- **Supplemental Lead:** Prior to June 1992, supplemental lead was used in the production of Model 660 Series projectors with the depleted-uranium shield. Although the addition of supplemental lead is no longer a production technique, the TP70 test specimen will be fabricated with the supplemental lead to ensure the maximum device mass.
- **Package Weight:** Because of more efficient casting and the elimination of supplemental lead shielding, the average weight of Model 660 units produced in the last five years is three pounds less than the average weight for units produced in the early years of the series history. Two steps will be taken to build test specimens that will weigh at least 54 pounds:
  - Heavier depleted-uranium shields will be fabricated.
  - Supplemental lead will be added to the shield.

  The TP70 will be consistent with current manufacturing procedures and will represent the heavier units in the Model 660 population. Ninety-seven percent of all 660 units produced weigh 54 pounds or less.

## 5.0 Material and Equipment List

The test worksheets in Section 7.0 list the key materials and equipment specified in 10 CFR 71 and the necessary measurement instruments.

When video recording is specified in the following tests, select video cameras with the highest shutter speed practical to record testing.

Additional materials and equipment may be used to facilitate the tests.

## 6.0 Test Procedure

Four units are tested in parallel with the same sequence but with the focus on the transport integrity of different components and assemblies for each sample, as described in Section 3.0.

The tests have the following sequence:

1. Test specimen preparation and inspection
2. Compression test (10 CFR 71.71(c)(9))
3. Penetration test (10 CFR 71.71(c)(10))
4. Four-foot free drop (10 CFR 71.71(c)(7))
5. First intermediate test inspection
6. 30-foot free drop (10 CFR 71.73(c)(1))
7. Puncture test (10 CFR 71.73(c)(3))
8. Second intermediate test inspection
9. Thermal test (10 CFR 71.73(c)(4))
10. Final test inspection

## 6.1 Roles and Responsibilities

The responsibilities of the groups identified in this plan are:

- Engineering executes the tests according to the test plan and summarizes the test results. Engineering also provides technical input to assist Regulatory Affairs and Quality Assurance as needed.
- Regulatory Affairs monitors the tests and reviews test reports for compliance with regulatory requirements.
- Quality Assurance oversees test execution and test report generation to ensure compliance with 10 CFR 71, other regulatory requirements and the Amersham Quality Assurance Program.
- Engineering, Regulatory Affairs and Quality Assurance are jointly responsible for assessing test and specimen conditions relative to 10 CFR 71.
- Quality Control, a function that reports directly to Quality Assurance, is responsible for measuring and recording test and specimen data throughout the test cycle.
- The managers directly responsible for Engineering, Regulatory Affairs and Quality Assurance will identify and document personnel who are qualified to represent their departments in carrying out this test plan.

## 6.2 Test Specimen Preparation and Inspection

To prepare the test units:

1. Manufacture five standard production units with the changes indicated on Amersham Drawing TP70, Rev. B. The fifth unit is a spare.
2. Measure and record the weight of the shield.
3. Measure and record the weight of the total package.
4. Inspect the test units to ensure that:
   - All fabrication and inspection records are documented in accordance with the Amersham Quality Assurance Program.
   - The test units comply with the requirements of Drawing TP70, Rev. B.
5. Perform and record the radiation profile in accordance with Amersham Work Instruction WI-Q05.
6. Engineering, Regulatory Affairs and Quality Assurance will jointly verify that the test specimen complies with Drawing TP70, Rev. B, and the Amersham Quality Assurance Program.
7. Measure and record the location of the dummy source from the front end using the source location tool (Amersham Drawing BT10142, Rev. A).
8. Prepare the package for transport.

## 6.3 Compression Test (10 CFR 71.71(c)(9))

The first test is the compression test per 10 CFR 71.71(c)(9), in which the package is placed under a load of 280 to 290 pounds for at least 24 hours.

Use *Checklist 1: Compression Test* on page 41 to date and initial all action items and to record required data.

**NOTE:** *The worksheet identifies those steps which must be witnessed by Engineering, Regulatory Affairs and Quality Assurance.*

The following describes the orientation of the test specimen during the compression test and the test assessment.

### 6.3.1 Compression Test Setup

The same setup is used in the compression test for all test samples.

To prepare a specimen for the compression test:

1. Review the setup shown in Figure 2.

2. Place the specimen upright on a concrete surface with only the feet of the package touching the floor.

   The package is oriented in its normal transport position.

3. Place 280 to 290 pounds uniformly distributed onto the specimen as shown in Figure 2.

   The weight is five times the package weight and greater than 2 lbf/in$^2$ multiplied by the vertically projected area (5.25" wide x 9.875" long x 2 lbf/in$^2$ = 104 lbf).

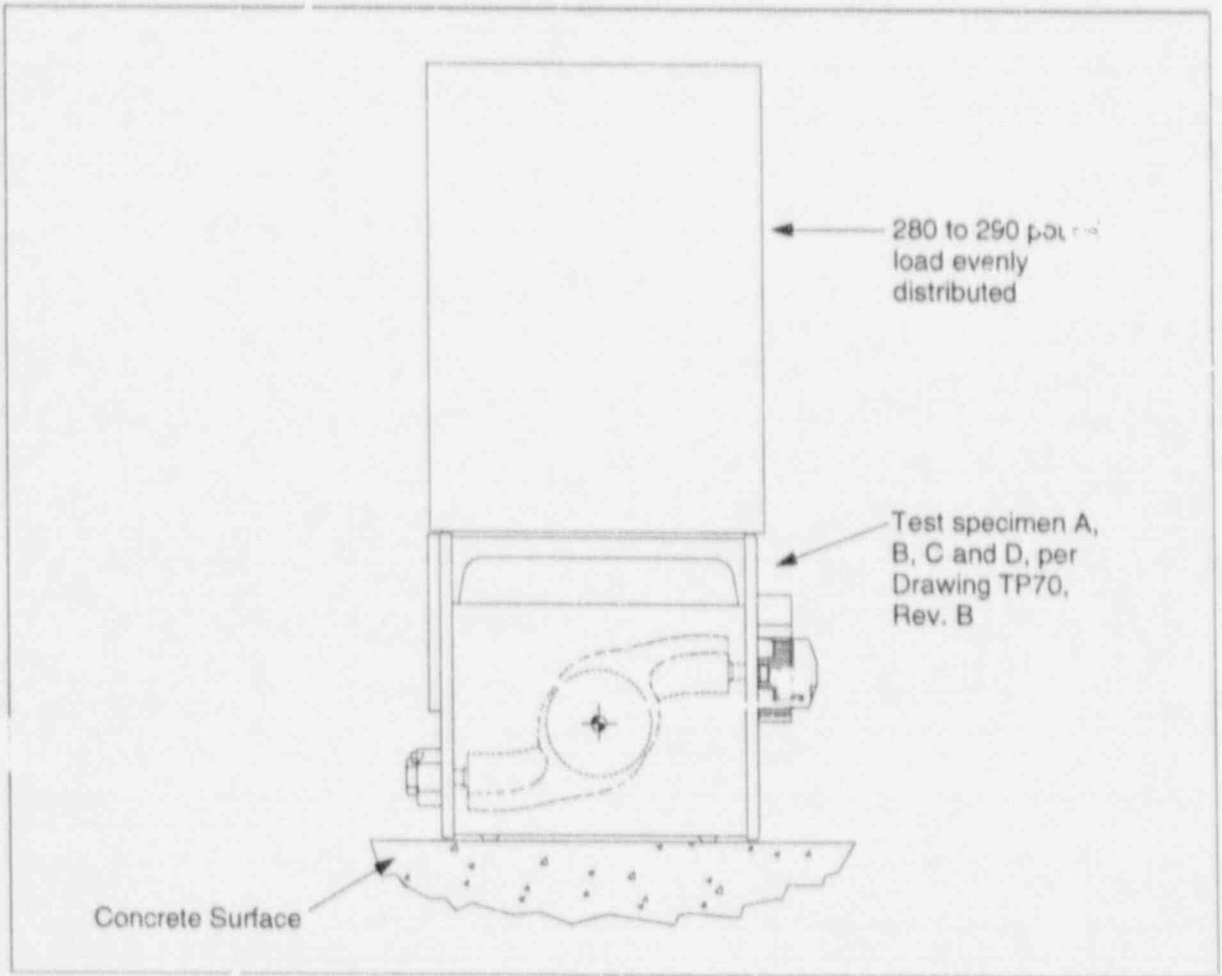



*Figure 2: Specimen Orientation for the Compression Test*

### 6.3.2 Compression Test Assessment

Upon completion of the test, Engineering, Regulatory Affairs and Quality Assurance team members will jointly perform the following:

- Review the test execution to ensure that the test was performed in accordance with 10 CFR 71.
- Make a preliminary evaluation of the specimen relative to the requirements of 10 CFR 71.
- Assess the damage to the specimen to decide whether testing of that specimen is to continue.
- Evaluate the condition of the specimen to determine what changes are necessary in package orientation in the penetration test to achieve maximum damage.

## 6.4 Penetration Test (10 CFR 71.71(c)(10))

The compression test is followed by the penetration test per 10 CFR 71.71(c)(10), in which a penetration bar is dropped from a height of at least 40 inches to impact a specified point on the package. The bar is dropped through free air.

Use *Checklist 2: Penetration Test* on page 43 to ensure that test sequence is followed. Date and initial all action items and record required data.

**NOTE:** *The worksheet identifies those steps which must be witnessed by Engineering, Regulatory Affairs and Quality Assurance.*

The following describes the orientation of each test specimen immediately before the bar is dropped and the test evaluation for the test.

### 6.4.1 Penetration Test Setup

There is a specific orientation for each specimen so that the penetration bar is aimed at the component or assembly of interest.

**NOTE:** *Because each test is designed to add to damage inflicted on a specific component or assembly in the preceding test, it is important that each specimen maintain its identity throughout the battery of tests and that the setup instructions specific to the specimen are strictly followed.*

This test requires that the test specimen be at or below -40° C at the time of the penetration bar release. The worksheet calls for measuring and recording the specimen temperature before and after the test.

To set up a package for the penetration test:

1. Measure the specimen's internal and surface temperature to ensure that the package is at or below -40° C.
2. Place the specimen on the drop surface (Drawing AT10122, Rev. B) and position it according to the specimen-specific orientation described below.
3. Use steel shims to position the package, if necessary.
4. Position the penetration bar shown in Drawing BT10129, Rev. B, directly above the specified point of impact, and raise the bar 40 to 42 inches above the target.

### 6.4.2 Specimen A Orientation for Penetration Test

The penetration target for Specimen A is the hit marker on the left side of the package (when facing the lock assembly), as shown in Figure 3. There are two objectives for this orientation:

- Move the shield and thus disrupt the source tube connections at either end plate
- Fracture the shield

This setup was chosen because the depleted-uranium shield is closer to the exterior on the left side than it is in any other location.

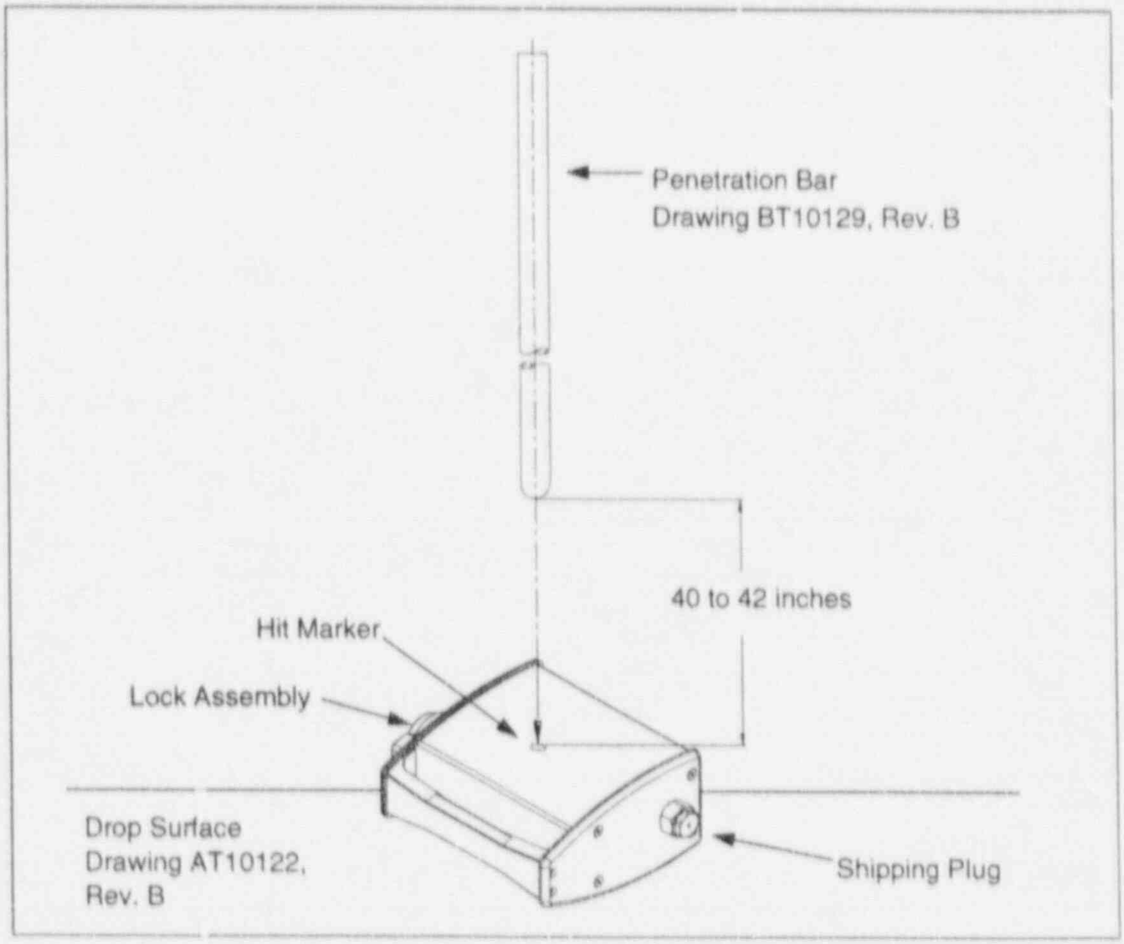



*Figure 3: Specimen A Orientation for the Penetration Test*

### 6.4.3 Specimen B Orientation for Penetration Test

The setup for Specimen B (Figure 4) provides the greatest impact moment on the lock assembly with the penetration bar. The resulting damage could include loosening or shearing the lock assembly screws, disruption of the source tube-end plate connection at either end, and movement of the source. Note that the point of impact is the outer edge of the lock selector ring.

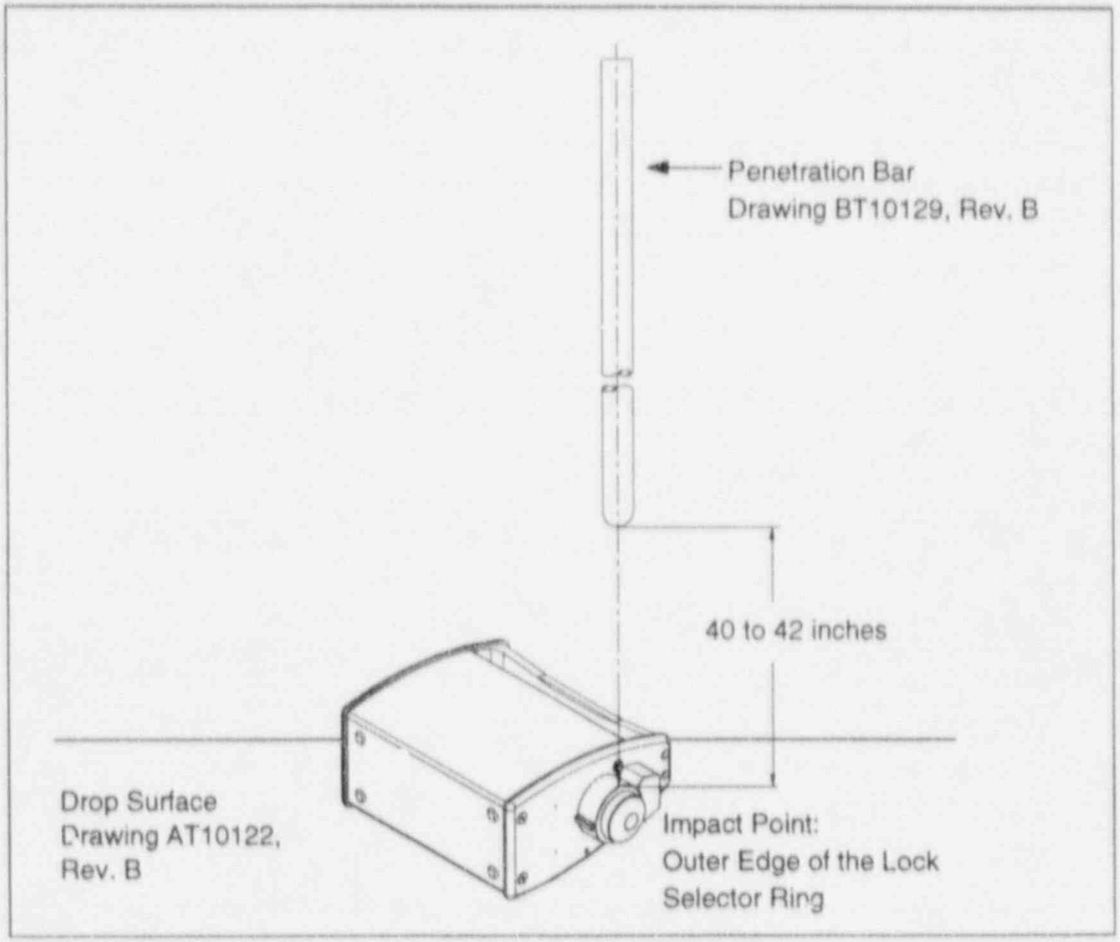



*Figure 4: Specimen B Orientation for the Penetration Test*

Other orientations that were considered, but not included in this test include:

- **Normal Transport**: If the package were oriented in its normal transport position, the plunger lock-mount would interfere.
- **Inverted**: If the package were inverted, that is, positioned on its handle, the plunger lock-mount would restrict the lock assembly movement, reducing the likelihood of shearing the screws, disrupting the source tube-end plate connections and moving of the source.

### 6.4.4 Specimen C Orientation for Penetration Test

The Specimen C setup attacks the shipping plug in much the same way as Setup B attacks the lock assembly. This test causes an initial round of damage to the plug which is compounded by the two drop tests for the Specimen C.

The point of the penetration bar should impact a flat portion on the shipping plug fitting as close to the outer edge as possible (Figure 5).

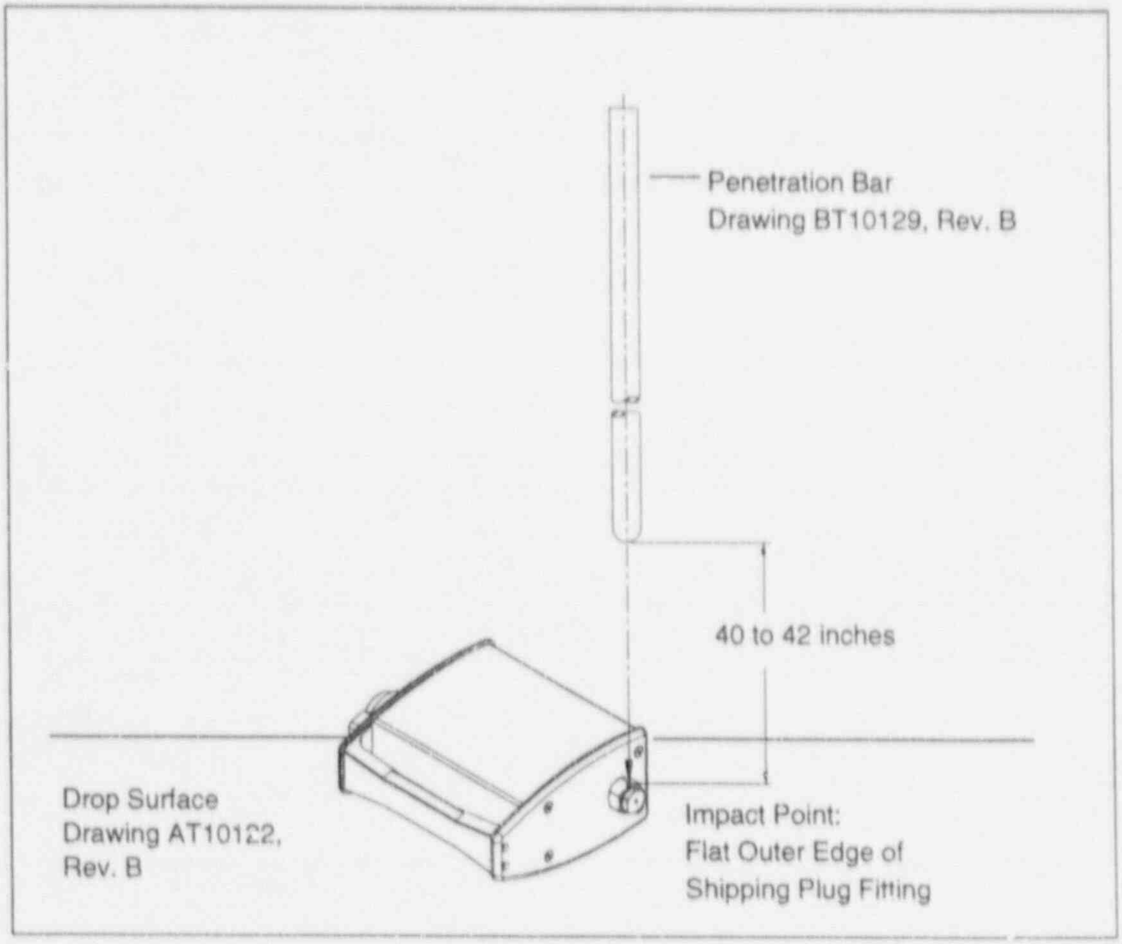



*Figure 5: Specimen C Orientation for the Penetration Test*

### 6.4.5 Specimen D Orientation for Penetration Test

The object of the penetration test setup for Specimen D is to impact the end-plate attachment screw in the lower left corner of the rear end-plate (Figure 6). A hit marker indicates the target.

Damage that may result from the bar drop includes loosening or shearing of the end-plate screws.

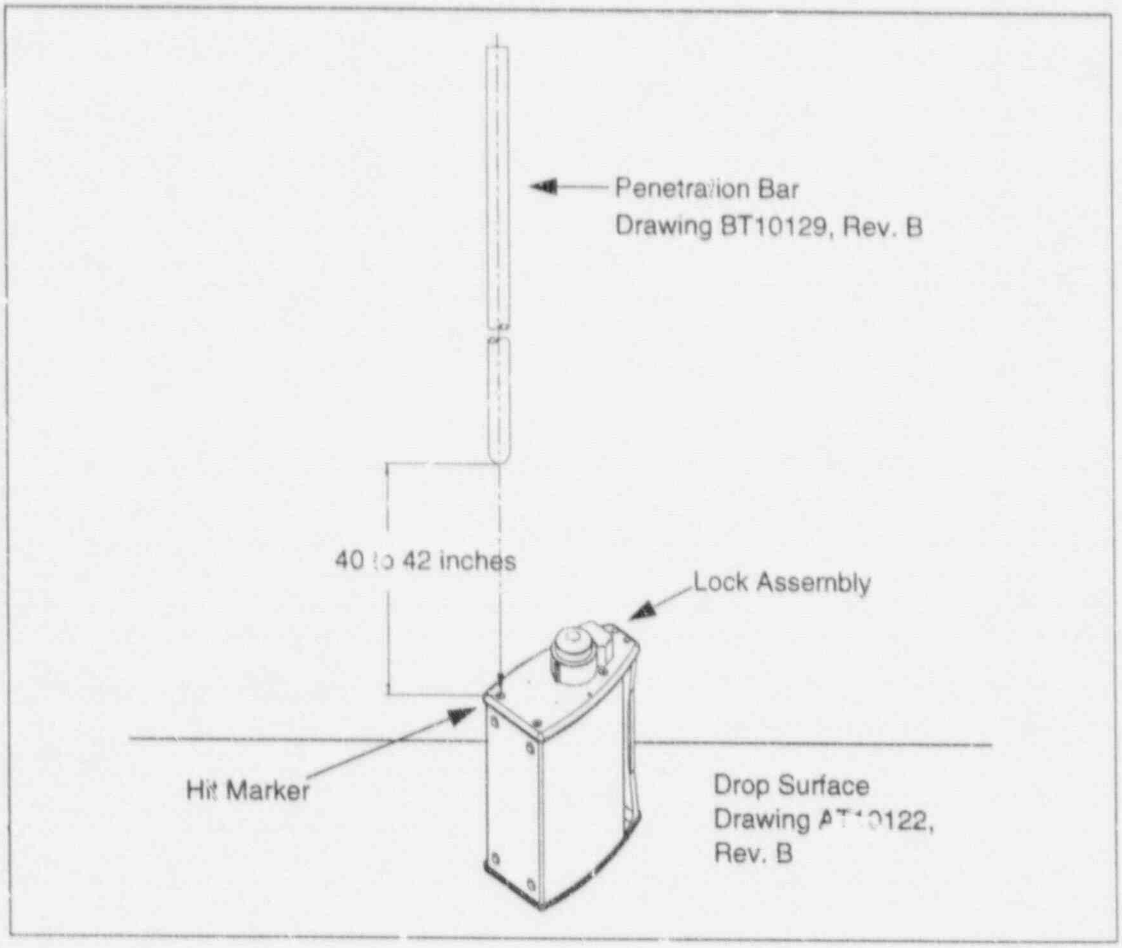



*Figure 6: Specimen D Orientation for the Penetration Test*

### 6.4.6 Penetration Test Assessment

Upon completion of the test, Engineering, Regulatory Affairs and Quality Assurance team members will jointly perform the following:

- Review the test execution to ensure that the test was performed in accordance with 10 CFR 71.
- Make a preliminary evaluation of the specimen relative to the requirements of 10 CFR 71.
- Assess the damage to the specimen to decide whether testing of that specimen is to continue.
- Evaluate the condition of the specimen to determine what changes are necessary in package orientation in the 4-foot free drop to achieve maximum damage.

## 6.5 Four-foot Free Drop Test (10 CFR 71.71(c)(7))

The final Normal Transport Conditions test is the four-foot free drop as described in 10 CFR 71.71(c)(7). This drop compounds any damage caused in the first two tests. Upon completion of this step, you will perform the first intermediate test inspections.

Use *Checklist 3: Four-foot Free Drop* on page 46 to ensure that the test sequence is followed. Date and initial all action items, and record required data on the worksheet.

**NOTE:** *The worksheet identifies those steps which must be witnessed by Engineering, Regulatory Affairs and Quality Assurance.*

### 6.5.1 Four-foot Free Drop Setup

In this test, the package is released from a height of four feet and lands on the steel drop surface specified in Drawing AT10122, Rev. B. There is a specific orientation for each specimen so that the package lands on the component or assembly of interest.

**NOTE:** *Because each test is designed to add to damage inflicted on a specific component or assembly in the preceding test, it is important that each specimen maintain its identity throughout the battery of tests and that the setup instructions specific to the specimen are strictly followed.*

This test requires that the test specimen be at or below -40° C at the time of the drop. Follow the Worksheet instructions for measuring and recording the specimen temperature before and after the drop.

To set up a package for the four-foot drop test:

1. Use the drop surface specified in Drawing AT10122, Rev B.
2. Measure the specimen's internal and surface temperature to ensure that the package is at or below -40° C.
3. Place the specimen on the drop surface and position it according to the specimen-specific orientation described below.
4. Raise the package so that the impact target is 4.0 to 4.5 feet above the drop surface.
5. Align the selected center of gravity marker as shown in the referenced drawing.

### 6.5.2 Specimen A Orientation for Four-foot Free Drop

The impact points are the bottom edges of the two end plates as shown in Figure 7. Align the center of gravity marker on the sides of the packages with the middle of the drop surface.

This orientation attempts to break the connection between the source tube and the end plates, and move the shield away from the source. Each end plate provides a rigid structure which limits deformation and directs the shock load to the source tube connections of the shield. The momentum of the shield toward the bottom of the package may cause the end plates to separate from the shell.

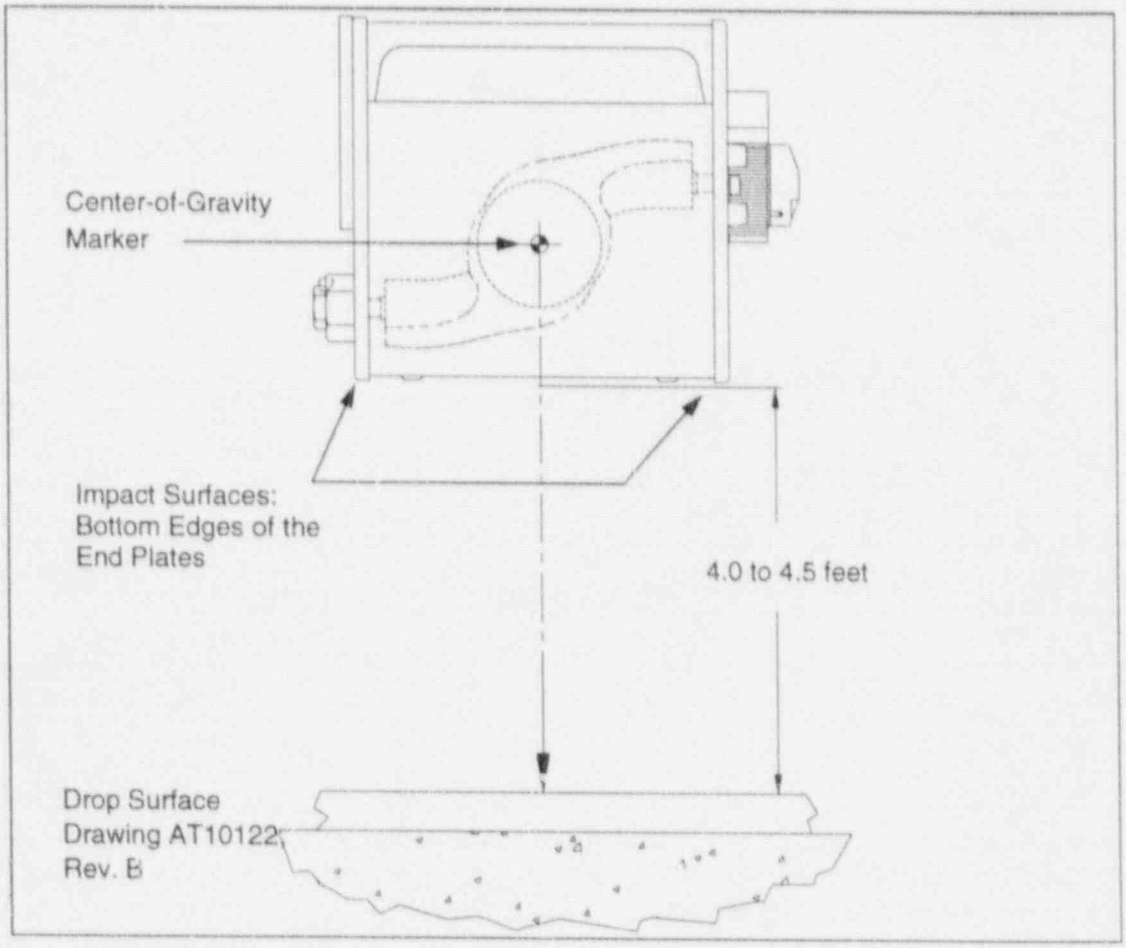



*Figure 7: Specimen A Orientation for the Four-foot Free Drop*

As the bottom edges make contact with the drop surface, the plates rapidly decelerate while the downward momentum of the shield (the heaviest component in the package and the center of gravity) increases the likelihood of damaging the source tube-to-end plate connections. The shield may act as a wedge forcing the end plates apart. The downward momentum may also have the secondary effect of mo·ing the source.

### 6.5.3 Specimen B Orientation for Four-foot Free Drop

The four-foot drop setup for Specimen B is shown in Figure 8. The object of the drop is to shear or loosen the lock assembly screws and damage the connection with the shield.

The impact point is the outer edge of the lock assembly cover. It is important to position test specimen B so that its center of gravity is directly above the lock assembly.

The impact will add to any damage to the lock assembly caused by the penetration bar in the second test.

This orientation directs the maximum obtainable shear force to the lock assembly attachment screws in an attempt to move the lock and the source. Other orientations for attacking the lock assembly would not benefit from the center of gravity aligned with the impact position and/or would be limited by interference from the plate edges.

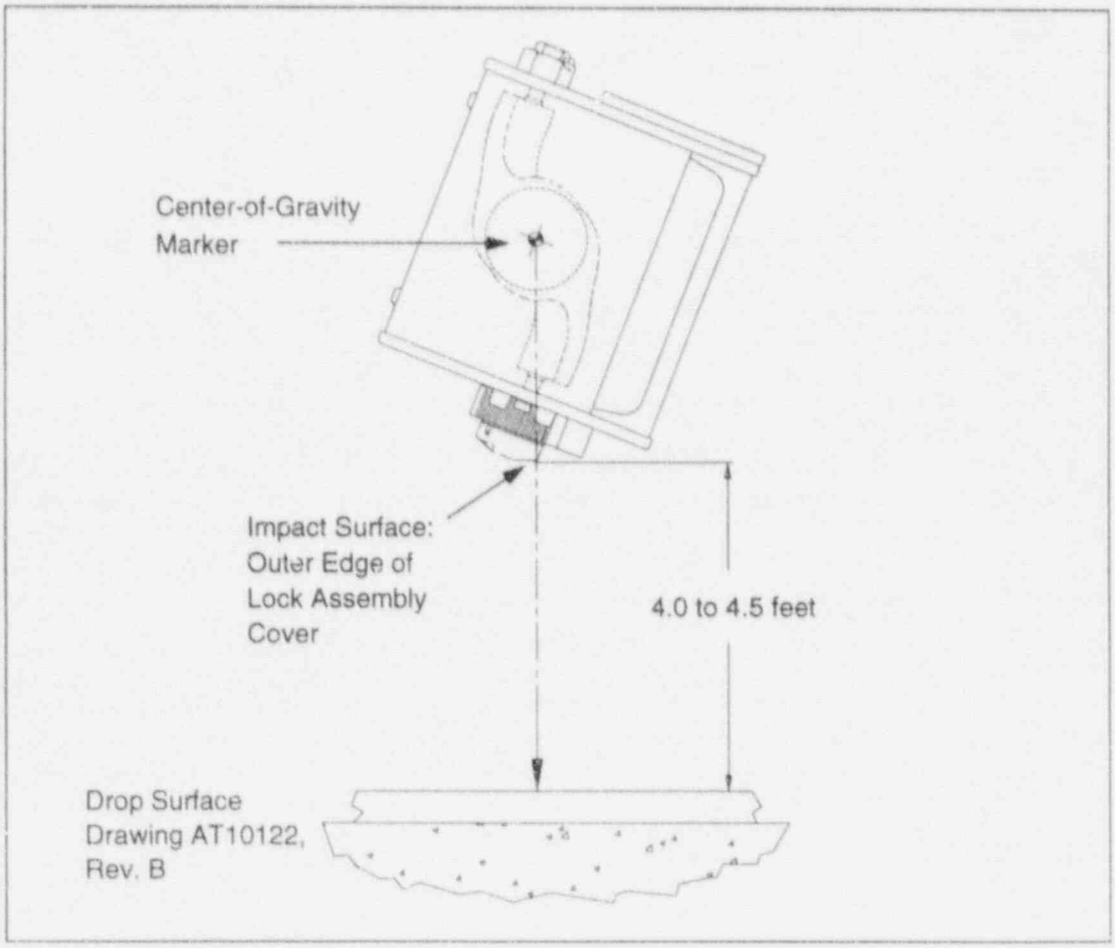



*Figure 8: Specimen B Orientation for the Four-foot Free Drop*

### 6.5.4 Specimen C Orientation for Four-foot Free Drop

The setup for Specimen C is similar to the Specimen B orientation except that the point of impact is a flat outer edge on the shipping plug. The object in this drop is to disrupt the connection between the source tube and the shipping plug, which in turn could cause movement of the source. A secondary effect could be disruption of the connection between the source tube and the rear end-plate.

Figure 9 shows the Four-foot Drop setup for Specimen C. Again, the center of gravity is directly above the point of impact and there is no interference from the plate edges or other package components.

