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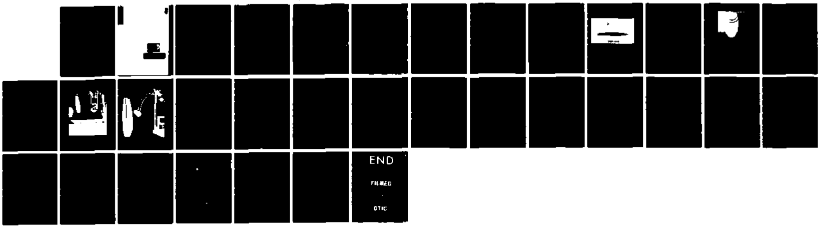

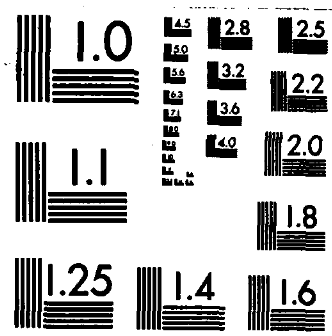

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A simple technique has been used to determine the sealing status of the O-ring in the body joint of assembled two-piece projectiles. The technique is based on the pumpdown rate when a vacuum pump is connected to the projectile internal volume. A laboratory demonstration system was assembled and was later successfully used in a production-line environment.

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FOREWORD

This report describes a laboratory demonstration system for nondestructive inspection of the body joint O-ring seal in a two-piece projectile. A demonstration system was conceived and assembled at the Naval Surface Weapons Center (NSWC). While this system was originally intended for feasibility demonstration only, it was later successfully used at the Naval Ammunition Depot (NAD), Crane, Indiana, in the HIFRAG projectile pilot production program.

This report has been reviewed and approved by W. S. Burnley III, HIFRAG Program Manager, Ammunition Branch; D. L. Brunson, Head, Technology Branch; and C. A. Cooper, Head, Gun Systems and Munitions Division.

Released by:

R. J. ARTHUR, Deputy Head
Weapons Systems Department

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The author would like to acknowledge the assistance of J. B. Bickley in the design of the projectile test fixture, in the determination of system operating parameters for actual projectile hardware, and in the interfacing with NAD/Crane personnel in preparation for the use of the laboratory demonstration system in the HIFRAG projectile pilot production program. The author would also like to acknowledge helpful discussions with A. S. Wenborne, T. E. Swierk, W. Mock, Jr., and W. S. Burnley III.

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I. INTRODUCTION

In 1970 the Naval Surface Weapons Center (NSWC) was tasked to develop and field a new family of 5 in./54 gun ammunition. Projectile design improvements included provision for increased safety via the use of a separate, encapsulated billet of explosive and a two-piece projectile body. The explosive billet could be subjected to nondestructive testing and acceptance procedures prior to insertion into the metal projectile body. The emphasis on safety was motivated by dissatisfaction with the safety record of conventional 5-in./54 ammunition, having experienced a series of disastrous inbore premature explosions that commenced late in the 1960s.[1]

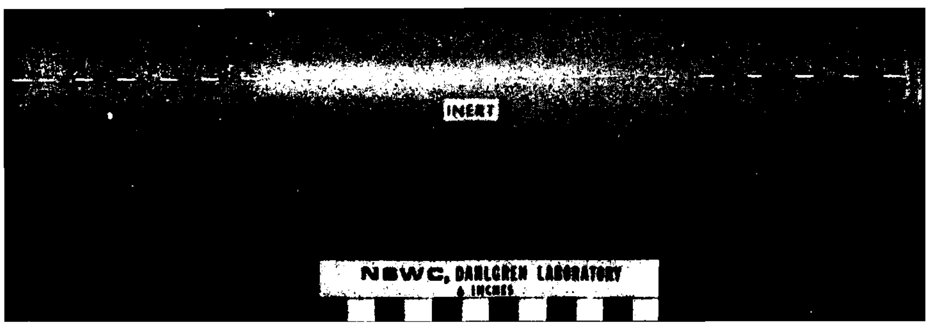
Figure 1 shows a disassembled two-piece 5-in./54 projectile along with a simulated explosive billet. The fore and aft parts of the metal projectile body are held together by a press-fit knurled joint. An important part of the joint is the O-ring seal. Figure 2 is a schematic of an assembled two-piece 5-in./54 (HIFRAG) projectile. Figure 3 shows an O-ring on the aft body part prior to projectile assembly.

The purpose of the O-ring is to provide a hermetic seal for the projectile cavity; i.e., to prevent moisture from entering the cavity. The seal also prevents hot propellant gases that may leak past the projectile obturating band from entering the projectile. For these reasons the integrity of the joint seal is essential.

