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Tamper-Indicating Devices and Safeguards Seals Evaluation Test Report

Volume I

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Abstract

Sandia National Laboratories was asked to evaluate the seals used as tamper-indicating devices at DOE facilities. Initially, a survey determined what seal manufacturers were being used and what similar seal types were available. Once the required specifications for TIDs were defined, a test plan measured the currently available seals against the requirements. Environmental and physical type tests stressed the seals under two broad categories: (1) handling durability and (2) tamper resistance. Results of the testing provide comparative ratings for the various seals, recommendations for using currently available seals, and a new tamper-indicating technology.

MASTER

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Acronyms

DOE	Department of Energy
GA	General Atomic
INEL	Idaho National Engineering Laboratory
LANL	Los Alamos National laboratory
LLNL	Lawrence Livermore National laboratory
LS	loop seal
NTS	Nevada Test Site
OSS	Office of Safeguards & Security
PCI	Product Consultant International
PNL	Pacific Northwest Laboratory
PSS	pressure-sensitive seal
RF	Rocky Flats
SNL	Sandia National Laboratories
SNM	special nuclear material
SRS	Savannah River Site
TID	tamper-indicating devices
WINCO	Westinghouse Idaho Nuclear Company
Y12	A DOE facility at Oak Ridge, TN

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Tamper-Indicating Devices and Safeguards Seals Evaluation Test Report Volume 1

1. INTRODUCTION

Sandia National Laboratories (Sandia) was asked to evaluate the tamper-indicating devices (TIDs) at Department of Energy (DOE) facilities. The evaluation included those seals currently in use, as well as those that could be considered for possible use in the future. The overall project goal was to develop information and recommendations regarding what seal types could best be adapted for use at the DOE complex. This report provides general information on how to use the various seal types, describes the evaluation tests conducted in the study, summarizes test results, and documents recommendations based on those test results.

1.1 Background

DOE safeguards and security inspections and evaluations have resulted in concerns relative to TIDs used in the special nuclear materials (SNM) area. TIDs are used to help protect and monitor accountable material and are of two types:

1) the pressure-sensitive seal (PSS) type
2) the loop seal (LS) type

The seals are placed on containers that store accountable material. They are also used on smaller containers when the smaller containers are placed inside larger containers.

Typically, large containers are 5, 10, 30, or 55 gallon painted drums with closure-locking collars. There are also 3 gallon, plated "lard" cans, and 5 gallon paint cans.

Typical small containers are:

- i/8 gallon to 1 gallon plated fruit cans
- 1 gallon plated paint cans
- 1/2 liter 8801 stainless steel canisters
- 2.5 liters 8802 stainless steel canisters
- 4 liters 8808 stainless steel canisters
- 1/2 gallon polyethlene fruit jars
- 2 gallon polyethlene clam shells

Generally, the sealed containers are stored in a vault controlled by two-person access rules. When the vault is open, at least two individuals must be involved and observe each other's acitivities.

1.2 User Survey

OSS distributed functional specifications for the seals in July 1990. In February 1991, Sandia mailed questionnaires to DOE facilities to determine who was using the seals and how the seals were being used. The questionnaire included:

- type and model of seals used
- manufacturer (address and phone number)
- application/usage (number per year)
- known vulnerabilities and pertinent documents
- evaluation results and pertinent documents

The results of the questionnaire were used to:

- develop standard evaluation methods
- refine the seals functional specifications
- develop a list of seals as a base for standardization within DOE facilities

Results of the survey indicate that there were nine seal manufacturers; eight were identified and one was not known. Eleven different types of TIDs were used at the 18 facilities within the DOE complex. Five different PSSs and three LSs were identified and considered for testing. Two independent manufacturers of PSSs were added to the test group; this gave a total of seven PSS manufacturers and four LS manufacturers. Survey results are shown in Tables 1 and 2, below.

Table 1. Types of PSSs

PSS MANUFACTURER	DOE FACILITY
AVERY -paper	- GA
ADVERTAPE -vinyl	-Mound
VALMARK -vinyl	-LLNL
DESIGNER -vinyl	-PNL -WINCO
YORK -mylar	-RF -SRS -Y12
TYDEN -mylar	
ADVERTAPE -mylar	

Table 2. Types of LSs

LS MANUFACTURER	DOE FACILITY
AMERICAN CASTING & MANUFACTURING -E Cup w/ wire	SRS, INEL, Pantex, Rockwell Nuc Ops, Brookhaven, RF, LANL, Mound, GA, PNL, Bettis, SNL, WINCO, LLNL, Nev Ops Off, LLNL-NTS.
MASTERLOCK -padlock	-GA
E.J. BROOKS -Griploc	-Argonne West
PCI (Product Consultant International) -cable lock	Y-12

2. SPECIFICATIONS and TEST PARAMETERS

The required specifications of TIDs are:

- low cost
- resistance to harsh environmental conditions
- visual verification of seal serial number and integrity
- ability to withstand service handling of containers
- able to show evidence of tampering
- relative ease and speed of application
- ability to fit and adhere to a variety of containers and their surface materials

2.1 Test Parameters

The TIDs were examined to see how well they met the required specifications. In December 1991 before the test plan was finalized, a memo was sent to DOE facilities asking that the material the container was made of be identified. Responding facilities identified three surfaces: stainless steel, enamel-coated steel, and polyethylene. Thus, three sets of test coupons (3" x 3" x .125" thick) were procured. Using the coupons, the PSSs were subjected to the following environmental tests and mechanical tests:

- erasing tests
- peeling tests
- radiation tests
- shearing tests
- solvent tests

Most testing was done in the area of environmental tests (see Table 3). The mechanical tests were conducted at room temperature.

Table 3. Environmental Test Group

1	**Control** (tested as received at room temperature).
2	**24-hour temperature shock @ 50% humidity** (switched from 20°F to 95°F every hour)
3	**7-day cycled high/low temperature @ ambient (38%) humidity**. For each 24 hours: • 6 hrs. @ 35°F • 6 hrs. ramp to 95° F • 6 hrs. @ 95°F • 6 hrs. ramp to 35°F
4	**7-day cycled high/low temperature @ high (95%) humidity**. For each 24 hours: • 6 hrs. @ 35°F • 6 hrs. ramp to 95°F • 6 hrs. @ 95°F • 6 hrs. ramp to 35°F
5	**20-day 95°F @ 95% humidity**. (No mechanical test; visual inspection only.)

There were seven sets (one set per manufacturer) of the peel-, shear-, and solvent-prepared coupons for each of the four environmental test groups to be mechanically tested. One extra set of the "peel and shear sets" was included in the seven-day, high and low temperature/high humidity group for radiation testing prior to their peel and shear test.

An environmental test group consisted of a set of the peel, shear, and solvent groups. After the environmental test, the solvent group was segregated into mechanical test groups, marked, and boxed for mechanical testing. Erasure testing was done on the peel groups after all testing sequences.

2.2 Testing Guidelines

The seals are to be used primarily in protected environments, such as inside buildings or transport vehicles. There will be brief periods when the seals are exposed to outside elements. The intent of the following environmental requirements is to ensure the seal will remain intact, and that it will be readable and viable for at least two years subsequent to application. Most of the conditions specified will be taken from MIL-STD-810D, dated July 19, 1983. In this document, the military standard will be referred to as 810D and the method and section in the document will be provided.

The tests include temperature tests, temperature shock, humidity, and radiation.

- **Control Group Tests.** Multiple samples of each seal were mechanically tested, but were not environmentally tested.