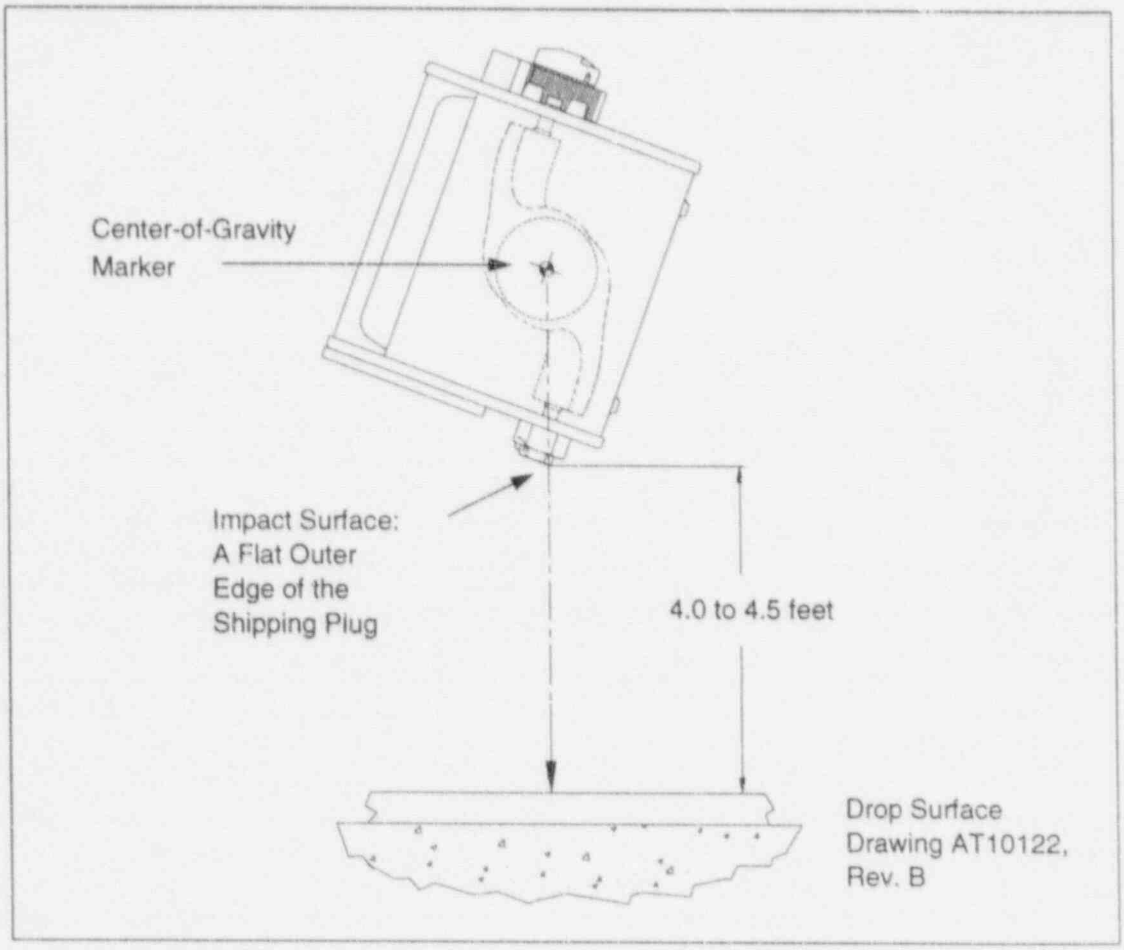



*Figure 9: Specimen C Orientation for the Four-foot Free Drop*

### 6.5.5 Specimen D Orientation for Four-foot Free Drop

The four-foot drop setup for Specimen D (Figure 10) targets the bottom edge of the rear end-plate. Here, the objective is to loosen or shear the end-plate screws which hold the plate to the steel connecting rods. The bottom edge of the plate provides the greatest surface area for a direct hit, and thus the most rapid deceleration. Other locations were rejected as follows:

- The top edge provides less than half the surface area of the bottom edge, and much of the load would be directed through the carrying handle.
- The curved side edges would only provide a point impact.
- The lock assembly and the shipping plug would interfere with a direct hit to the face of their respective end plates.
- Dropping the package on any corner would absorb the impact energy by deforming the end plate into the foam.

Make sure the center of gravity is directly over the point of impact.

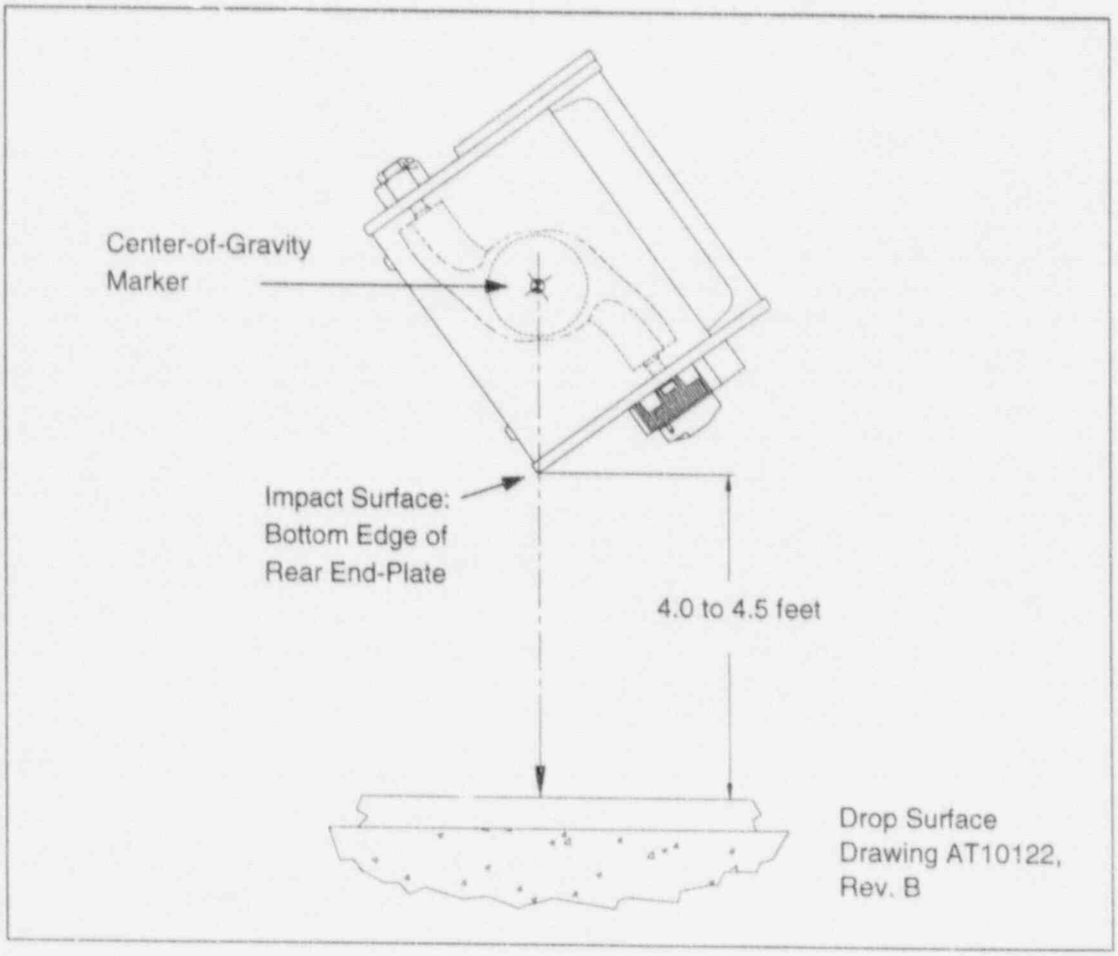



*Figure 10: Specimen D Orientation for the Four-foot Free Drop*

### 6.5.6 Four-foot Free Drop Assessment

Upon completion of the test, Engineering, Regulatory Affairs and Quality Assurance team members will jointly perform the following:

- Review the test execution to ensure that the test was performed in accordance with 10 CFR 71.
- Make a preliminary evaluation of the specimen relative to the requirements of 10 CFR 71.
- Assess the damage to the specimen to decide whether testing of that specimen is to continue.
- Evaluate the condition of the specimen to determine what changes are necessary in package orientation in the 30-foot free drop to achieve maximum damage.

## 6.6 First Intermediate Test Inspection

Perform an intermediate test inspection after the four-foot free drop test.

1. Measure and record any damage to the test specimen.
2. Measure and record the location of the source from the front end-plate using the source location tool (Amersham Drawing BT10142, Rev. A).
3. Remove and assess the condition of the dummy source.
4. Reassemble the package using an active 424-9 source, making sure that the source wire position and the package configuration are the same as they were immediately after the four-foot free drop.
5. Measure and record a radiation profile of the test specimen in accordance with Amersham Work Instruction WI-Q09.
6. Assess the significance of any change in radiation at the surface or at one meter from the package.
7. Reassemble the package using the same dummy source used in the specimen during the first three tests.
8. Make sure that the source wire position and the package configuration are the same as they were immediately after the four-foot free drop.

Engineering, Regulatory Affairs, and Quality Assurance team members will make a final assessment of the test specimen and jointly determine whether the specimen meets the requirements of 10 CFR 71.71.

## 6.7 30-foot Free Drop Test (10 CFR 71.73(c)(1))

The first Hypothetical Accidents Test is the 30-foot free drop as described in 10 CFR 71.73(c)(1). This drop compounds any damage caused in the three Normal Conditions Tests.

Use *Checklist 4: 30-foot Free Drop* on page 50 to ensure that the test sequence is followed. Date and initial all action items, and record required data on the worksheet.

**NOTE:** *The worksheet identifies those steps which must be witnessed by Engineering, Regulatory Affairs and Quality Assurance.*

Figure 11 through Figure 14 illustrate the orientations for the four test units, which are the same as those for the four-foot free drop except the package is raised 30 feet above the drop surface.

This test requires that the test specimen be at or below -40° C. at the time of the drop. Follow the worksheet instructions for measuring and recording the specimen temperature before and after the drop.

### 6.7.1 30-foot Free Drop Setup

To set up a package for the 30-foot drop test:

1. Use the drop surface specified in Drawing AT10122, Rev B.
2. Measure and record the weight of test specimen.
3. Measure the specimen's internal and surface temperature to ensure that the package is at or below -40° C.
4. Place the specimen on the drop surface and position it according to the specimen-specific orientation described below.
5. Raise the package so that the impact target is 30 to 32 feet above the drop surface.
6. Align the selected center-of-gravity marker as shown in the referenced drawing.

### 6.7.2 Specimen A Orientation for the 30-foot Free Drop

Figure 11 shows the package orientation for Specimen A.

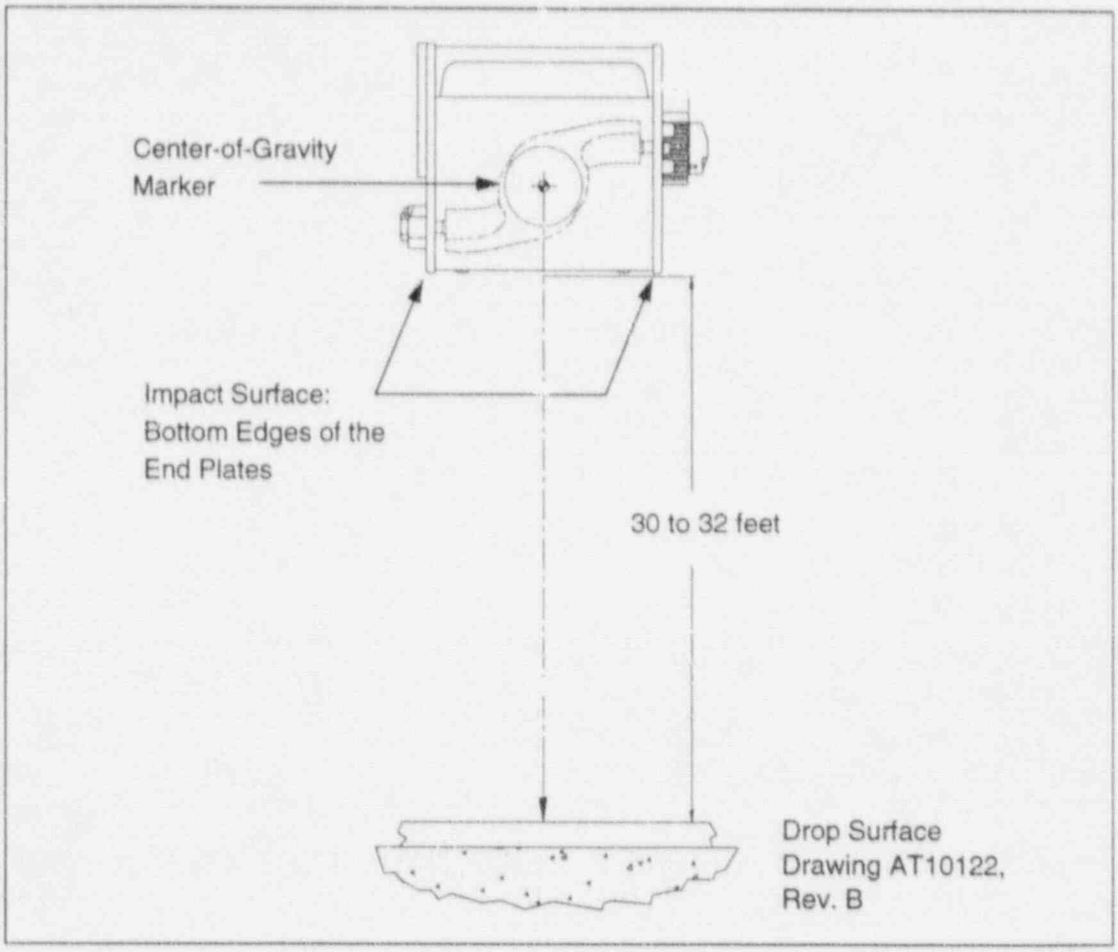



*Figure 11: Specimen A Orientation for the 30-foot Free Drop*

### 6.7.3 Specimen B Orientation for the 30-foot Free Drop

Figure 12 shows the package orientation for Specimen B.

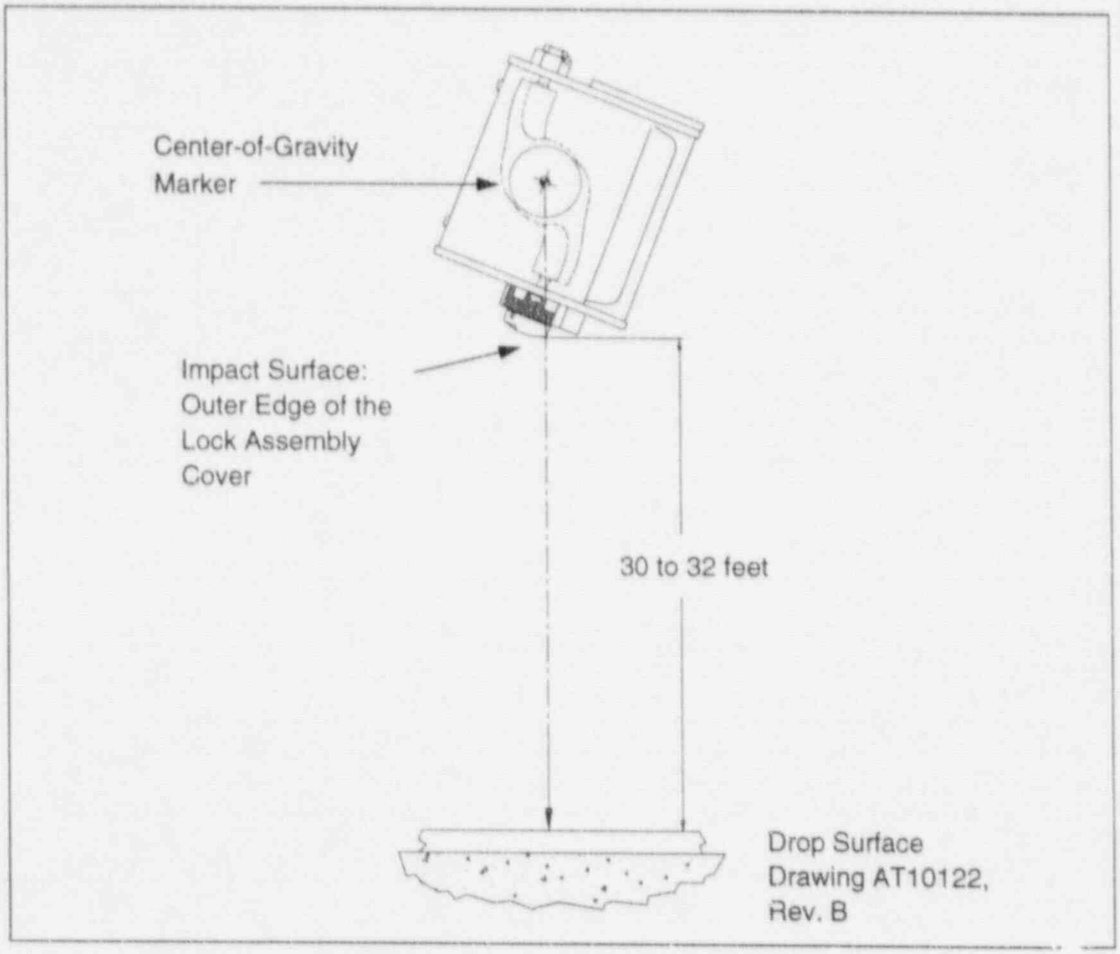



*Figure 12: Specimen B Orientation for the 30-foot Free Drop*

## 6.7.4 Specimen C Orientation for the 30-foot Free Drop

Figure 13 shows the package orientation for test specimen C.

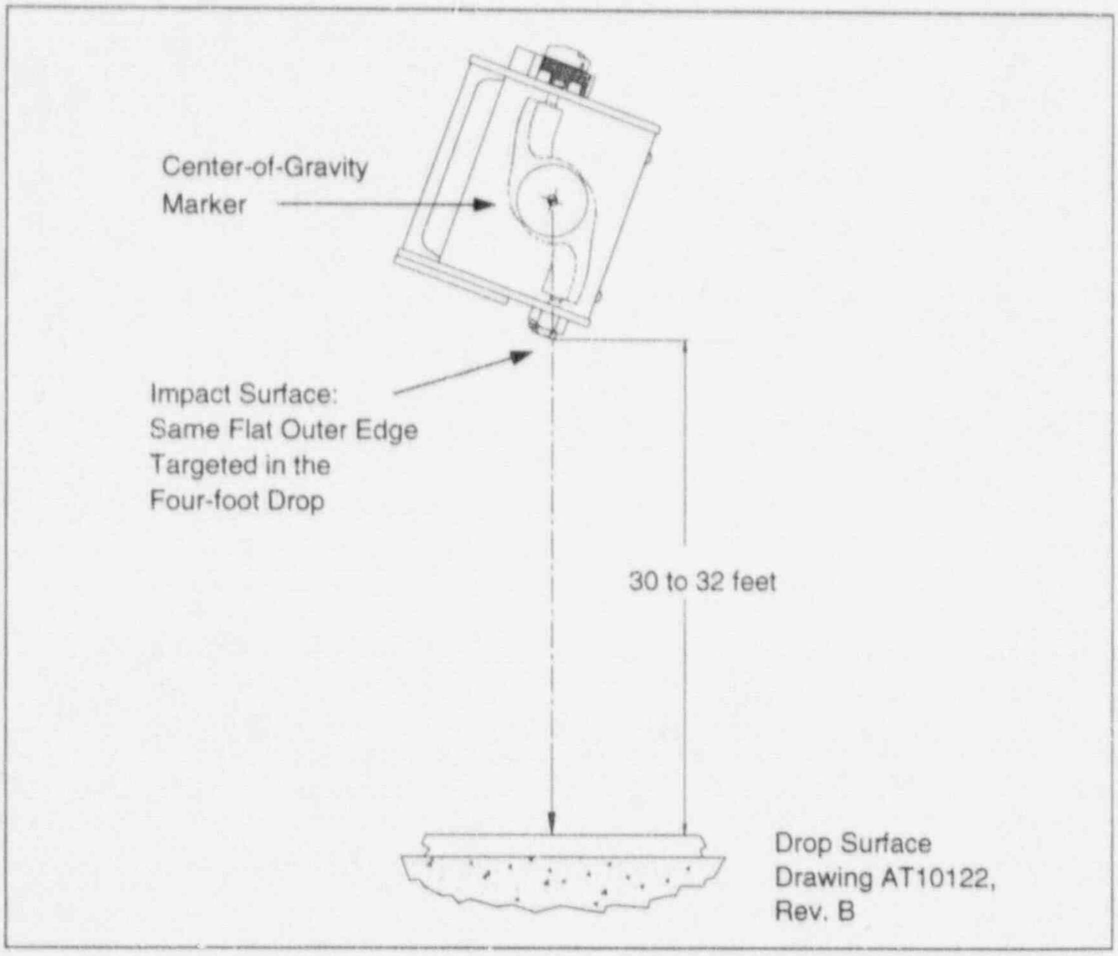



*Figure 13: Specimen C Orientation for the 30-foot Free Drop*

### 6.7.5 Specimen D Orientation for the 30-foot Free Drop

Figure 14 shows the package orientation for test specimen D.

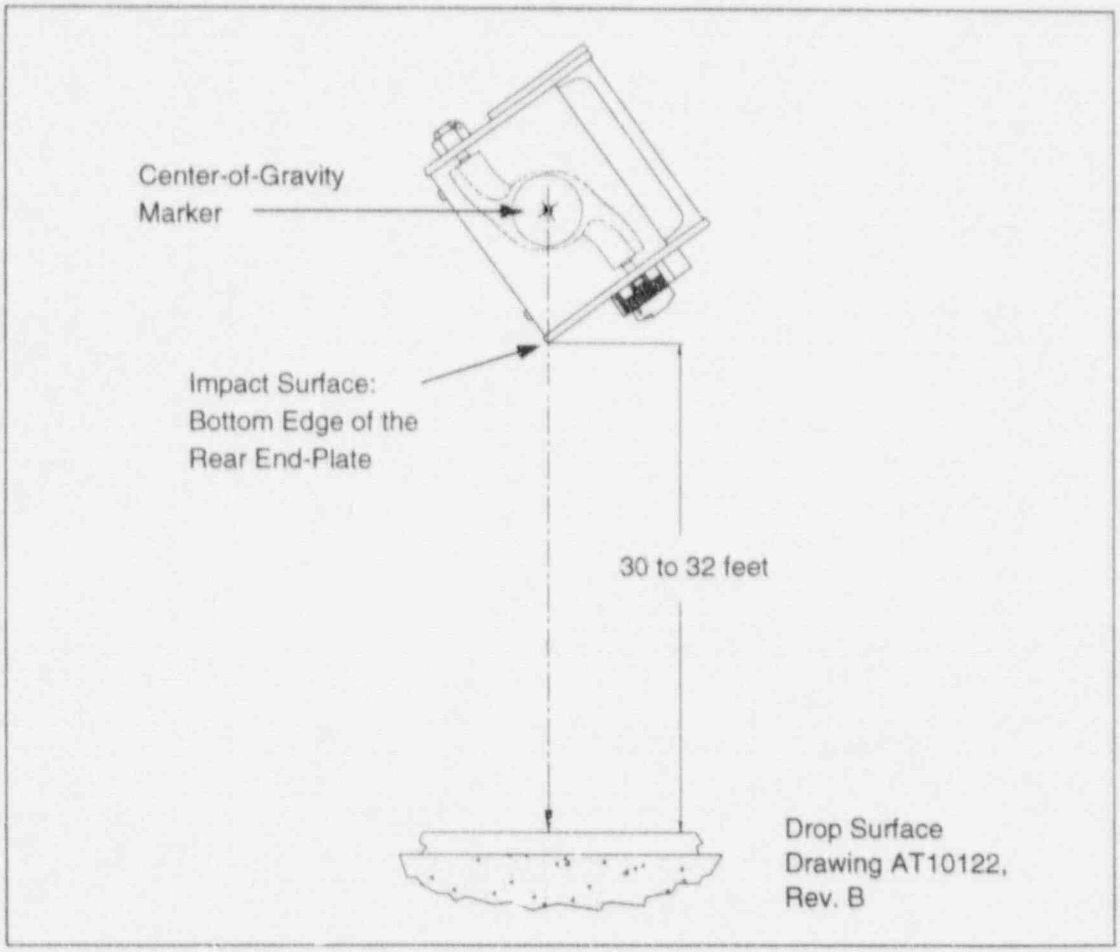



*Figure 14: Specimen D Orientation for the 30-foot Free Drop*

### 6.7.6 30-foot Free Drop Test Assessment

Upon completion of the test, Engineering, Regulatory Affairs and Quality Assurance team members will jointly perform the following:

- Review the test execution to ensure that the test was performed in accordance with 10 CFR 71.
- Make a preliminary evaluation of the specimen relative to the requirements of 10 CFR 71.
- Assess the damage to the specimen to decide whether testing of that specimen is to continue.
- Evaluate the condition of the specimen to determine what changes are necessary in package orientation in the puncture test to achieve maximum damage.

## 6.8 Puncture Test (10 CFR 71.73(c)(3))

The 30-foot free drop is followed by the puncture test per 10 CFR 71.73(c)(3), in which a package is dropped from a height of at least 40 inches onto the puncture billet specified in Drawing CT10119, Rev. C.

The billet is to be bolted to the drop surface used in the free drop tests (Figure 15).

Use *Checklist 5: Puncture Test* on page 53 to ensure that test sequence is followed. Date and initial all action items and record required data.

**NOTE:** *The worksheet identifies those steps which must be witnessed by Engineering, Regulatory Affairs and Quality Assurance.*

The following describes the orientation of each test specimen immediately before the package is dropped onto the billet and the test evaluation.

### 6.8.1 Puncture Test Setup

There is a specific orientation for each specimen so that the package lands on the component or assembly of interest.

**NOTE:** *Because each test is designed to add to damage inflicted on a specific component or assembly in the preceding test, it is important that each specimen maintain its identity throughout the battery of tests and that the setup instructions specific to the specimen are strictly followed.*

This test requires that the test specimen be at or below -40° C at the time of the test. The worksheet calls for measuring and recording the specimen temperature before and after the test.

This test uses the 12-inch high puncture billet (Drawing CT10119, Rev. C). The billet meets the minimum height (8 inches) required in 10 CFR 71.73(c)(3). The specimen has no projections or overhanging members longer than 8 inches which could act as impact absorbers, thus allowing the billet to cause the maximum damage to the specimen.

To set up a package for the puncture test:

1. Measure and record the weight of the package.
2. Ensure that the package is at or below -40° C.
3. Position it according to the specimen-specific orientation described below.
4. Raise the package so that there is 40 to 42 inches between the package and the top of the puncture billet.
5. Check the alignment of the specified center-of-gravity marker with the targeted point of impact.

Figure 15 through Figure 18 illustrate the four package orientations for the puncture tests. The justification for each orientation is the same as the orientation for the specimen's free drops.

### 6.8.2 Specimen A Orientation for the Puncture Test

The objective of the Specimen A orientation (Figure 15) is to puncture the shell and move the shield. The impact area is the bottom of the package, the largest flat surface on the shell. This surface will yield the greatest deceleration, while the momentum of the shield continues downward. Align the center of gravity marker on the side of the package with the center of the puncture billet.

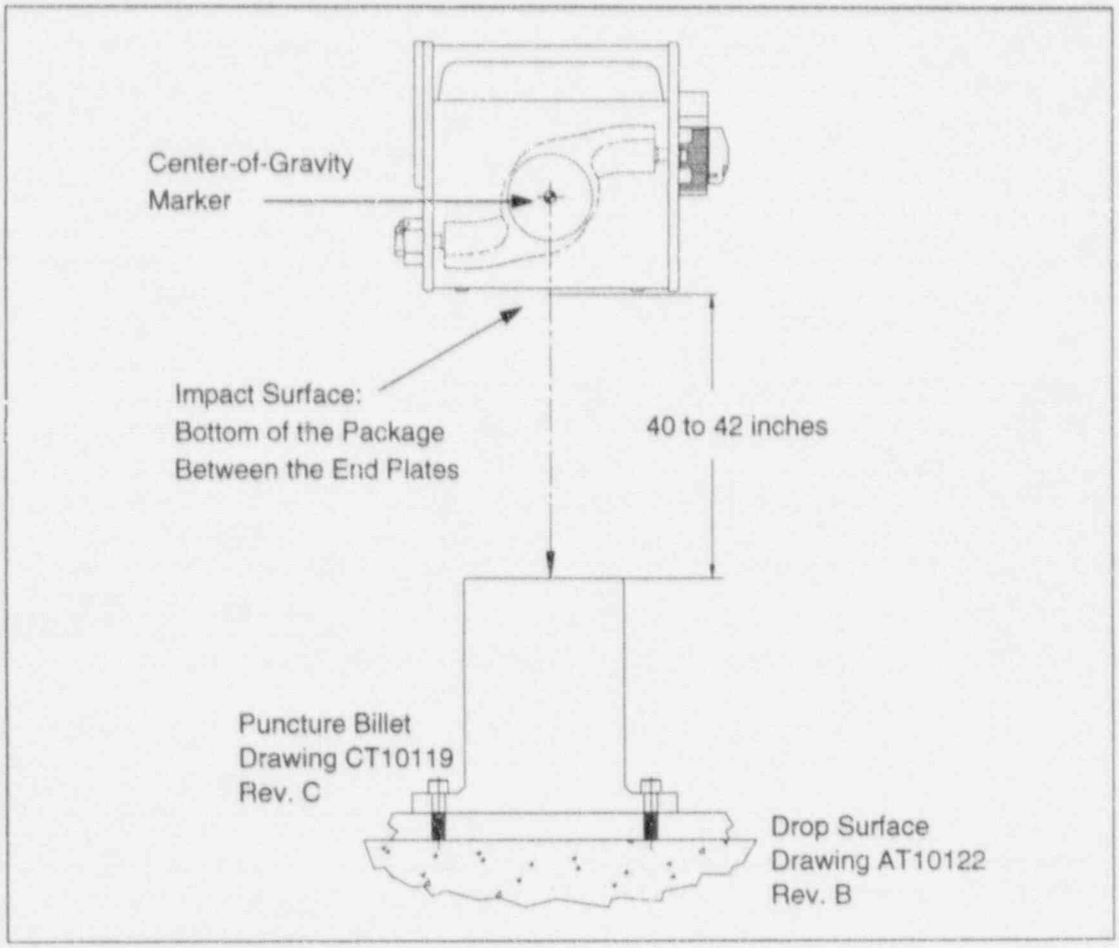



*Figure 15: Specimen A Orientation for the Puncture Test*

### 6.8.3 Specimen B Orientation for the Puncture Test

The objective of the Specimen B setup (Figure 16) is to continue the damage inflicted on the lock assembly caused by the penetration test and the two free drops. To achieve the same point of attack as the free drops, you must align the center-of-gravity marker over the lock assembly and ensure that the plunger lock clears the top of the billet.

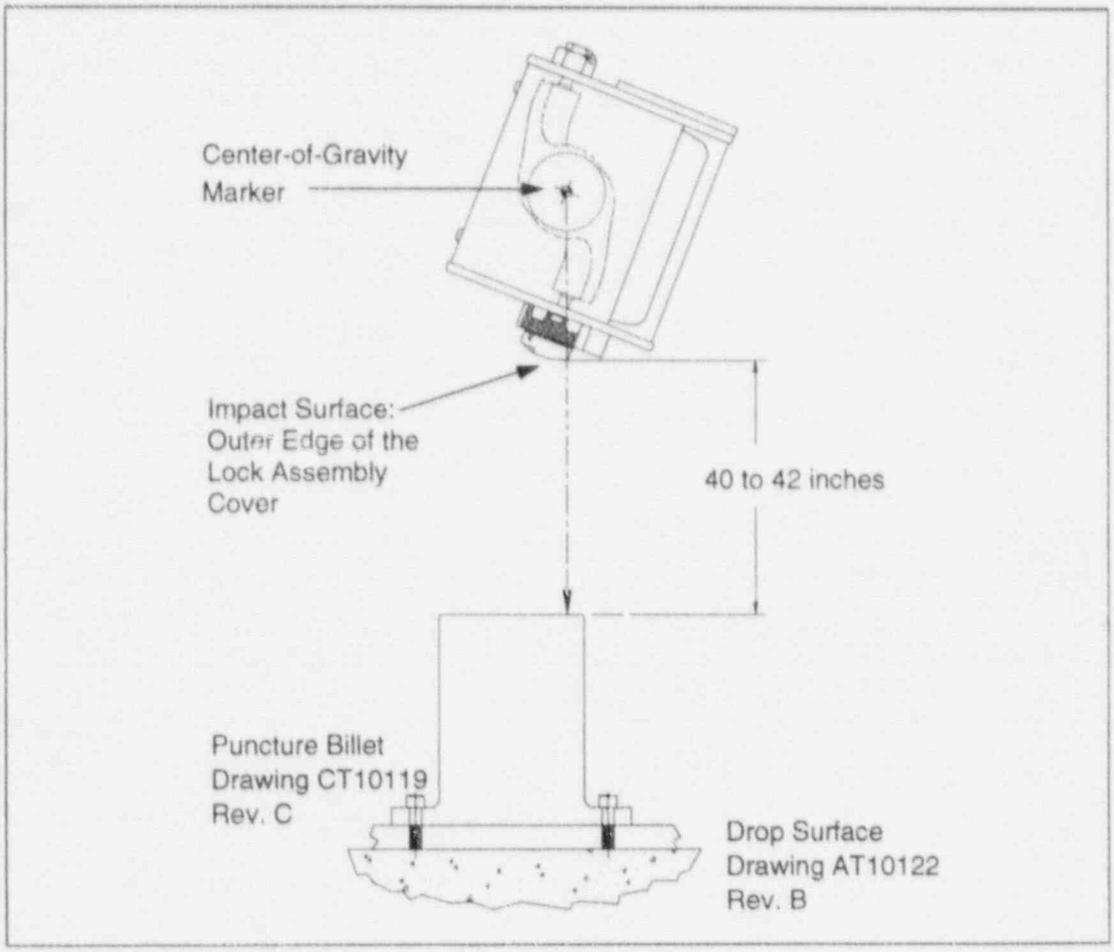



*Figure 16: Specimen B Orientation for the Puncture Test*

### 6.8.4 Specimen C Orientation for the Puncture Test

The objective of the Specimen C setup (Figure 17) is to continue the damage inflicted on the shipping plug assembly caused by the penetration test and the two free drops. The impact point should be the same flat outer edge on the shipping plug targeted in the previous tests. Align the center-of-gravity marker directly above the impact point on the shipping plug assembly.

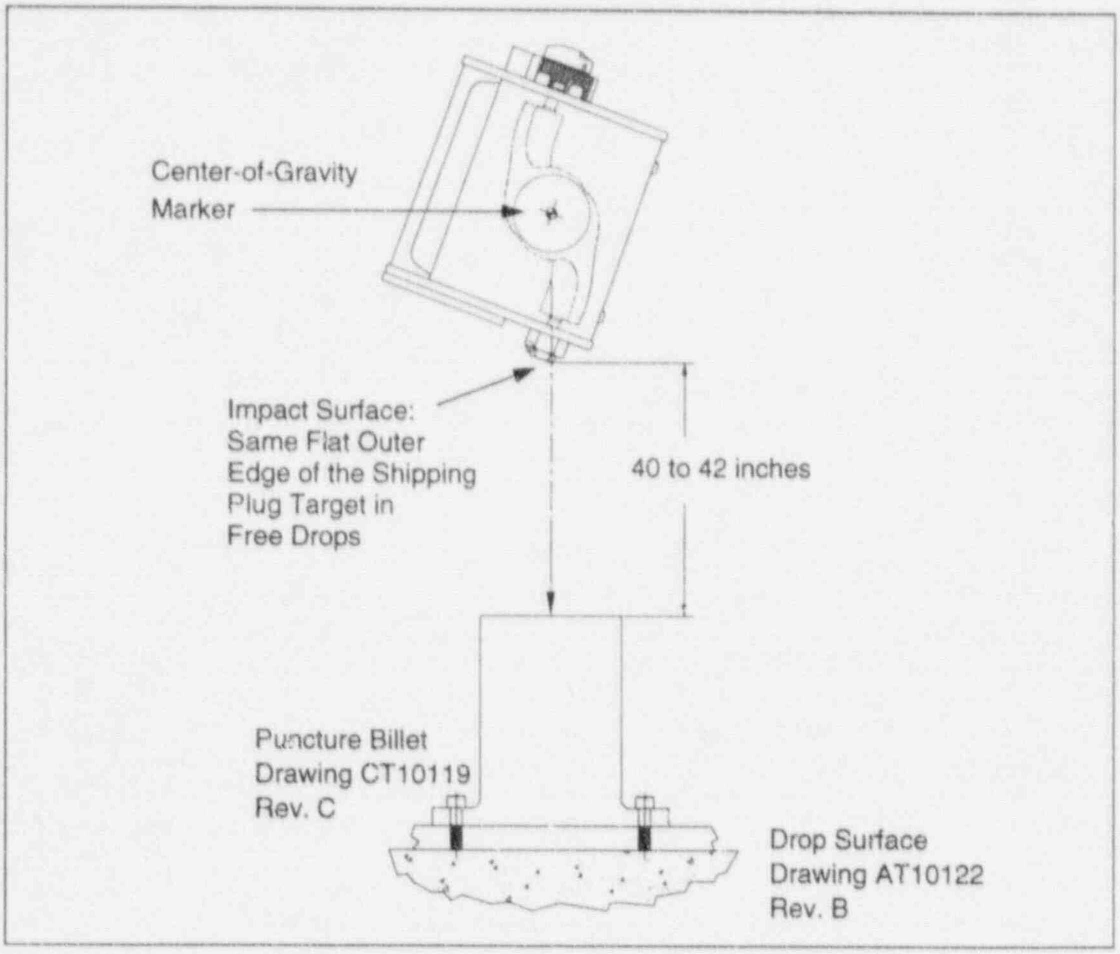



*Figure 17: Specimen C Orientation for the Puncture Test*

### 6.8.5 Specimen D Orientation for the Puncture Test

The Specimen D setup (Figure 18) targets the bottom edge of the rear end-plate to distort the end plate and loosen or shear the screws securing the end plate to the interior metal rods.