The design of the joint prevents visual inspection of the O-ring when the fore and aft body parts of the projectile are properly assembled.

Initial considerations for joint seal inspection were based on: (a) radioisotope tagging of the O-ring and the use of an external radiation detector to determine the presence or absence of an O-ring in the assembled projectile, or (b) immersion of an internally air-pressurized projectile in a water tank with visual inspection for bubbles to indicate a leaking joint seal. The radioisotope approach had been suggested because of its prior successful production-line application in determining the presence of a critical shear pin inside assembled propellant charge primers for 76mm projectiles. Each of these techniques had a number of disadvantages for the present application, and it was recognized that a still different approach was needed.

The new approach is to vacuum leak test the assembled projectile. A vacuum pump and appropriate pressure gauge are connected to the nose fuze opening. If the O-ring is in place and is sealing properly, a low pressure measured in the line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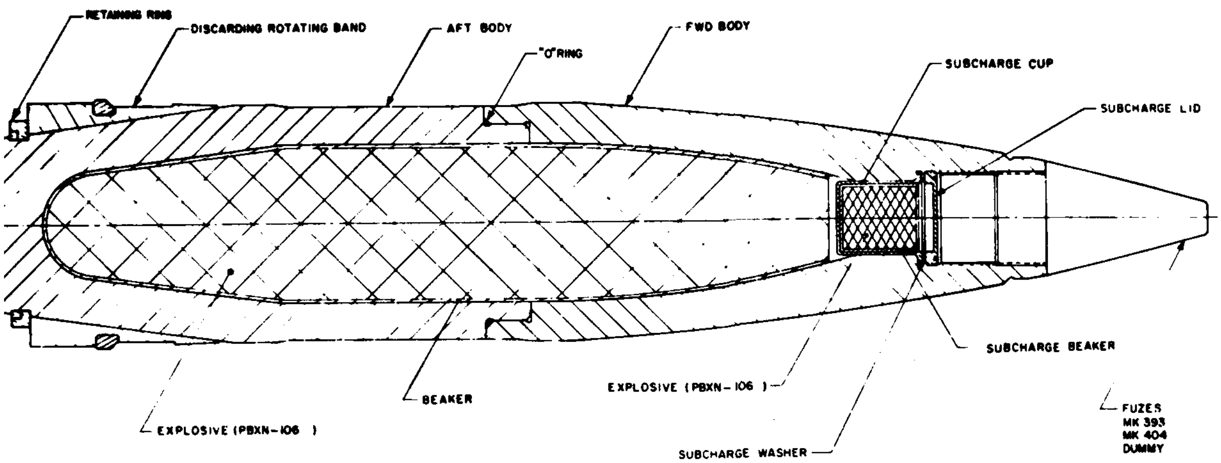

FIGURE 2. SCHEMATIC OF AN ASSEMBLED TWO-PIECE 5"/54 (HIFRAG) PROJECTILE.

3. Tests for the presence of the O-ring, but more important, tests the integrity of the seal. A damaged O-ring would still pass the radioactivation type of test.

4. No problems of activation, transportation, storage, handling, or disposal of radioactive materials; no environmental impact problems.

5. No problems of shelf or service life of radioactive O-rings due to isotope half-life or radiation damage to the O-ring material.

6. No requirements for an electronic detection system to determine the presence of a radioactive O-ring in the projectile.

7. Inexpensive, fast testing technique.

8. Simple technique--does not require special skills to install, operate, or maintain testing equipment.

9. Tests the seal in the proper direction; i.e., pressure outside projectile is greater than that inside, as would be the conditions inside the gun. Internal pressurization forces the O-ring outward as opposed to inward toward the interior of the projectile.

10. Technique can be automated.

FIGURE 3. CLOSE-UP VIEW OF AFT BODY PART OF TWO-PIECE PROJECTILE SHOWING O-RING SEAL LOCATION.

It should be noted that vacuum methods are commonly used for leak testing; .g., hermetic seals in semiconductor electronic component packages, or even refrig- ration heat exchanger coils. However, the commercially available systems used for hese types of leak tests operate in the 10^{-2} to 10^{-4} Pa pressure range and are used or relatively "clean" items; i.e., items containing only trace amounts of high- apor-pressure contaminants. The use of cavity paints or adhesives on the inner urfaces of a projectile would make the use of standard commercial high-vacuum leak letection equipment impractical. Pressures in the 10^{-2} Pa range could take hours or lays to achieve because of the out-gassing of these materials.