- **Temperature Tests**. Multiple samples of each seal were environmentally tested to the specifications listed below. The high and low temperature procedures of 810D Section II, have been combined into two tests:

  A) Cycled Low/High Temperature @ Low Humidity
  B) Cycled Low/High Temperature @ High Humidity

2.2.1 Temperature Tests

- Cycled Low/High Temperature @ Low Humidity. This test was conducted according to 810D, paragraph 4.5.5, page 13.

  Low Temperature. This portion of the test was conducted according to 810D, Method 502.2, Section II, at 35°F at ambient humidity.

  High Temperature. This portion of the test was conducted according to 810D, Method 501.2, Section II, at 95°F at ambient humidity. At the conclusion of the cycled temperature test, the seal samples were raised to the ambient temperature defined in 810D, paragraph 4.4a, "Test Conditions," page 10. The test items were inspected per 810D, paragraph 4.5.6 "Post Test Data," page 113.

- Cycled Low/High Temperature @ High Humidity. This test was conducted according to 810D, paragraph 4.5.5, page 13.

  Low Temperature. This portion of the test was conducted according to 810D, Method 502.2, Section II, at 35ºF at 95% humidity.

  High Temperature. This portion of the test was conducted according to 810D, Method 501.2, Section II, at 95ºF at 95% humidity. At the end of the cycled temperature test, the seal samples were raised to the ambient temperature defined in 810D, paragraph 4.4a "Test Conditions," page 10. The test items were inspected per 810D, paragraph 4.5.6 "Post Test Data," page 113.

2.2.2 Temperature Shock. This test was conducted according to 810D, Method 502.2, Section II. Cycle test was 24-hours long using Procedure I, interchanging the sealed specimen between a 20ºF and a 95ºF chamber each hour. Uncontrolled humidity conditions sufficed for the test.

2.2.3 Humidity. This test was conducted according to 810D, Method 507.2, Section II. The constant tests described for High Temperature were extended to 20 days.

2.2.4 Radiation. This test was conducted by submitting the seal to 1000 rad cumulative gamma exposure.

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3. PRESSURE SENSITIVE SEAL TESTING

In the PSS testing, we subjected the seals to a peel test, a shear test, and a solvent test. These tests used seals from each of the seven manufacturers.

3.1 Peel Test

The peel test measures the ability of the PSS to adhere to various container surface materials. The materials used in these tests include a polyethylene surface, an enamel-coated surface, and a stainless steel surface.

3.1.1 Test Description. In the peel group, 1" wide by 7.125" long seals were placed (adhered) across the center of (1 each) a coupon. Approximately 4.125" of PSSs extend beyond the edge of the coupon (see Figure 1). The non-stick paper backing was left on approximately 4.25" of the PSSs 7.125" for gripping purposes.

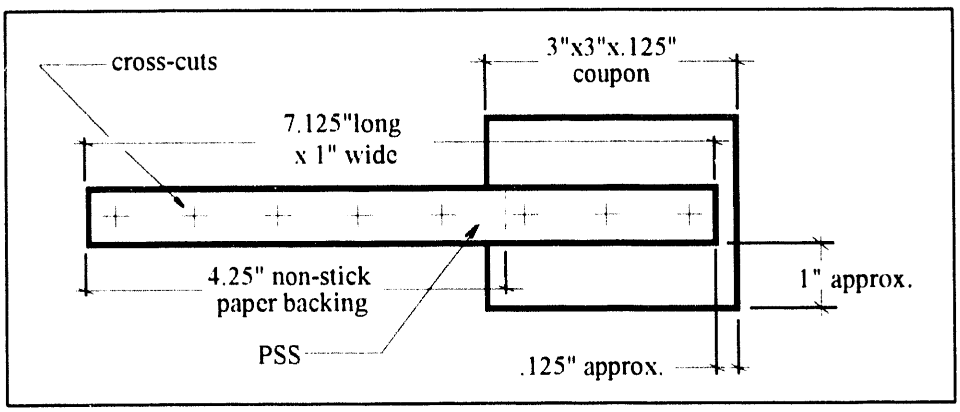

Figure 1. Peel Test Configuration

The peel test (see Figure 2) was performed using an Instron® 1125 linear tensile tester. The test was programmed for a rate of travel of 5 inches/minute at one pound of vertical force. The pulley cables were attached to the Instron's stationary upper assembly. This allows the table assembly to travel at a rate that keeps the vertical portion of the seal perpendicular to the coupon's surface.

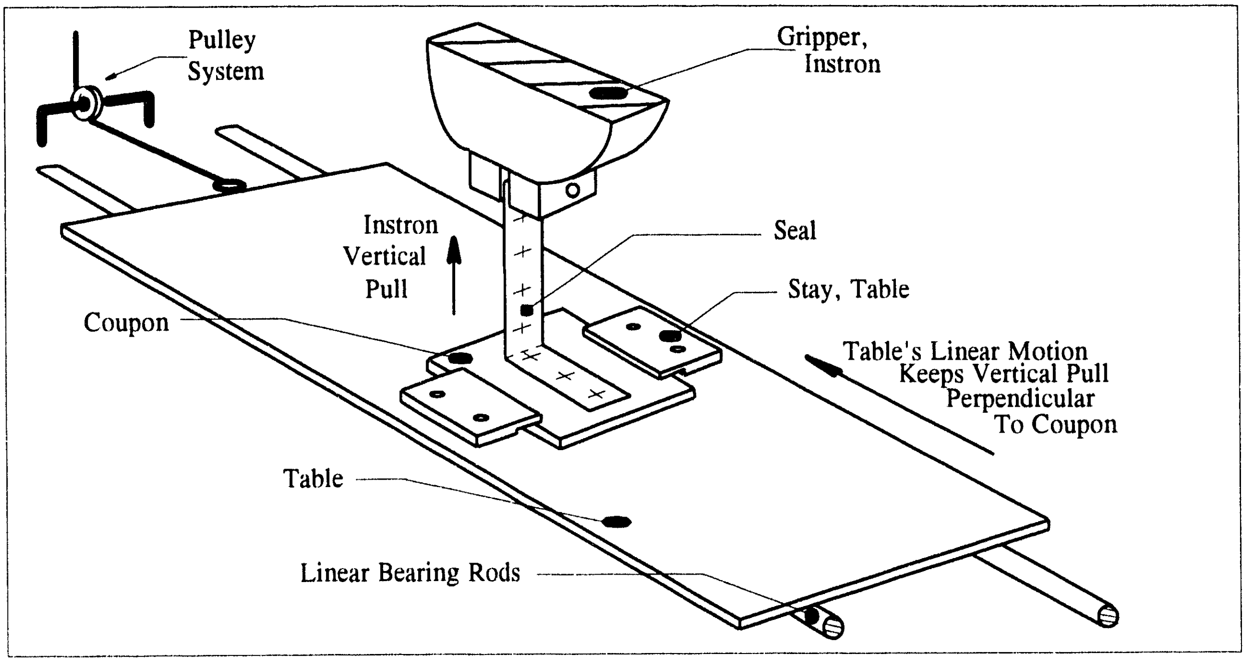

Figure-2. Peel Test Setup

3.1.2 Test Results. Environmental tests did not affect the outcome of the peel tests. Peel distance varies because of the random application of the seals in regard to the cross-cuts and their relationship to the edge of the coupon where the peeling procedure begins. Because of their fragile state, some paper seals failed prior to testing during setup.

The **polyethylene surface** proved to be the most difficult surface to adhere to:

- The vinyl seals without cross-cuts would completely peel off.
- The vinyl seals with cross-cuts would peel up to the cross-cuts and then tear.
- The mylar seals would peel leaving 10% to 25% void printing behind.
- The paper seal would tear almost immediately.