The bottom edge provides the largest, unobstructed flat surface on the plate. The impact will crush the bottom of the end plate into the polyurethane foam, the softest material in the package, and cause the maximum distortion of the plate. Attacking the top edge was rejected because the flat surface area is less than half that of the bottom edge and the carrying handle would deflect much of the energy.

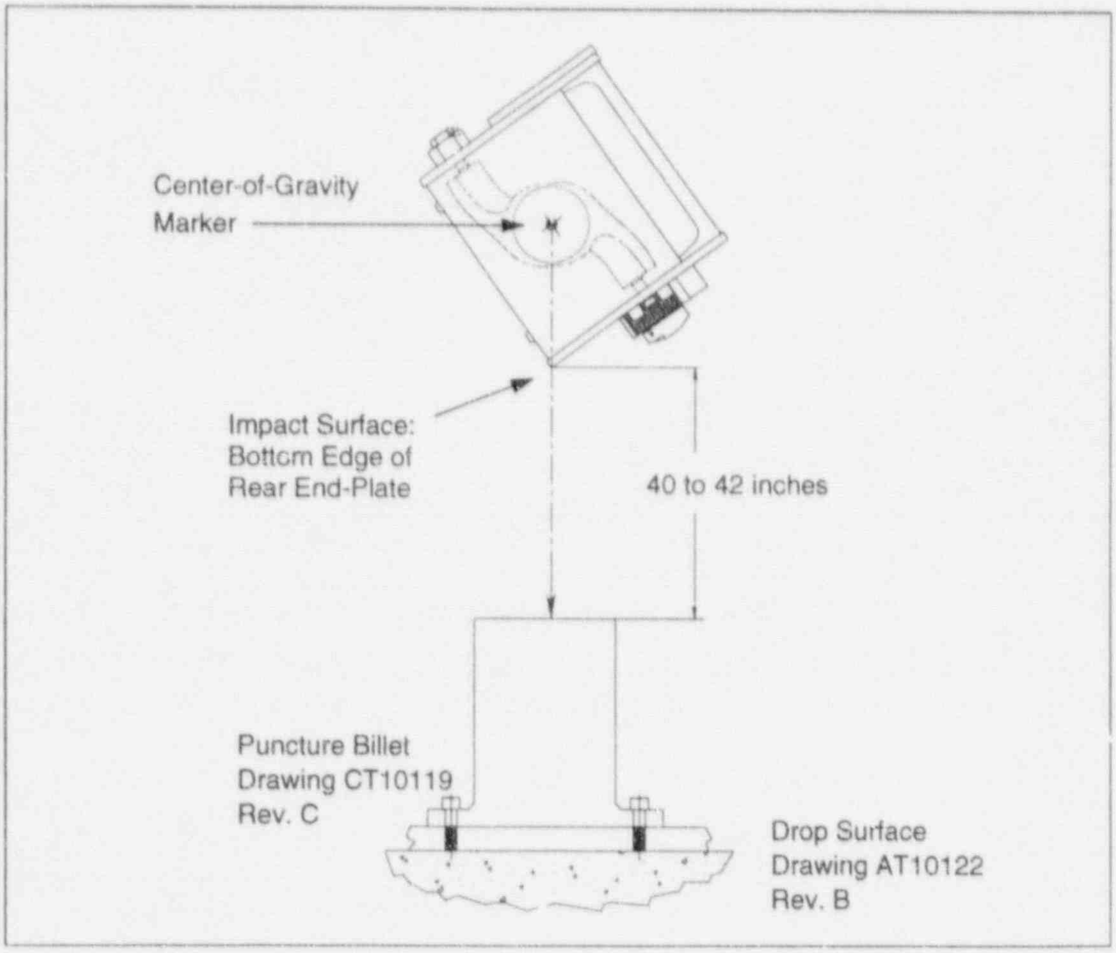



*Figure 18: Specimen D Orientation for the Puncture Test*

### 6.8.6 Puncture Test Assessment

Upon completion of the test, Engineering, Regulatory Affairs and Quality Assurance team members will jointly perform the following:

- Review the test execution to ensure that the test was performed in accordance with 10 CFR 71.
- Make a preliminary evaluation of the specimen relative to the requirements of 10 CFR 71.
- Assess the damage to the specimen to decide whether testing of that specimen is to continue.
- Evaluate the condition of the specimen to determine the package orientation for the thermal test to achieve maximum damage.

As part of the evaluation, measure the weight of the specimen.

## 6.9 Second Intermediate Test Inspection

Perform a second intermediate test inspection after the puncture test and before the thermal test.

1. Measure and record any damage to the test specimen.
2. Measure and record the location of the source from the front end using the source location tool (Amersham Drawing B f10142, Rev. A).
3. Remove and assess the condition of the dummy source.
4. Reassemble the package using an active 424-9 source, making sure that the source wire position and the package configuration are the same as they were immediately after the puncture test.
5. Measure and record a radiation profile of the test specimen in accordance with Amersham Work Instruction WI-Q09.
6. Reassemble the package using the same dummy source used in the specimen during the first three tests.
7. Make sure that the source wire position and the package configuration are the same as they were immediately after the puncture test.

## 6.10 Thermal Test (10 CFR 71.73(c)(4))

The final requirement is the thermal test specified in 10 CFR 71.73(c)(4).

To ensure sufficient heat input to the test specimens, each specimen will be pre-heated to a temperature of at least 800° C and held to at least that temperature for 30 minutes. This test condition provides heat input in excess of the requirements specified in 10 CFR 71.73(c)(4), which does not include a pre-heat condition. The pre-heat condition assures equivalent heat input regardless of emissivity and absorptivity coefficients.

The test environment is a vented electric oven operating at 900° C. There will be sufficient air flow to allow combustion. Air will be forced into the oven at a minimum rate of 9.6 cubic feet per minute to ensure sufficient oxygen to fully combust all package materials that are capable of burning. This rate is based on the following analysis:

1. The only combustible material in the TP70 is the polyurethane foam.
2. The chemical composition of polyurethane is $[C_{26}H_{33}NO_{13}]_n$.
3. The products of combustion are carbon dioxide ($CO_2$) and water ($H_2O$) and the molecular weights of the component materials are:

   C = 12 H = 1 O = 16 N = 14

4. The maximum mass of the polyurethane in a TP70 is 988 grams. The maximum amounts of carbon and hydrogen present in the polyurethane are computed as follows:

| Polyurethane | $C_{26}$ | $H_{33}$ | N | $O_{13}$ |
|---|---|---|---|---|
| Molecular Weight | (26x12) + | (33x1) + | (1x14) + | (13x16) |
| 567 = | 312 + | 33 + | 14 + | 208 |
| Percent by Mass | 55.0% | 5.8% | 2.5% | 36.7% |
| 988 g = | 543g + | 57g + | 25g + | 363g |

5. The amount of oxygen required to fully combust the carbon to carbon dioxide is computed as follows:

| Carbon Dioxide | C | $O_2$ |
|---|---|---|
| Molecular Weight | (1x12) + | (2x16) |
| 44 = | 12 + | 32 |

For a given mass of carbon, 32/12 = 2.67 times that mass of oxygen is required to fully combust the carbon to carbon dioxide. For a TP70 containing 543 grams of carbon, full combustion would require 1450 grams of oxygen.

6. The amount of oxygen required to fully convert the hydrogen to water is computed as follows:

| Water | $H_2$ | O |
|---|---|---|
| Molecular Weight | (2x1) + | 16 |
| 18 = | 2 + | 16 |

For a given mass of hydrogen, 16/2 = 8 times that mass of oxygen is required to fully convert the hydrogen to water. For a TP70 with 57 grams of hydrogen, full combustion would require 456 grams of oxygen.

7. The sum of these oxygen requirements (1450g + 456 g) less the oxygen supplied by the polyurethane (-363 g) equals 1543 grams of oxygen to assure sufficient oxygen to burn the polyurethane foam. At standard conditions, the composition of air is 23.2% oxygen by mass[1]. Therefore, 6650 grams of air are required.

8. The volume of air is computed at a density of 1.225 grams/liter to be 192 cubic feet:

$6650g/1.225g/l = 5430\ l = 5.43m^3 = 192\ ft^3$

9. A 50% safety factor is added and the volume is distributed over the 30-minute test period to determine a minimum air flow rate of 9.6 cubic feet per minute:

$(192\ ft^3)\ (1.5)\ /\ 30\ min. = 9.6\ ft^3/min.$

The air will be introduced as compressed air passing through a flowmeter and into the oven via metal tubing. A sufficient length of tubing will be inside the oven to ensure sufficient pre-heating.

The temperature of the package's exterior surface closest to the air entry point will be monitored throughout the test to ensure that the package remains above 800° C.

If the specimen is burning when it is removed, the unit is allowed to extinguish by itself and then cool naturally. The final evaluation of the package is performed when the specimen reaches ambient temperature.

---

1. Avallone, Eugene A. and Theodore Baumeister III, Editors, *Marks' Standard Handbook for Mechanical Engineers*, Ninth Edition (New York: McGraw-Hill Book Company, 1987), page 4-27

### 6.10.1 Thermal Test

To perform the thermal test:

1. Heat the oven to 900° C.
2. Attach thermocouples to the package's internal and external measurement locations.
3. Place the package in the oven and close the door.
4. When the internal temperature of the package goes above 800° C, start air flow and start a 30-minute timer.
5. Measure and record the oven temperature, test specimen internal and external temperatures and the air flow rate. Record whether there is any combustion.
6. Monitor the specimen's internal and external temperatures, and the oven temperature throughout the 30-minute test period to ensure that all temperatures remain above 800° C.
7. Monitor the airflow rate throughout the test period to ensure that it remains above 9.6 $ft^3$/minute.
8. At the end of the 30 minutes, repeat Step 5.
9. Remove the test specimen from the oven.
10. Allow the package to self-extinguish and cool.

### 6.10.2 Orientation

The orientation and justification should be based on an assessment of the test specimen condition immediately after the puncture test. Record, justify and approve the orientation for this test in accordance with Amersham SOP-E005.

### 6.10.3 Thermal Test Assessment

Upon completion of the test, Engineering, Regulatory Affairs and Quality Assurance team members will jointly perform the following:

- Review the test execution to ensure that the test was performed in accordance with 10 CFR 71.
- Make a preliminary evaluation of the specimen relative to the requirements of 10 CFR 71.

## 6.11 Final Test Inspection

Perform the following inspections after completion of the thermal test:

1. Measure and record any damage to the test specimen.
2. Measure and record the location of the source from the front end-plate using the source location tool (Drawing BT10142, Rev A).
3. Remove and assess the condition of the dummy source.
4. Reassemble the package using an active 424-9 source, making sure that the source wire position and the package configuration are the same as they were immediately after the thermal test.
5. Measure and record a radiation profile of the test specimen in accordance with Amersham Work Instruction WI-Q09.
6. Assess the significance of any change in radiation at one meter from the package.
7. Determine whether it is necessary to dismantle the test specimen for inspection of hidden component damage or failure.
8. If you decide to proceed with the inspection, record and photograph the process of removing any component.
9. Measure and record any damage or failure found in the process of dismantling the test specimen.

Engineering, Regulatory Affairs, and Quality Assurance team members will make a final assessment of the test specimen and jointly determine whether the specimen meets the requirements of 10 CFR 71.73

# 7.0 Worksheets

Use the following worksheets for executing these tests. There are two worksheets for each test: an equipment list and a test procedure checklist.

Use the test equipment list to record the serial number of each measurement device used. Attach a copy of the relevant inspection report or calibration certificate after you have verified the range and accuracy of the equipment.

Quality Control will initial each step on the checklist as it is executed and record data as required. The Engineering, Regulatory Affairs and Quality Assurance representatives must witness all testing to ensure the testing is performed in accordance with this test plan and 10 CFR 71.

Make copies of the forms for additional attempts. Maintain records of all attempts.

**Equipment List 1: Compression Test**

| Description | Enter the Model and Serial Number | Attach Inspection Report or Calibration Certificate |
|---|---|---|
| Weight Scale | | |
| Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate. | | |
| | | |
| | | |
| | | |
| Verified by: | Signature | Date |
| Engineering | | |
| Regulatory Affairs | | |
| Quality Assurance | | |

## Checklist 1: Compression Test

**Test Location:**

**Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 1. Engineering, RA and QA confirm that test specimen complies with Drawing TP70, Rev. B, and the Amersham Quality Assurance Program. | | | | |
| 2. Position specimen on concrete surface per the appropriate drawing. | Figure 2 | Figure 2 | Figure 2 | Figure 2 |
| 3. Measure ambient temperature. | | | | |
| Record ambient temperature: | | | | |
| Note the instrument used: | | | | |
| 4. Apply a uniformly distributed weight of 280 to 290 pounds on the top surface of the handle for a period of 24 hours. | | | | |
| Record the actual weight: | | | | |
| Note the instrument used: | | | | |
| Record start time and date: | | | | |
| Steps 1 through 4 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 5. After 24 hours, remove the weight. | | | | |
| Record end date: | | | | |
| Record end time: | | | | |
| 6. Measure the ambient temperature. | | | | |
| Record the ambient temperature: | | | | |
| Note the instrument used: | | | | |
| 7. Photograph the test specimen and any subsequent damage. | | | | |
| 8. Record damage to test specimen on a separate sheet and attach. | | | | |

## Checklist 1: Compression Test (Continued)

**Test Location:**

**Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| Steps 5 through 8 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 9. Engineering, Regulatory Affairs and Quality Assurance make a preliminary assessment relative to 10 CFR 71. Record the assessment on a separate sheet and attach.<br>Determine what changes are necessary in package orientation for the penetration test to achieve maximum damage. | | | | |

| Test Data Accepted by: | Signature | Date |
|---|---|---|
| Engineering: | | |
| Regulatory Affairs: | | |
| Quality Assurance: | | |

## Equipment List 2: Penetration Test Equipment

| Description | Enter the Model and Serial Number | Attach Inspection Report or Calibration Certificate |
|---|---|---|
| Penetration Bar, Drawing BT10129, Rev. B | | |
| Drop Surface, Drawing AT10122, Rev. B | | |
| Thermometer | | |
| Thermocouple flexible probe | | |
| Thermocouple surface probe | | |
| Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate. | | |
| | | |
| | | |
| | | |
| Verified by: | Signature | Date |
| Engineering | | |
| Regulatory Affairs | | |
| Quality Assurance | | |

## Checklist 2: Penetration Test

**Test Location:**

**Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 1. Immerse the test specimen in dry ice as needed to bring specimen temperature below -40° C. | | | | |
| Step 1 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 2. Remove the specimen from the dry ice, and position it as shown in the referenced figure. | Figure 3 | Figure 4 | Figure 5 | Figure 6 |

## Checklist 2: Penetration Test (Continued)

**Test Location:**

**Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 3. Begin video recording of the test so that the impact is recorded. | | | | |
| 4. Inspect the orientation setup and verify the bar height. | | | | |
| 5. Measure the ambient temperature and the test specimen internal and surface temperatures. Ensure that specimen temperature is below -40° C. | | | | |
| Record ambient temperature: | | | | |
| Note the instrument used: | | | | |
| Record the specimen internal temperature: | | | | |
| Note the instrument used: | | | | |
| Record the specimen surface temperature: | | | | |
| Note the instrument used: | | | | |
| Steps 2 through 5 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 6. Drop the penetration bar onto the specified area shown in the referenced figure. | Figure 3 | Figure 4 | Figure 5 | Figure 6 |
| 7. Check to ensure that penetration bar hit the specified area. | | | | |
| 8. Measure the test specimen's surface temperature. Ensure that specimen is below -40° C. | | | | |
| Record the specimen surface temperature: | | | | |
| Note the instrument used: | | | | |
| 9. Pause the video recorder. Ensure that the point of impact and orientation specified in the plan have been achieved and recorded. | | | | |

## Checklist 2: Penetration Test (Continued)

**Test Location:**

**Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 10. Record damage to test specimen on a separate sheet and attach. | | | | |
| Steps 6 through 10 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 11. Engineering, Regulatory Affairs and Quality Assurance make a preliminary assessment relative to 10 CFR 71. Record the assessment on a separate sheet and attach. Determine what changes are necessary in package orientation for the four-foot free drop to achieve maximum damage. | | | | |

| Test Data Accepted by: | Signature | Date |
|---|---|---|
| Engineering: | | |
| Regulatory Affairs: | | |
| Quality Assurance: | | |

## Equipment List 3: Four-foot Free Drop Equipment List

| Description | Enter the Model and Serial Number | Attach Inspection Report or Calibration Certificate |
|---|---|---|
| Drop Surface, Drawing AT10122, Rev. B | | |
| Thermometer | | |
| Thermocouple flexible probe | | |
| Thermocouple surface probe | | |
| Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate. | | |
| | | |
| | | |
| | | |
| Verified by: | Signature | Date |
| Engineering | | |
| Regulatory Affairs | | |
| Quality Assurance | | |

## Checklist 3: Four-foot Free Drop

**Test Location:** **Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 1. Immerse the test specimen in dry ice as need to bring specimen temperature below -40° C. | | | | |
| Step 1 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 2. Measure the ambient temperature. | | | | |
| Record ambient temperature: | | | | |

## Checklist 3: Four-foot Free Drop (Continued)

**Test Location:**

**Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| Note the instrument used: | | | | |
| 3. Attach the test specimen to the release mechanism. | | | | |
| 4. Begin video recording of test so that impact is recorded. | | | | |
| 5. Measure the temperature of the specimen. Ensure that specimen is below -40° C. | | | | |
| Record the specimen internal temperature: | | | | |
| Note the instrument used: | | | | |
| Record the specimen surface temperature. | | | | |
| Note the instrument used: | | | | |
| 6. Lift and orient the test specimen as shown in the referenced figure for the specimen. | Figure 7 | Figure 8 | Figure 9 | Figure 10 |
| 7. Inspect the orientation setup and verify drop height. | | | | |
| 8. Photograph the setup in at least two perpendicular planes. | | | | |
| Steps 2 through 8 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 9. Release the test specimen. | | | | |
| 10. Measure the surface temperature of the test specimen. | | | | |
| Record the surface temperature: | | | | |
| Note the instrument used: | | | | |
| 11. Pause the video recorder. Ensure that the point of impact and orientation specified in the plan have been achieved and recorded. | | | | |

## Checklist 3: Four-foot Free Drop (Continued)

**Test Location:**

**Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 12. Record damage to test specimen on a separate sheet and attach. | | | | |
| Steps 9 through 12 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 13. Engineering, Regulatory Affairs and Quality Assurance make a preliminary assessment relative to 10 CFR 71. Record the assessment on a separate sheet and attach. Determine what changes are necessary in package orientation for the 30-foot free drop to achieve maximum damage. | | | | |

| Test Data Accepted by: | Signature | Date |
|---|---|---|
| Engineering: | | |
| Regulatory Affairs: | | |
| Quality Assurance: | | |

## Equipment List 4: 30-foot Free Drop Equipment List

| Description | Enter the Model and Serial Number | Attach Inspection Report or Calibration Certificate |
|---|---|---|
| Drop Surface, Drawing AT10122, Rev. B | | |
| Weight Scale | | |
| Thermometer | | |
| Thermocouple flexible probe | | |
| Thermocouple surface probe | | |
| Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate. | | |
| | | |
| | | |
| | | |
| Verified by: | Signature | Date |
| Engineering | | |
| Regulatory Affairs | | |
| Quality Assurance | | |

## Checklist 4: 30-foot Free Drop

**Test Location:** **Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 1. Measure and record test specimen weight. | | | | |
| Record the specimen's weight: | | | | |
| Note the instrument used: | | | | |
| 2. Immerse the test specimen in dry ice as need to bring specimen temperature below -40° C. | | | | |
| Steps 1 through 2 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 3. Measure the ambient temperature. | | | | |
| Record ambient temperature: | | | | |
| Note the instrument used: | | | | |
| 4. Attach the test specimen to the release mechanism. | | | | |
| 5. Begin video recording of test so that the impact is recorded. | | | | |
| 6. Measure the temperature of the specimen. Ensure that specimen is below -40° C. | | | | |
| Record the specimen internal temperature: | | | | |
| Note the instrument used: | | | | |
| Record the specimen surface temperature. | | | | |
| Note the instrument used: | | | | |
| 7. Lift and orient the test specimen as shown in the referenced figure for the specimen. | Figure 11 | Figure 12 | Figure 13 | Figure 14 |
| 8. Inspect the orientation setup and verify drop height. | | | | |
| 9. Photograph the setup in at least two perpendicular planes. | | | | |

## Checklist 4: 30-foot Free Drop (Continued)

**Test Location:** **Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| Steps 3 through 9 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 10. Release the test specimen. | | | | |
| 11. Measure the surface temperature of the test specimen. | | | | |
| Record the surface temperature: | | | | |
| Note the instrument used: | | | | |
| 12. Measure and record the test specimen's weight. | | | | |
| Record the specimen's weight: | | | | |
| Note the instrument used: | | | | |
| 13. Pause the video recorder. Ensure that the point of impact and orientation specified in the plan have been achieved and recorded. | | | | |
| 14. Record damage to test specimen on a separate sheet and attach. | | | | |
| Steps 10 through 14 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |

## Checklist 4: 30-foot Free Drop (Continued)

**Test Location:**

**Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 15. Engineering, Regulatory Affairs and Quality Assurance make a preliminary assessment relative to 10 CFR 71. Record the assessment on a separate sheet and attach. Determine what changes are necessary in package orientation for the puncture test to achieve maximum damage. | | | | |

| Test Data Accepted by | Signature | Date |
|---|---|---|
| Engineering: | | |
| Regulatory Affairs: | | |
| Quality Assurance: | | |

## Equipment List 5: Puncture Test Equipment

| Description | Enter the Model and Serial Number | Attach Inspection Report or Calibration Certificate |
|---|---|---|
| Drop Surface, Drawing AT10122, Rev. B | | |
| Puncture Billet, Drawing CT10119, Rev. C | | |
| Weight Scale | | |
| Thermometer | | |
| Thermocouple flexible probe | | |
| Thermocouple surface probe | | |
| Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate. | | |
| | | |
| | | |
| | | |
| Verified by: | Signature | Date |
| Engineering | | |
| Regulatory Affairs | | |
| Quality Assurance | | |

## Checklist 5: Puncture Test

**Test Location:** **Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 1. Immerse the test specimen in dry ice as need to bring specimen temperature below -40° C. | | | | |
| Step 1 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 2. Measure the weight of the specimen. | | | | |

## Checklist 5: Puncture Test (Continued)

**Test Location:**

**Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| Record the specimen's weight: | | | | |
| Note instrument used: | | | | |
| 3. Measure the ambient temperature. | | | | |
| Record ambient temperature: | | | | |
| Note the instrument used: | | | | |
| 4. Attach the test specimen to the release mechanism. | | | | |
| 5. Begin video recording of test so that the impact is recorded. | | | | |
| 6. Measure the surface temperature of the specimen.<br>Ensure that specimen is below -40° C. | | | | |
| Record the specimen surface temperature. | | | | |
| Note the instrument used: | | | | |
| 7. Lift and orient the test specimen as shown in the referenced figure for the specimen. | Figure 15 | Figure 16 | Figure 17 | Figure 18 |
| 8. Inspect the orientation setup and verify drop height. | | | | |
| 9. Photograph the setup in at least two perpendicular planes. | | | | |
| Steps 2 through 9 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 10. Release the test specimen. | | | | |
| 11. Measure the surface temperature of the test specimen. | | | | |
| Record the surface temperature: | | | | |
| Note the instrument used: | | | | |

## Checklist 5: Puncture Test (Continued)

**Test Location:**

**Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 12. Measure and record the test specimen's weight. | | | | |
| Record the specimen's weight: | | | | |
| Note the instrument used: | | | | |
| 13. Pause the video recorder. Ensure that the point of impact and orientation specified in the plan have been achieved and recorded. | | | | |
| 14. Record damage to test specimen on a separate sheet and attach. | | | | |
| Steps 10 through 14 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 15. Engineering, Regulatory Affairs and Quality Assurance make a preliminary assessment relative to 10 CFR 71. Record the assessment on a separate sheet and attach. Determine the package orientation for the thermal test that will achieve maximum damage. | | | | |

| Test Data Accepted by: | Signature | Date |
|---|---|---|
| Engineering: | | |
| Regulatory Affairs: | | |
| Quality Assurance: | | |

## Equipment List 6: Thermal Test Equipment

| Description | Enter the Model and Serial Number | Attach Inspection Report or Calibration Certificate |
|---|---|---|
| Air Flowmeter | | |
| Thermocouple flexible probe | | |
| Thermocouple surface probe | | |
| Oven thermostat | | |
| Record any additional tools used to facilitate the test and attach the appropriate inspection report or calibration certificate. | | |
| | | |
| | | |
| | | |
| Verified by: | Signature | Date |
| Engineering | | |
| Regulatory Affairs | | |
| Quality Assurance | | |

## Checklist 6: Thermal Test

**Test Location:**

**Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 1. Pre-heat the oven to 900° C. | | | | |
| 2. Attach the thermocouple the specimen's internal measuring point. | | | | |
| 3. Place the package in the oven and close the oven door. | | | | |
| Record date and time placed in oven. | | | | |
| 4. When the specimen temperature exceeds 800° C, start the air flow into the oven. Record time. | | | | |
| Steps 1 through 4 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 5. Measure the oven temperature, the specimen's internal and external temperatures and the air flow rate. | | | | |
| Record the oven temperature: | | | | |
| Note instrument used: | | | | |
| Record the specimen's internal temperature: | | | | |
| Note instrument used: | | | | |
| Record the specimen's external temperature: | | | | |
| Note instrument used: | | | | |
| Record airflow rate: | | | | |
| Note instrument used: | | | | |
| 6. Monitor the specimen temperatures and oven temperature throughout the 30-minute period to ensure that they are above 800° C. | | | | |

## Checklist 6: Thermal Test (Continued)

**Test Location:**

**Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 7. Monitor the airflow throughout the 30-minute period to ensure a rate of at least 9.6 $ft^3$/min. | | | | |
| 8. At the end of the 30-minute period, repeat step 5 using the same measurement devices. | | | | |
| Record the oven temperature: | | | | |
| Record the specimen's internal temperature: | | | | |
| Record the specimen's external temperature: | | | | |
| Record intake air flow velocity: | | | | |
| Steps 5 through 8 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |
| 9. Remove test specimen from the oven. | | | | |
| Record time the specimen is removed. | | | | |
| Describe combustion when door is opened to remove specimen. | | | | |
| NOTE: If specimen continues to burn, let it self-extinguish and cool naturally. | | | | |
| 10. Measure the ambient temperature. | | | | |
| Record the ambient temperature: | | | | |
| Note the instrument used: | | | | |
| 11. Photograph the test specimen and any subsequent damage | | | | |
| 12. Record damage to test specimen on a separate sheet and attach. | | | | |
| Steps 9 through 12 witnessed by: | | | | |
| Engineering | | | | |
| Regulatory Affairs | | | | |
| Quality Assurance | | | | |

## Checklist 6: Thermal Test (Continued)

**Test Location:**

**Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 13. Engineering, Regulatory Affairs and Quality Assurance make a preliminary assessment relative to 10 CFR 71. Record the assessment on a separate sheet and attach. | | | | |

| Test Data Accepted by: | Signature | Date |
|---|---|---|
| Engineering: | | |
| Regulatory Affairs: | | |
| Quality Assurance: | | |

**Checklist 6: Thermal Test (Continued)**

**Test Location:** **Attempt Number:**

| Step | Specimen A | Specimen B | Specimen C | Specimen D |
|---|---|---|---|---|
| 13. Engineering, Regulatory Affairs and Quality Assurance make a preliminary assessment relative to 10 CFR 71. Record the assessment on a separate sheet and attach. | | | | |

| Test Data Accepted by: | Signature | Date |
|---|---|---|
| Engineering: | | |
| Regulatory Affairs: | | |
| Quality Assurance: | | |

# Appendix A
# Drawings

Model 660 Test Specimen
TP70, Rev. B (1 sheet)

Model 660 Gamma Ray Projector Shipping Container Descriptive Assembly
C66025, Rev. F (3 sheets)

Model 660 Gamma Ray Projector Shipping Container Descriptive Assembly
C66025, Rev. B (4 sheets)

Model 660 Gamma Ray Projector Shipping Container Descriptive Assembly
C66030, Rev. D (3 sheets)

Model 660 Gamma Ray Projector Shipping Container Descriptive Assembly
C66030, Rev. A (3 sheets)

Model 660 Gamma Ray Projector Shipping Container Descriptive Assembly
C66030, Rev. – (4 sheets)

| REV | REVISED BY | DATE | DESCRIPTION | ECO# |
|---|---|---|---|---|
| A | SEE TITLE BLOCK | | RELEASE FOR PRODUCTION | 2339 |
| B | | | SEE ECO FOR CHANGES | 2342 |

NOTES:

1. MATERIAL:
EXCEPT AS SHOWN, MANUFACTURE TEST UNIT PER DRAWING NUMBER D68010, REVISION C AND IN ACCORDANCE WITH THE AMERSHAM QUALITY ASSURANCE PROGRAM. ALSO, INSTALL DUMMY SOURCE, DRAWING NUMBER A42409XL. SEE NOTE 3.2

2. WEIGHT:
2.1. USE DU SHIELDS WEIGHING 37 TO 39 POUNDS.

2.2. TEST UNIT SHALL WEIGH 54 TO 56 POUNDS.

2.3. ADD 1 TO 2 POUNDS OF LEAD (1/4 THICK MAX) TO THE DU SHIELD. DISTRIBUTE THE LEAD SYMMETRICALLY AND ATTACH WITH GLASS TAPE. TOTAL SHIELD ASSEMBLY WEIGHT MUST NOT EXCEED 40 POUNDS.

2.4. PHOTOGRAPH COMPLETED SHIELD ASSEMBLY WITH LEAD APPLIED.

3. LABELING AND IDENTIFICATION
3.1. LABEL TYPE B (U) INFORMATION WITH LABEL STATING: "TP70 TEST SPECIMEN".

3.2. MARK EACH TEST SPECIMEN, ITS SHIPPING PLUG, AND ITS DUMMY SOURCE WITH AN IDENTIFICATION LETTER: "A", "B", "C", "D", & "S".

4. CENTER OF GRAVITY:
4.1 DETERMINE THE TEST UNIT CENTER OF GRAVITY LOCATION BY:

4.1.1. SUSPEND THE TEST UNIT BY A CORD OR CABLE.

4.1.2. ATTACH A CORD OR CABLE WITH A WEIGHT (PLUMB BOB) TO THE TEST UNIT AT THE SUSPENDED ATTACHMENT POINT.

4.1.3. WAIT UNTIL THE TEST UNIT COMES TO REST.

4.1.4. MARK A LINE ON THE TEST UNIT ALONG THE PLUMB BOB.

4.1.5. REMOVE THE TEST UNIT FROM ITS SUSPENSION POINT.

4.1.6. REATTACH THE TEST UNIT TO A POINT APPROXIMATELY 90 DEGREES FROM THE PREVIOUS ATTACHMENT POINT.

4.1.7. REPEAT STEPS 4.1.2 THROUGH 4.1.5.

4.1.8. INDICATE THE CENTER OF GRAVITY LOCATION AT THE INTERSECTION OF THE TWO MARKED LINES.

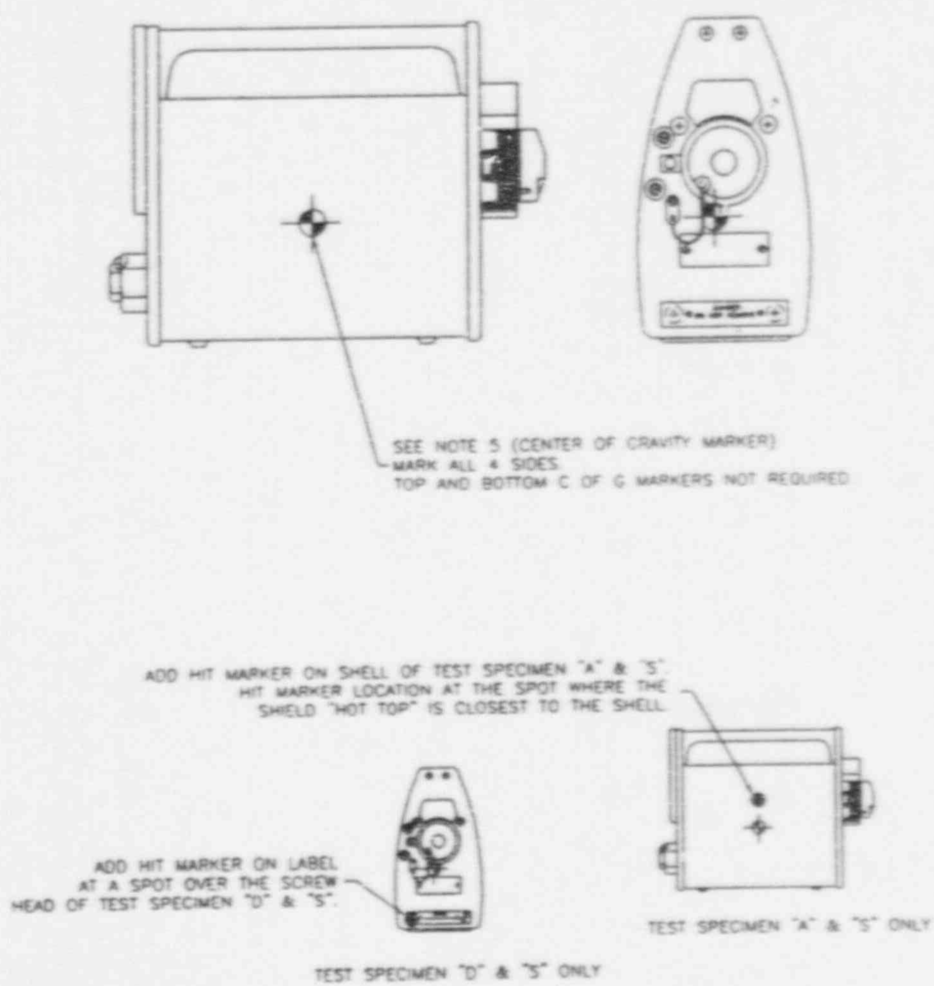
4.1.9. REPEAT STEPS 4.1.1 THROUGH 4.1.8 FOR EACH SIDE OF THE TEST UNIT.

5. ATTACHMENT POINTS:
5.1. USE THE ORIENTATION FIGURES OF THE TEST PLAN TO LOCATE ANY ATTACHMENT POINTS ON THE TEST UNIT, IF NEEDED.

5.2. ATTACHMENT POINTS SHALL NOT INTERFERE WITH THE CENTER OF GRAVITY LOCATION OR AFFECT THE PERFORMANCE OF THE TEST UNIT DURING TESTING.