One common vacuum leak detection procedure that had been suggested is to onitor the rate at which pressure rises in a sealed volume. This approach is imited by the presence of out-gassing materials in the test volume. Under high acuum conditions, the predominant cause of pressure rise is often out-gassing, and relatively high rate of pressure increase may be observed even in the absence of eakage.[2]

A relatively simplified leak detection demonstration system was conceived that based on the pumpdown rate (i.e., the time required to attain a preselected pres- e in a test projectile and connecting valve-and-tubing network when using a uum pump of selected capacity). This demonstration system is described in Sec- n II. The results obtained with an actual projectile body are presented in Sec- n III, along with suggestions for production-line application of the technique. tion IV is a brief summary. Appendix A contains the detailed instructions that e provided for initial setup and operation of the demonstration system when pped to NAD/Crane, Crane, Indiana, for use in the HIFRAG projectile pilot produc- n program. Appendix B contains mathematical expressions and a graph relating pdown time, pump capacity, volume to be evacuated, and the dimensions of the necting tubing between the pump and the projectile volume. Appendix C contains ematics of the test fixture for connecting the vacuum system valve manifold to a jectile and of the adapter for connecting the valve manifold to the vacuum pump e.

The following equation from Reference 3, p. 124, relates the pumpdown time to he volume to be evacuated, the pump capacity, and the dimensions of the connecting ubing between the pump and the volume to be evacuated:

$$\frac{t}{V} = \frac{1}{E}\left[\frac{1}{P} - \frac{1}{Pi}\right] + \frac{1}{S}\left[\frac{B}{P} - \frac{Bi}{Pi}\right]$$

$$+ \frac{1}{S}\left[\ln\left(\frac{Pi + Bi}{P + B}\right)\right]$$

here

$$E = \frac{\pi}{128\eta}\,\frac{D^4}{L}$$

$$B = \left[(S/E)^2 + P^2\right]^{1/2}$$

$$B_i = \left[(S/E)^2 + P_i^{\,2}\right]^{1/2}$$

nd

t is the pumpdown time, in sec

P_i is the initial pressure, in torr

P is the final pressure, in torr

V is the volume to be evacuated, in ℓ

S is the average capacity of the pump, in ℓ/sec

η is the viscosity of the gas being pumped, in poise

D is the inside diameter of the connecting tubing, in cm

L is the length of the connecting tubing, in cm

This equation was derived for gas flow in vacuum systems at relatively higher ressures, known as the viscous flow range. Viscous flow occurs when collisions etween the gas molecules themselves are more important in affecting the flow than ollisions with the wall of the tube. At lower pressures, collisions with the wall ecome the chief factor and the gas flow is said to be molecular.[4] For the pressure ange and tubing sizes of interest in the projectile O-ring seal inspection system, he flow will be predominantly viscous. It should be emphasized that this equation hould only be used to obtain an estimate of the vacuum pump capacity needed to chieve a certain pumpdown rate. The details of the pumpdown time will be related o the pressure dependence of the pump capacity, constrictions within the valves, tc. In generating values for the graph (Figure B-1), the gas viscosity parameter η as taken to be 1.8×10^{-4} poise (1.8×10^{-5} Pa-sec) for air at 20°C.[4]

APPENDIX B

EQUATIONS AND GRAPH RELATING PUMPDOWN TIME TO SYSTEM PARAMETERS

IV. MAINTENANCE

1. At least twice a day, close Whitey valve and Nupro vent valve. Check pump-down rate as in Step 11 of Installation.

2. Vacuum pump oil level should be checked daily and changed whenever oil appears dirty or vacuum is degraded.

3. Spare parts on hand should include the following:

   1 Rubber vacuum hose, 3/4 in. I.D. (This may degrade and begin to leak after six months to a year due to pump oil vapors and/or weathering.)

   1 Bendix Thermistor Gauge Tube, Model GT-034

   2 Test fixture O-rings, MS9068-329

   2 Swagelok flexible metal hoses

   6 Quarts or more Welch Duo-Seal Vacuum Pump Oil

   1 Spare belt for pump

   2 or more exhaust filter elements for vacuum pump

4. The pump may be difficult to start on a cold day, if outside, and may require forced air or radiant warming for initial starting. If pump does not start readily, the motor overload switch will click on and off repeatedly. DO NOT PERMIT MOTOR TO CONTINUE IF THIS OCCURS. Warm pump and then try again to start it.

5. The pump is designed for continuous operation, and it is actually beneficial to allow the pump to run continuously. This helps the pump to purge itself of trapped air and vapors.