The **enamel painted surface** proved a much better surface for adhesion:

- The vinyl seals without cross-cuts would tear, usually within the first .2 inch of travel.

- The vinyl seals with cross-cuts would, 50% of the time, peel up to the cross-cuts and then tear.
- The mylar seals would peel leaving 45% to 65% void printing behind.
- The paper seal would tear almost immediately.

The **stainless steel surface** proved to be the best surface for adhesion:

- The vinyl seals without cross-cuts would tear, usually within the first .1 inch of travel.
- The vinyl seals with cross-cuts would, 25% of the time, peel up to the cross-cuts and then tear.
- The mylar seals would peel leaving 70% to 85% void printing behind.
- The paper seal would tear almost immediately.

3.2 Shear Test

The shear test measures the adhesive ability of the PSS, as well as the strength of the PSS material. Again, the container surface materials used in the tests included polyethylene, enamel painted, and stainless steel.

3.2.1 Test Description. In the shear group, two coupons (see Figure 3) were placed end-to-end. Then 1" wide by 5" long seals were adhered across the center of the set of two coupons. An approximate 5" space was left at each end of the coupons to allow for mechanical gripping during shear testing. The PSSs were placed on both sides of the butted coupons to balance and strengthen the assemblies due to the fragile state of some of the seals. These steps were taken for each of the three groups of coupons.

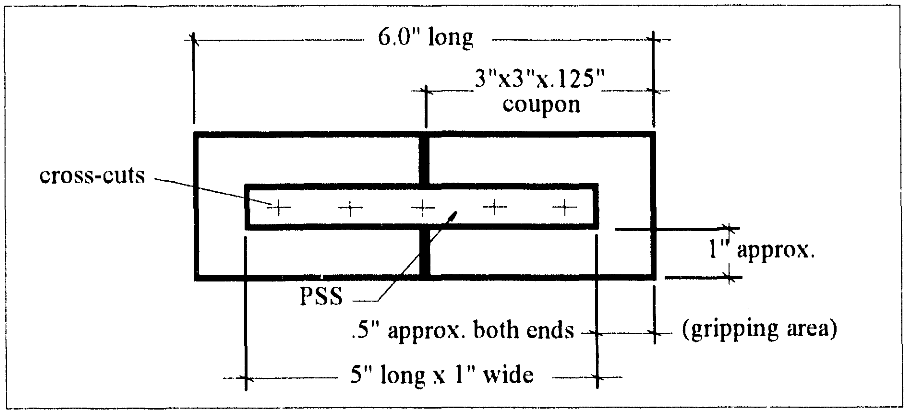

Figure 3. Shear Test Configuration

The **shear test,** shown in Figure 4, was performed using an MTS® linear tensile tester.

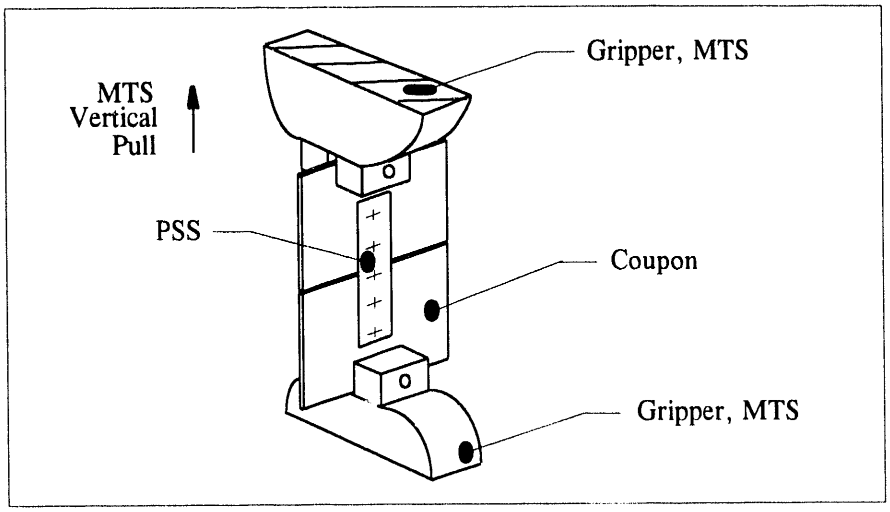

Figure 4. Shear Test Setup

3.2.2 Test Results. Environmental testing did not affect the outcome of the shear tests. Of the three coupon surfaces tested, the polyethylene surface proved to be the most difficult surface to adhere to. The enamel painted surface proved a much better surface for adhesion, and the stainless steel surface proved to be the best surface for adhesion.

The vinyl and paper seals would shear at the butted joint of the two coupons. This was typical of all three surface materials. First, the mylar seals would stretch, then adhesive failure would occur. This was typical of all three surface materials.

The main difference in material surface-to-seal failure was observed with the mylar seals. Similar to the peel test, the polyethylene surface in the shear tests had total adhesive failure at a lower level (55.6 lb.) compared to the enamel-coated surface total adhesive failure at 59.9 lb., and the stainless steel failure at 61.0 lb. (This information is from the 24-hour temperature shock test on Advantage mylar seals.)

The shear test showed adhesive failure and the strength of the seal material. The vinyl seals failed at the lowest poundage, the paper at a slightly higher level, and the mylar would stretch until adhesive failure occurred.

For example, the results of the 24-hour temperature shock test were:

- ***vinyl*** average material failure @ 10.97 lb.
- ***paper*** average material failure @ 18.87 lb.
- ***mylar*** average adhesive failure @ 85.30 lb.

3.3 Solvent Test

The adhesive and integrity retention ability of the PSS was tested. The PSS was subjected to several different solvents of varying levels of aggressiveness. The container surface included polyethylene, enamel-coated, and stainless steel materials .

3.3.1 Test Description. In the solvent group, three manufacturers' .75" wide by 2.75" long seals were adhered to a coupon's front surface (see Figure 5). Three other manufacturers' seals were adhered to the back side of the same coupon. The seals were evenly distributed across the coupon's surface, making sure even gaps were left between the seals and the coupon's edges. This was done for each of the three material groups of coupons.

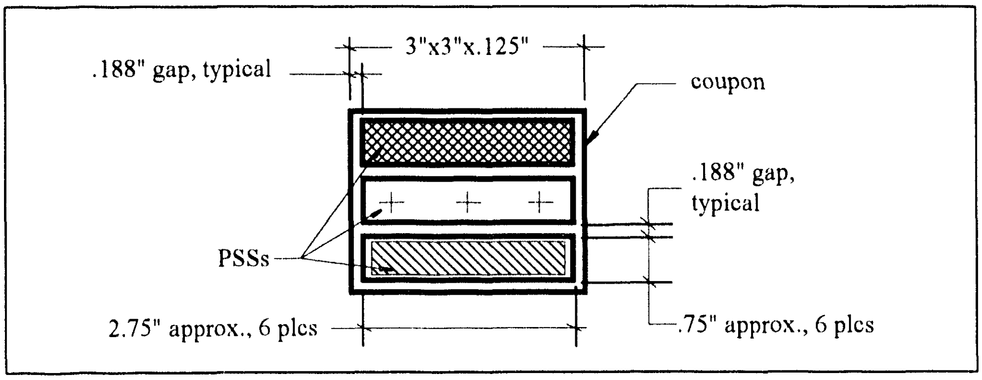

Figure 5. Solvent Test Configuration

Nine solvents are listed below in order of descending aggressiveness. Acetone is the most aggressive solvent.