5.3. ATTACHMENT POINT SIZE AND LOCATION SHALL BE DOCUMENTED BEFORE TESTING CAN PROCEED.

5.4. ADHESIVE, HOOKS, AND STRAPS TO BE DETERMINED BY ENGINEERING PRIOR TO TEST.




USED ON: TEST PLAN #70
MATERIALS: SEE NOTE 1
SURFACE TEXTURE
FINISH: FINISH
REMOVE ALL BURRS
APPROVED DRAWING ON FILE

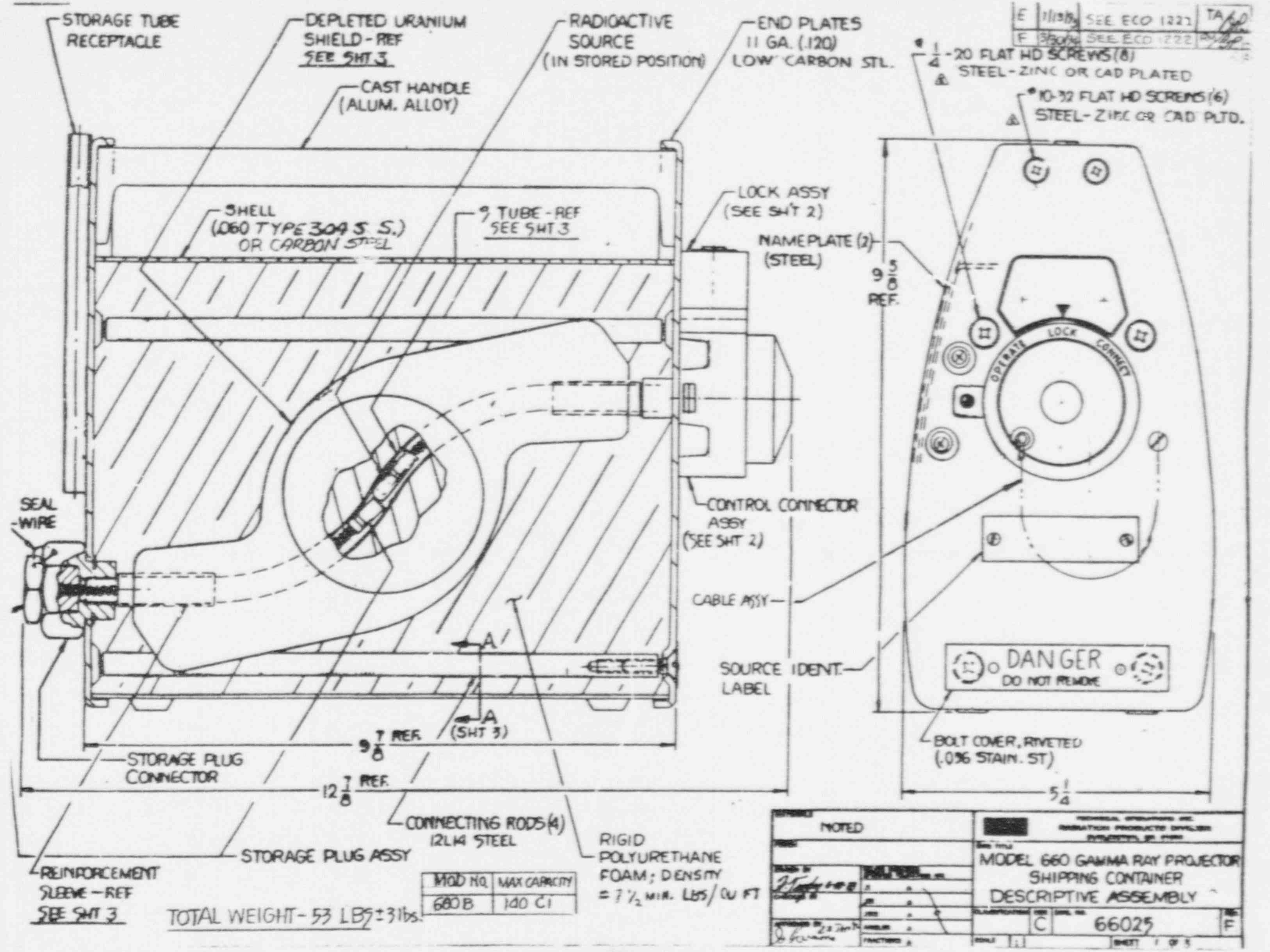
| | |
|---|---|
| .X | ± 0.1 |
| .XX | ± 0.01 |
| .XXX | ± 0.005 |
| ANGLES | ± 1° |
| FRACT | ± 1/64 |

AMERSHAM CORPORATION
BURLINGTON, MA 01803
**SENTINEL**

DWG. TITLE: MODEL 660 TEST SPECIMEN

| SAFETY CLASS | SIZE | DWG. NO. | REV |
|---|---|---|---|
| A | C | TP70 | B |

SCALE: NONE SHEET 1 OF 1




| MOD NO. | MAX CAPACITY |
|---|---|
| 680B | 140 CI |

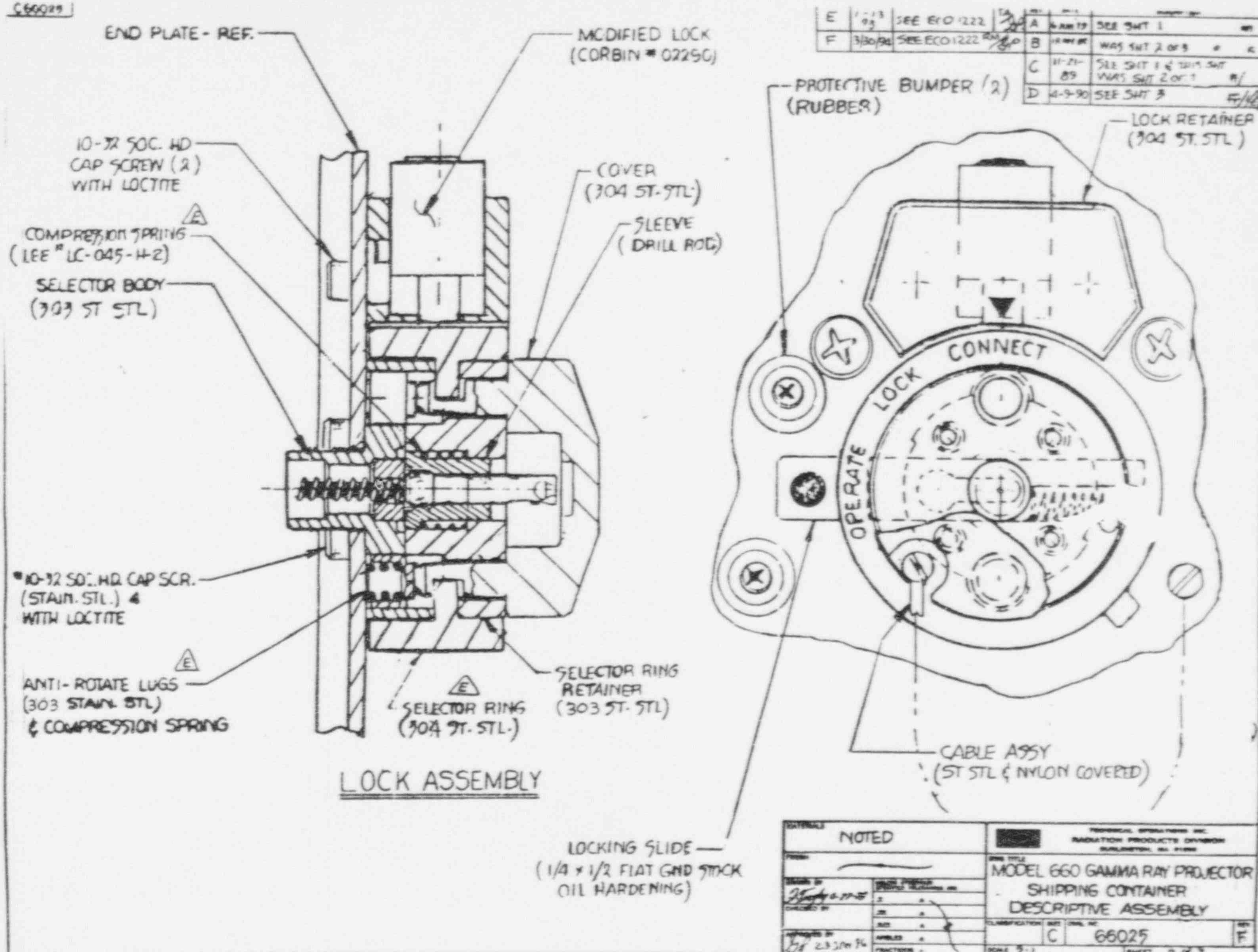
| | | | |
|---|---|---|---|
| E | 11/13/86 | SEE ECO 1221 | TA |
| F | 3/30/86 | SEE ECO 1222 | |

NOTED

MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY

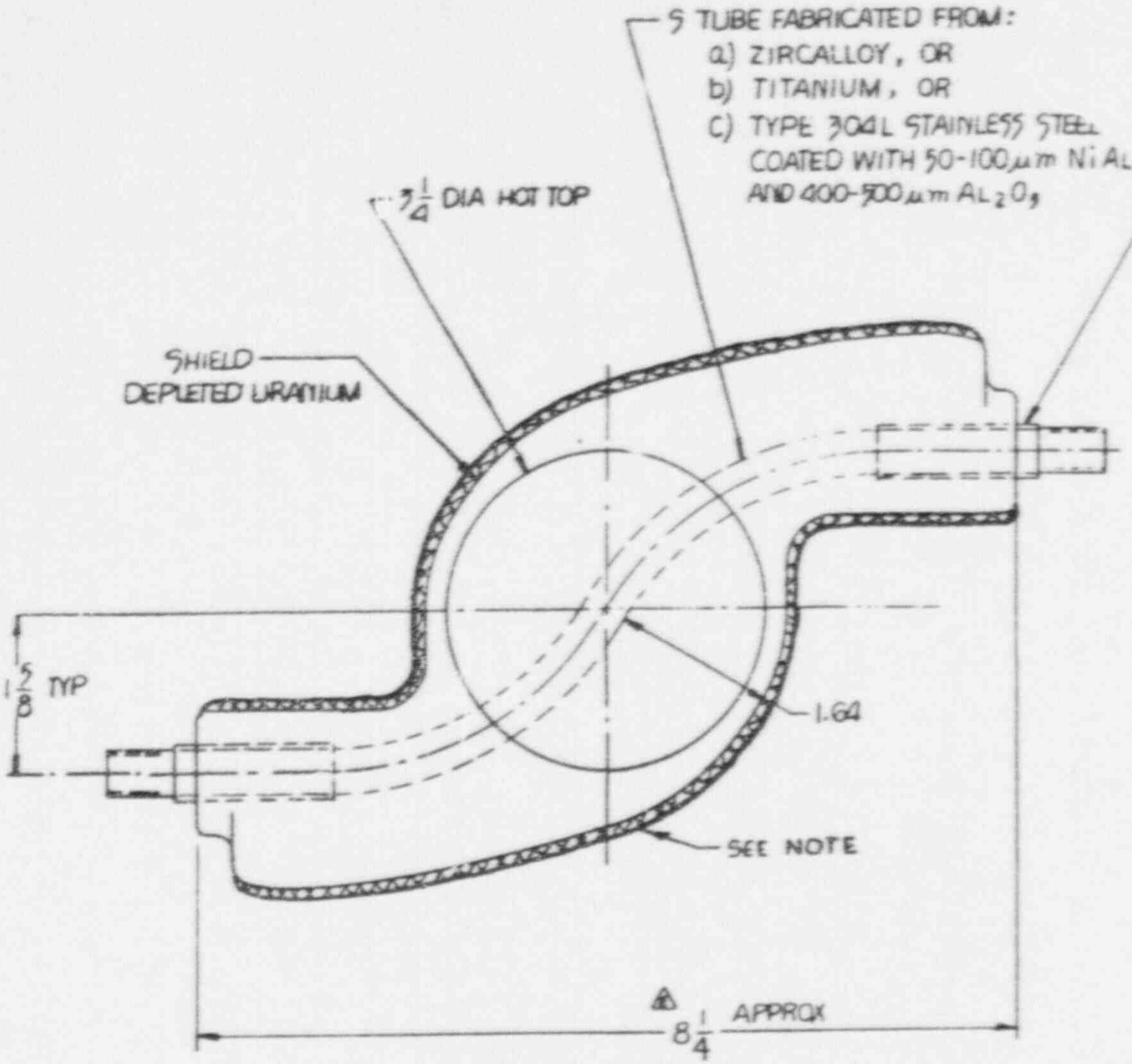
C | 66025 | F

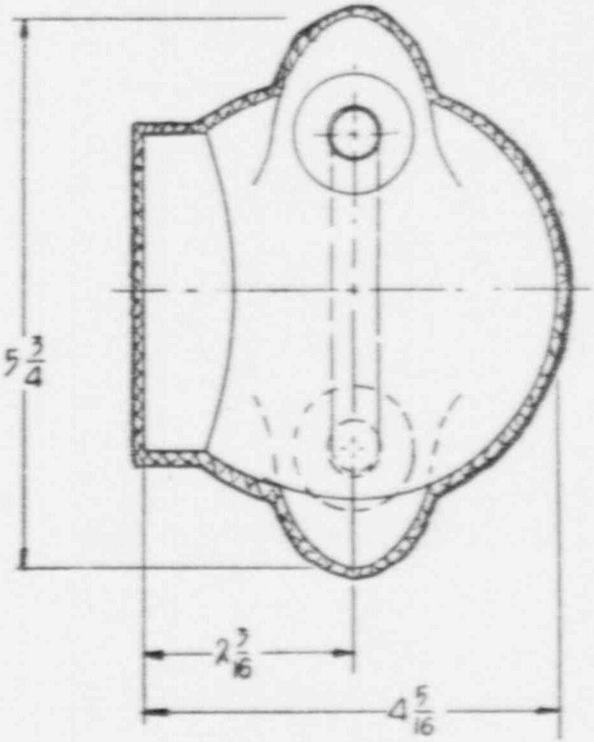
SHEET 1 OF 3



C66025
E SEE ECO 1222
F 3/30/94 SEE ECO 1222
A SEE SHT 1
B WAS SHT 2 OF 3
C 11-21-89 SEE SHT 1
D 4-9-90 SEE SHT 3
END PLATE - REF.
MODIFIED LOCK (CORBIN # 02290)
10-32 SOC. HD CAP SCREW (2) WITH LOCTITE
COVER (304 ST. STL.)
SLEEVE (DRILL ROD)
COMPRESSION SPRING (LEE # LC-045-H-2)
SELECTOR BODY (303 ST STL)
*10-32 SOC. HD CAP SCR. (STAIN. STL.) & WITH LOCTITE
ANTI-ROTATE LUGS (303 STAIN. STL) & COMPRESSION SPRING
SELECTOR RING (304 ST. STL.)
SELECTOR RING RETAINER (303 ST. STL)
LOCK ASSEMBLY
PROTECTIVE BUMPER (2) (RUBBER)
LOCK RETAINER (304 ST. STL)
CONNECT
LOCK
OPERATE
CABLE ASSY (ST STL & NYLON COVERED)
LOCKING SLIDE (1/4 x 1/2 FLAT GND STOCK OIL HARDENING)
NOTED
MODEL 660 GAMMA RAY PROJECTOR
SHIPPING CONTAINER
DESCRIPTIVE ASSEMBLY
C
66025
F
SCALE 2:1
SHEET 2 OF 3

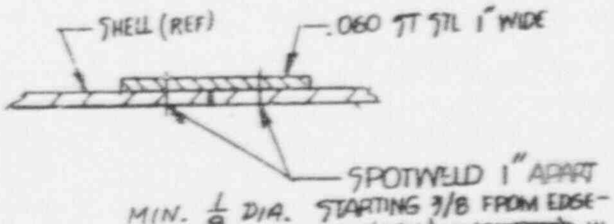
| REV | DATE | DESCRIPTION | BY |
|---|---|---|---|
| C | 11-22 89 | WAS SHT 4 OF 4 & REV OF THIS SHT WAS — & ADDED SECT. A-A | |
| D | 9-4 90 | ADDED "WELDED & INSPECTED IN ACCORDANCE WITH ---" WAS -(MIL-W-6858)- E.C.O. # 718 | |
| E | 1-13 93 | SEE ECO 1222 | |
| F | 3/30/93 | ADDED 'LEAD' TO NOTE PER ECO 1222 | |



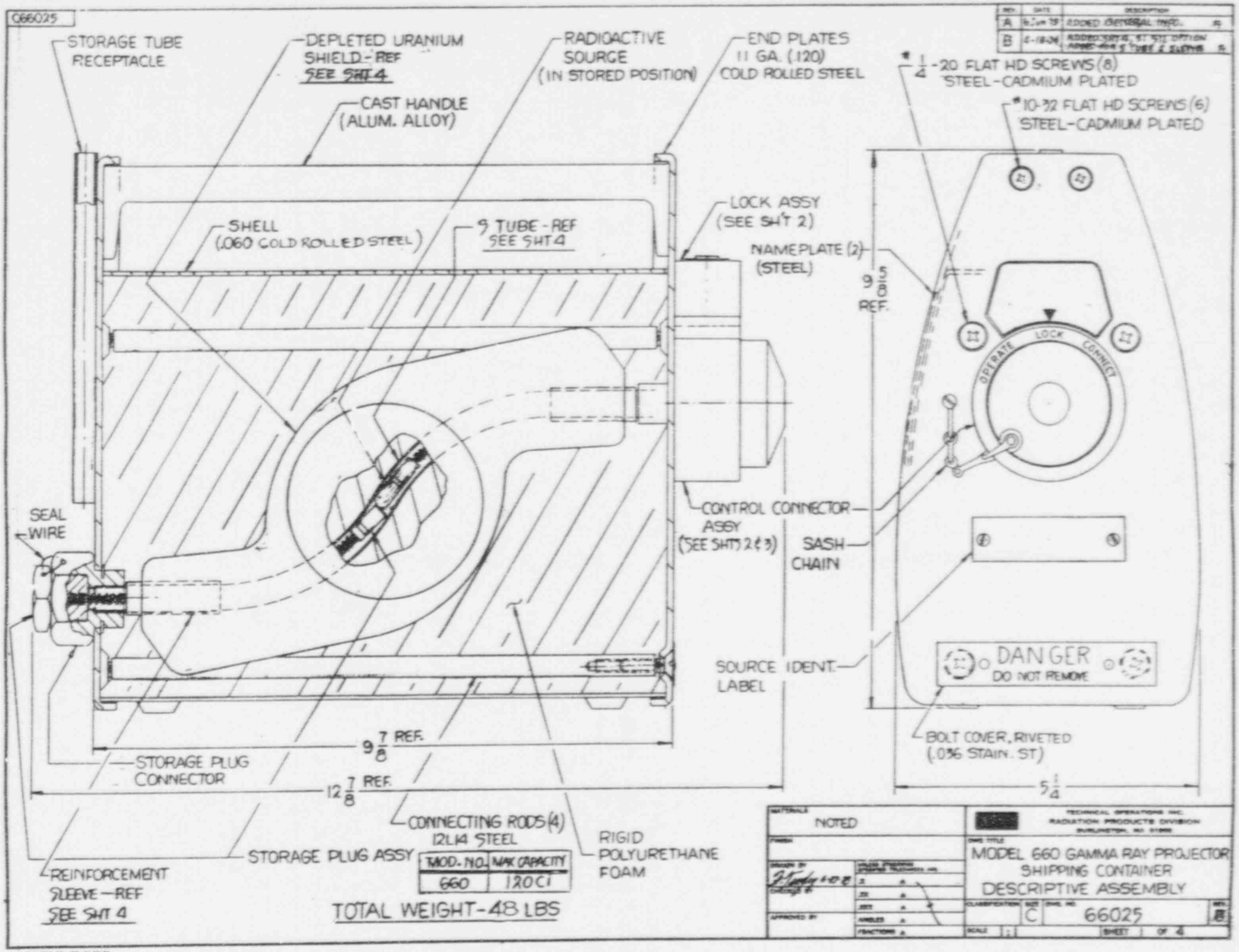

NOTE: ADDITIONAL LEAD SHIELDING NOT TO EXCEED 3 lbs. MAX. THICKNESS 1/4". TUNGSTEN NOT SHOWN. (F)

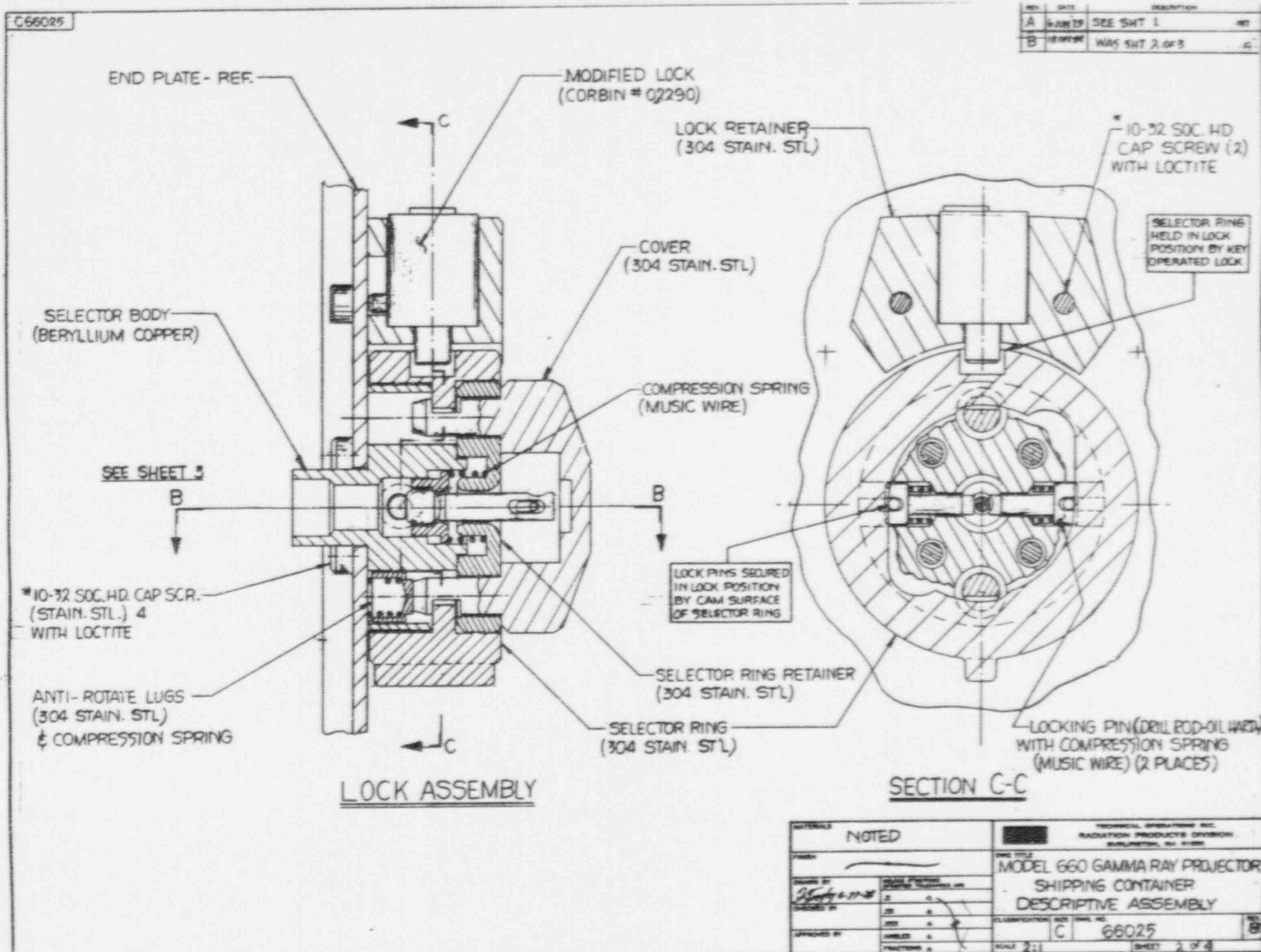
SHIELD DATA
37 LBS ± 3 lbs. (E)




SECTION A-A
SCALE: 1/1 (D)

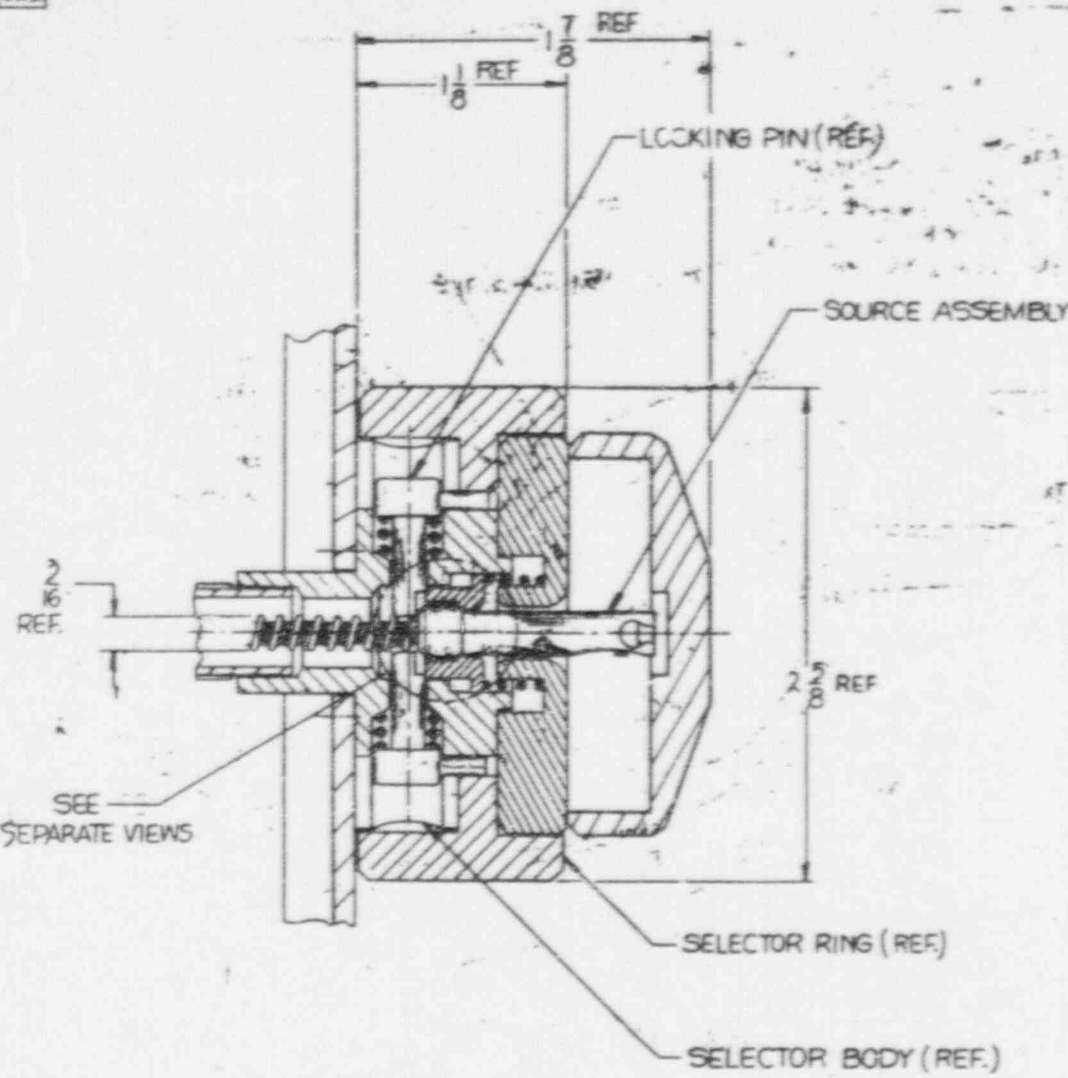
| | |
|---|---|
| MATERIAL | AS NOTED |
| | TechOps, Inc. RADIATION PRODUCTS DIVISION BURLINGTON, MA |
| TITLE | MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY |
| SIZE | C |
| DWG. NO. | 66025 |
| REV | F |
| SCALE | 1:1 |
| SHEET | 3 OF 3 |


C66025
STORAGE TUBE RECEPTACLE
DEPLETED URANIUM SHIELD - REF SEE SHT 4
RADIOACTIVE SOURCE (IN STORED POSITION)
END PLATES 11 GA. (.120) COLD ROLLED STEEL
1/4-20 FLAT HD SCREWS (8) STEEL-CADMIUM PLATED
10-32 FLAT HD SCREWS (6) STEEL-CADMIUM PLATED
CAST HANDLE (ALUM. ALLOY)
SHELL (.060 COLD ROLLED STEEL)
9 TUBE - REF SEE SHT 4
LOCK ASSY (SEE SH'T 2)
NAMEPLATE (2) (STEEL)
9 5/8 REF.
LOCK
OPERATE
CONNECT
SEAL WIRE
CONTROL CONNECTOR ASSY (SEE SHTS 2 & 3)
SASH CHAIN
SOURCE IDENT. LABEL
DANGER DO NOT REMOVE
BOLT COVER, RIVETED (.036 STAIN. ST)
9 7/8 REF.
STORAGE PLUG CONNECTOR
12 7/8 REF.
5 1/4
CONNECTING RODS (4) 12L14 STEEL
RIGID POLYURETHANE FOAM
STORAGE PLUG ASSY
MOD. NO. 660
MAX CAPACITY 120 CI
REINFORCEMENT SLEEVE - REF SEE SHT 4
TOTAL WEIGHT - 48 LBS
A ADDED GENERAL INFO.
B
NOTED
TECHNICAL OPERATIONS INC. RADIATION PRODUCTS DIVISION
MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY
C
66025
B
OF 4

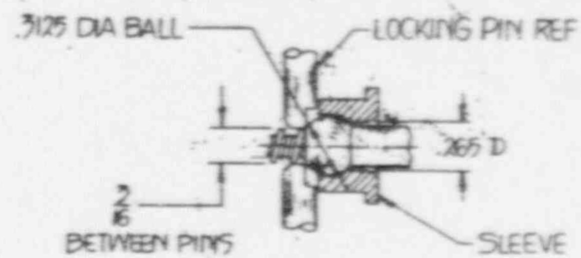

C66025
A SEE SHT 1
B WAS SHT 2 of 3
END PLATE - REF.
MODIFIED LOCK
(CORBIN # 02290)
LOCK RETAINER
(304 STAIN. STL)
*10-32 SOC. HD
CAP SCREW (2)
WITH LOCTITE
SELECTOR RING HELD IN LOCK POSITION BY KEY OPERATED LOCK
COVER
(304 STAIN. STL)
SELECTOR BODY
(BERYLLIUM COPPER)
COMPRESSION SPRING
(MUSIC WIRE)
SEE SHEET 3
B
B
LOCK PINS SECURED IN LOCK POSITION BY CAM SURFACE OF SELECTOR RING
*10-32 SOC. HD. CAP SCR.
(STAIN. STL.) 4
WITH LOCTITE
SELECTOR RING RETAINER
(304 STAIN. ST'L)
ANTI-ROTATE LUGS
(304 STAIN. STL)
& COMPRESSION SPRING
SELECTOR RING
(304 STAIN. ST'L)
LOCKING PIN (DRILL ROD-OIL HARD)
WITH COMPRESSION SPRING
(MUSIC WIRE) (2 PLACES)
C
C
LOCK ASSEMBLY
SECTION C-C
NOTED
TECHNICAL OPERATIONS INC.
RADIATION PRODUCTS DIVISION
MODEL 660 GAMMA RAY PROJECTOR
SHIPPING CONTAINER
DESCRIPTIVE ASSEMBLY
C
66025
2:1
SHEET 2 of 4

C66025

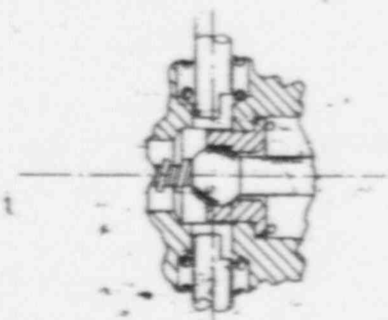
| REV | DATE | DESCRIPTION | |
|---|---|---|---|
| A | 6 JAN 79 | SEE SHT 1 | |
| B | | WAS SHT 3 OF 3 | |




SECTION B-B

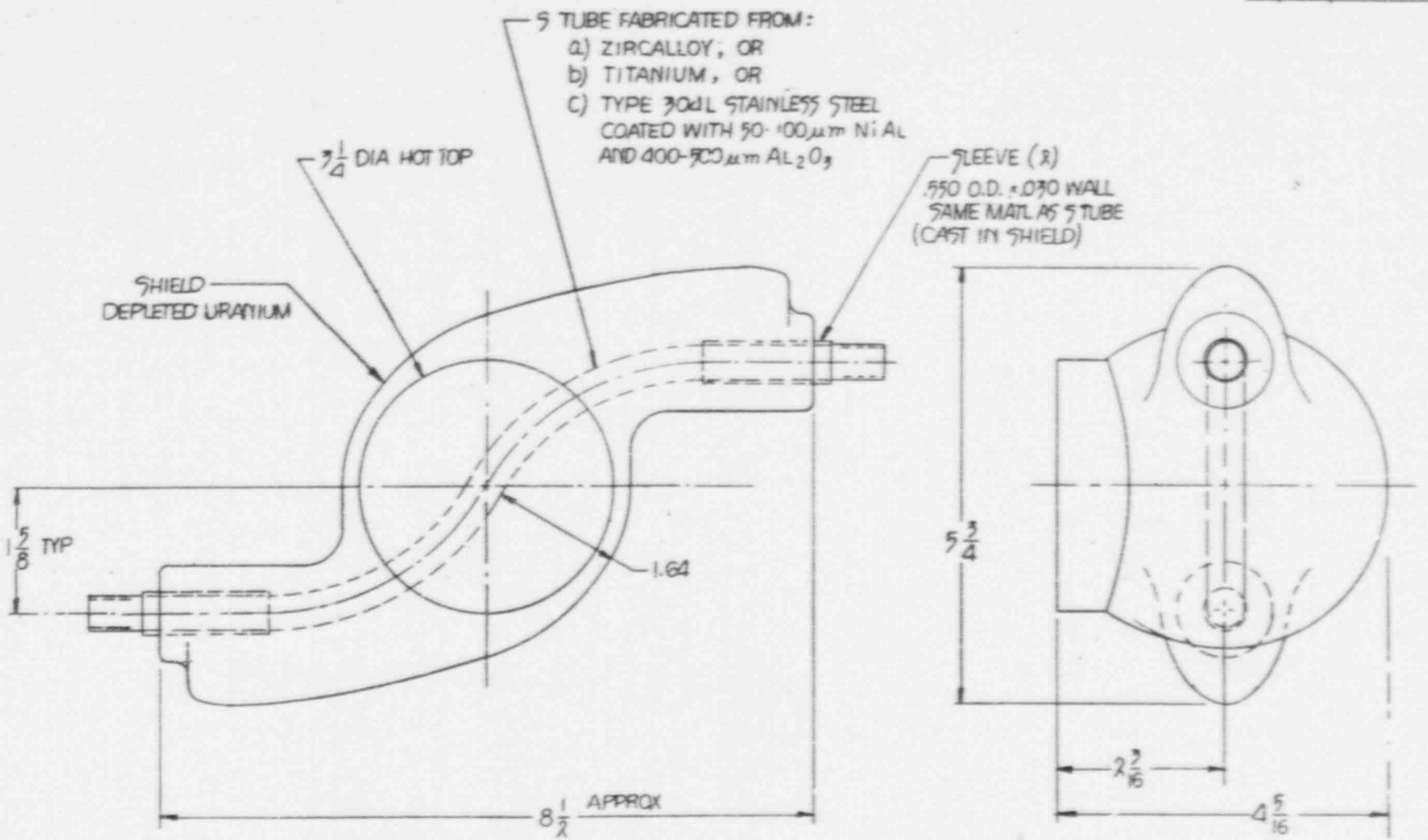



LOCKED POSITION



UNLOCKED POSITION

| | |
|---|---|
| NOTED | RADIATION PRODUCTS DIVISION<br>BURLINGTON, MA |
| | MODEL 660 GAMMA RAY PROJECTOR<br>SHIPPING CONTAINER<br>DESCRIPTIVE ASSEMBLY |
| | SIZE C | DWG. NO. 66025 | REV. B |
| | SCALE 2:1 | SHEET 3 OF 4 |




SHIELD DATA

35 LBS

| | | | |
|---|---|---|---|
| REV. | DATE | DESCRIPTION | |
| B | 4-18-84 | SEE SHT 1 | |

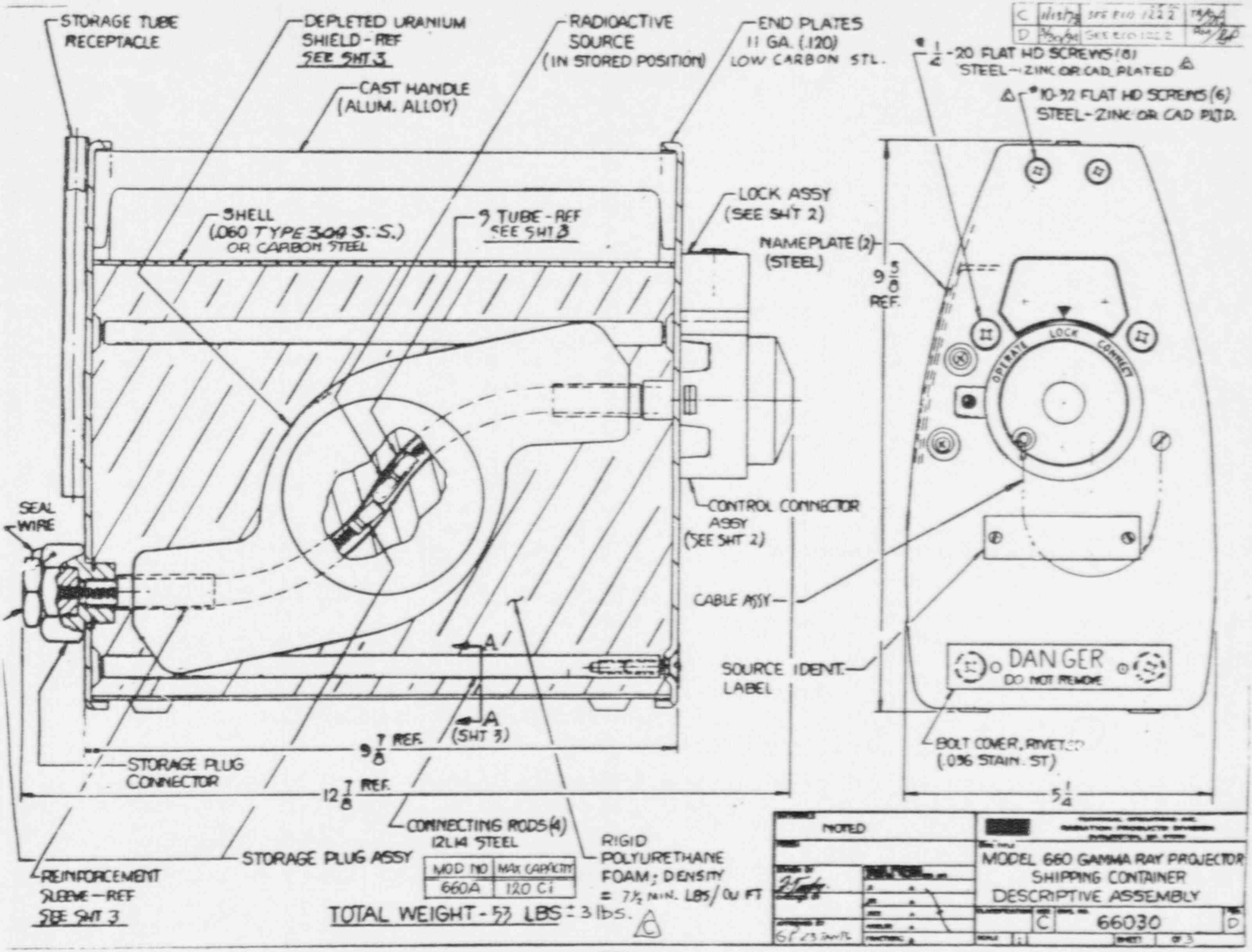
MATERIALS: AS NOTED

TechOps, Inc. RADIATION PRODUCTS DIVISION BURLINGTON, MA 01803

DWG TITLE: MODEL 660 GAMMA RAY PROJEC SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY

SIZE C DWG NO. 66025 REV B

SHEET 4 OF 4


STORAGE TUBE RECEPTACLE
DEPLETED URANIUM SHIELD - REF SEE SHT 3
RADIOACTIVE SOURCE (IN STORED POSITION)
END PLATES 11 GA. (.120) LOW CARBON STL.
CAST HANDLE (ALUM. ALLOY)
SHELL (.060 TYPE 304 S.S.) OR CARBON STEEL
S TUBE - REF SEE SHT 3
LOCK ASSY (SEE SHT 2)
NAMEPLATE (2) (STEEL)
1/4 -20 FLAT HD SCREWS (8) STEEL - ZINC OR CAD. PLATED
#10-32 FLAT HD SCREWS (6) STEEL - ZINC OR CAD PLTD.
9 5/8 REF.
OPERATE
LOCK
CONNECT
SEAL WIRE
CONTROL CONNECTOR ASSY (SEE SHT 2)
CABLE ASSY
SOURCE IDENT. LABEL
DANGER
DO NOT REMOVE
BOLT COVER, RIVETED (.036 STAIN. ST)
A
A
(SHT 3)
9 7/8 REF.
12 7/8 REF.
5 1/4
STORAGE PLUG CONNECTOR
CONNECTING RODS (4) 12L14 STEEL
RIGID POLYURETHANE FOAM; DENSITY = 7½ MIN. LBS/CU FT
STORAGE PLUG ASSY
REINFORCEMENT SLEEVE - REF SEE SHT 3
MOD NO | MAX CAPACITY
660A | 120 Ci
TOTAL WEIGHT - 53 LBS ± 3 lbs.
C
NOTED
MODEL 660 GAMMA RAY PROJECTOR
SHIPPING CONTAINER
DESCRIPTIVE ASSEMBLY
C
66030
D

| REV | REVISED BY | DATE | DESCRIPTION | ECO# |
|---|---|---|---|---|
| A | SEE TITLE BLOCK | | RELEASE FOR PRODUCTION | 2339 |
| B | | | SEE ECO FOR CHANGES | 2342 |

NOTES:

1. MATERIAL:
EXCEPT AS SHOWN, MANUFACTURE TEST UNIT PER DRAWING NUMBER D66010, REVISION C AND IN ACCORDANCE WITH THE AMERSHAM QUALITY ASSURANCE PROGRAM. ALSO, INSTALL DUMMY SOURCE, DRAWING NUMBER A42409KL. SEE NOTE 3.2

2. WEIGHT:

2.1. USE DU SHIELDS WEIGHING 37 TO 39 POUNDS.

2.2. TEST UNIT SHALL WEIGH 54 TO 56 POUNDS.

2.3. ADD 1 TO 2 POUNDS OF LEAD (1/4 THICK MAX) TO THE DU SHIELD. DISTRIBUTE THE LEAD SYMMETRICALLY AND ATTACH WITH GLASS TAPE. TOTAL SHIELD ASSEMBLY WEIGHT MUST NOT EXCEED 40 POUNDS.