6. Exhaust filter elements should be changed whenever visible oil vapor emissions are present.

8. Attach cable of Bendix Thermistor Gauge Control box to Thermistor Gauge be on manifold.

9. Close all valves on manifold.

10. Turn on pump motor and gauge control box. Place gauge control switch in GH position and wait about 5 min for pump and gauge to warm up.

11. Open Nupro valve nearest pump and observe manifold pressure in torr (top ale). If no leaks are present, gauge should move full scale from right to left in sec or less. Note: The Thermistor Gauge has a thermal time constant and will t respond instantaneously to pressure changes. Also, operation at atmospheric essure will not affect this type of vacuum gauge.

12. Inspect brass test fixture to ensure proper positioning of internal O-ng.

13. Close Nupro valve nearest pump. Open Whitey valve all the way.

III. OPERATION

1. Place test fixture on projectile nose. Hold down with light manual pres-ıre to effect seal.

2. Open Nupro valve nearest pump and monitor pressure on torr scale.

3. If projectile has properly sealed joint, pressure should change from mospheric to about 1 torr in 20 sec or less, and will continue to decrease slowly. IIS TIME WILL BE LONGER IF A LONG PIPE AND/OR FILTERS ARE USED TO CONNECT PUMP TO ST MANIFOLD. The test fixture will be held on the projectile by the vacuum after e initial seal.

4. If the projectile does not contain an O-ring or has a damaged O-ring, the essure will reach a minimum value higher than 1 torr and this pressure will not crease farther, regardless of pumping time. If there is no O-ring present, it may difficult to get the fixture to seal to the projectile.

5. When the test indicates a proper seal, DO NOT PULL TEST FIXTURE OFF PRO-CTILE. Close the Nupro valve nearest the pump. Open the other Nupro valve to nt the system. The test fixture will then be loose and may even fall off the ojectile.

6. To repeat test, close Nupro vent valve and repeat Steps 1 through 5.

DO NOT ALLOW PUMP TO OPERATE FOR EXTENDED TIMES ON A SYSTEM OPEN TO ATMOSPHERIC PRESSURE.

I. PARTS LIST

Qty

1 Welch Duo-Seal Vacuum Pump Model 1402, with motor (115 VAC), belt, exhaust filter, and 1 quart Welch Duo-Seal Pump Oil.

1 Vacuum manifold consisting of all stainless steel parts: two Nupro bellows sealed vacuum valves, one Whitey forged body valve, two Swagelok 1/4-in. tees, two Swagelok 1/4-in. union elbows, three Swagelok 1/4-in. port connectors, two Swagelok 1/4-in. flexible metal hoses, one Swagelok 1/4-in. tube to 1/8-in. pipe adapter for rubber vacuum hose, one piece rubber vacuum hose, one brass test fixture with O-ring, and one Bendix Thermistor Vacuum Gauge Tube.

1 Bendix Thermistor Vacuum Gauge Control Box (115 VAC) with cable.

II. INSTALLATION

1. Unpack all items with care. The flexible metal hoses can be damaged, if the brass test fixture is allowed to swing unsupported on the hoses.

2. Inspect vacuum pump for possible oil spillage. The oil level can be checked at the glass window in the side of the pump body. Add oil if needed. NOTE: USE WELCH DUO-SEAL PUMP OIL ONLY.

3. Remove exhaust cap and screw on exhaust filter (the exhaust cap and vacuum intake port are at the top of the pump body next to the pulley). DO NOT DISTURB KNURLED ASSEMBLY AT TOP OF PUMP BODY ON SIDE AWAY FROM PULLEY. Take care not to damage the fine threads on exhaust filter part. This filter traps oil vapors that could otherwise be hazardous to health.

4. Secure vacuum test manifold to a vertical stand or wall, with the 1/4-in. tubing horizontal and with Nupro valve handles convenient to operator.

5. Attach a string or wire to the joint between the two flexible metal hoses and tie to some support above the test manifold. (This will support the hoses, if the test fixture is dropped and will prevent the hoses from being damaged by being bent into too small a radius of curvature; small cracks (leaks) will occur in the metal hoses, if proper caution is not observed).

6. Remove plastic plug from vacuum intake port hose adapter on pump. Apply a small amount of vacuum grease to the outside of the hose adapter.

7. Press rubber vacuum hose onto pump adapter and tighten hose clamp. DO NOT OVERTIGHTEN CLAMP. Tighten only until hose begins to bulge very slightly through slots in clamp.

APPENDIX A

INSTRUCTIONS FOR INITIAL SETUP AND OPERATION OF LABORATORY DEMONSTRATION SYSTEM

(These instructions were sent to NAD/Crane with the demonstration system for use in the HIFRAG projectile pilot production program. Prior to shipment of the system to NAD/Crane, an additional length of flexible metal hose was installed between the test fixture and the valve manifold.)