1. acetone	4. heptane	7. methyl alcohol
2. ethyl acetate	5. turpentine	8. Alconox ® (detergent solution)
3. ethylene dichloride	6. kerosene	9. distilled or ionized water

The solvent test was divided into three progressive soaks:

A one-minute soak. After being soaked, the seals were removed from the solvent and an attempt was made to slide the seal from the coupon. A visual inspection was made and the results were documented.

A two-minute soak. After being soaked, the seals were removed from the solvent and an attempt was made to slide the seal from the coupon. A visual inspection was made and the results were documented.

A two-minute soak. After being soaked, the seals were removed from the solvent and an attempt was made to slide the seal from the coupon. A visual inspection was made and the results were documented.

3.3.2 Test Results. Environmental testing had no real affect on the outcome of the solvent tests. All solvent testing was done at room temperature. Of the three coupon surfaces tested, the seals found it most difficult to adhere to the polyethylene surface. The enamel-coated surface allowed much better adhesion than did the polyethylene surface, but, the stainless steel surface proved to be the best surface for adhesion.

- **Mylar**. The mylar seals are very durable against solvent attack. This is due to the non-permeable outer clear coat. This durability is apparent when viewing the results of the paper and vinyl seals. The mylar seals fail around their perimeters. They show no damage to the outer clear coat after a total of five minutes of soak time, but they do show visual damage to the delicate substrate (logo and serial number embossed color coat) that is bonded with the adhesive coat. The more aggressive solvents attack the acrylic adhesive and distort the color coat in the process. This distortion is visually obvious and makes tampering with solvents difficult.

- **Paper**. The paper seals are very delicate. The paper is crispy and easily cracked if mishandled. When an aggressive solvent attacks the seal successfully, the lamination between the paper and acrylic adhesive separates, leaving the adhesive attached to the metal surface. This usually occurs in the final two-minute soak. The paper seal is permeable to liquids, allowing the aggressive solvents to attack the adhesive over the entire surface area of the seal. By the time the adhesive breaks down enough to slide the seal off the coupon's surface, the paper has lost its integrity and falls apart at the touch.

- **Vinyl**. The vinyl seals turn rubbery after being soaked approximately three minutes in the aggressive solvents. The vinyl seal is permeable to liquids (but not as much as are the paper seals), allowing the aggressive solvents to attack the adhesive over the entire surface area of the seal. This causes a failure of the adhesive bond to the seal and allows the seal to wrinkle while the vinyl is transforming into a rubbery state. The rubbery state of the seal continues while still wet with the solvent. The seal then gets quite hard after drying. This reaction is visually obvious and makes it difficult to do undetected solvent tampering.

- **Logo's and Serial Number.** Acetone, ethyl acetate, ethylene dichloride, heptane and turpentine all attack the printing on the seals. The green dots on PNL's seals seem to deteriorate first; the dots come off randomly with some of the solvents. In the case of random-dot removal and associated serial numbers, the serial numbers come off with the dots. Other solvents seem to fade the green ink. The serial numbers, which are black, seem to be of a different type of ink and hold up quite well. The serial numbers can be removed, but not without visible damage to the vinyl.

The reds and greens of the different vinyl seals seem to deteriorate first. Black is more durable. The black serial numbers have an added clear coat (Advertape) or a different type of ink and hold up quite well; they can be removed, but not without visible damage to the vinyl.

The aqua blue logo of the General Atomics paper seal can be progressively rubbed off, more with each additional soak time. After five minutes the logo can be 95% rubbed out. After only one minute, the paper is saturated and the seal starts to wrinkle slightly; the paper fails mechanically at the touch. Acetone is the most aggressive; and ethyl acetate is next. The black serial numbers hold up quite well. The serial numbers can be removed, but not without visible damage to the paper.

Due to their clear mylar coat, the mylar seals are not directly affected by the solvent as the vinyl and paper seals are.

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4. LOOP SEAL TESTING

Loop seals were subjected to drop, pull, and humidity tests. These tests were conducted using two different types of loop seals: E-cup and Griploc.

4.1 Mechanical Drop and Pull Test

The mechanical drop and pull tests measure the ability of the LS to withstand the physical stresses encountered in normal handling.

4.1.1 Test Description

A. Three sets of tests were done on the E-cup seals:

- the #78 twisted pair stainless steel wire
- the #51 stainless steel wire rope treated with clear-coated Polyethylene
- the #51 stainless steel untreated wire rope

An eight-inch length of each type of wire was looped and its ends inserted through the two holes of the E-cup. A double-hole-crimp was then placed onto the two wire ends and securely crimped with a crimping tool. The crimped ends were inspected for proper attachment (see Figure 6) and then the opposite half of the E-cup was snapped into place securing the crimped ends within the cup assembly.

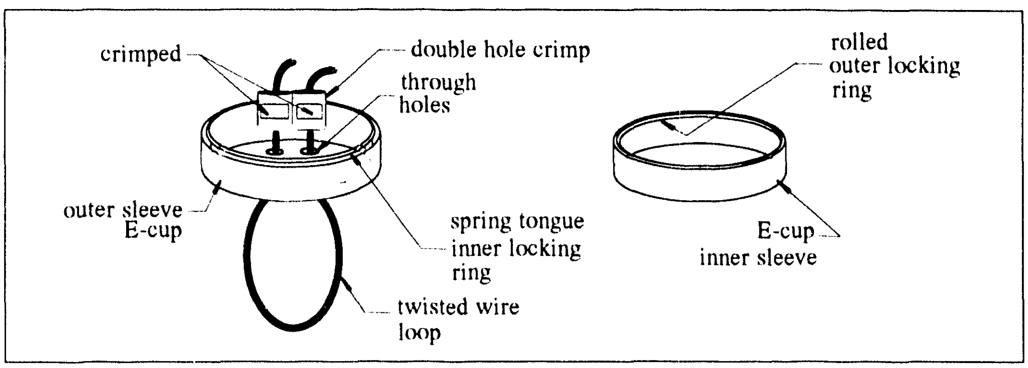

Figure 6. E-cup Seal Configuration

B. Three sets of tests were done on the Griploc seals from the DOE facility:

- the #78 twisted pair stainless steel wire provided with the Griploc
- the #51 stainless steel wire rope treated with clear-coated Polyethylene
- the #51 stainless steel untreated wire rope

An eight-inch length of each type wire was looped and its ends inserted through the hole of the Griploc (see Figure 7). The first tab was folded over the looped wire. The second tab was folded over the first tab, securing the crimping action of the first tab to the wire loop. The final two tabs were then folded on the second tab, securing the assembly. A tamper will be indicated when there is an attempt to fold back the finished assembly; the folding will cause the tab leg to be broken.

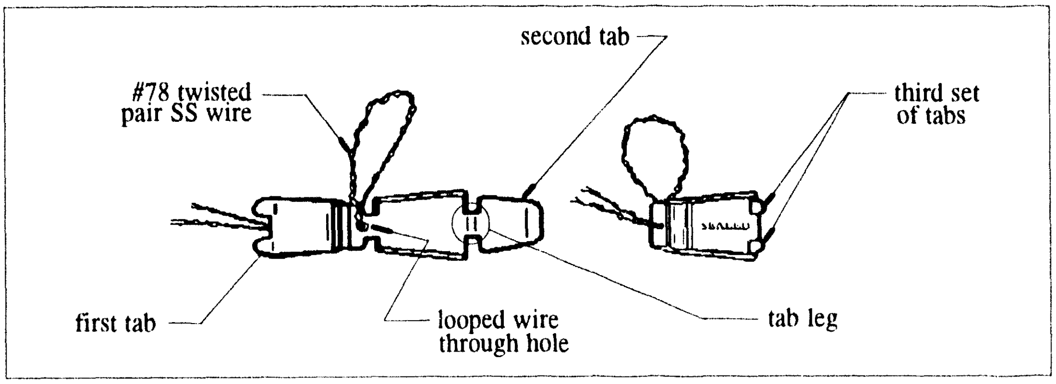

Figure 7. Griploc Seal Configuration

The test equipment (see Figures 8 and 9) consists of:

(1) 10-inch long cord (1/8" diameter nylon, minimum 75-lb.)