2.4. PHOTOGRAPH COMPLETED SHIELD ASSEMBLY WITH LEAD APPLIED.

3. LABELING AND IDENTIFICATION

3.1. LABEL TYPE B (U) INFORMATION WITH LABEL STATING: "TP70 TEST SPECIMEN".

3.2. MARK EACH TEST SPECIMEN, ITS SHIPPING PLUG, AND ITS DUMMY SOURCE WITH AN IDENTIFICATION LETTER: "A", "B", "C", "D", & "S".

4. CENTER OF GRAVITY:

4.1 DETERMINE THE TEST UNIT CENTER OF GRAVITY LOCATION BY:

4.1.1. SUSPEND THE TEST UNIT BY A CORD OR CABLE.

4.1.2. ATTACH A CORD OR CABLE WITH A WEIGHT (PLUMB BOB) TO THE TEST UNIT AT THE SUSPENDED ATTACHMENT POINT.

4.1.3. WAIT UNTIL THE TEST UNIT COMES TO REST.

4.1.4. MARK A LINE ON THE TEST UNIT ALONG THE PLUMB BOB.

4.1.5. REMOVE THE TEST UNIT FROM ITS SUSPENSION POINT.

4.1.6. REATTACH THE TEST UNIT TO A POINT APPROXIMATELY 90 DEGREES FROM THE PREVIOUS ATTACHMENT POINT.

4.1.7. REPEAT STEPS 4.1.2 THROUGH 4.1.5.

4.1.8. INDICATE THE CENTER OF GRAVITY LOCATION AT THE INTERSECTION OF THE TWO MARKED LINES.

4.1.9. REPEAT STEPS 4.1.1 THROUGH 4.1.8 FOR EACH SIDE OF THE TEST UNIT.

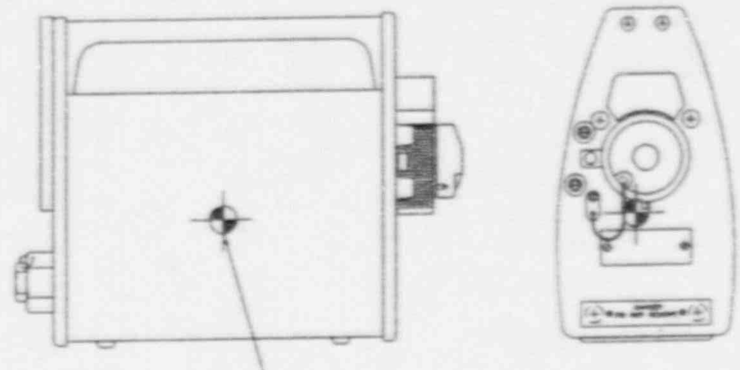
5. ATTACHMENT POINTS:

5.1. USE THE ORIENTATION FIGURES OF THE TEST PLAN TO LOCATE ANY ATTACHMENT POINTS ON THE TEST UNIT, IF NEEDED.

5.2. ATTACHMENT POINTS SHALL NOT INTERFERE WITH THE CENTER OF GRAVITY LOCATION OR AFFECT THE PERFORMANCE OF THE TEST UNIT DURING TESTING.

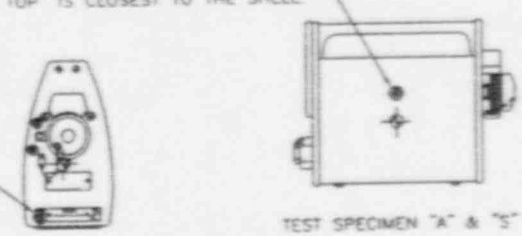
5.3. ATTACHMENT POINT SIZE AND LOCATION SHALL BE DOCUMENTED BEFORE TESTING CAN PROCEED.

5.4. ADHESIVE, HOOKS, AND STRAPS TO BE DETERMINED BY ENGINEERING PRIOR TO TEST.



SEE NOTE 5 (CENTER OF GRAVITY MARKER)
MARK ALL 4 SIDES.
TOP AND BOTTOM C OF G MARKERS NOT REQUIRED

ADD HIT MARKER ON SHELL OF TEST SPECIMEN "A" & "S".
HIT MARKER LOCATION AT THE SPOT WHERE THE SHIELD "HOT TOP" IS CLOSEST TO THE SHELL.



ADD HIT MARKER ON LABEL AT A SPOT OVER THE SCREW HEAD OF TEST SPECIMEN "D" & "S".

TEST SPECIMEN "D" & "S" ONLY

TEST SPECIMEN "A" & "S" ONLY

THIS DRAWING IS THE EXCLUSIVE PROPERTY OF AMERSHAM CORPORATION. IT MAY ONLY BE USED FOR THE PURPOSE FOR WHICH IT WAS SOLD. IT MAY NOT BE DUPLICATED IN ANY WAY, NOR TRANSMITTED TO ANY THIRD PARTY WITHOUT THE EXPRESS PERMISSION OF AMERSHAM CORPORATION.

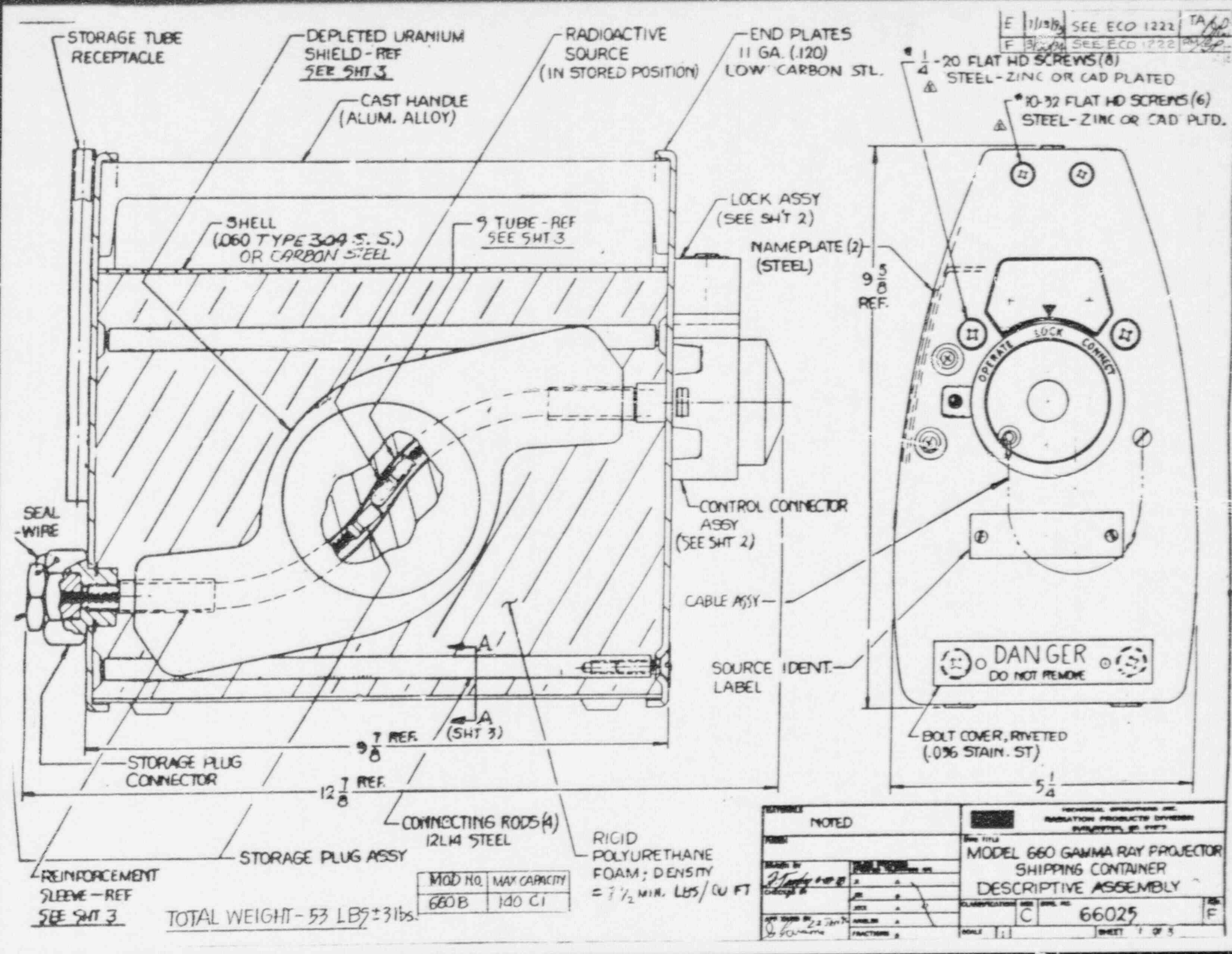
| | |
|---|---|
| USED ON: | TEST PLAN #70 |
| MATERIALS: | SEE NOTE 1 |
| SURFACE TEXTURE: | 63/ UNLESS OTHERWISE STATED |
| FINISH: FINISH | UNLESS OTHERWISE NOTED, TOLERANCES ARE: |
| REMOVE ALL BURRS | X ± 0.1 |
| DRAWN: APPROVED | XX ± 0.01 |
| CHECKED: DRAWING | XXX ± 0.005 |
| APPROVED: ON FILE | ANGLES ± 1° |
| | FRACT ± 1/64 |

AMERSHAM CORPORATION
BURLINGTON, MA 01803

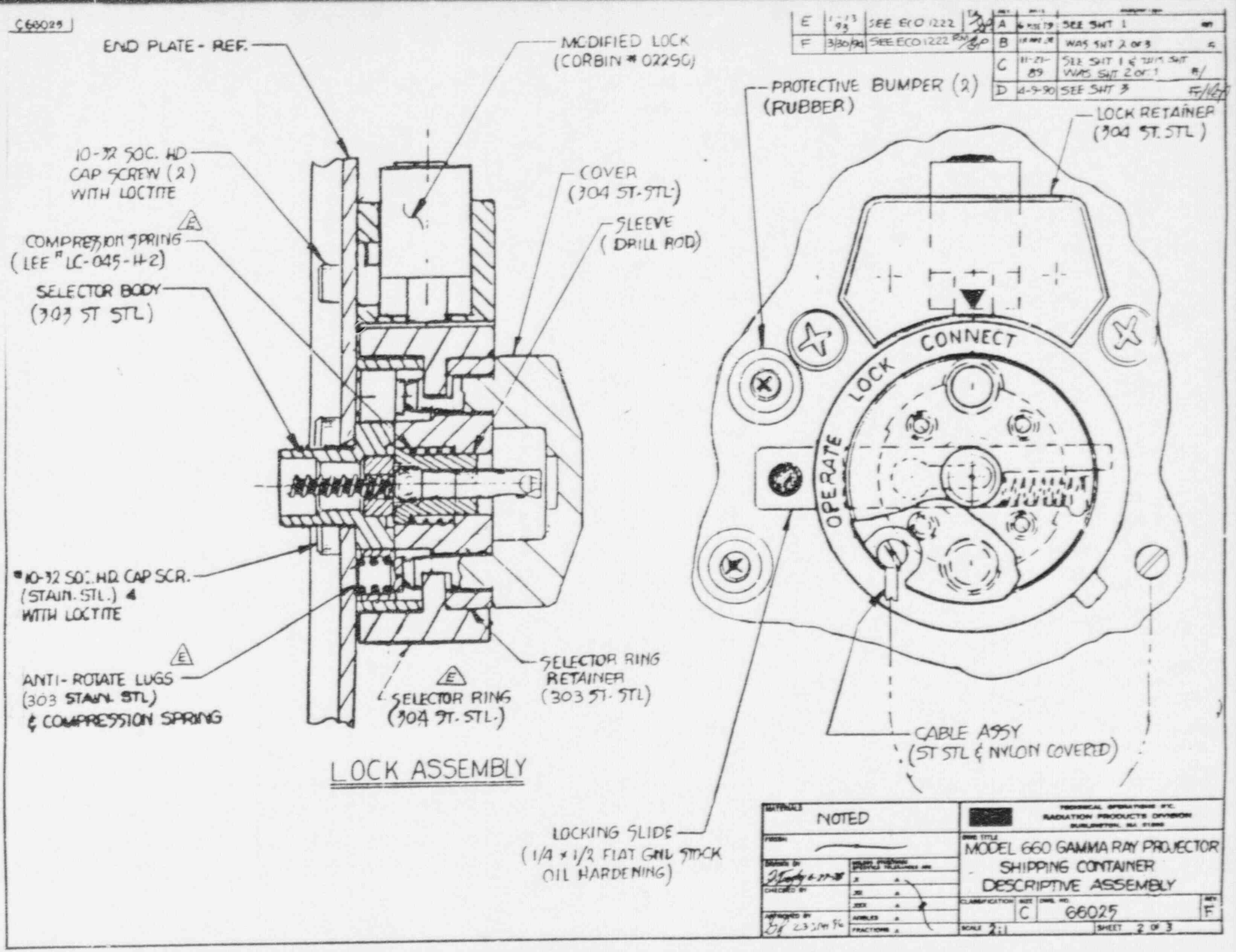
**SENTINEL**

DWG. TITLE: MODEL 660 TEST SPECIMEN

| SAFETY CLASS | SIZE | DWG. NO. | REV |
|---|---|---|---|
| A | C | TP70 | B |
| SCALE: NONE | | SHEET 1 OF 1 | |

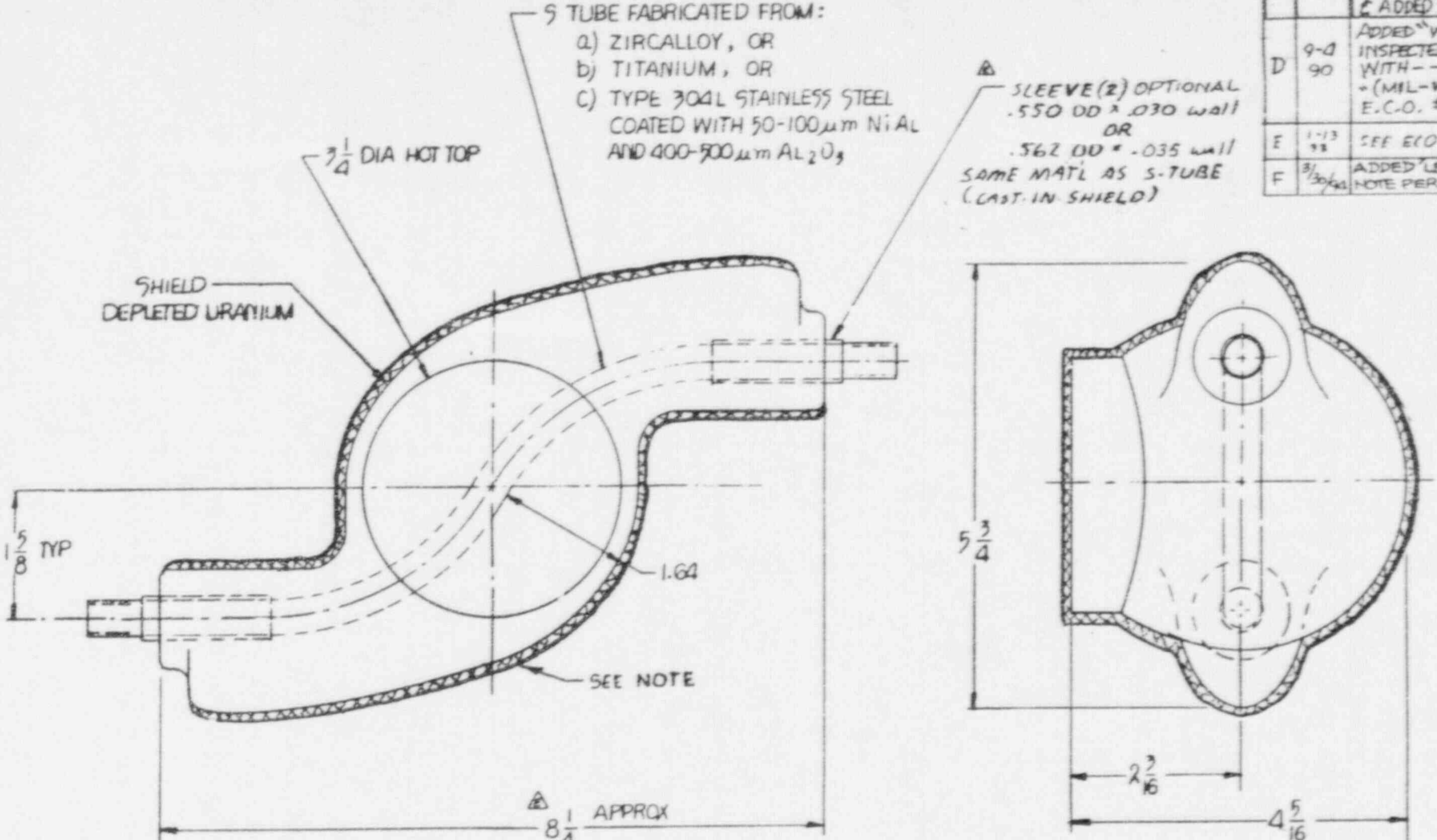


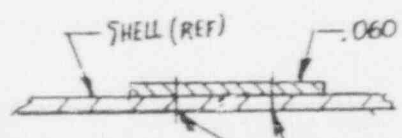

| MOD NO. | MAX CAPACITY |
|---|---|
| 660 B | 140 Ci |



C66025
E 1-13-93 SEE ECO 1222
F 3/30/94 SEE ECO 1222
A SEE SHT 1
B WAS SHT 2 OF 3
C 11-21-89 SEE SHT 1 & THIS SHT WAS SHT 2 OF 1
D 4-9-90 SEE SHT 3
END PLATE - REF.
MODIFIED LOCK (CORBIN # 02290)
10-32 SOC. HD CAP SCREW (2) WITH LOCTITE
COVER (304 ST-STL)
SLEEVE (DRILL ROD)
COMPRESSION SPRING (LEE # LC-045-H-2)
SELECTOR BODY (303 ST STL)
#10-32 SOC. HD CAP SCR. (STAIN. STL.) 4 WITH LOCTITE
ANTI-ROTATE LUGS (303 STAIN. STL) & COMPRESSION SPRING
SELECTOR RING (304 ST. STL.)
SELECTOR RING RETAINER (303 ST. STL)
LOCK ASSEMBLY
PROTECTIVE BUMPER (2) (RUBBER)
LOCK RETAINER (304 ST. STL)
CONNECT
LOCK
OPERATE
CABLE ASSY (ST STL & NYLON COVERED)
LOCKING SLIDE (1/4 × 1/2 FLAT GND STOCK OIL HARDENING)
NOTED
TECHNICAL OPERATIONS INC. RADIATION PRODUCTS DIVISION BURLINGTON, MA 01803
MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY
C 66025 F
SCALE 2:1
SHEET 2 OF 3

| | | | |
|---|---|---|---|
| C | 11-22 89 | WAS SHT 4 OF 4 & REV OF THIS SHT WAS — & ADDED SECT. A-A | |
| D | 9-4 90 | ADDED "WELDED & INSPECTED IN ACCORDANCE WITH ---" WAS •(MIL-W-6858)• E.C.O. # 718 | |
| E | 1-13 93 | SEE ECO 1222 | |
| F | 3/30/94 | ADDED "LEAD" TO NOTE PER ECO 1222 | |




SECTION A-A

SCALE: 1/1

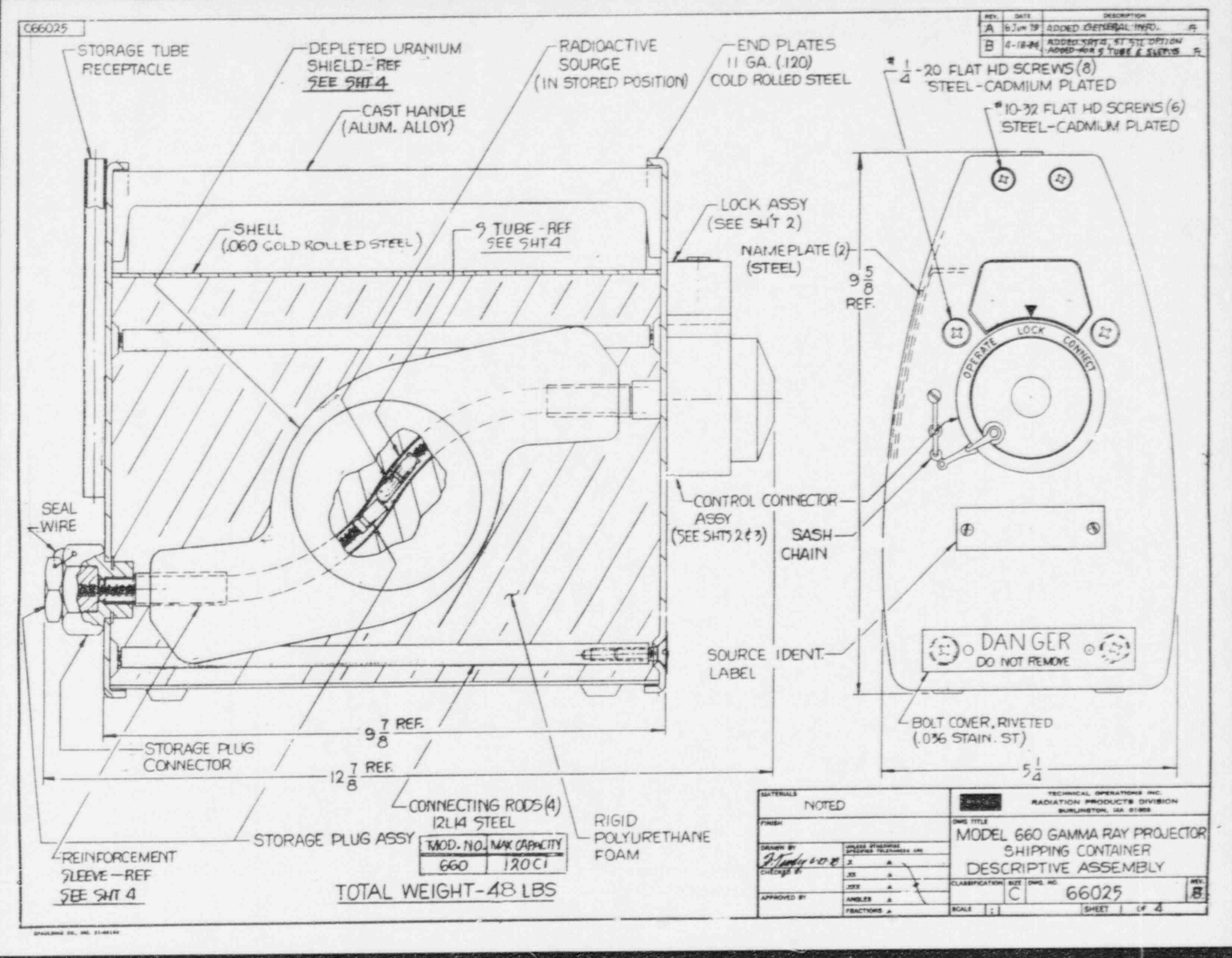
D

SHIELD DATA

37 LBS ± 3 lbs. E

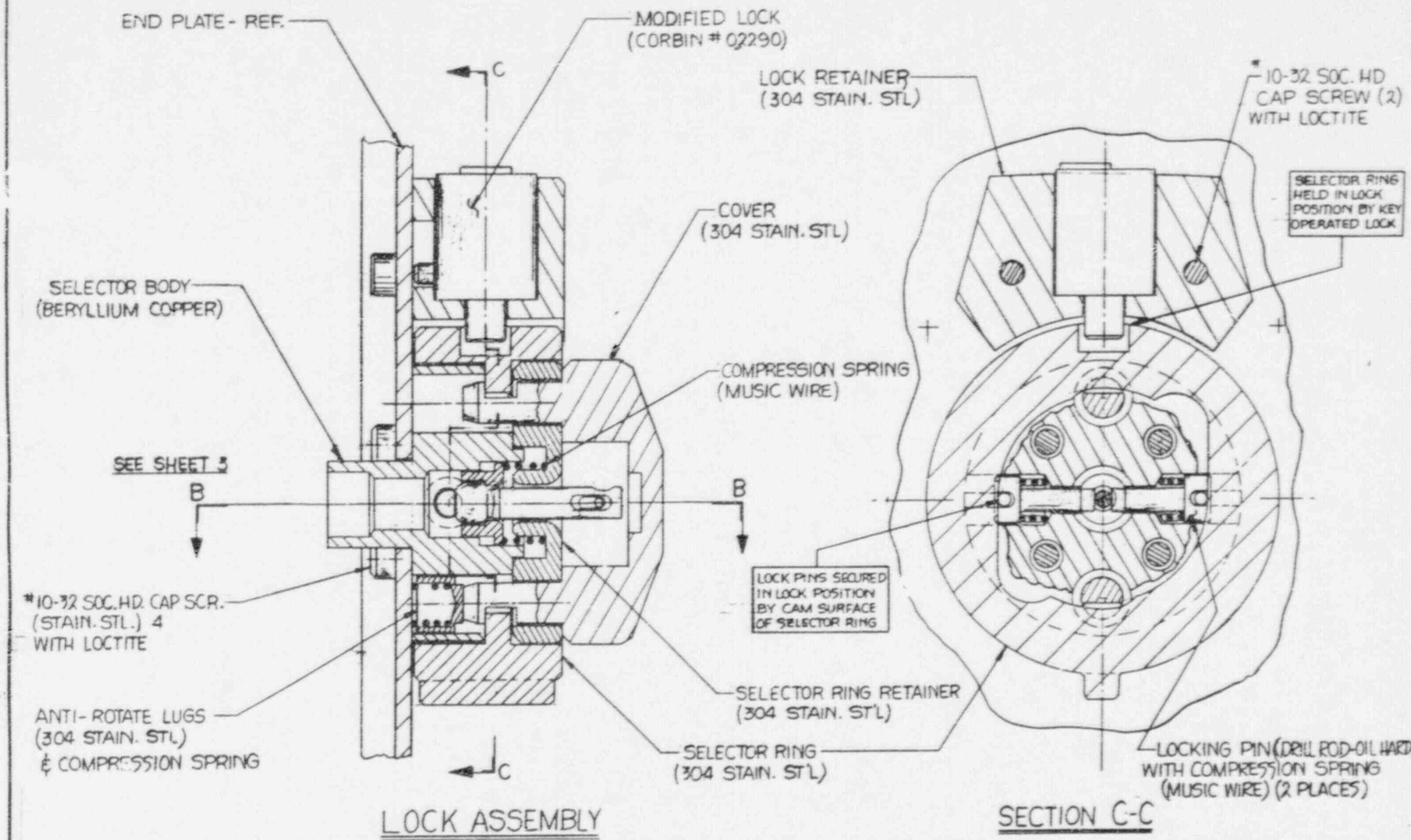
NOTE: ADDITIONAL LEAD SHIELDING NOT TO EXCEED 3 lbs. MAX. THICKNESS 1/4". TUNGSTEN NOT SHOWN. F

| | |
|---|---|
| MATERIALS: AS NOTED | Tech/Ops, Inc. RADIATION PRODUCTS DIVISION BURLINGTON, MA |
| | MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY |
| SIZE: C | DWG. NO. 66025 — REV. F |
| SCALE: 1:1 | SHEET 3 OF 3 |


C66025
STORAGE TUBE RECEPTACLE
DEPLETED URANIUM SHIELD - REF SEE SHT 4
RADIOACTIVE SOURCE (IN STORED POSITION)
END PLATES 11 GA. (.120) COLD ROLLED STEEL
CAST HANDLE (ALUM. ALLOY)
# 1/4 -20 FLAT HD SCREWS (8) STEEL-CADMIUM PLATED
# 10-32 FLAT HD SCREWS (6) STEEL-CADMIUM PLATED
LOCK ASSY (SEE SH'T 2)
SHELL (.060 COLD ROLLED STEEL)
S TUBE - REF SEE SHT 4
NAMEPLATE (2) (STEEL)
9 5/8 REF.
LOCK
OPERATE
CONNECT
CONTROL CONNECTOR ASSY (SEE SHTS 2 & 3)
SASH CHAIN
SEAL WIRE
SOURCE IDENT. LABEL
DANGER
DO NOT REMOVE
BOLT COVER, RIVETED (.036 STAIN. ST.)
9 7/8 REF.
STORAGE PLUG CONNECTOR
12 7/8 REF.
5 1/4
CONNECTING RODS (4) 12L14 STEEL
RIGID POLYURETHANE FOAM
STORAGE PLUG ASSY
REINFORCEMENT SLEEVE - REF SEE SHT 4
MOD. NO. | MAX CAPACITY
660 | 120 Ci
TOTAL WEIGHT - 48 LBS
REV. | DATE | DESCRIPTION
A | 6 Jun 79 | ADDED GENERAL INFO.
B | 4-18-86 | ADDED SHT 4, ST STL OPTION ADDED FOR S TUBE & SLEEVES
MATERIALS NOTED
TECHNICAL OPERATIONS INC. RADIATION PRODUCTS DIVISION BURLINGTON, MA
MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY
SIZE C
DWG. NO. 66025
REV. B
SHEET 1 OF 4

C65025

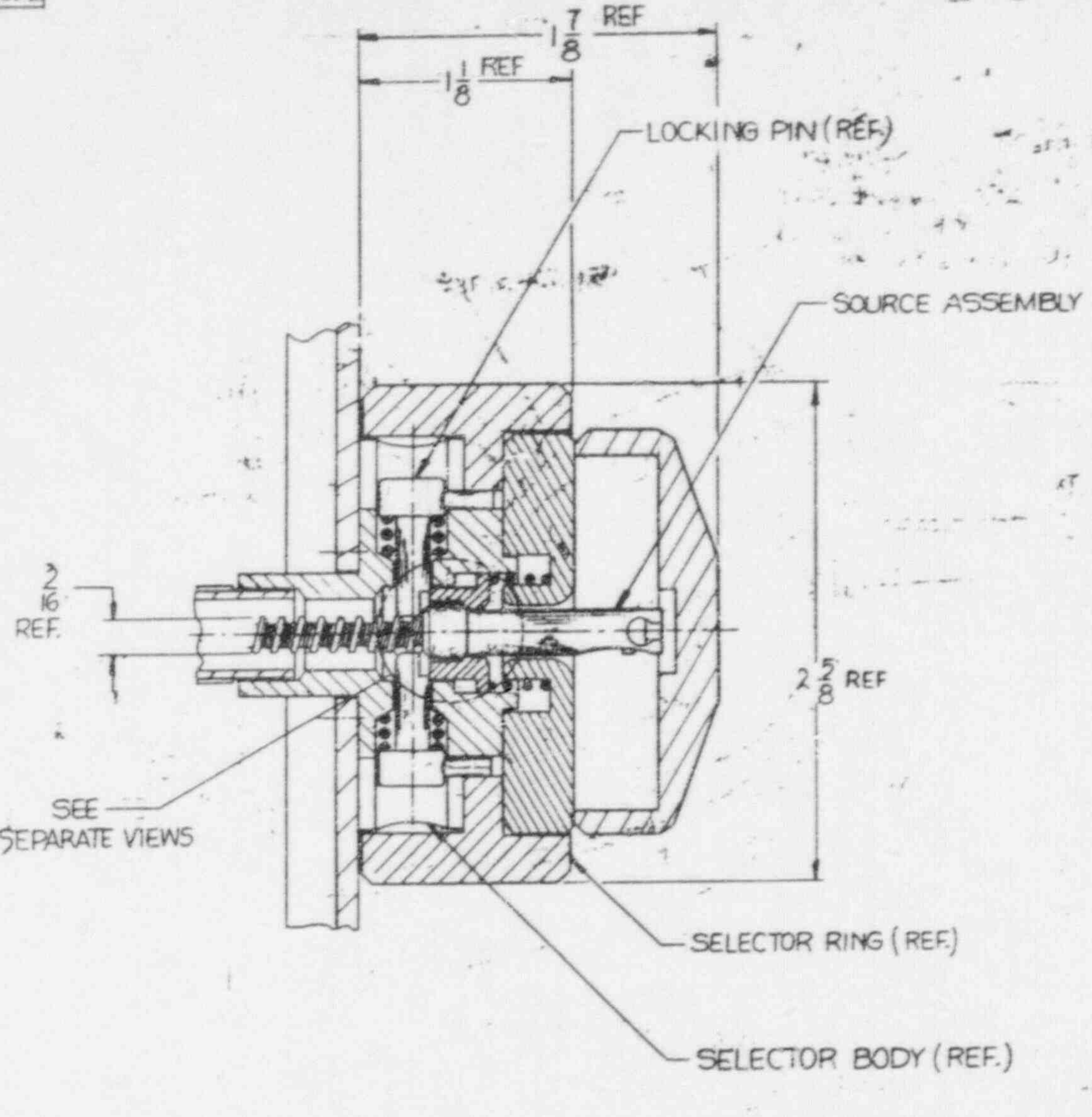
| REV. | DATE | DESCRIPTION | |
|---|---|---|---|
| A | 6 JUN 79 | SEE SHT 1 | |
| B | [illegible] | WAS SHT 2 OF 3 | |