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2. Technical Reference Data, Veeco Instruments, Inc., Plainview, New York, 1979.

3. A. Roth, *Vacuum Technology*, North Holland Publishing Co., New York, 1976.

4. J. Yarwood, *High Vacuum Technique*, 4th Ed., Chapinall and Hall, Ltd., London, 1967.

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IV. SUMMARY

A simple technique has been applied to the inspection of the body joint O-ring seal in assembled two-piece projectiles. The technique is based on the vacuum pump-down rate for the projectile internal volume (i.e., the time required to obtain a preselected pressure in a test projectile and connecting valve-and-tubing network when using a vacuum pump of known capacity). A laboratory demonstration system was assembled at NSWC and was then used at NAD/Crane in the HIFRAG projectile technical evaluation program. This simple vacuum pumpdown rate inspection technique may have other applications in the ordnance nondestructive inspection field, as well as in civilian problems.

References 2 through 5 provide general information about vacuum technology, as well as equations that can be used to estimate the pumpdown time from atmospheric pressure to a desired pressure when a known volume is connected by a tube of known internal dimensions to a pump of known pumping capacity. In Appendix A, a graph has been generated that relates the pumpdown time to the system parameters for a desired pressure of 1 torr, which is a value selected for use with the laboratory demonstration system.

Note that for multiple test stations on a production line, each station should have its own vacuum pump. Connection of multiple stations to a single pump and/or a large evacuated reservoir would not be consistent with the operating principles of the demonstration system. Multiple stations could be on a manifold connected to the same pump as long as the pump serves only a single station at a time. Otherwise the loading of the pump is varying in time and the pumpdown times will be erratic. Adding a large reservoir to the system only slows down the process since each time the system is opened to a projectile interior at atmospheric pressure, the entire system must then be pumped down again; i.e., the reservoir would have to be pumped down to the same initial pressure prior to each projectile inspection.

Note that the graph of Appendix B indicates that the pumpdown time can be greatly influenced by the dimensions of the tubing and valves between the vacuum pump and the projectile volume. For small diameter, relatively long tubing, an increase in pump capacity will not necessarily reduce the pumpdown time.

III. RESULTS AND DISCUSSION

The laboratory demonstration system was used to verify the presence of an O-ring and its sealing status in an actual two-piece projectile configuration. To facilitate determination of the operating parameters of the system, the knurling on the joint portion of the aft body part of a projectile was trimmed slightly to permit hand assembly and disassembly of the two body parts.

Three conditions of O-ring seal were investigated: (a) a good O-ring in the joint, (b) no O-ring in the joint, and (c) a damaged O-ring in the joint. To simulate a damaged O-ring, a good O-ring was cut (with a razor blade) half-way through the cross-section of the O-ring material, parallel to and toward the axis of the torus formed by the O-ring. The results obtained with the demonstration system of Figure 4 are given in Table 1. When the cut O-ring was stretched onto the aft body part of the projectile, the cut was oriented toward the outer surface of the projectile; the stretching caused the cut to be open like a V-notch. When this O-ring was twisted so the cut was oriented toward the inside of the projectile, the cut was held closed by O-ring geometry. For this latter condition, the seal was effective and the same results were obtained as for a good O-ring.

TABLE 1. PROJECTILE O-RING SEAL TEST RESULTS OBTAINED WITH LABORATORY DEMONSTRATION SYSTEM

Projectile Joint Test Condition[a]	System Pressure[b] (torr)	(Pa)	Time after Opening Pump Valve (sec)
With O-ring	<1	<130	<15
Without O-ring	>5	>670	anytime
With damaged O-ring[c]	>2	>270	anytime

[a]Projectile did not contain a polyethlene beaker of explosive or explosive simulant

[b]Measured with Bendix GT-340A thermistor gauge with GT-034 gauge tube

[c]Cut in O-ring oriented toward outer surface of projectile

As an added variation on the joint seal inspection, the demonstration projectile (with a good O-ring in the joint) was placed vertically on its base in a drum of boiling water. The water level was above the joint. The test fixture was placed on the projectile nose and pumpdown proceeded. The boiling water environment did not affect the integrity of the seal.

Note that the results indicated in Table 1 were obtained with an empty projectile (no polyethylene beaker filled with explosive or explosive simulant inside the projectile). With an explosive billet in place, the pumpdown times for a good joint seal will be significantly reduced because of the greatly reduced free volume (ullage) inside the projectile.