(2) 5-lb. and 50-lb. weight

(3) hasp

(4) 4-screw wall mount (1/8" diameter cross section, U-shaped with minimum 3/16" modified opening)

- Mechanical Drop Test Procedures. Mechanical drop tests (see Figure 8) followed environmental tests. The loop seals were attached to a 10-inch-long cord. The seals assembly loop was hooked onto the hasp. (This also served as a loop bend test.) The hasp was secured to the face of a vertical fixture approximately 24 inches above a horizontal surface. The 5-lb. weight was attached to the opposite end of the cord and dropped for a free-fall of 12 inches. A loop seal failed if it did not survive all the tests.

- Mechanical Pull Test procedures. Mechanical pull tests (see Figure 9) followed environmental tests. The loop seals were attached to a 10-inch-long cord. The seals assembly loop was hooked onto the hasp, which was secured to the face of a vertical fixture approximately 24 inches above a horizontal surface. The loop seal was subjected to a constant 50-lb. pull on the hasp for one minute. A loop seal failed if it did not survive the test.

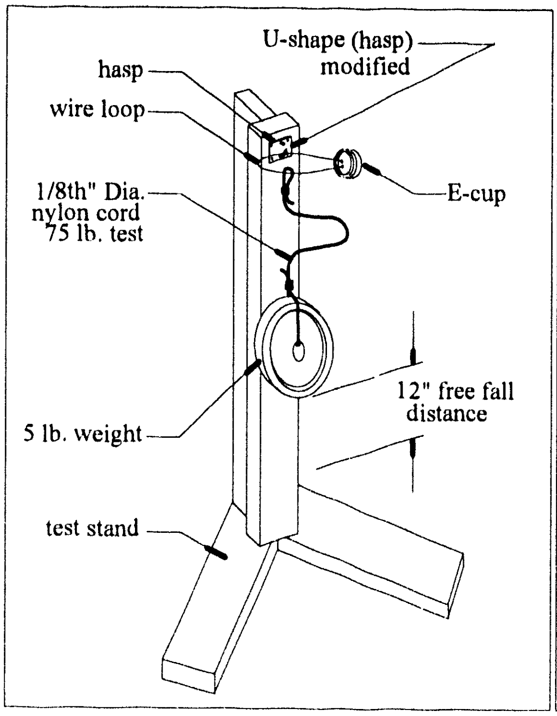

Figure 8. Drop Test Setup

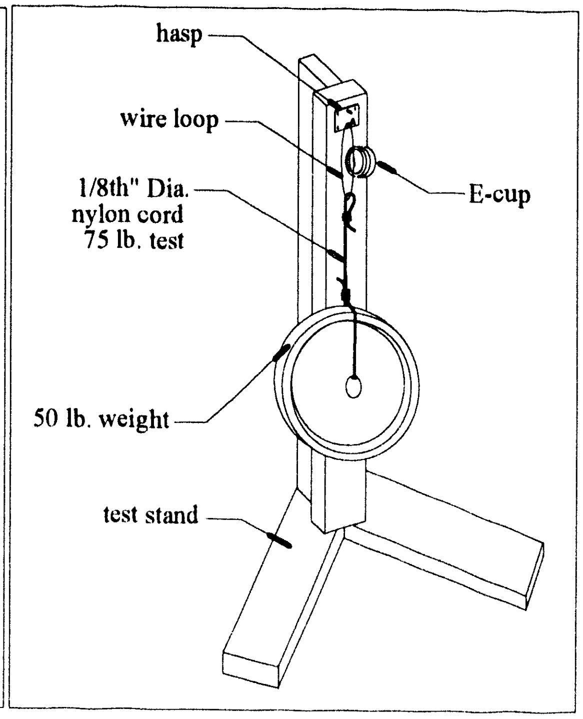

Figure 9. Pull Test Setup

4.1.2 Test Results

A. E-Cup Tests. The LS testing demonstrated that the E-cup subassembly passed the drop and pull tests. However, the wire gauge used was the determining factor in the pass/fail of the complete assembly. Both types of #51 wire tested passed the drop and pull testing. The #78 wire failed in all testing. The environmental testing had no affects on the results of any of the testing.

The crimps furnished by the facilities were designed to be used with the polycoated #51 wire. The minimal difference in the diameter of the plain #51 wire allowed proper crimping and was used as shown in Figure 6. The crimps passed all environmental testing and mechanical testing. The #78 wire was tied into a square-knot configuration in lieu of the crimp, which held without a failure at the knotted area. The #78 wire failure usually occurred at the edge of the E-cup's through-hole. The edge appeared to have a cutting effect on the #78 wire, especially in the drop test.

B. GripLoc Tests. The Griploc, furnished with the #78 wire, failed all testing. The environmental testing appeared to have no affect on these test results. During the pull test, two of the wires pulled through the Griploc subassembly. In the retest, the wire failed again. This type of assembly appears to be a light-duty configuration. If a heavier-duty gauge wire had been used, the Griploc would have been the "weak link." Most likely, the Griploc would have failed all testing. However, the wire gauge provided was the only gauge tested. The through-hole would not accommodate a larger diameter wire without modification. It is likely that the modification would have weakened the subassembly, making the test data useless.

4.2 Humidity Test

The loop seals were subjected to humidity testing to determine their ability to resist corrosion and deterioration under controlled environmental conditions.

4.2.1 Test Description. Three samples of loop seals were placed in an environmental chamber. After a 20-day test, the seals were removed and inspected for deterioration and corrosion.

A loop seal failed the test if a functional disability occurred because of corrosion or deterioration. A functional disability is defined as:

- a locking mechanism failure
- rust or oxidation that causes loss of structural integrity
- a serial number that cannot be read

4.2.2 Test Results. The E-cups and Griploc assemblies passed the 20-day humidity test with minor corrosion visible on the Griploc body and on the non-coated steel #51 gauge wire. In both cases, the corrosion was insufficient to consider failing the assemblies.

The stainless steel cable lock with its red anodized aluminum crimp showed no affects of the humidity testing. However, some of the cables received for testing were assembled through user facilities' eyebolts. These eyebolts were made of galvanized steel and showed very minor corrosion from the testing.

Inspection of loop seals following the humidity test revealed that the concentric configuration had changed on one of the two locking spring rings of the padlock. The padlock was humidity tested without the U-bolt being engaged into its main body. A later inspection of the padlock revealed that the locking spring had partially sprung open. What affects this would have on the performance of the seal are unknown, but in fact the test did affect the seal. The rating in Section 6.2 was given to the padlock because of the adverse effects that were noted during the test.

5. INDIVIDUAL TESTING

There were three individual tests; a vibration test, a drop shock test, and an abrasion test. The 20-day high temperature/high humidity test (see Section 2.1) can also be considered an additional individual test.

5.1 Vibration Test

Vibration tests subject the seals to physical stresses expected under normal handling and transportation.