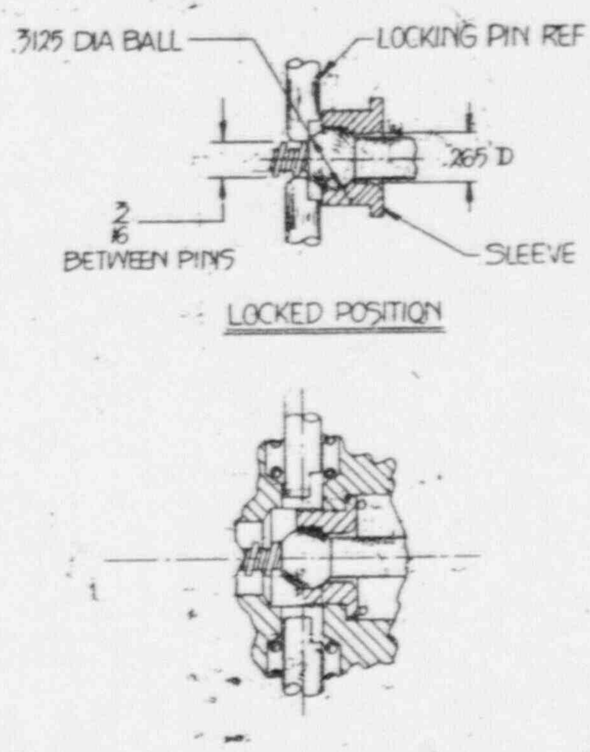

| | |
|---|---|
| MATERIALS: NOTED | TECHNICAL OPERATIONS INC. RADIATION PRODUCTS DIVISION BURLINGTON, MA 01803 |
| FINISH: — | DWG TITLE: MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY |
| DRAWN BY: [signature] 6-27-78 | CLASSIFICATION: — SIZE: C DWG. NO. 66025 REV. B |
| CHECKED BY: | SCALE 2:1 SHEET 2 OF 4 |
| APPROVED BY: | |

C66025

| REV. | DATE | DESCRIPTION | |
|---|---|---|---|
| A | 6JUN79 | SEE SHT 1 | FGT |
| B | 18APR91 | WAS SHT 3 OF 3 | F |



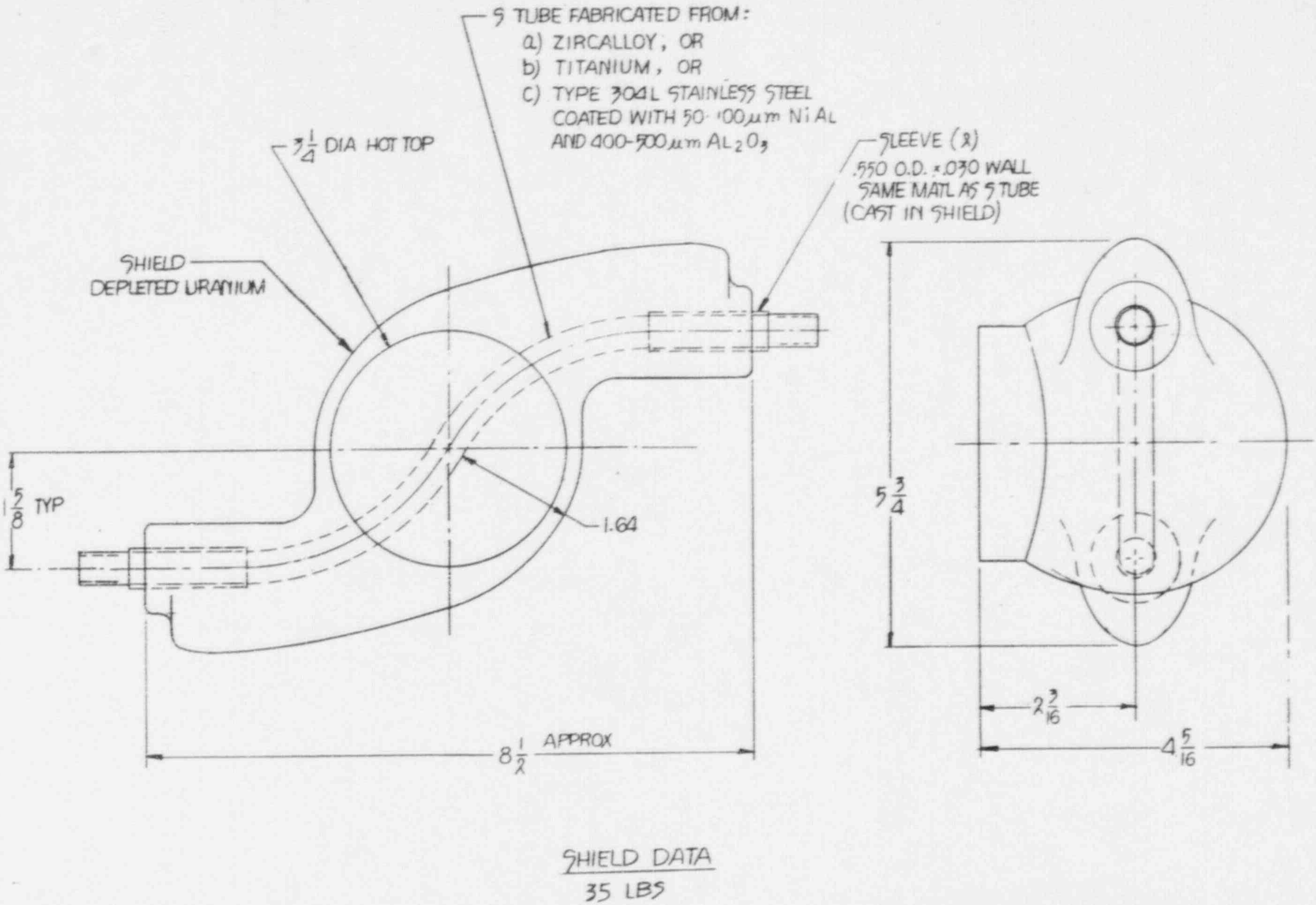

SECTION B-B




UNLOCKED POSITION

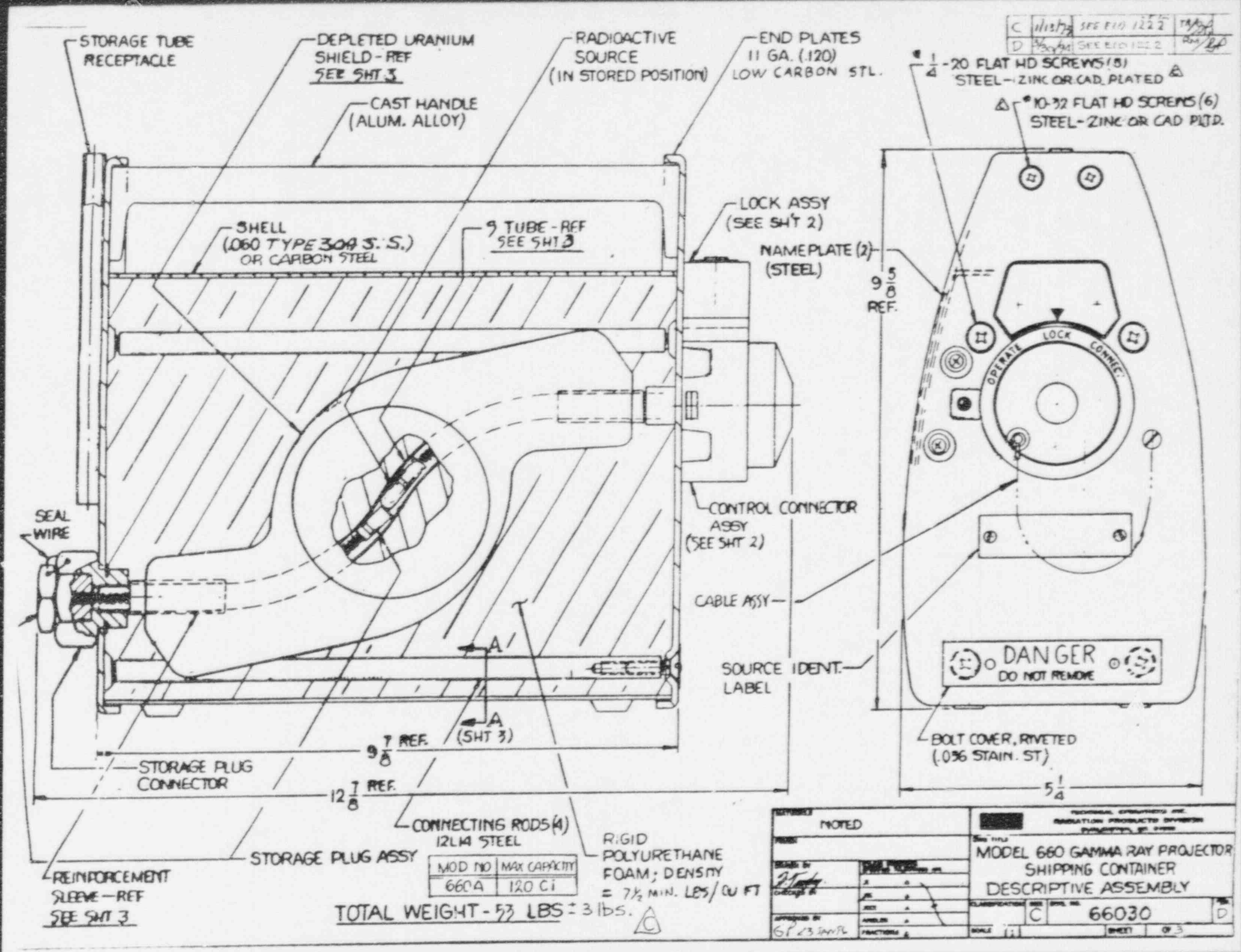
| | | |
|---|---|---|
| MATERIALS: NOTED | TECHNICAL OPERATIONS INC. RADIATION PRODUCTS DIVISION BURLINGTON, MA 01803 | |
| FINISH | DWG TITLE: MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY | |
| DRAWN BY | SIZE: C | DWG. NO. 66025 |
| CHECKED | REV. B | |
| APPROVED BY | SCALE 2:1 | SHEET 3 OF 4 |

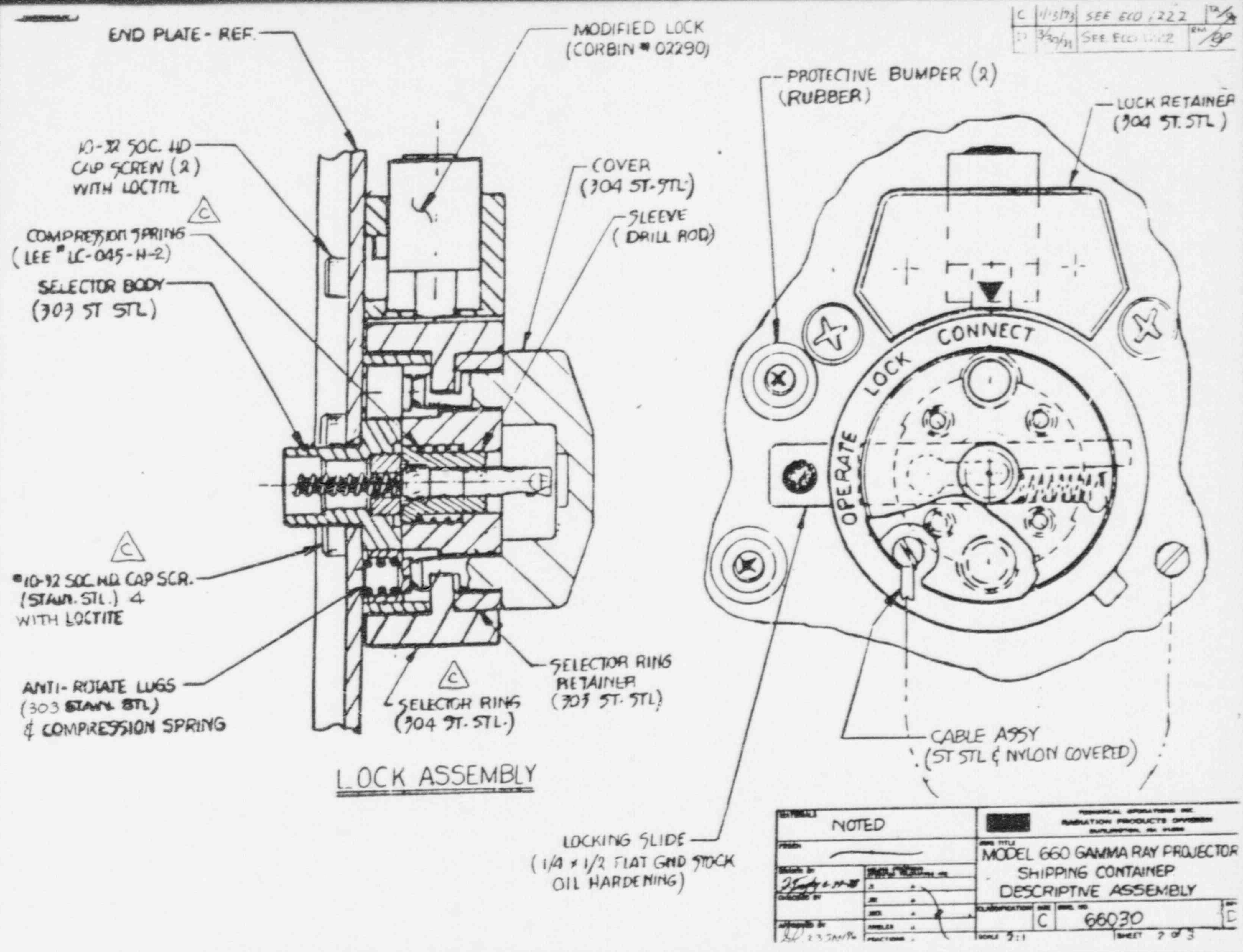
| REV. | DATE | DESCRIPTION |
|---|---|---|
| B | 4-18-86 | SEE SHT 1 |



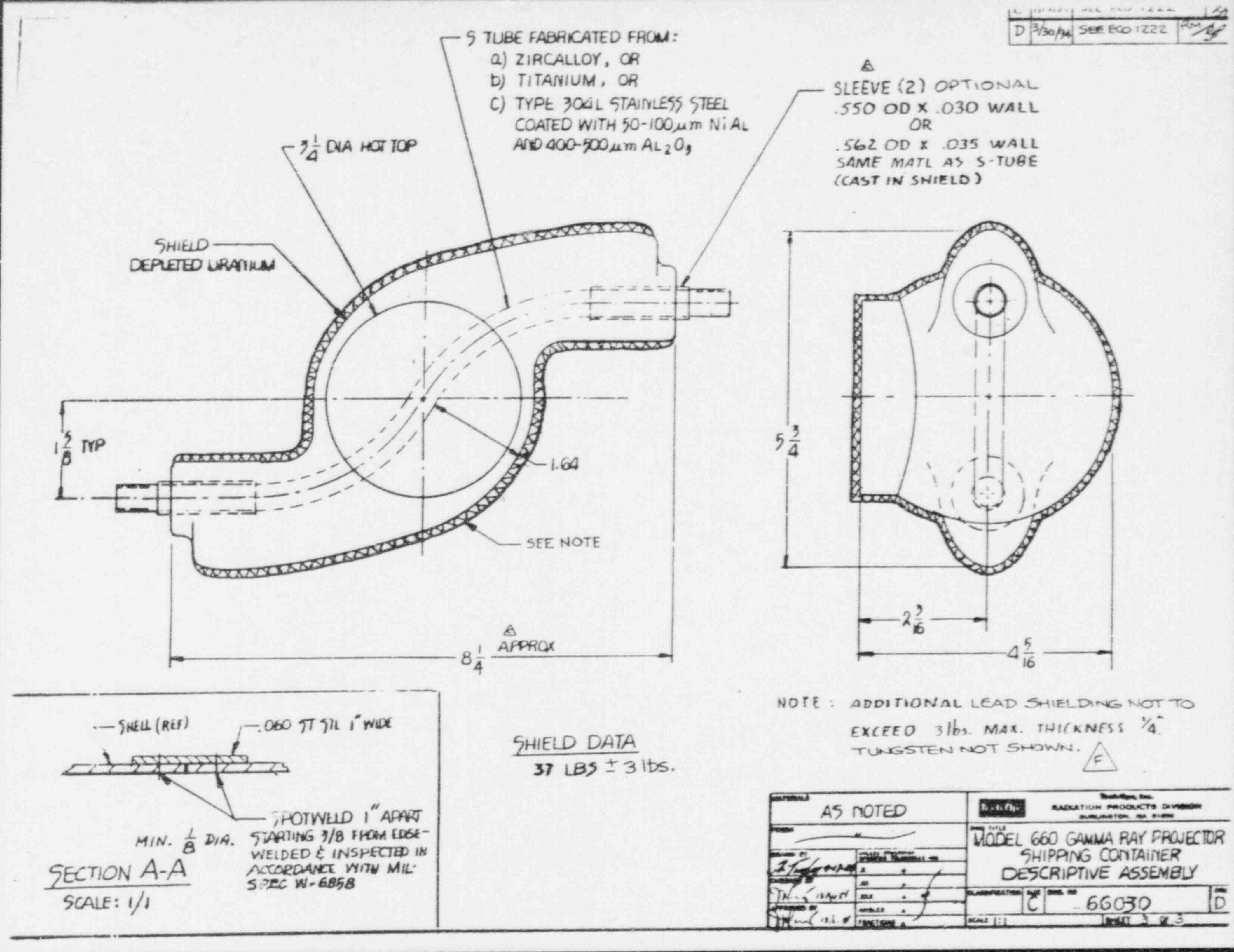

| | |
|---|---|
| MATERIALS | AS NOTED |
| FINISH | " |
| DWG TITLE | MODEL 660 GAMMA RAY PROJEC SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY |
| SIZE | C |
| DWG. NO. | 66025 |
| REV. | B |
| SCALE | 1:1 |
| SHEET | 4 OF 4 |

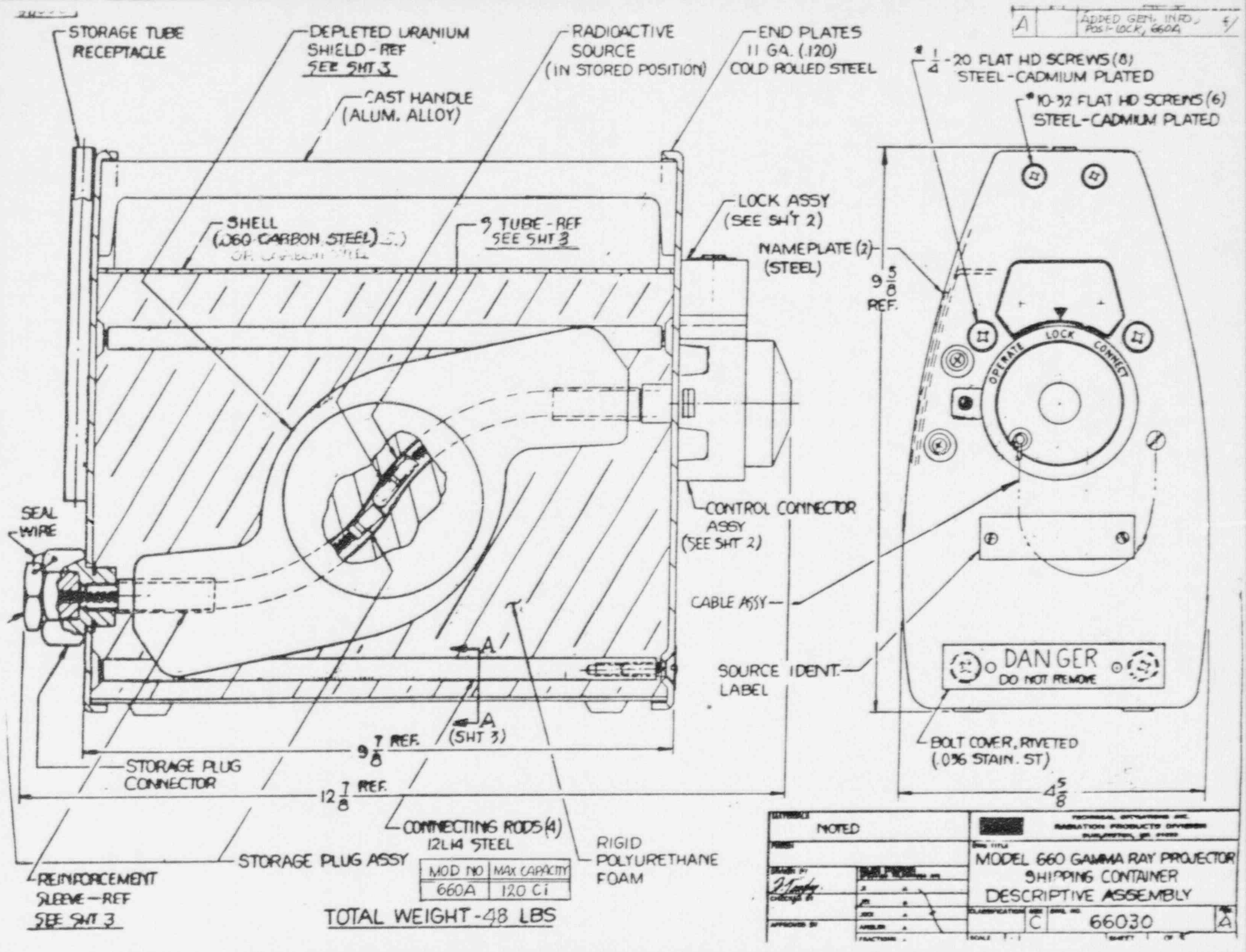
Tech/Ops, Inc.
RADIATION PRODUCTS DIVISION
BURLINGTON, MA 01803


STORAGE TUBE RECEPTACLE
DEPLETED URANIUM SHIELD-REF SEE SHT 3
RADIOACTIVE SOURCE (IN STORED POSITION)
END PLATES 11 GA. (.120) LOW CARBON STL.
CAST HANDLE (ALUM. ALLOY)
LOCK ASSY (SEE SHT 2)
SHELL (.060 TYPE 304 S. S.) OR CARBON STEEL
TUBE-REF SEE SHT 3
NAMEPLATE (2) (STEEL)
1/4-20 FLAT HD SCREWS (8) STEEL-ZINC OR CAD. PLATED
10-32 FLAT HD SCREWS (6) STEEL-ZINC OR CAD PLTD.
OPERATE
LOCK
CONNEC.
SEAL WIRE
CONTROL CONNECTOR ASSY (SEE SHT 2)
CABLE ASSY
SOURCE IDENT. LABEL
DANGER
DO NOT REMOVE
BOLT COVER, RIVETED (.036 STAIN. ST)
9 5/8 REF.
5 1/4
9 7/8 REF.
12 7/8 REF.
A
A (SHT 3)
STORAGE PLUG CONNECTOR
CONNECTING RODS (4) 12L14 STEEL
RIGID POLYURETHANE FOAM; DENSITY = 7½ MIN. LBS/CU FT
STORAGE PLUG ASSY
REINFORCEMENT SLEEVE-REF SEE SHT 3
MOD NO | MAX CAPACITY
660A | 120 Ci
TOTAL WEIGHT - 53 LBS ± 3 lbs.
C
NOTED
MODEL 660 GAMMA RAY PROJECTOR
SHIPPING CONTAINER
DESCRIPTIVE ASSEMBLY
C
66030
D

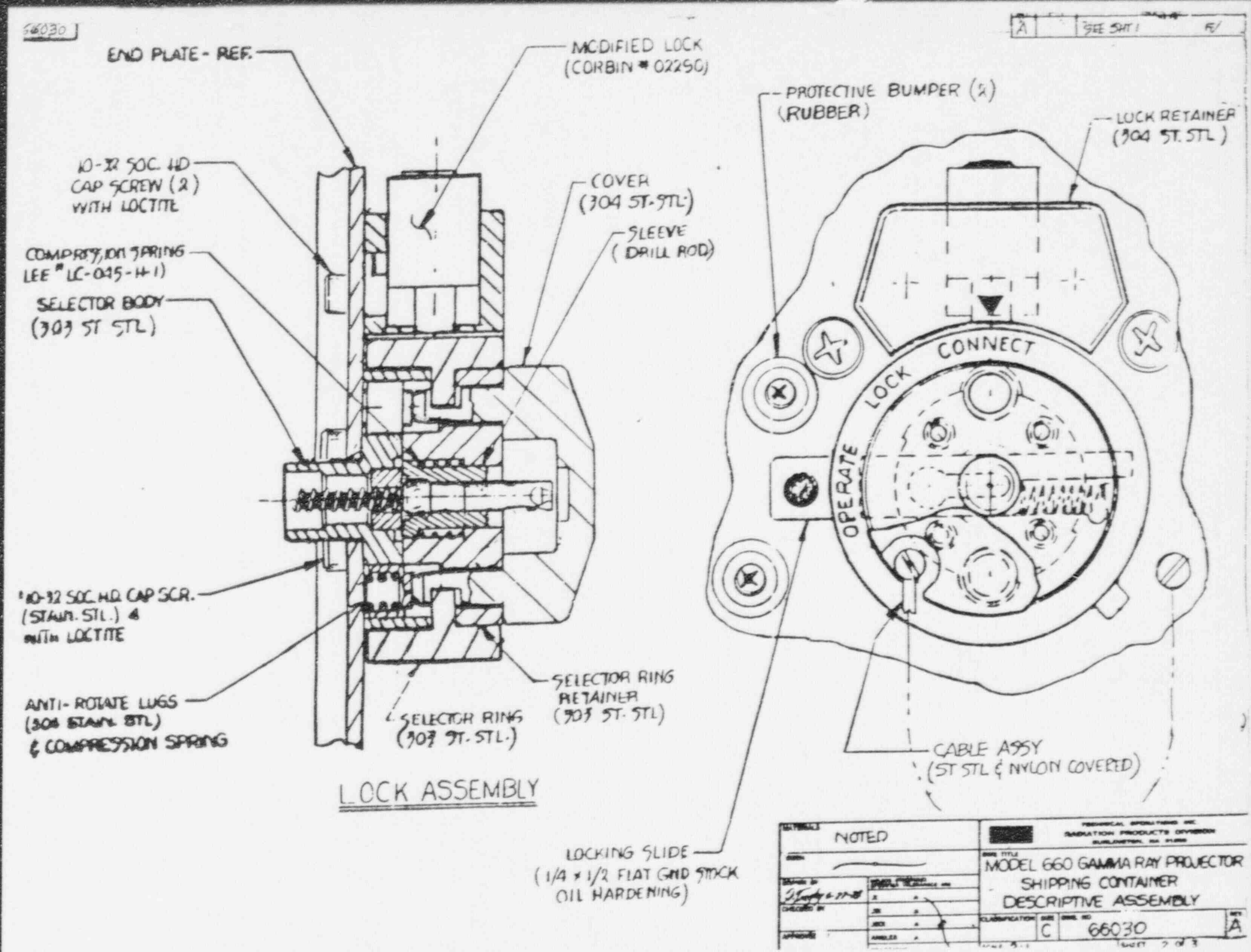


C 1/13/73 SEE ECO 1222
D 3/30/81 SEE ECO
END PLATE - REF.
MODIFIED LOCK
(CORBIN # 02290)
10-32 SOC. HD
CAP SCREW (2)
WITH LOCTITE
COMPRESSION SPRING
(LEE # LC-045-H-2)
SELECTOR BODY
(303 ST STL)
COVER
(304 ST-STL)
SLEEVE
(DRILL ROD)
#10-32 SOC. HD CAP SCR.
(STAIN. STL.) 4
WITH LOCTITE
ANTI-ROTATE LUGS
(303 STAIN. STL)
& COMPRESSION SPRING
SELECTOR RING
(304 ST. STL.)
SELECTOR RING
RETAINER
(303 ST. STL)
LOCK ASSEMBLY
PROTECTIVE BUMPER (2)
(RUBBER)
LOCK RETAINER
(304 ST. STL)
CONNECT
LOCK
OPERATE
CABLE ASSY
(ST STL & NYLON COVERED)
LOCKING SLIDE
(1/4 x 1/2 FLAT GND STOCK
OIL HARDENING)
NOTED
MODEL 660 GAMMA RAY PROJECTOR
SHIPPING CONTAINER
DESCRIPTIVE ASSEMBLY
C
66030
D
SCALE 5:1
SHEET 2 OF 3

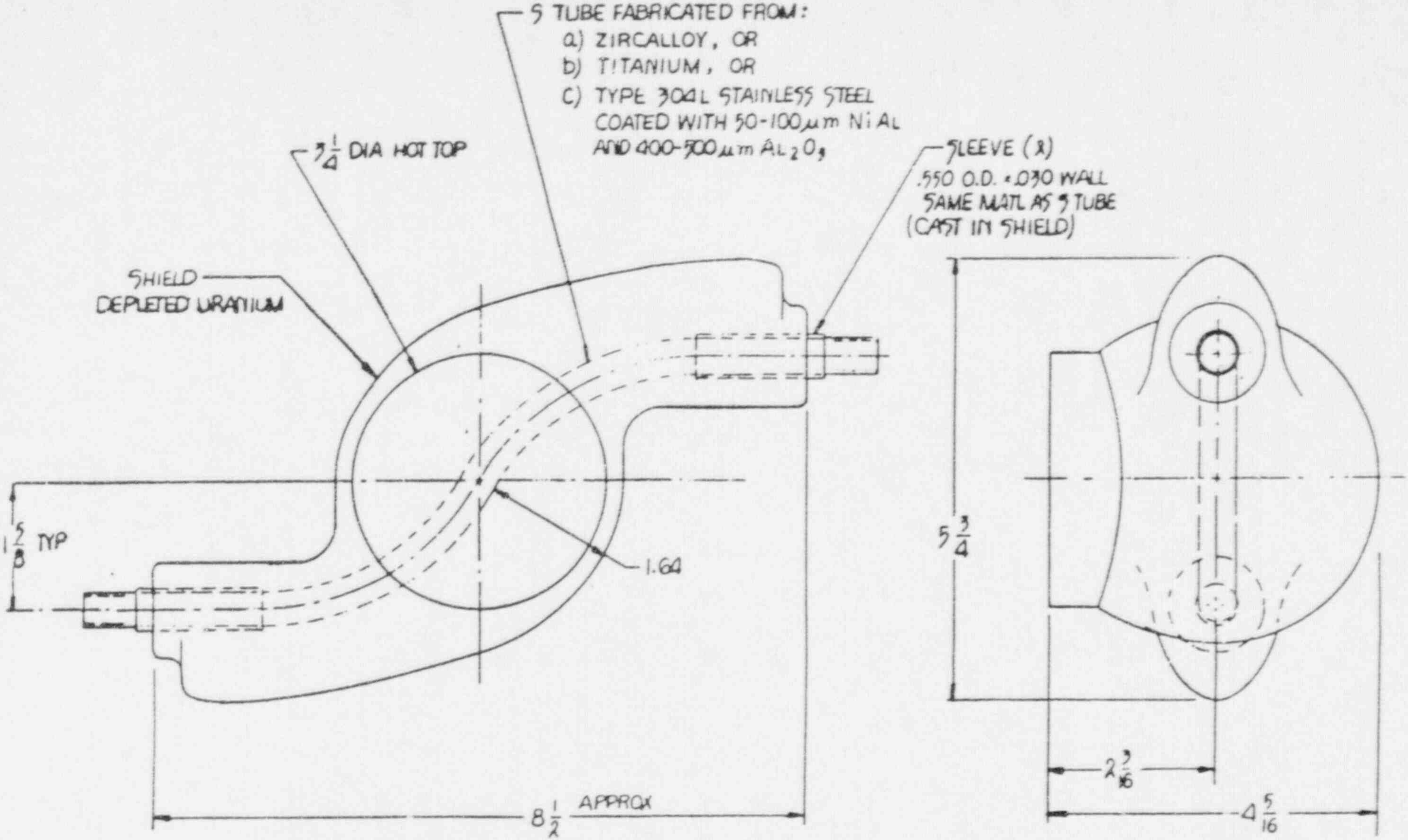

D 3/30/94 SEE ECO 1222
S TUBE FABRICATED FROM:
a) ZIRCALLOY, OR
b) TITANIUM, OR
c) TYPE 304L STAINLESS STEEL COATED WITH 50-100 µm NiAL AND 400-500 µm $AL_2O_3$
SLEEVE (2) OPTIONAL .550 OD X .030 WALL OR .562 OD X .035 WALL SAME MATL AS S-TUBE (CAST IN SHIELD)
3 1/4 DIA HOT TOP
SHIELD DEPLETED URANIUM
1 5/8 TYP
1.64
SEE NOTE
8 1/4 APPROX
5 3/4
2 3/16
4 5/16
SHELL (REF)
.060 ST STL 1" WIDE
SPOTWELD 1" APART STARTING 3/8 FROM EDGE-WELDED & INSPECTED IN ACCORDANCE WITH MIL-SPEC W-6858
MIN. 1/8 DIA.
SECTION A-A
SCALE: 1/1
SHIELD DATA
37 LBS ± 3 lbs.
NOTE: ADDITIONAL LEAD SHIELDING NOT TO EXCEED 3 lbs. MAX. THICKNESS 1/4". TUNGSTEN NOT SHOWN. F
AS NOTED
RADIATION PRODUCTS DIVISION
MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY
C
66030
D
SCALE 1:1
SHEET 3 OF 3

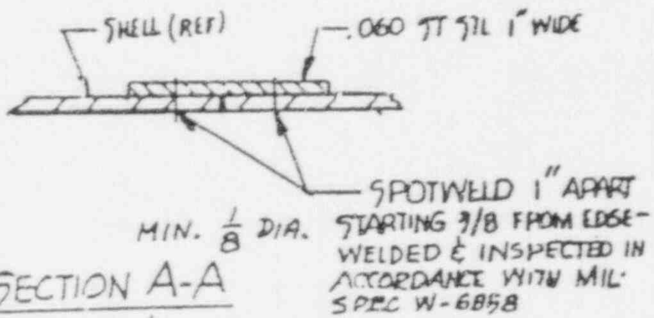



| MOD NO | MAX CAPACITY |
|---|---|
| 660A | 120 Ci |



66030
A
SEE SHT 1
END PLATE - REF.
MODIFIED LOCK
(CORBIN # 02290)
10-32 SOC. HD
CAP SCREW (2)
WITH LOCTITE
COMPRESSION SPRING
LEE # LC-045-H-1)
SELECTOR BODY
(303 ST STL)
COVER
(304 ST-STL)
SLEEVE
(DRILL ROD)
#10-32 SOC. HD. CAP SCR.
(STAIN. STL.) 4
with LOCTITE
ANTI-ROTATE LUGS
(304 STAIN. STL)
& COMPRESSION SPRING
SELECTOR RING
(303 ST. STL.)
SELECTOR RING
RETAINER
(303 ST. STL)
LOCK ASSEMBLY
PROTECTIVE BUMPER (2)
(RUBBER)
LOCK RETAINER
(304 ST. STL)
CONNECT
LOCK
OPERATE
CABLE ASSY
(ST STL & NYLON COVERED)
LOCKING SLIDE
(1/4 x 1/2 FLAT GND STOCK
OIL HARDENING)
NOTED
MODEL 660 GAMMA RAY PROJECTOR
SHIPPING CONTAINER
DESCRIPTIVE ASSEMBLY
C
66030
A