If the projectile body joint O-ring is in place and is sealing properly, the pressure should decrease rapidly at first, followed by a continued decrease at a lower rate after most of the air has been removed from the projectile interior. If the O-ring is in place but is only partially sealing, the initial decrease in pressure will be slower, and will be followed by a plateau in pressure versus time, with no subsequent decrease. If the O-ring is absent, the pressure may decrease initially and then plateau at a relatively high value for which the leak rate is balanced by the pump capacity, or, no decrease in pressure may be evident, depending on the sensitivity and response time of the gauge.

For any of the above cases, the actual rate of pressure decrease will depend primarily on the capacity of the vacuum pump and on the internal dimensions of the connecting tubing and valves.

After completion of the test, the pump valve is closed and the vent valve is opened to relieve the vacuum on the projectile; the test fixture can be easily removed from the projectile nose.

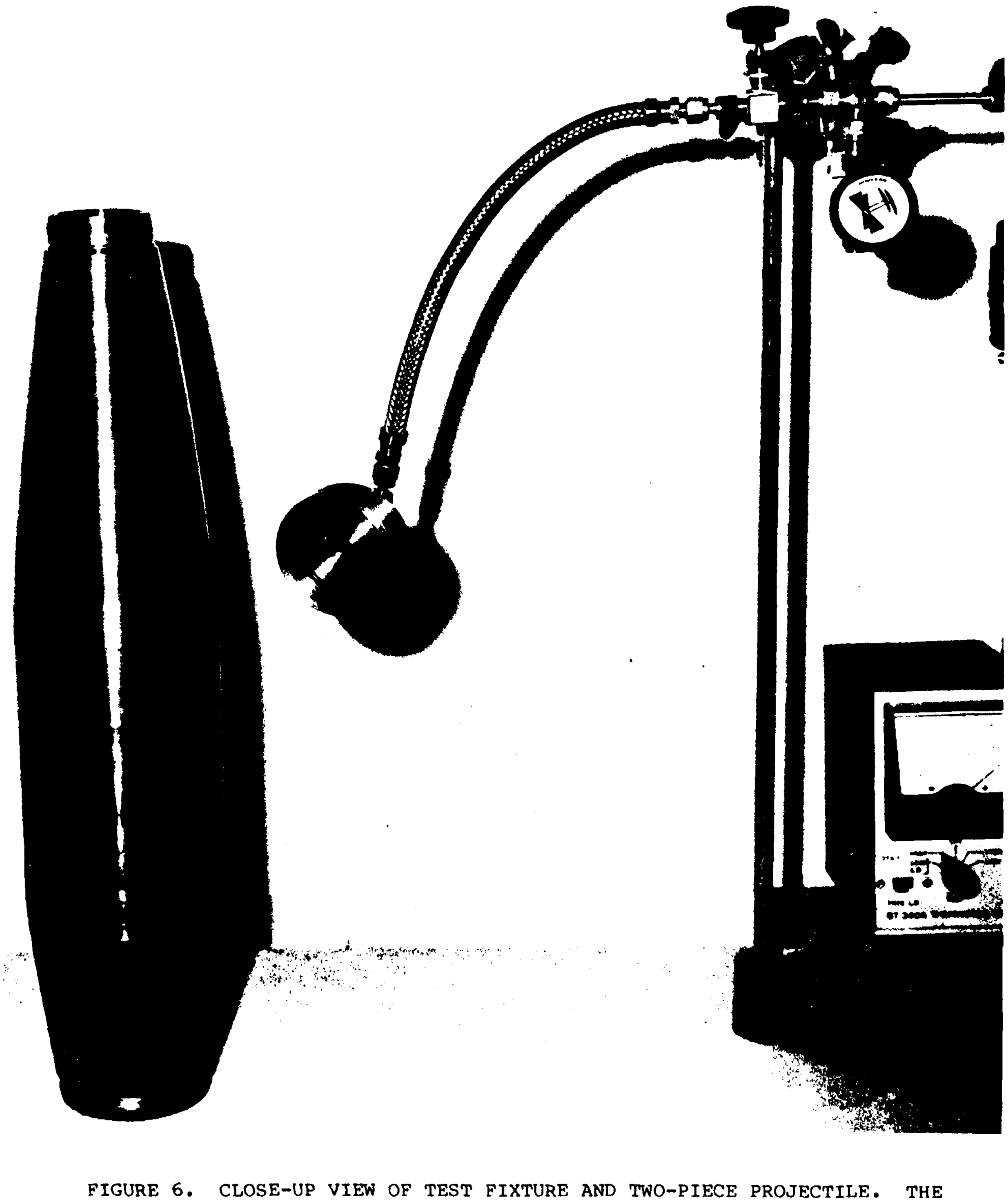

FIGURE 6. CLOSE-UP VIEW OF TEST FIXTURE AND TWO-PIECE PROJECTILE. THE O-RING THAT SEALS TO THE PROJECTILE NOSE CAN BE SEEN INSIDE THE TEST FIXTURE.