5.1.1 Test Description. Vibration testing was done using:

- a modified, 30 gallon drum with locking collar and lid. The drum was secured to a longitudinal axis or a transverse axis vibration unit
- a 1 gallon paint can
- 5"-thick white Celetex® with an 18"-diameter disk
- rings with 2" wide x 12" long stays

Basic transportation and common-carrier environmental data was taken from Figures 514.3-1, 514.3-2, and 514.3-3 of 810D and were used as a guide for vibration testing. The data consisted of:

- vertical axis
- transverse axis
- longitudinal axis

See Figure 10 for a cross section view of the assembly procedure. As can be seen by the figure, the disks were placed at the bottom of the drum; then, the washer shaped rings were put into the drum to the height of the paint can. The paint can assemblies were preheated in environmental chambers to 10° F and 120° F. (The low and high temperature tests averaged 45° F and 95° F.) The paint cans (filled with fine sand and sealed by the lid) were placed inside the diameter of the Celetex rings. The stays were snug fit and placed in the gap between the paint can and the rings. The stays (4 places) were positioned against two sets of manufacturers' seals that were adhered 90° apart on the outside of the can. The PSSs overlapped the paint can's lid and sides. A thermocouple lead was then metal-taped to the top of the paint can to record the temperature during vibration testing. A spacer ring (not shown in Figure10) was placed into the void of the top ring, located on top of the paint can. Two more disks were placed on top of the rings and paint can assembly. The drum lid was then put into place and secured by the drum's locking collar. E-cup and Griploc LSs were alternately double-figure-eight wired to the two holes in the drum collar bolt. The bottom of the modified drum had 2" square x 1/8" thick steel tubing welded to the inner walls of the drum. One leg of this mount extended outside the drum to be attached to the load cell. Prior to placing the assembly into the modified drum, it was bolted onto the vibration unit through bolt holes in the mount tubing.

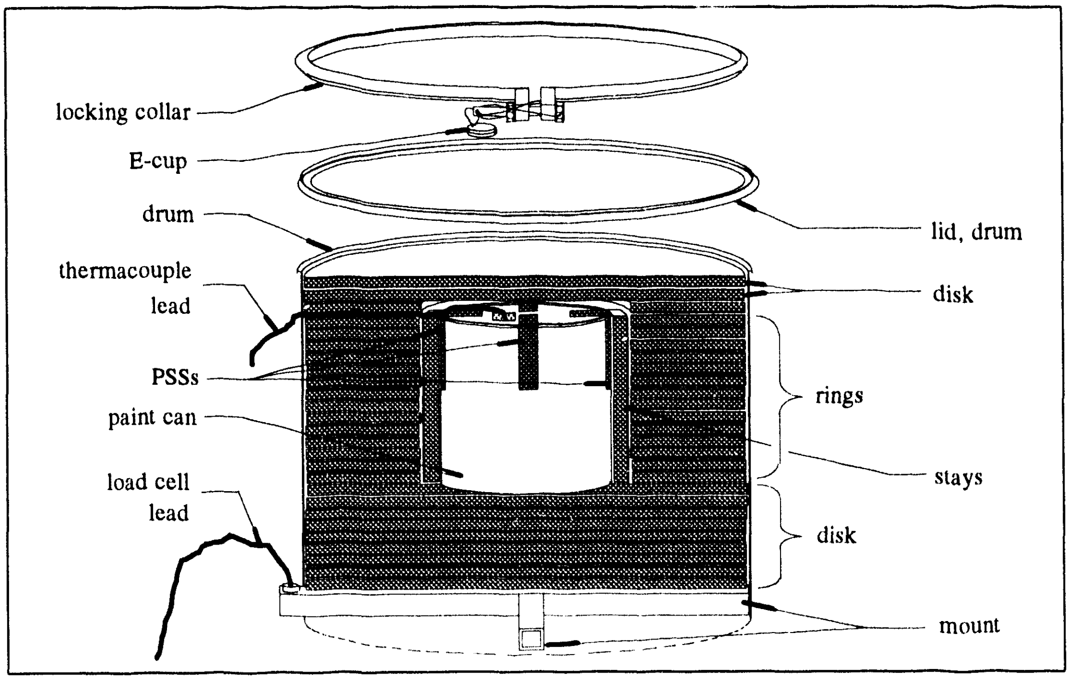

Figure 10. Vibration Test Setup

5.1.2 Test Results. All PSSs and LSs passed the vibration tests at low and high temperatures. There was minor abrasion wear on the paper and vinyl PSSs. However, more than the vibration tests, the snug fit during the installation of the stays was responsible for the partial rubbing off of the logos. To verify this, one set-up and take-down procedure was done without the vibration test, using paper and vinyl PSSs.

5.2 Shock Test

The durability of the seals is tested by the normal physical stresses and handling of the equipment in the process of doing the test. This wear-and-tear handling is similar to what can be expected during normal moving and transporting conditions and is an indicator of how well the seals will do in a normal environment.

5.2.1 <u>Test Description</u>. There were two parts to the drop test.

1) The first part of the test consisted of a 30 gallon drum assembly with the same disk, rings, and paint can. As was true in the vibration test, the drum was not modified. This was a 30 inch drop test (see Figure 11).

2) The second part of the test used the paint can in the 30 inch drop. (See Figure 12.)