SECTION A-A

SCALE: 1/1

SHIELD DATA

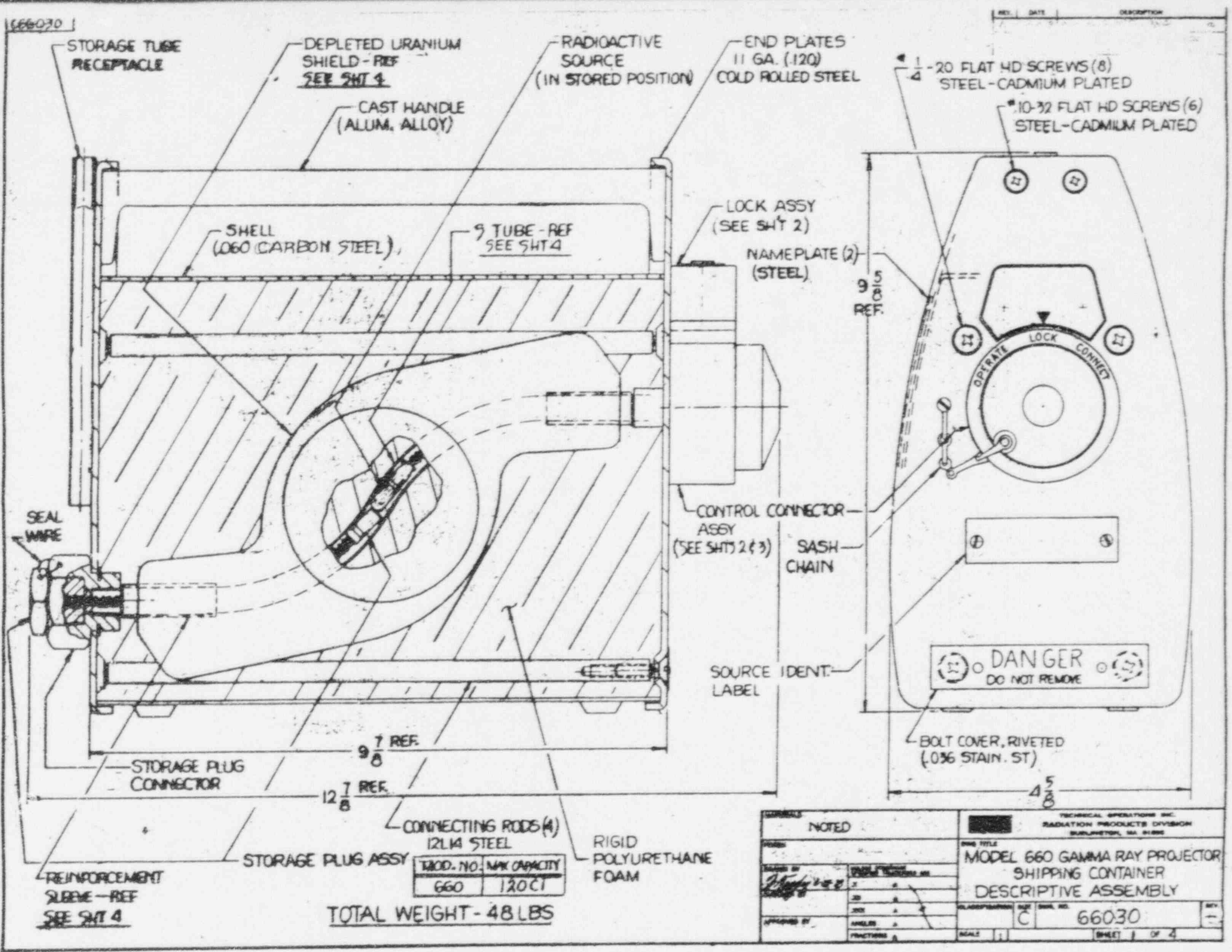
35 LBS

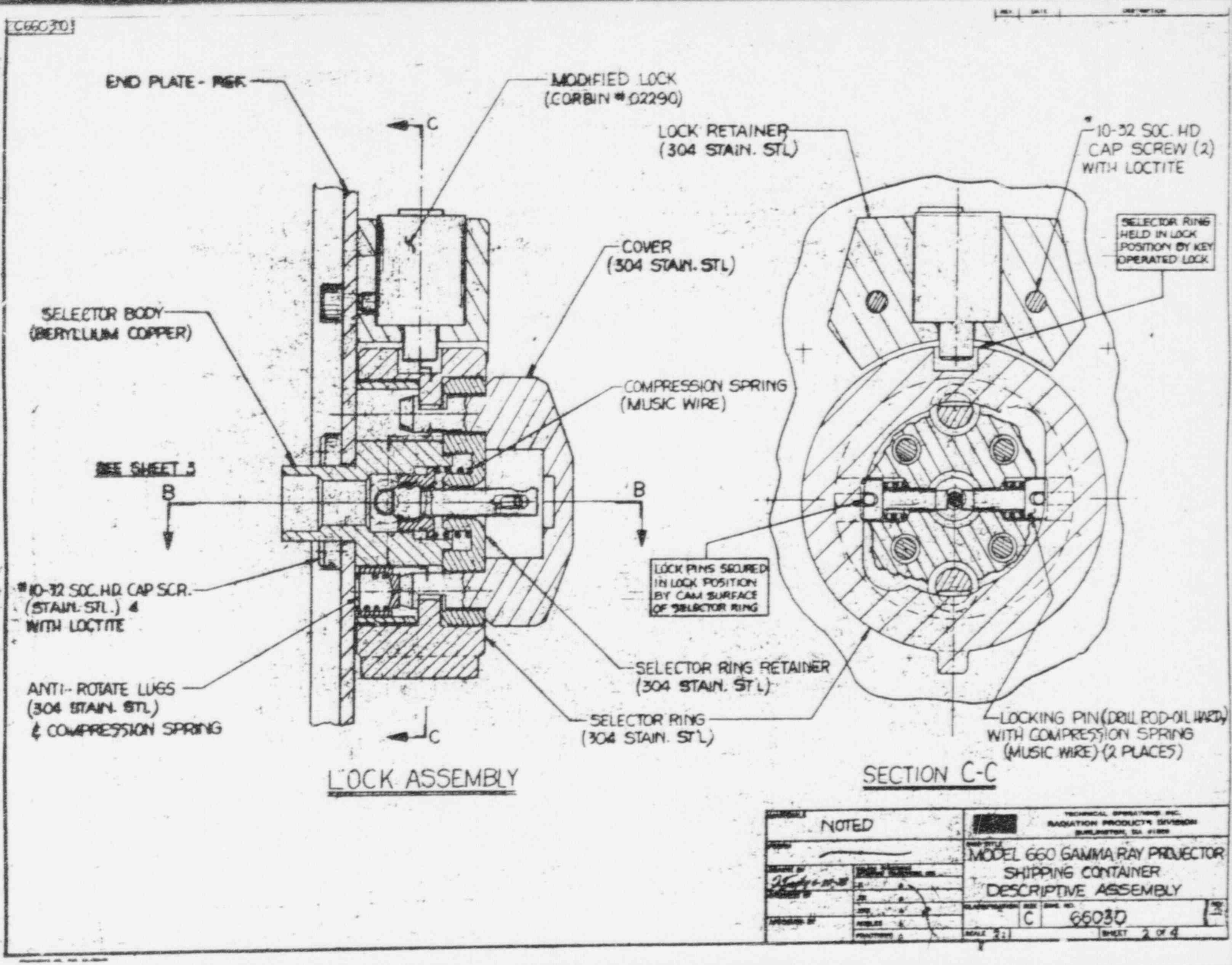
SHT. 3 of 3

AS NOTED

RADIATION PRODUCTS DIVISION

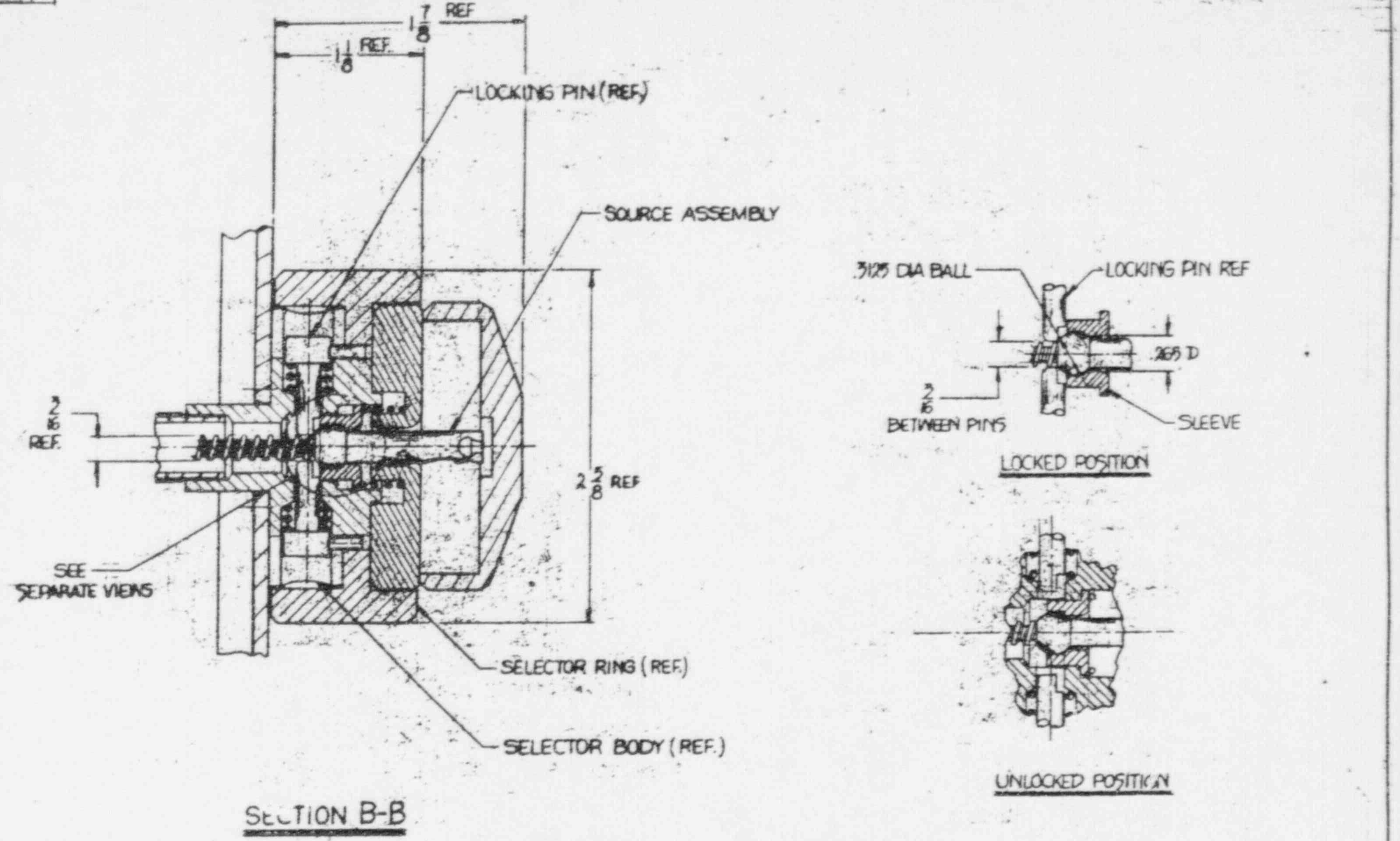
MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY


66030
STORAGE TUBE RECEPTACLE
DEPLETED URANIUM SHIELD-REF SEE SHT 4
RADIOACTIVE SOURCE (IN STORED POSITION)
END PLATES 11 GA. (.120) COLD ROLLED STEEL
1/4-20 FLAT HD SCREWS (8) STEEL-CADMIUM PLATED
#10-32 FLAT HD SCREWS (6) STEEL-CADMIUM PLATED
CAST HANDLE (ALUM. ALLOY)
LOCK ASSY (SEE SHT 2)
SHELL (.060 CARBON STEEL)
S TUBE-REF SEE SHT 4
NAMEPLATE (2) (STEEL)
9 5/8 REF.
LOCK
OPERATE
CONNECT
SEAL WIRE
CONTROL CONNECTOR ASSY (SEE SHTS 2 & 3)
SASH CHAIN
SOURCE IDENT. LABEL
DANGER DO NOT REMOVE
BOLT COVER, RIVETED (.036 STAIN. ST)
9 7/8 REF.
STORAGE PLUG CONNECTOR
12 7/8 REF.
4 5/8
CONNECTING RODS (4) 12L14 STEEL
RIGID POLYURETHANE FOAM
STORAGE PLUG ASSY
REINFORCEMENT SLEEVE-REF SEE SHT 4
MOD. NO. | MAX CAPACITY
660 | 120 CI
TOTAL WEIGHT - 48 LBS
NOTED
TECHNICAL OPERATIONS INC. RADIATION PRODUCTS DIVISION
MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY
C
66030
SHEET 1 OF 4

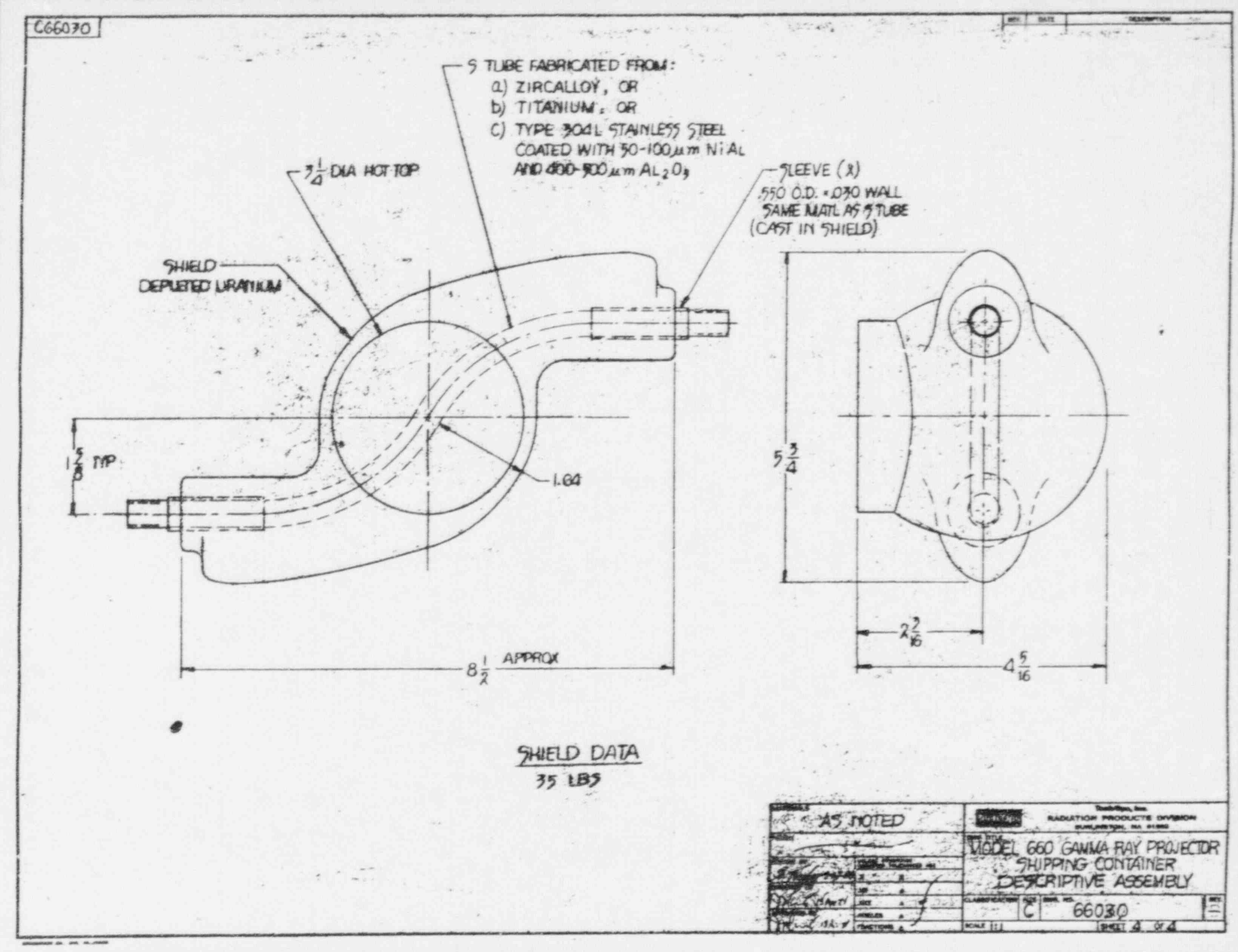


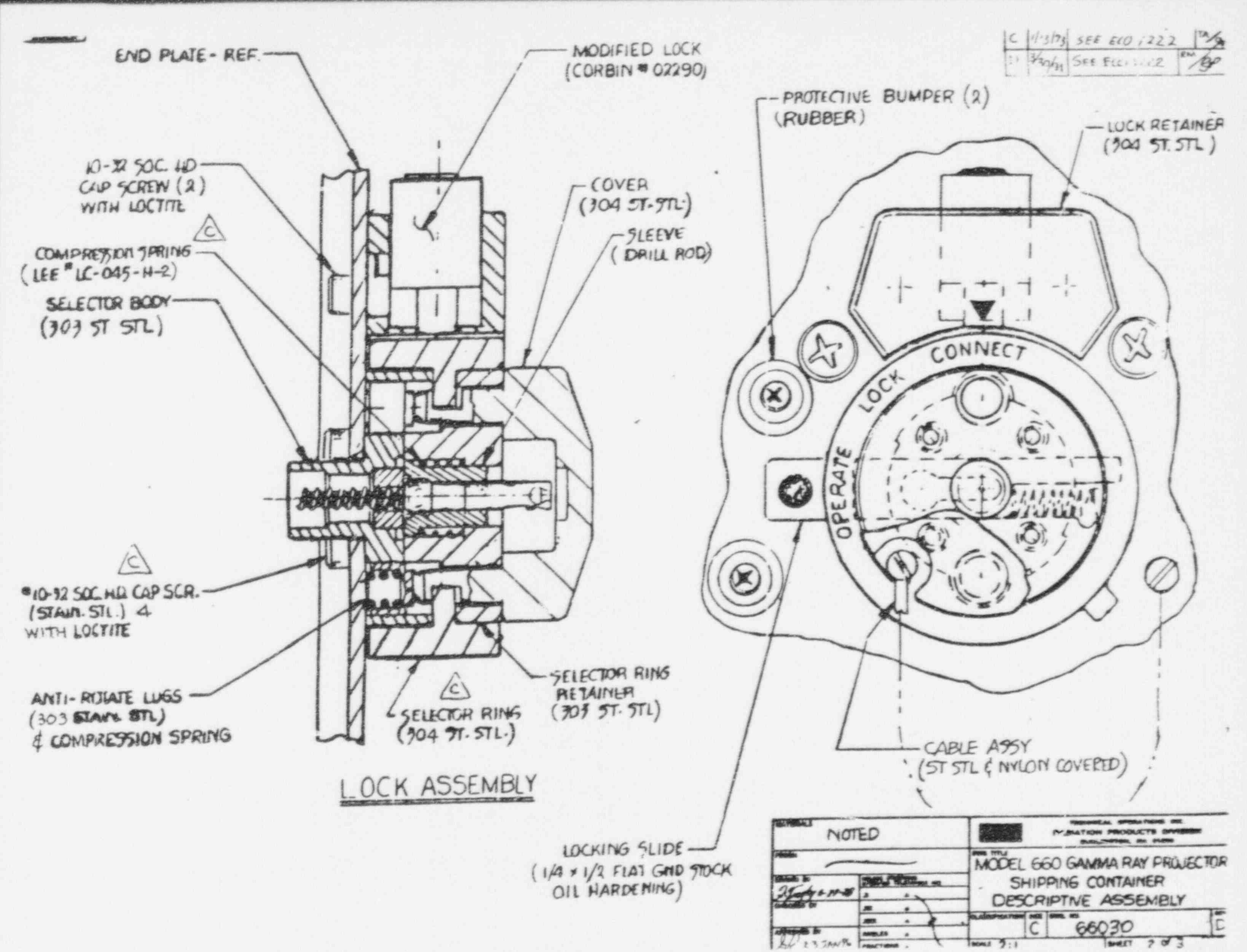
C66030
END PLATE - REF
MODIFIED LOCK (CORBIN #02290)
LOCK RETAINER (304 STAIN. STL)
10-32 SOC. HD CAP SCREW (2) WITH LOCTITE
SELECTOR RING HELD IN LOCK POSITION BY KEY OPERATED LOCK
COVER (304 STAIN. STL)
SELECTOR BODY (BERYLLIUM COPPER)
COMPRESSION SPRING (MUSIC WIRE)
SEE SHEET 3
B
B
C
C
LOCK PINS SECURED IN LOCK POSITION BY CAM SURFACE OF SELECTOR RING
#10-32 SOC. HD. CAP SCR. (STAIN. STL.) 4 WITH LOCTITE
ANTI-ROTATE LUGS (304 STAIN. STL) & COMPRESSION SPRING
SELECTOR RING RETAINER (304 STAIN. STL)
SELECTOR RING (304 STAIN. STL)
LOCKING PIN (DRILL ROD-OIL HARD) WITH COMPRESSION SPRING (MUSIC WIRE) (2 PLACES)
LOCK ASSEMBLY
SECTION C-C
NOTED
MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY
C
66030
SHEET 2 OF 4

E66030



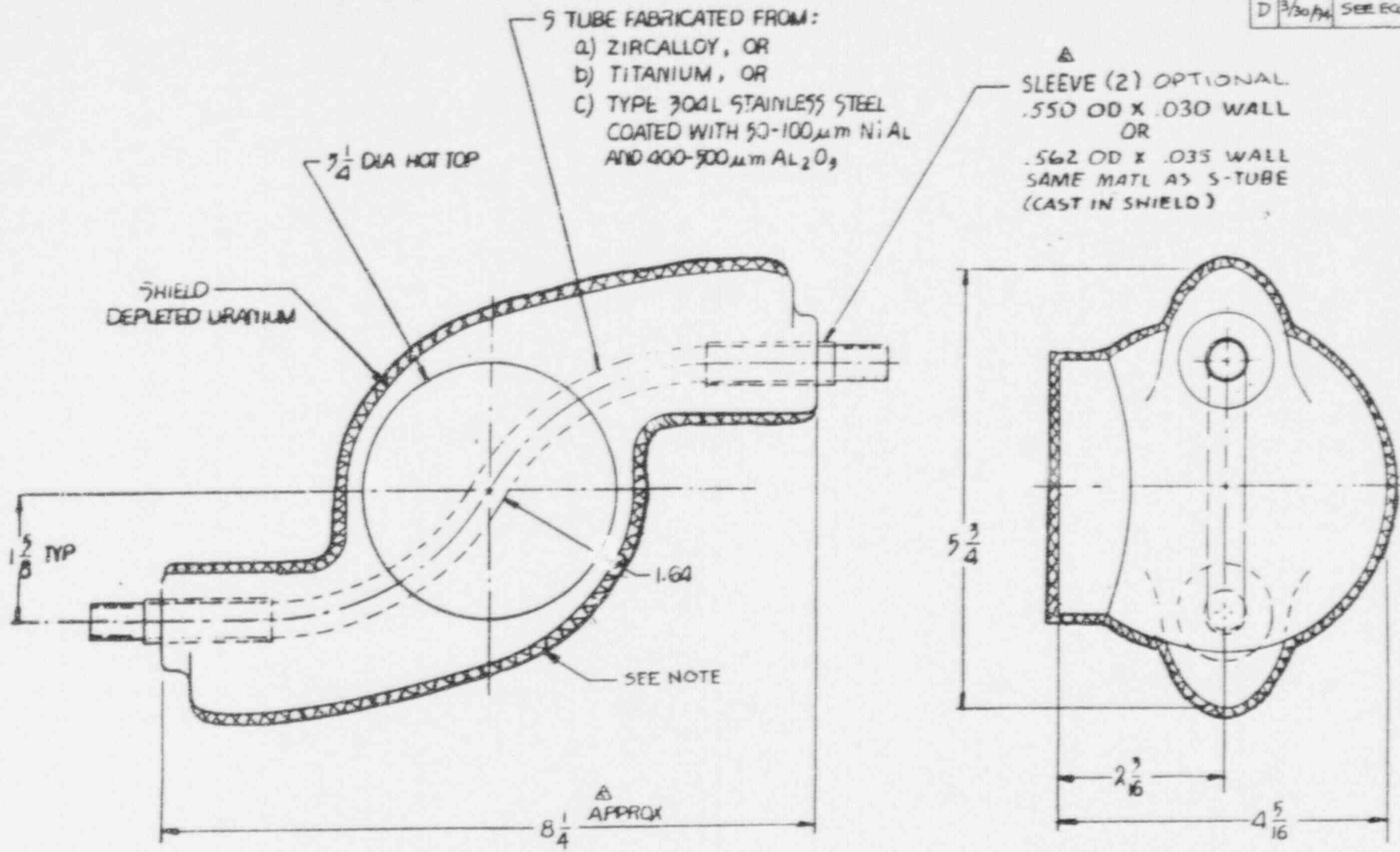

| | |
|---|---|
| NOTED | TECHNICAL OPERATIONS INC. RADIATION PRODUCTS DIVISION BURLINGTON, MA |
| | MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY |
| | C 66030 |
| | SCALE 2/1 SHEET 3 OF 4 |


C66030
5 TUBE FABRICATED FROM:
a) ZIRCALLOY, OR
b) TITANIUM, OR
C) TYPE 304L STAINLESS STEEL COATED WITH 50-100 μm NiAL AND 400-500 μm $AL_2O_3$
$3\frac{1}{4}$ DIA HOT TOP
SLEEVE (2)
.550 O.D. × .030 WALL
SAME MATL AS 5 TUBE
(CAST IN SHIELD)
SHIELD
DEPLETED URANIUM
$1\frac{5}{8}$ TYP
1.64
$5\frac{3}{4}$
$2\frac{9}{16}$
$8\frac{1}{2}$ APPROX
$4\frac{5}{16}$
SHIELD DATA
35 LBS
AS NOTED
RADIATION PRODUCTS DIVISION
MODEL 660 GAMMA RAY PROJECTOR
SHIPPING CONTAINER
DESCRIPTIVE ASSEMBLY
C
66030
SHEET 4 OF 4

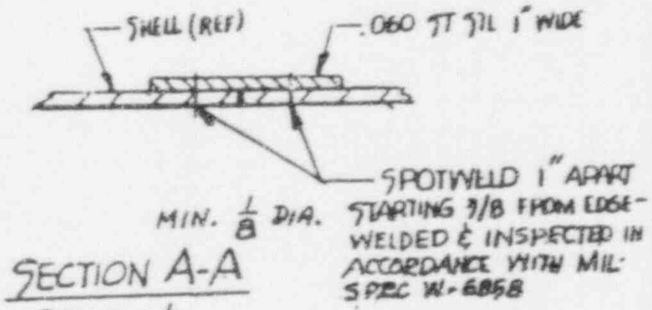


SEE ECO 1222
END PLATE - REF.
MODIFIED LOCK
(CORBIN # 02290)
10-32 SOC. HD
CAP SCREW (2)
WITH LOCTITE
COMPRESSION SPRING
(LEE # LC-045-H-2)
SELECTOR BODY
(303 ST STL)
COVER
(304 ST-STL)
SLEEVE
(DRILL ROD)
C
#10-32 SOC. HD CAP SCR.
(STAIN. STL.) 4
WITH LOCTITE
ANTI-ROTATE LUGS
(303 STAIN. STL)
& COMPRESSION SPRING
SELECTOR RING
(304 ST. STL.)
SELECTOR RING
RETAINER
(303 ST. STL)
LOCK ASSEMBLY
PROTECTIVE BUMPER (2)
(RUBBER)
LOCK RETAINER
(304 ST. STL)
CONNECT
LOCK
OPERATE
CABLE ASSY
(ST STL & NYLON COVERED)
LOCKING SLIDE
(1/4 x 1/2 FLAT GND STOCK
OIL HARDENING)
NOTED
MODEL 660 GAMMA RAY PROJECTOR
SHIPPING CONTAINER
DESCRIPTIVE ASSEMBLY
C
66030
D
2 of 3

| | | | |
|---|---|---|---|
| D | 3/30/94 | SEE ECO 1222 | RM |




NOTE: ADDITIONAL LEAD SHIELDING NOT TO EXCEED 3 lbs. MAX. THICKNESS 1/4. TUNGSTEN NOT SHOWN. (F)



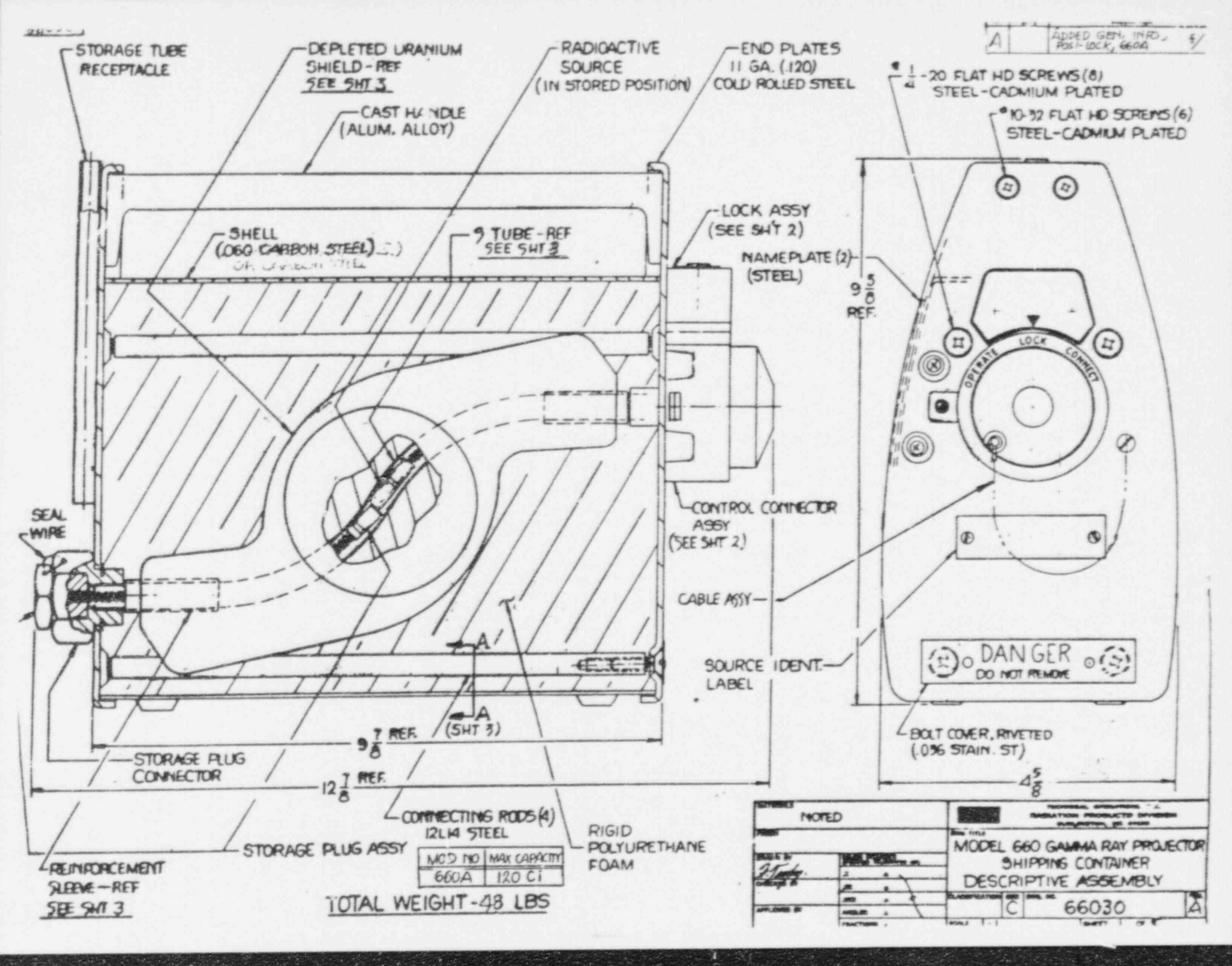

SECTION A-A

SCALE: 1/1

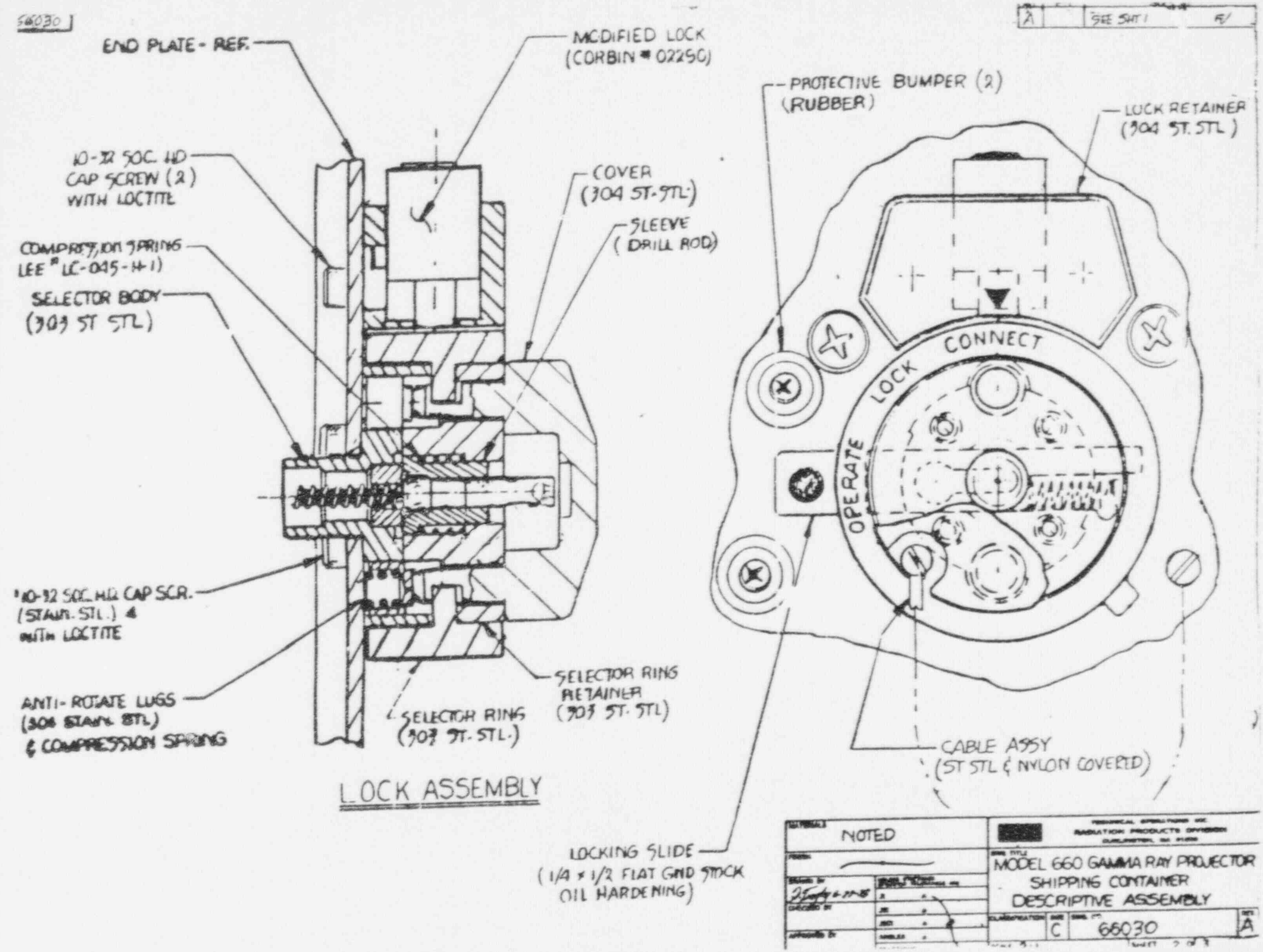
SHIELD DATA

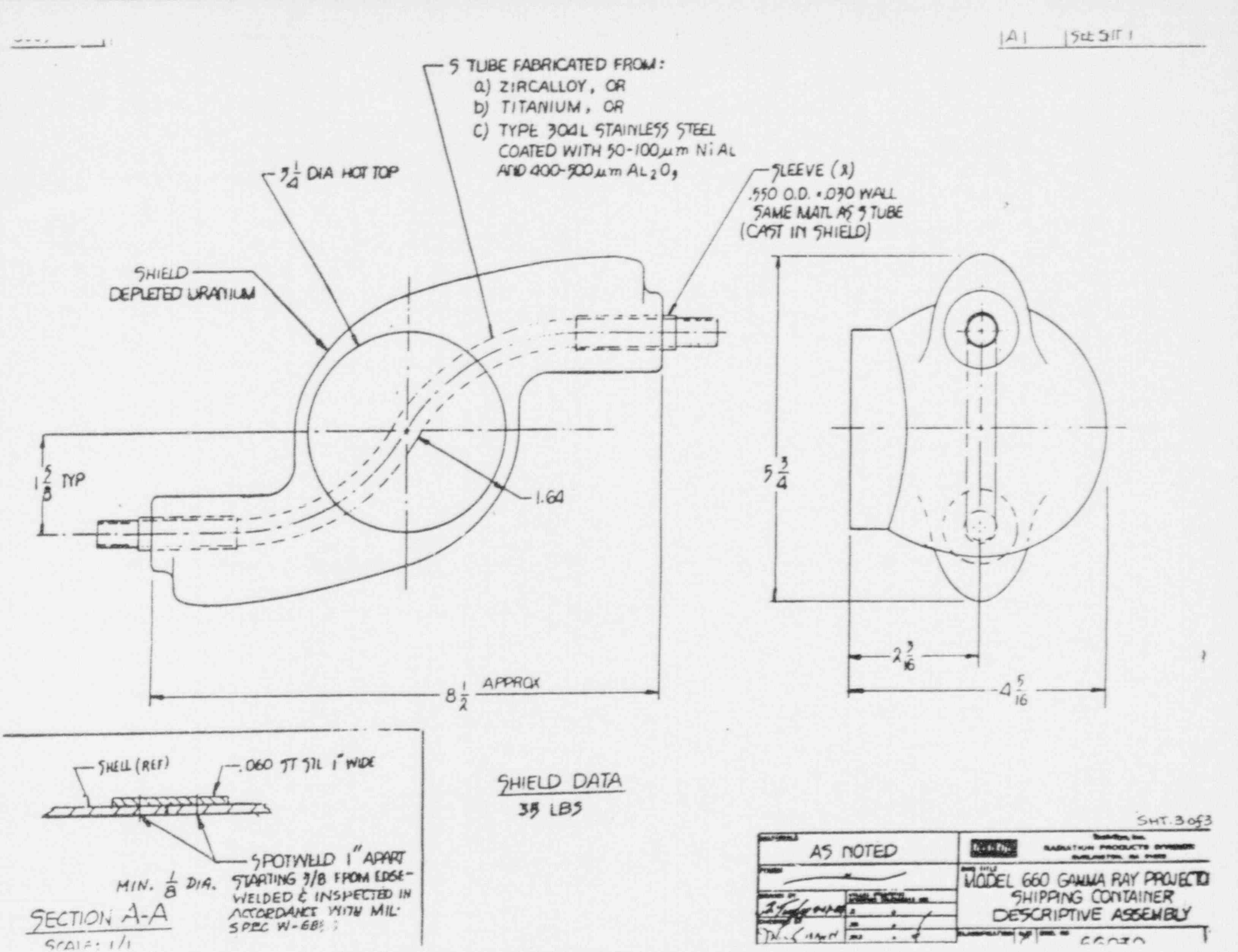
37 LBS ± 3 lbs.