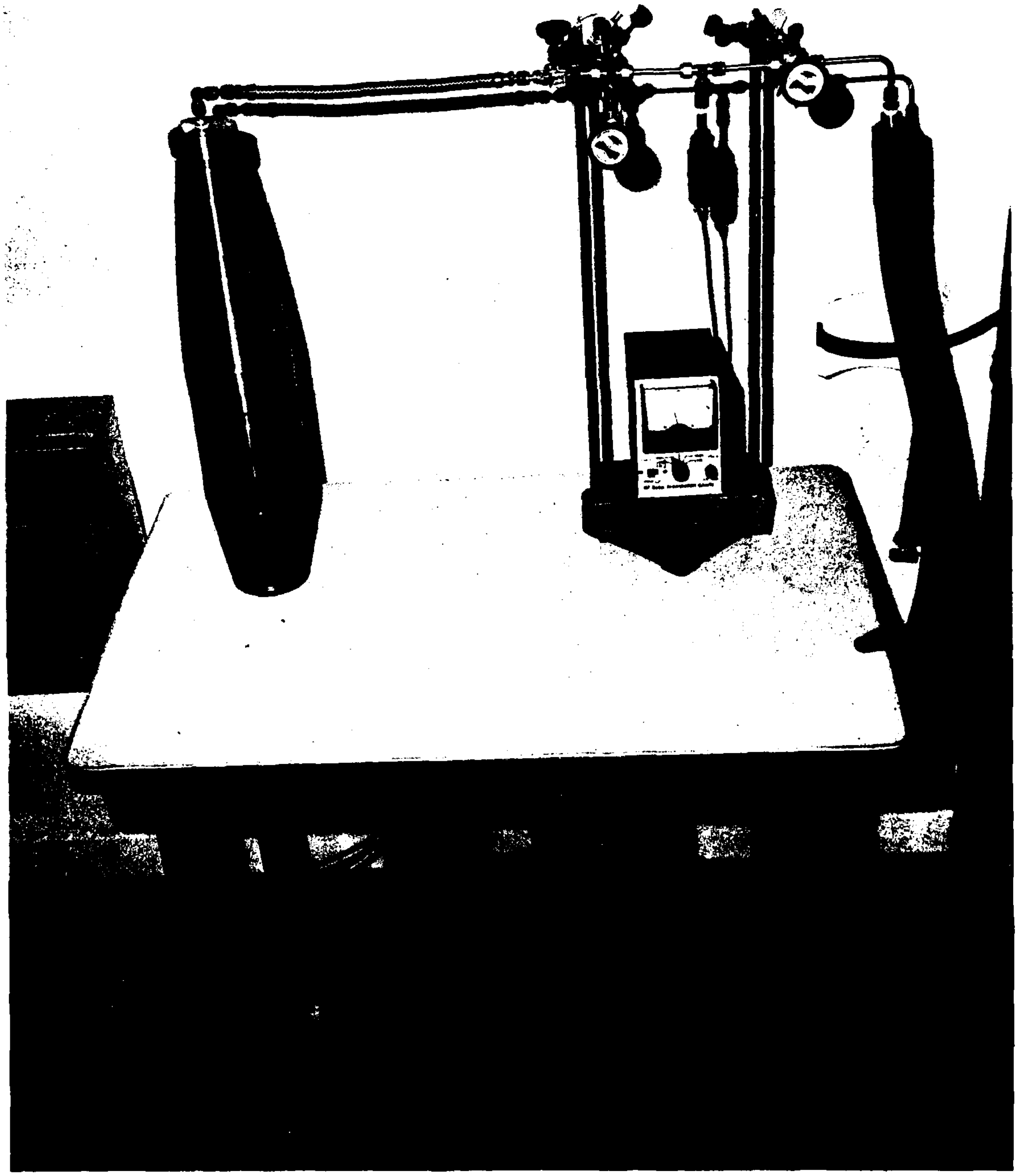

FIGURE 5. LABORATORY DEMONSTRATION SYSTEM FOR O-RING SEAL INSPECTION. THE TWO-PIECE PROJECTILE ON THE TABLE IS CONNECTED TO A VALVE MANIFOLD VIA A TEST FIXTURE AND A FLEXIBLE METAL HOSE. THE VACUUM PUMP IS LOCATED UNDER THE TABLE. AN ELECTRONIC PRESSURE INDICATOR IS CONNECTED TO THE VALVE MANIFOLD.