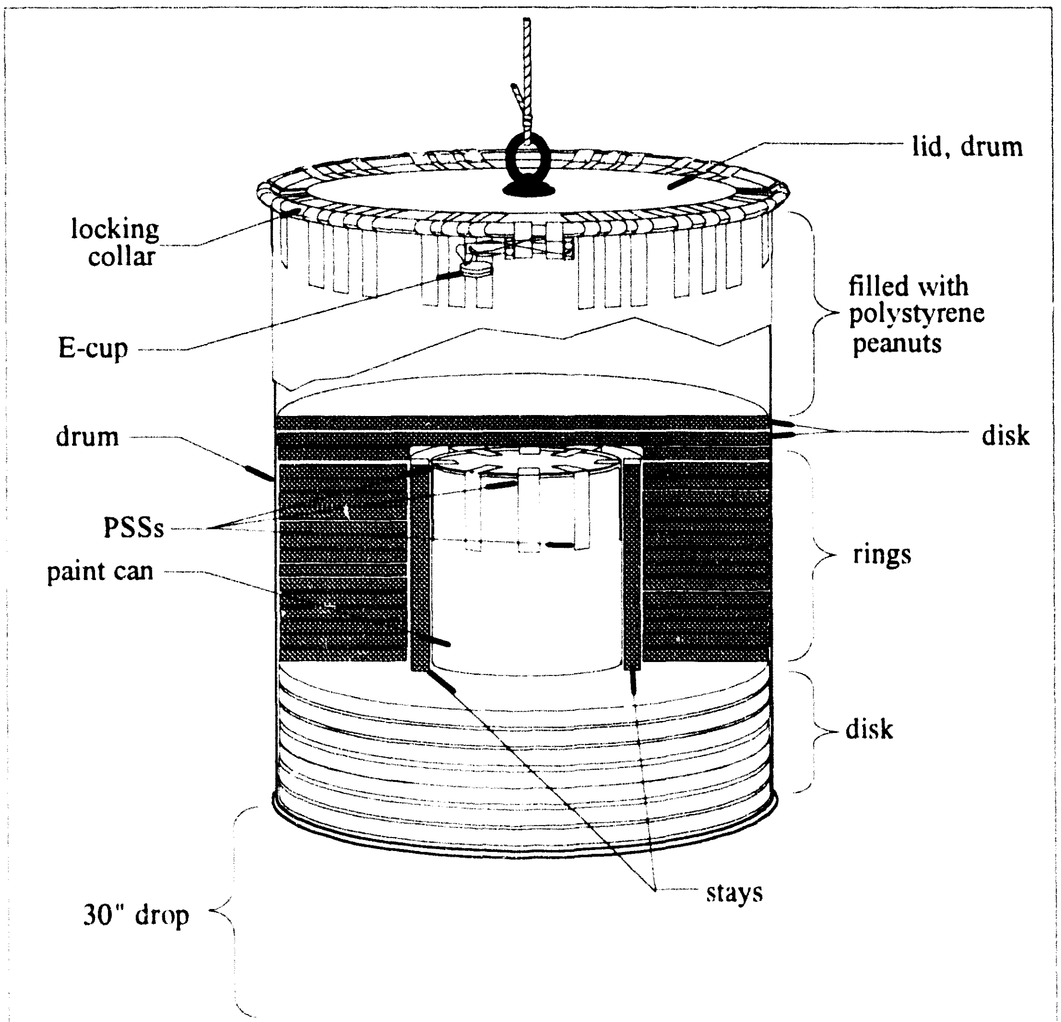

Figure 11. First Part of Shock Test Setup

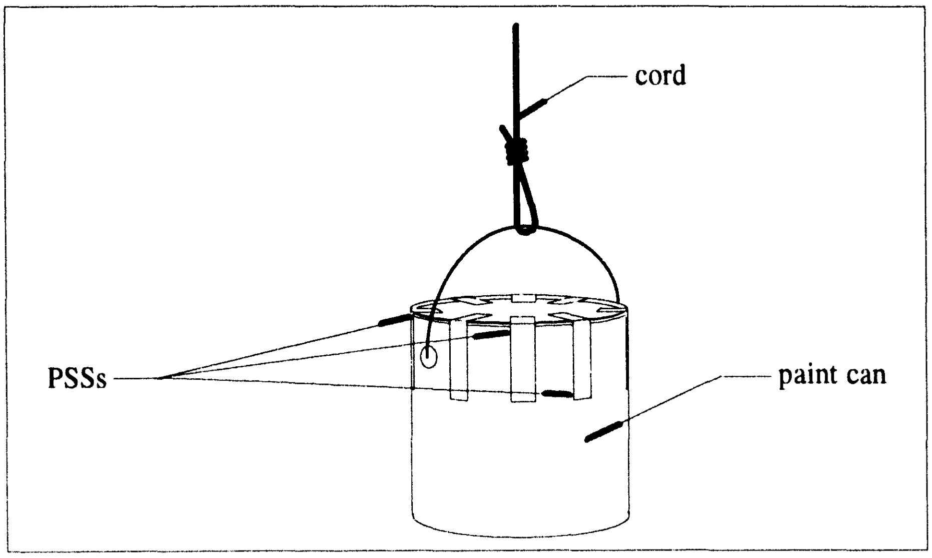

Figure 12. Second Part of the Shock Test Setup (Used the Paint Can)

In the drum assembly drop test, the PSSs were not only located on the paint can, but also on the outside of the 30 gallon drum. The PSSs were placed in groups of three (three of each manufacturers' seals) going from the lids around the locking collar and down the sides. The LSs were placed on the locking collar's bolt. The wire was double-figure-eight wrapped around the bolt, then threaded through two sets of through holes in the bolt. The loop wire ends were then secured with the E-cup seal. The assembly, weighing 87 pounds, was secured to an overhead hoist with 100-lb. test 1/8" thick nylon cord. The cord was attached to an eyebolt that had been bolted through the center of the drum lid. The cord was cut, dropping the drum 30 inches onto a concrete surface.

The paint can drop test (see Figure 12) assembly weighed 15.6 pounds. The assembly was secured to an overhead hoist with a 100-lb. test, 1/8" thick nylon cord. The cord was cut, dropping the paint can 30" above a concrete surface.

5.2.2 <u>Test Results</u>. The paint can seals suffered no visible damage. However, the PSSs on the outside of the drum all showed some damage. The paper and vinyl seals seemed to have the same type damage, showing stress cracks between the collar and the vertical walls of the drum. These cracks were usually parallel to the locking collar and never ran more then 75% of the width of the seal. Most of the cracks would start on each side and be about 1/8"-thick long. The mylar seals showed minor, if any, void print around the area of the locking collar on the lid and sides of the drum. This void usually was visible within the first 1/8" of adhesive contact from the gap of the collar on the surface of the lid and/or sides. Overall, the three PSS types were affected the same as others within their material group. The LSs showed no affect at all.

All PSSs in the paint can drop test survived the test with no visible damage.

5.3 Abrasive Test

The abrasive test measures the durability of the seals under stresses that can be expected under normal handling and moving conditions.

5.3.1 Test Description. The abrasive test was performed on the PSSs using 400 grit sand paper. The sandpaper (1" wide in 6" long strips) was adhered to a 1" wide x 6" long x 5" high 5.5-lb. rectangular weight. The seals were adhered to a flat steel plate. The weight was pushed across the seals (see Figure 13) three times. After each pass, the results were recorded. Once the seal's abrasive test was concluded, the sandpaper was replaced.

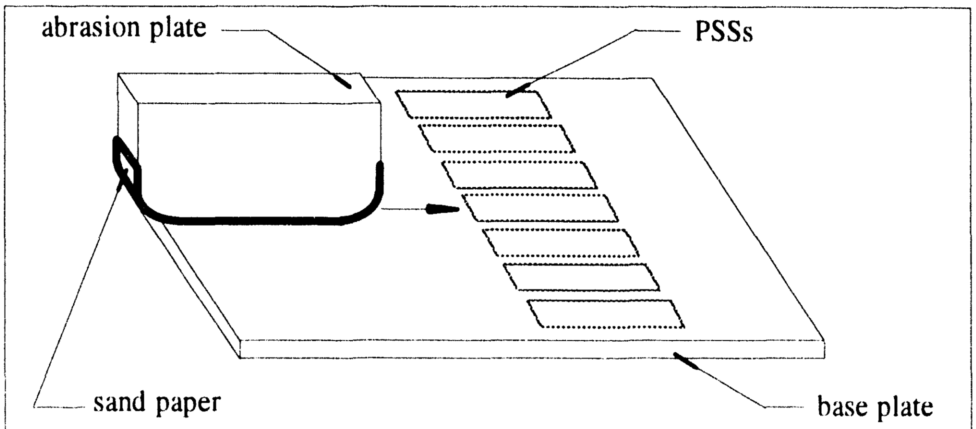

Figure 13. Abrasive Test Setup

5.3.2 Test Results. On all seals where the logos and serial numbers were not clear-coated, the abrasion would partially remove the print. The logos came off easier than the serial numbers, but all seal materials held up quite well. Though the clear coating of the mylar seals would scuff up, it held up very well.

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6. TEST RESULTS SUMMARY

Test results in this section provide comparative ratings for the pressure sensitive seals and the loop seals that were tested as part of the Sandia evaluation of TIDs. The following summary combines the results previously described in this report, as well as the comparative ratings for the PSSs and LSs.

6.1 Pressure Sensitive Seals

In Table 4 the PSSs are rated by applicable test performance for the peel, shear, shock, solvent, vibration, abrasion, handling durability, and tamper-resistance tests. The ratings in the first seven columns are an interpolation of test results. The tamper resistance ratings are primarily derived from vulnerability testing which is too sensitive to include in this report. The mechanical and environmental testing also support the rating. The numerical ratings in Table 4 are 1, 2, 3, etc. Number "1" represents the best rating. The "Total" column reflects the low number as having overall best performance.