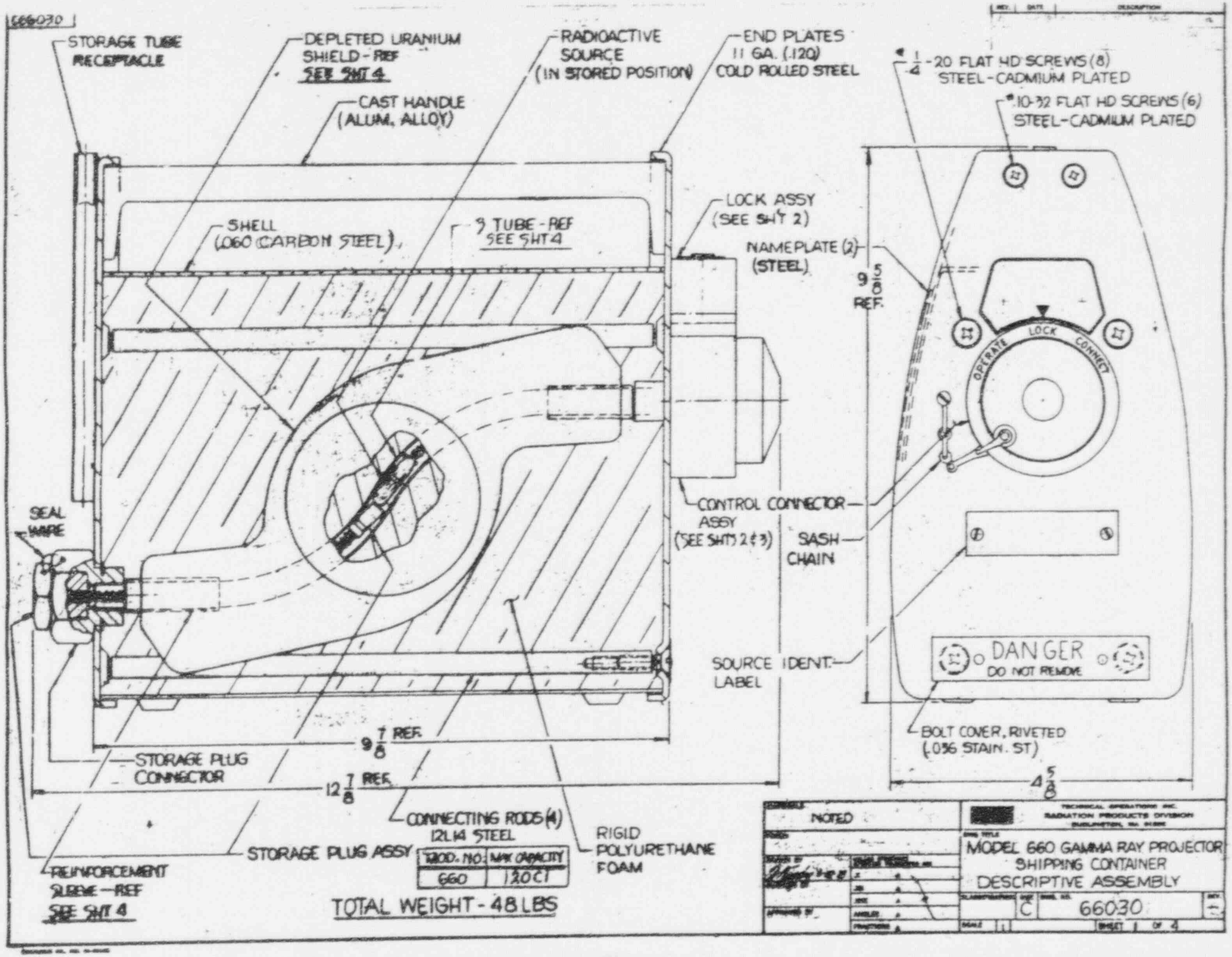
| | |
|---|---|
| MATERIAL: AS NOTED | RADIATION PRODUCTS DIVISION |
| | MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY |
| SIZE: C | DWG. NO. 66030 — REV. D |
| SCALE: 1:1 | SHEET 3 OF 3 |



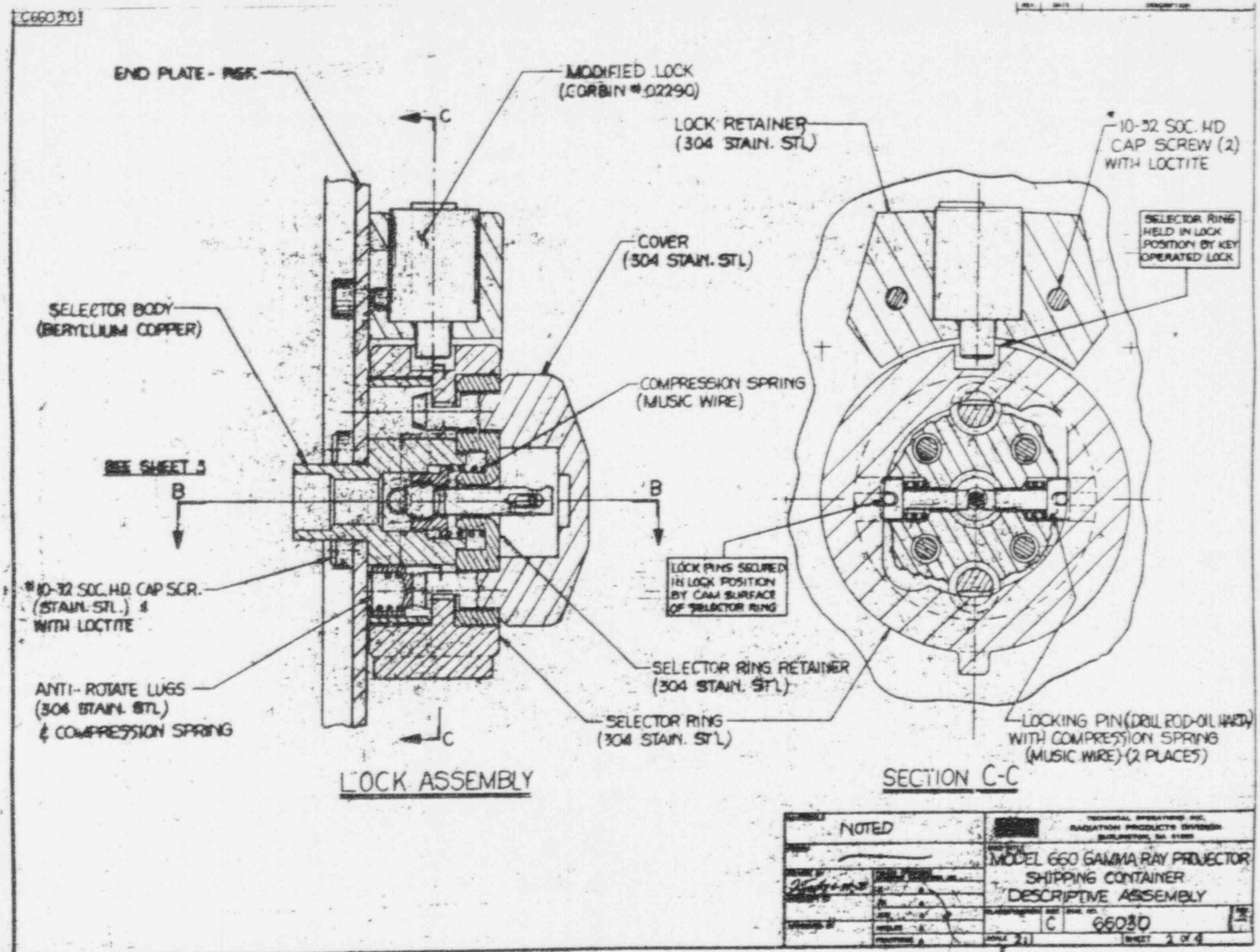
A | ADDED GEN. INFO., POST-LOCK, 660A
STORAGE TUBE RECEPTACLE
DEPLETED URANIUM SHIELD-REF SEE SHT 3
RADIOACTIVE SOURCE (IN STORED POSITION)
END PLATES 11 GA. (.120) COLD ROLLED STEEL
CAST HANDLE (ALUM. ALLOY)
* 1/4-20 FLAT HD SCREWS (8) STEEL-CADMIUM PLATED
* 10-32 FLAT HD SCREWS (6) STEEL-CADMIUM PLATED
LOCK ASSY (SEE SH'T 2)
SHELL (.060 CARBON STEEL)
9 TUBE-REF SEE SHT 3
NAMEPLATE (2) (STEEL)
9 5/8 REF.
LOCK
OPERATE
CONNECT
SEAL WIRE
CONTROL CONNECTOR ASSY (SEE SHT 2)
CABLE ASSY
SOURCE IDENT. LABEL
DANGER DO NOT REMOVE
A
A (SHT 3)
BOLT COVER, RIVETED (.036 STAIN. ST)
9 7/8 REF.
STORAGE PLUG CONNECTOR
12 7/8 REF.
4 5/8
CONNECTING RODS (4) 12L14 STEEL
RIGID POLYURETHANE FOAM
STORAGE PLUG ASSY
REINFORCEMENT SLEEVE-REF SEE SHT 3
MOD NO | MAX CAPACITY
660A | 120 Ci
TOTAL WEIGHT-48 LBS
NOTED
MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY
C
66030
A

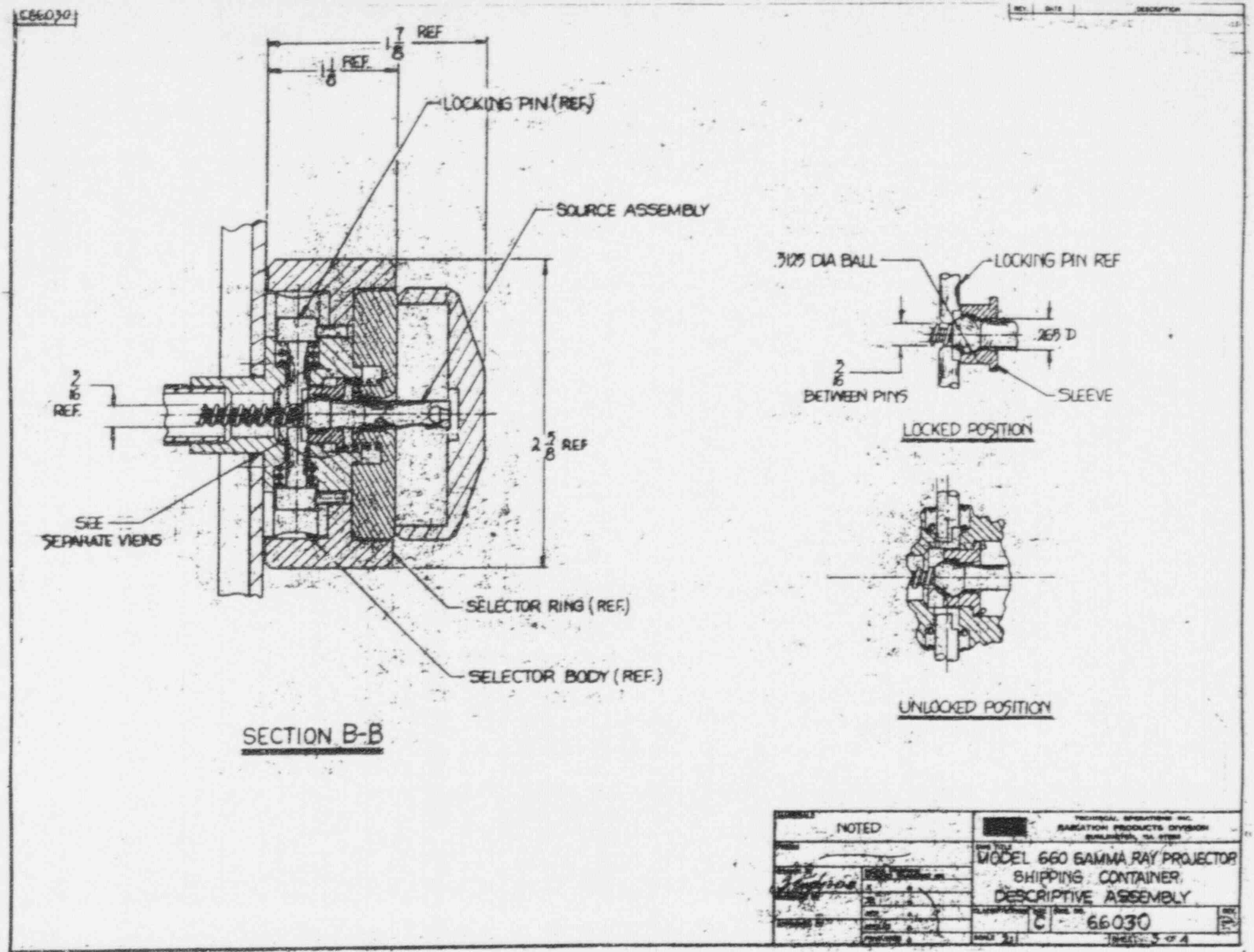

66030
A
SEE SHT 1
END PLATE - REF.
MODIFIED LOCK
(CORBIN # 02250)
10-32 SOC. HD
CAP SCREW (2)
WITH LOCTITE
COMPRESSION SPRING
LEE # LC-045-H-1
SELECTOR BODY
(303 ST STL)
COVER
(304 ST-STL)
SLEEVE
(DRILL ROD)
10-32 SOC. HD CAP SCR.
(STAIN. STL.) 4
WITH LOCTITE
ANTI-ROTATE LUGS
(304 STAIN. STL)
& COMPRESSION SPRING
SELECTOR RING
(303 ST-STL.)
SELECTOR RING
RETAINER
(303 ST. STL)
LOCK ASSEMBLY
PROTECTIVE BUMPER (2)
(RUBBER)
LOCK RETAINER
(304 ST. STL)
CONNECT
LOCK
OPERATE
CABLE ASSY
(ST STL & NYLON COVERED)
LOCKING SLIDE
(1/4 x 1/2 FLAT GND STOCK
OIL HARDENING)
NOTED
MODEL 660 GAMMA RAY PROJECTOR
SHIPPING CONTAINER
DESCRIPTIVE ASSEMBLY
C
66030
A


A
SEE SHT 1
S TUBE FABRICATED FROM:
a) ZIRCALLOY, OR
b) TITANIUM, OR
C) TYPE 304L STAINLESS STEEL COATED WITH 50-100 µm NiAL AND 400-500 µm $AL_2O_3$
5 1/4 DIA HOT TOP
SLEEVE (2)
.550 O.D. × .030 WALL
SAME MATL AS S TUBE
(CAST IN SHIELD)
SHIELD
DEPLETED URANIUM
1 5/8 TYP
1.64
5 3/4
2 3/16
4 5/16
8 1/2 APPROX
SHELL (REF)
.060 SS STL 1" WIDE
SPOTWELD 1" APART
STARTING 3/8 FROM EDGE-
WELDED & INSPECTED IN
ACCORDANCE WITH MIL-
SPEC W-6858
MIN. 1/8 DIA.
SECTION A-A
SCALE: 1/1
SHIELD DATA
35 LBS
SHT. 3 of 3
AS NOTED
RADIATION PRODUCTS DIVISION
MODEL 660 GAMMA RAY PROJECTOR
SHIPPING CONTAINER
DESCRIPTIVE ASSEMBLY



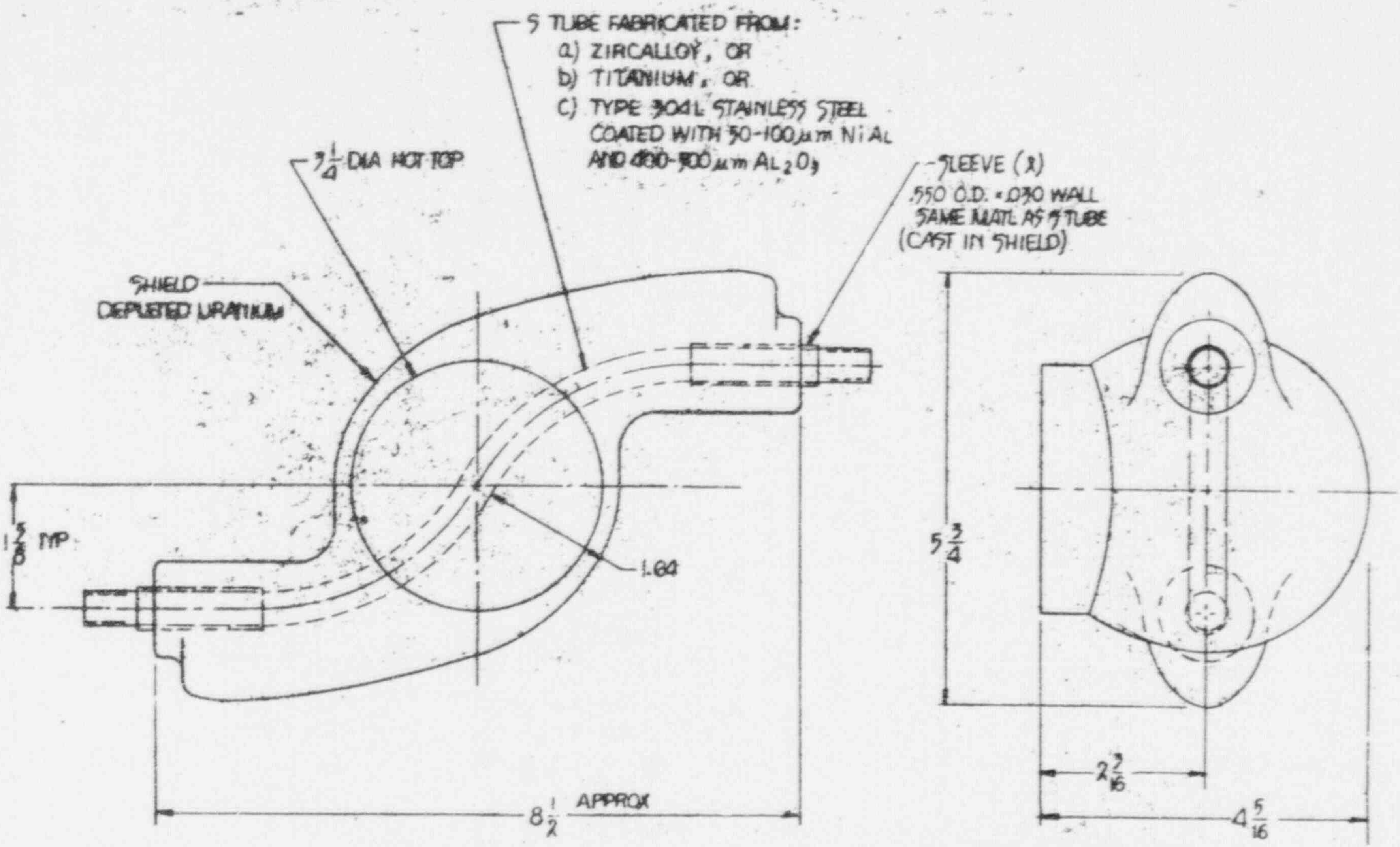
666030
STORAGE TUBE RECEPTACLE
DEPLETED URANIUM SHIELD - REF SEE SHT 4
CAST HANDLE (ALUM. ALLOY)
RADIOACTIVE SOURCE (IN STORED POSITION)
END PLATES 11 GA. (.120) COLD ROLLED STEEL
SHELL (.060 CARBON STEEL)
S TUBE - REF SEE SHT 4
LOCK ASSY (SEE SHT 2)
NAMEPLATE (2) (STEEL)
1/4-20 FLAT HD SCREWS (8) STEEL-CADMIUM PLATED
10-32 FLAT HD SCREWS (6) STEEL-CADMIUM PLATED
9 5/8 REF.
LOCK
OPERATE
CONNECT
SEAL WIRE
CONTROL CONNECTOR ASSY (SEE SHTS 2 & 3)
SASH CHAIN
SOURCE IDENT. LABEL
DANGER
DO NOT REMOVE
BOLT COVER, RIVETED (.036 STAIN. ST)
4 5/8
9 7/8 REF.
12 7/8 REF.
STORAGE PLUG CONNECTOR
CONNECTING RODS (4) 12L14 STEEL
RIGID POLYURETHANE FOAM
STORAGE PLUG ASSY
PROD. NO. | MAX CAPACITY
660 | 120 CI
REINFORCEMENT SLEEVE - REF SEE SHT 4
TOTAL WEIGHT - 48 LBS
NOTED
TECHNICAL OPERATIONS INC.
RADIATION PRODUCTS DIVISION
MODEL 660 GAMMA RAY PROJECTOR SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY
C
66030
SHEET 1 OF 4


C66030
END PLATE - REF.
MODIFIED LOCK
(CORBIN #02290)
C
SELECTOR BODY
(BERYLLIUM COPPER)
COVER
(304 STAIN. STL)
COMPRESSION SPRING
(MUSIC WIRE)
SEE SHEET 3
B
B
#10-32 SOC. HD. CAP SCR.
(STAIN. STL.) &
WITH LOCTITE
ANTI-ROTATE LUGS
(304 STAIN. STL)
& COMPRESSION SPRING
SELECTOR RING RETAINER
(304 STAIN. STL)
SELECTOR RING
(304 STAIN. STL)
C
LOCK ASSEMBLY
LOCK RETAINER
(304 STAIN. STL)
#10-32 SOC. HD
CAP SCREW (2)
WITH LOCTITE
SELECTOR RING
HELD IN LOCK
POSITION BY KEY
OPERATED LOCK
LOCK PINS SECURED
IN LOCK POSITION
BY CAM SURFACE
OF SELECTOR RING
LOCKING PIN (DRILL ROD-OIL HARD)
WITH COMPRESSION SPRING
(MUSIC WIRE) (2 PLACES)
SECTION C-C
NOTED
MODEL 660 GAMMA RAY PROJECTOR
SHIPPING CONTAINER
DESCRIPTIVE ASSEMBLY
C
66030
2:1
2 OF 6



C66030
1 7/8 REF
1 1/8 REF.
LOCKING PIN (REF.)
SOURCE ASSEMBLY
3/16 REF.
2 5/8 REF
SEE SEPARATE VIEWS
SELECTOR RING (REF.)
SELECTOR BODY (REF.)
SECTION B-B
.3125 DIA BALL
LOCKING PIN REF
.265 D
3/16 BETWEEN PINS
SLEEVE
LOCKED POSITION
UNLOCKED POSITION
NOTED
MODEL 660 GAMMA RAY PROJECTOR
SHIPPING CONTAINER
DESCRIPTIVE ASSEMBLY
C
66030
SHEET 3 OF 4

C66030




SHIELD DATA
35 LBS

| | |
|---|---|
| AS NOTED | Radiation Products Division |
| | MODEL 660 GAMMA RAY PROJECTOR, SHIPPING CONTAINER DESCRIPTIVE ASSEMBLY |
| | C 66030 |
| | SCALE 1 SHEET 4 OF 4 |

# Appendix B
# Referenced Material

The following is an excerpt from Avallone, Eugene A., and Theodore Baumeister III, Editors, *Marks' Standard Handbook for Mechanical Engineers*, Ninth Edition (New York: McGraw-Hill Book Company, 1987), page 4-27.

**Table 4.1.5 Approximate Inversion-Curve Locus for Air**

| $P$, bar | 0 | 25 | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 |
|---|---|---|---|---|---|---|---|---|---|---|
| $T_l$, K | (112)* | 114 | 117 | 120 | 124 | 128 | 132 | 137 | 143 | 149 |
| $T_u$, K | 653 | 641 | 629 | 617 | 606 | 594 | 582 | 568 | 555 | 541 |
| $P$, bar | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 432 | |
| $T_l$, K | 156 | 164 | 173 | 184 | 197 | 212 | 230 | 265 | 300 | |
| $T_u$, K | 526 | 509 | 491 | 470 | 445 | 417 | 386 | 345 | 300 | |

*Hypothetical low-pressure limit

**Loss Due to Throttling** A throttling process in a cycle of operations always introduces a loss of efficiency. If $T_0$ is the temperature corresponding to the back pressure, the loss of available energy is the product of $T_0$ and the increase of entropy during the throttling process. The following example illustrates the calculation in the case of ammonia passing through the expansion valve of a refrigerating machine.

Example. The liquid ammonia at a temperature of 70°F passes through the valve into the brine coil in which the temperature is 20 deg and the pressure is 48.21 psia. The initial enthalpy of the liquid ammonia is $h_{f1} = 120.5$, and therefore the final enthalpy is $h_{f2} + x_2 h_{fg2} = 64.7 + 553.1 x_2 = 120.5$, whence $x_2 = 0.101$. The initial entropy is $s_{f1} = 0.254$. The final entropy is $s_{f2} + (x_2 h_{fg2}/T_2) = 0.144 + 0.101 \times 1.153 = 0.260$. $T_0 = 20 + 460 = 480$; hence the loss of refrigerating effect is $480 \times (0.260 - 0.254) = 2.9$ Btu.

## COMBUSTION

References: Chigier, "Energy, Combustion and Environment," McGraw-Hill, 1981. Campbell, "Thermodynamic Analysis of Combustion Engines," Wiley, 1979. Glassman, "Combustion," Academic Press, New York, 1977. Lefebvre, "Gas Turbine Combustion," McGraw-Hill, New York, 1983. Strehlow, "Combustion Fundamentals," McGraw-Hill, New York, 1984. Williams et al., "Fundamental Aspects of Solid Propellant Rockets," *Agardograph*, 116, Oct. 1969. Basic thermodynamic table type information needed in this area is found in Glushko et al., "Thermodynamic and Thermophysical Properties of Combustion Products," Moscow, and IPST translation; Gordon, NASA Technical Paper 1906, 1982, "JANAF Thermochemical Tables," NSRDS-NBS-37, 1971.

**Fuels** For special properties of various fuels, see Sec. 7. In general, fuels may be classed under three heads: (1) gaseous fuels, (2) liquid fuels, and (3) solid fuels.

The combustible elements that characterize fuels are carbon, hydrogen, and, in some cases, sulphur. The complete combustion of carbon gives, as a product, carbon dioxide, $CO_2$; the combustion of hydrogen gives water, $H_2O$.

### Combustion of Gaseous and Liquid Fuels

**Combustion Equations** The approximate molecular weights of the important elements and compounds entering into combustion calculations are:

| Material | C | $H_2$ | $O_2$ | $N_2$ | CO | $CO_2$ | $H_2O$ | $CH_4$ | $C_2H_4$ | $C_2H_6O$ | S | NO | $NO_2$ | $SO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Molecular weight | 12 | 2 | 32 | 28 | 28 | 44 | 18 | 16 | 28 | 46 | 32 | 30 | 46 | 64 |

For the elements C and H, the equations of complete combustion are

$$\begin{cases} C + O_2 = CO_2 \\ 12\text{ lb} + 32\text{ lb} = 44\text{ lb} \end{cases} \qquad \begin{cases} H_2 + ½O_2 = H_2O \\ 2\text{ lb} + 16\text{ lb} = 18\text{ lb} \end{cases}$$

For a combustible compound, as $CH_4$, the equation may be written

$$CH_4 + x \cdot O_2 = y \cdot CO_2 + z \cdot H_2O$$

Taking, as a basis, 1 molecule of $CH_4$ and making a balance of the atoms on the two sides of the equation, it is seen that

$$y = 1 \qquad z = 2 \qquad 2x = 2y + z \qquad \text{or} \qquad x = 2$$

Hence,

$$\begin{cases} CH_4 + 2O_2 = CO_2 + 2H_2O \\ 16\text{ lb} + 64\text{ lb} = 44\text{ lb} + 36\text{ lb} \end{cases}$$

The coefficients in the combustion equation give the combining volumes of the gaseous components. Thus, in the last equation 1 $ft^3$ of $CH_4$ requires for combustion 2 $ft^3$ of oxygen and the resulting gaseous products of combustion are 1 $ft^3$ of $CO_2$ and 2 $ft^3$ of $H_2O$. The coefficients multiplied by the corresponding molecular weights give the combining weights. These are conveniently referred to 1 lb of the fuel. In the combustion of $CH_4$, for example, 1 lb of $CH_4$ requires $64/16 = 4$ lb of oxygen for complete combustion and the products are $44/16 = 2.75$ lb of $CO_2$ and $36/16 = 2.25$ lb of $H_2O$.

**Air Required for Combustion** The composition of air is approximately 0.232 $O_2$ and 0.768 $N_2$ on a pound basis, or 0.21 $O_2$ and 0.79 $N_2$ by volume. For exact analyses, it may be necessary sometimes to take account of the water vapor mixed with the air, but ordinarily this may be neglected.

The minimum amount of air required for the combustion of 1 lb of a fuel is the quantity of oxygen required, as found from the combustion equation, divided by 0.232. Likewise, the minimum volume of air required for the combustion of 1 $ft^3$ of a fuel gas is the volume of oxygen divided by 0.21. For example, in the combustion of $CH_4$ the air required per pound of $CH_4$ is $4/0.232 = 17.24$ lb and the volume of air per cubic foot of $CH_4$ is $2/0.21 = 9.52$ $ft^3$. Ordinarily, more air is provided than is required for complete combustion. Let $a$ denote the minimum amount required and $xa$ the quantity of air admitted; then $x - 1$ is the excess coefficient.

**Products of Combustion** The products arising from the complete combustion of a fuel are $CO_2$, $H_2O$, and, if sulphur is present, $SO_2$. Accompanying these are the nitrogen brought in with the air and the oxygen in the excess of air. Hence the products of complete combustion are principally $CO_2$, $H_2O$, $N_2$, and $O_2$. The presence of CO indicates incomplete combustion. In simple calculations the reaction of nitrogen with oxygen to form noxious oxides, often termed $NO_x$, such as nitric oxide (NO), nitrogen peroxide ($NO_2$), etc., is neglected. In practice, an automobile engine is run at a lower compression ratio to reduce $NO_x$ formation. The reduced pollution is bought at the

# Appendix A
# Drawings

Model 660 Test Specimen
TP70, Rev. B (1 sheet)

Model 660 Gamma Ray Projector Shipping Container Descriptive Assembly
C66025, Rev. F (3 sheets)

Model 660 Gamma Ray Projector Shipping Container Descriptive Assembly
C66025, Rev. B (4 sheets)

Model 660 Gamma Ray Projector Shipping Container Descriptive Assembly
C66030, Rev. D (3 sheets)

Model 660 Gamma Ray Projector Shipping Container Descriptive Assembly
C66030, Rev. A (3 sheets)

Model 660 Gamma Ray Projector Shipping Container Descriptive Assembly
C66030, Rev. – (4 sheets)

# Appendix B
# Referenced Material

The following is an excerpt from Avallone, Eugene A., and Theodore Baumeister III, Editors, *Marks' Standard Handbook for Mechanical Engineers*, Ninth Edition (New York: McGraw-Hill Book Company, 1987), page 4-27.

**Table 4.1.5 Approximate Inversion-Curve Locus for Air**

| $P$, bar | 0 | 25 | 50 | 75 | 100 | 125 | 150 | 175 | 200 | 225 |
|---|---|---|---|---|---|---|---|---|---|---|
| $T_L$, K | (112)* | 114 | 117 | 120 | 124 | 128 | 132 | 137 | 143 | 149 |
| $T_U$, K | 653 | 641 | 629 | 617 | 606 | 594 | 582 | 568 | 555 | 541 |

| $P$, bar | 250 | 275 | 300 | 325 | 350 | 375 | 400 | 425 | 432 |
|---|---|---|---|---|---|---|---|---|---|
| $T_L$, K | 156 | 164 | 173 | 184 | 197 | 212 | 230 | 265 | 300 |
| $T_U$, K | 526 | 509 | 491 | 470 | 445 | 417 | 386 | 345 | 300 |

*Hypothetical low-pressure limit.

**Loss Due to Throttling** A throttling process in a cycle of operations always introduces a loss of efficiency. If $T_0$ is the temperature corresponding to the back pressure, the loss of available energy is the product of $T_0$ and the increase of entropy during the throttling process. The following example illustrates the calculation in the case of ammonia passing through the expansion valve of a refrigerating machine.

EXAMPLE. The liquid ammonia at a temperature of 70°F passes through the valve into the brine coil in which the temperature is 20 deg and the pressure is 48.21 psia. The initial enthalpy of the liquid ammonia is $h_{f1} = 120.5$, and therefore the final enthalpy is $h_{f2} + x_2h_{fg2} = 64.7 + 553.1x_2 = 120.5$, whence $x_2 = 0.101$. The initial entropy is $s_{f1} = 0.254$. The final entropy is $s_{f2} + (x_2h_{fg2}/T_2) = 0.144 + 0.101 \times 1.153 = 0.260$. $T_0 = 20 + 460 = 480$; hence the loss of refrigerating effect is $480 \times (0.260 - 0.254) = 2.9$ Btu.

## COMBUSTION

REFERENCES: Chigier, "Energy, Combustion and Environment," McGraw-Hill, 1981. Campbell, "Thermodynamic Analysis of Combustion Engines," Wiley, 1979. Glassman, "Combustion," Academic Press, New York, 1977. Lefebvre, "Gas Turbine Combustion," McGraw-Hill, New York, 1983. Strehlow, "Combustion Fundamentals," McGraw-Hill, New York, 1984. Williams et al., "Fundamental Aspects of Solid Propellant Rockets," *Agardograph*, 116, Oct. 1969. Basic thermodynamic table type information needed in this area is found in Glushko et al., "Thermodynamic and Thermophysical Properties of Combustion Products," Moscow, and IPST translation; Gordon, NASA Technical Paper 1906, 1982; "JANAF Thermochemical Tables," NSRDS-NBS-37, 1971.

**Fuels** For special properties of various fuels, see Sec. 7. In general, fuels may be classed under three heads: (1) gaseous fuels, (2) liquid fuels, and (3) solid fuels.

The combustible elements that characterize fuels are carbon, hydrogen, and, in some cases, sulphur. The complete combustion of carbon gives, as a product, carbon dioxide, $CO_2$; the combustion of hydrogen gives water, $H_2O$.

### Combustion of Gaseous and Liquid Fuels

**Combustion Equations** The approximate molecular weights of the important elements and compounds entering into combustion calculations are:

| Material | C | $H_2$ | $O_2$ | $N_2$ | CO | $CO_2$ | $H_2O$ | $CH_4$ | $C_2H_4$ | $C_2H_6O$ | S | NO | $NO_2$ | $SO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Molecular weight | 12 | 2 | 32 | 28 | 28 | 44 | 18 | 16 | 28 | 46 | 32 | 30 | 46 | 64 |

For the elements C and H, the equations of complete combustion are

$$\begin{cases} C + O_2 = CO_2 & H_2 + \tfrac{1}{2}O_2 = H_2O \\ 12 \text{ lb} + 32 \text{ lb} = 44 \text{ lb} & 2 \text{ lb} + 16 \text{ lb} = 18 \text{ lb} \end{cases}$$

For a combustible compound, as $CH_4$, the equation may be written

$$CH_4 + x \cdot O_2 = y \cdot CO_2 + z \cdot H_2O$$

Taking, as a basis, 1 molecule of $CH_4$ and making a balance of the atoms on the two sides of the equation, it is seen that

$$y = 1 \quad z = 2 \quad 2x = 2y + z \quad \text{or} \quad x = 2$$

Hence,

$$\begin{cases} CH_4 + 2O_2 = CO_2 + 2H_2O \\ 16 \text{ lb} + 64 \text{ lb} = 44 \text{ lb} + 36 \text{ lb} \end{cases}$$

The coefficients in the combustion equation give the combining volumes of the gaseous components. Thus, in the last equation 1 $ft^3$ of $CH_4$ requires for combustion 2 $ft^3$ of oxygen and the resulting gaseous products of combustion are 1 $ft^3$ of $CO_2$ and 2 $ft^3$ of $H_2O$. The coefficients multiplied by the corresponding molecular weights give the combining weights. These are conveniently referred to 1 lb of the fuel. In the combustion of $CH_4$, for example, 1 lb of $CH_4$ requires $64/16 = 4$ lb of oxygen for complete combustion and the products are $44/16 = 2.75$ lb of $CO_2$ and $36/16 = 2.25$ lb of $H_2O$.

**Air Required for Combustion** The composition of air is approximately 0.232 $O_2$ and 0.768 $N_2$ on a pound basis, or 0.21 $O_2$ and 0.79 $N_2$ by volume. For exact analyses, it may be necessary sometimes to take account of the water vapor mixed with the air, but ordinarily this may be neglected.

The minimum amount of air required for the combustion of 1 lb of a fuel is the quantity of oxygen required, as found from the combustion equation, divided by 0.232. Likewise, the minimum volume of air required for the combustion of 1 $ft^3$ of a fuel gas is the volume of oxygen divided by 0.21. For example, in the combustion of $CH_4$ the air required per pound of $CH_4$ is $4/0.232 = 17.24$ lb and the volume of air per cubic foot of $CH_4$ is $2/0.21 = 9.52$ $ft^3$. Ordinarily, more air is provided than is required for complete combustion. Let $a$ denote the minimum amount required and $xa$ the quantity of air admitted; then $x - 1$ is the excess coefficient.

**Products of Combustion** The products arising from the complete combustion of a fuel are $CO_2$, $H_2O$, and, if sulphur is present, $SO_2$. Accompanying these are the nitrogen brought in with the air and the oxygen in the excess of air. Hence the products of complete combustion are principally $CO_2$, $H_2O$, $N_2$, and $O_2$. The presence of CO indicates incomplete combustion. In simple calculations the reaction of nitrogen with oxygen to form noxious oxides, often termed $NO_x$, such as nitric oxide (NO), nitrogen peroxide ($NO_2$), etc., is neglected. In practice, an automobile engine is run at a lower compression ratio to reduce $NO_x$ formation. The reduced pollution is bought at the