Table 4. PSS Test Results

PSS Tested	Peel	Shear	Shock	Solvent	Vibration	Abrasion	Handling Durability	Tamper Resistance	Total
Mylar	1	1	1	1	1	1	1	3	10
Paper	3	2	2	3	3	3	2	2	20
Vinyl	2	3	3	2	2	2	3	1	18

The one area whereTable 4 fails to paint the whole picture is in the solvent testing portion of the test. The test relied on thumb pressure to slide the seal across the test coupon for a pass/fail rating. The mylar clearcoat protected the seal's adhesiveness. The mylar not being permeable to the aggressive solvents (see solvents 1, 2, and 3 in Section 3.3.1) did not allow the adhesive to break down during the soaks; there was only minor damage around the seal's perimeter. The vinyl seals, permeable to the aggressive solvents, were irreversibly deformed. The paper seals, also permeable to the solvents, were easily attacked by the aggressive solvents, and with minimal soak time (2 to 3 minutes) started losing their mechanical integrity.

The vinyl shows visual degradation with the aggressive solvents. Once the solvents start to loosen the adhesive, the paper seal cannot be handled without falling apart. The vinyl and paper seals could be slid across the coupons after the aggressive solvents soaks, whereas the mylar seal could not be moved. However, the vinyl and paper seals indicated tampering quite easily when the solvent soaks were able to loosen the adhesive. The "Tamper Resistance" column in Table 4 reflects this situation.

6.2 Loop Seals

In Table 5, the LSs are rated by applicable test performance for the drop/pull, shock, humidity, vibration, handling durability, and tamper-resistance tests. The ratings in the first five columns are an interpolation of the test results. The tamper resistance ratings are primarily derived from vulnerability testing which is too sensitive to include in this report. Our mechanical and environmental testing also support this tamper-resistance rating.

The numerical ratings in Table 5 are 1, 2, 3, etc. Number "1" represents the best rating. The "Total" column reflects the low number as having overall best performance.

Table 5. LS Test Results

LS Tested	Drop /Pull	Shock	Humidity	Vibration	Handling Durability	Tamper Resistance	Total
Cable lock	1	1	1	1	1	1	6
E-cup	3	3	2	3	3	2	16
Griploc	4	4	3	4	4	4	23
Padlock	2	2	4	2	2	3	15

The E-cup and Griploc loop seals were tested prior to testing the padlock and cable lock seals. Because of the positive performance of the #51 gauge wire, the drop/pull test was not considered necessary for the padlock and cable lock seals. In the drop/pull test, the padlock and cable lock would have been rated superior to the other two seals. Personal observations would tend toward rating the cable lock above the padlock.

The facility using the cable lock reported that it intentionally tried to deform and render the number unreadable by crimping the area where the serial number was located. They folded and tucked the anodized aluminum crimp in every way the crimper would allow. Nevertheless, they were unable to damage the serial number to a point that made it unreadable.

The padlock serial numbers are located on the bottom of the main body of the seal between two rivet heads. These protruding knobs protect the serial numbers from most abrasive encounters.

6.3 Unit Cost

Table 6 provides the unit cost for the PSSs and LSs included in the testing and evaluation. The cost, together with performance considerations, must be included in the overall evaluation and in the resulting recommendations. The cost shown varies somewhat based on the quantities, size, and features ordered.

Table 6. LS/PSS Unit Cost

LS/PSS	Manufacturer	Size	Unit Cost
Cable lock			
	PCI	3/16" dia. x 20"	$ 0.59
E-cup			
	American Casting	1" dia. x 7/16" height	$ 1.15
Griploc			
	Brooks -	1/8"x 5/8"x 1"	$ 0.11
Mylar			
	York -	1.25"x 13" straight	$ 2.00
	York -	1.25"x 8"x 8"x 8" U-shape	$ 2.70
	Tyden -	1"x 10"	$ 1.00
	Advantage -	.75" x 2"	$ 0.78
Padlock			
	Masterlock -	1"x 1"x 1.75" body w/ 1/4" dia. x 1.375"wide x 2.625" tall U-shank	$ 3.11
Paper			
	Avery -	1"x 12"	$ 0.19
Vinyl			
	Advertape -	1"x 8.5" w/4" square end plus 1"x 12" straight	$ 1.25
	Valmark -	2" x 3"	$ 1.25
	Designer -	1.25" x 9"	$ 0.25

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7. RECOMMENDATIONS

Our recommendations are based on the testing and evaluation of the seals and include a proposed new technology to be considered for TIDs. Our cost-oriented recommendations also consider the possibility of using currently available seals.

7.1 Pressure Sensitive Seals

All three types of PSSs performed well enough in the testing that all are considered acceptable. None of the three was found to be defeatable under the constraints of a two-man-rule environment. The "York seal" is the only mylar seal being used by DOE facilities. It costs considerably more than either the vinyl or paper seals, but performs much better in the environmental and mechanical tests. Therefore, it is the author's PSS of choice.

The material makeup of PSSs consists of paper, vinyl, or mylar with an acrylic adhesive for fastening to SNM containers. Our testing results have prompted a recommendation that a new technology be examined for possible use in the future. This technology should provide more tamper-resistant PSSs; they should also be more durable and thus better equipped to meet the handling requirements demanded by the test plan criteria. The fragile paper and vinyl PSSs tend to be more tamper resistant, but lack the desired durability. The mylar PSSs are very durable, but have weaknesses (due to their durability) in the area of tamper-resistance.

Based on our evaluation of PSS testing, we recommend that a new process in PSS technology be considered. The process would include a layering of:

- a laminated mylar clear outer coat
- a micro balloon of impregnated loose fiber paper substrate
- an acrylic adhesive bonding layer

The micro balloon would consist of an ink dye encapsulated in a gel-type coating that would rupture when tampered with. After the PSS is applied to a shipping or storage container, the micro balloon would rupture when:

- An attempt was made to peel the PSS from the container. This would separate the paper into two halves. One half would adhere to the clear outer coat; the other half would adhere to the bonding layer. The separation would cause the ink to dye the paper permanently in the areas where the mechanical tearing occurred.

- Aggressive solvents are used in attempts to defeat the adhesive bonding layer. The solvent would be soaked into the permeable paper material, dissolving the gel coat of the micro balloon and permanently dyeing the paper substrate.

- Extreme temperatures are used. (This option would take advantage of the durability of the mylar material.) The temperature would cause the expansion or contraction of the ink and gel coat.

Under the above conditions, the color changes of the PSS could easily be recognized as tampering.

Because of the lack of information on micro balloons for this type of application, it is not possible at this time to compare the pros and cons. Some negative considerations are:

- Potential bruising when bumped;

- The problems in formulating a gel coat. If this were possible, the formulation would respond well to all solvents trying to defeat it. (Perhaps a blend of multiple micro balloon gel coats could be used.) If a gel coat were formulated, would adhesives affect the coats over a long period? Would the discoloration due to rupture be readily visible a few months after the tampering?

As far as we know the gel coat concept is untried. The cost of the gel coat could equal the cost of standard mylar seals now in use. Sandia will continue to pursue new ideas and new technologies with a goal for cutting costs.

7.2 Loop Seals

Of the LSs tested and evaluated, the cable lock is the seal of choice. The lock:

- is 20.5-inch long #78 gauge;

- has a 15" diameter, stainless-steel cable with seven sets of twisted; five-wire bundles;

- has an anodized serialized crimp;

- costs 59 cents each.

The cable lock performed well in testing and requires specialized tampering to defeat it. The lock is durable and strong, is not affected by tested climatic conditions, and can be crimped with a manual or powered crimping tool. The cable lock can be purchased at a reasonable unit price for the level of protection it provides, and can be used in existing LS applications as well as in some PSS applications. However, many containers presently in use do not accommodate the relatively large diameter of the cable lock. In these cases, the E-cup is the first choice.

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