II. LABORATORY DEMONSTRATION SYSTEM

Figure 4 is a schematic showing the demonstration system connected to a two-piece projectile. The system consists of a mechanical vacuum pump, valve manifold, pressure indicator, and a test fixture that fits onto the nose of the projectile. Figure 5 is a photograph of the system and a projectile. Figure 6 shows the test fixture disconnected from the projectile. Note the O-ring on the inside of the test fixture; this O-ring forms a seal between the fixture and the projectile nose. With the exception of the brass test fixture and a brass adapter for the vacuum hose, the demonstration system was assembled from spare or borrowed parts available in the laboratory.

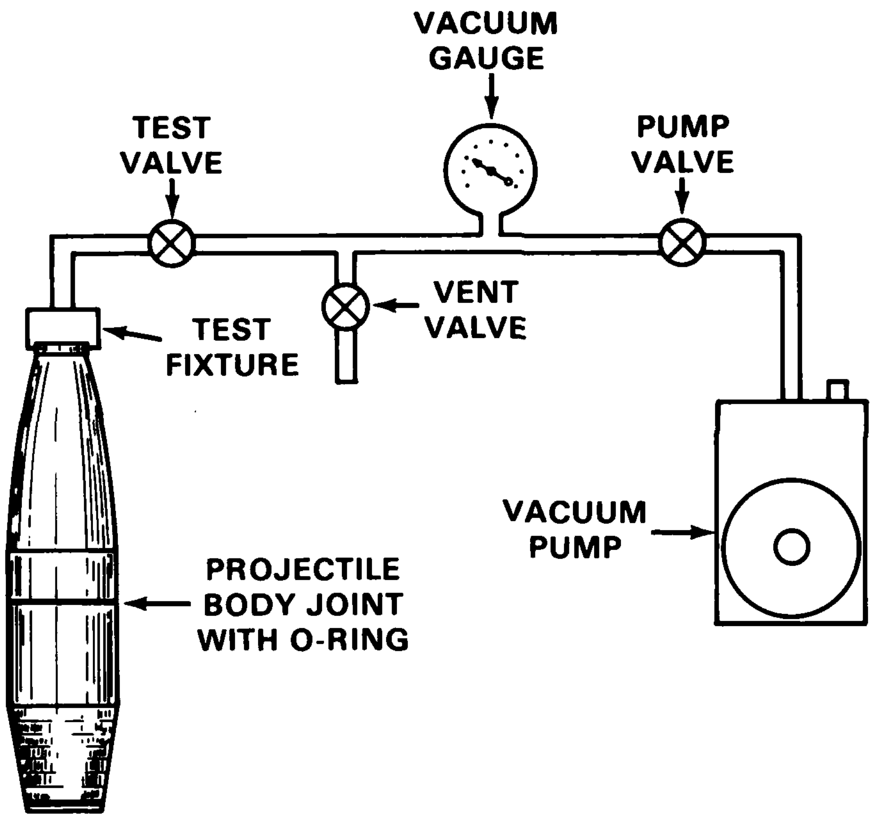

FIGURE 4. SCHEMATIC OF LABORATORY DEMONSTRATION SYSTEM FOR O-RING SEAL INSPECTION. THE PROJECTILE IS CONNECTED TO A VALVE MANIFOLD AND A VACUUM PUMP. THE RATE OF DECREASE IN THE SYSTEM PRESSURE INDICATES THE CONDITION OF THE O-RING SEAL IN THE PROJECTILE BODY JOINT.

The test procedure will now be outlined (see Figure 4). With the vacuum pump operating, and the pump valve closed, the test fixture is placed on the projectile nose. The test valve is opened and the vent valve is closed. The pump valve is then opened and the rate of decrease of the system pressure is monitored via the vacuum gauge and a timer.

The Welch 1402B vacuum pump used in the laboratory demonstration system has a capacity of 160 ℓ/min (= 2.7 ℓ/sec). The volume of a HIFRAG projectile without a billet is approximately 2 ℓ. The time to pump the projectile down to a pressure of 1 torr is approximately 15 sec. The ratio of pumpdown time to volume is then approximately 7. From the graph an appropriate value of D^4/L is then 3×10^{-3}. It can be seen that a 160 ℓ/min pump is adequate for this application, and an increase in pump capacity would not result in a significantly shorter pumpdown time unless the internal dimensions of the connecting tubing were changed to give a larger value of D^4/L.

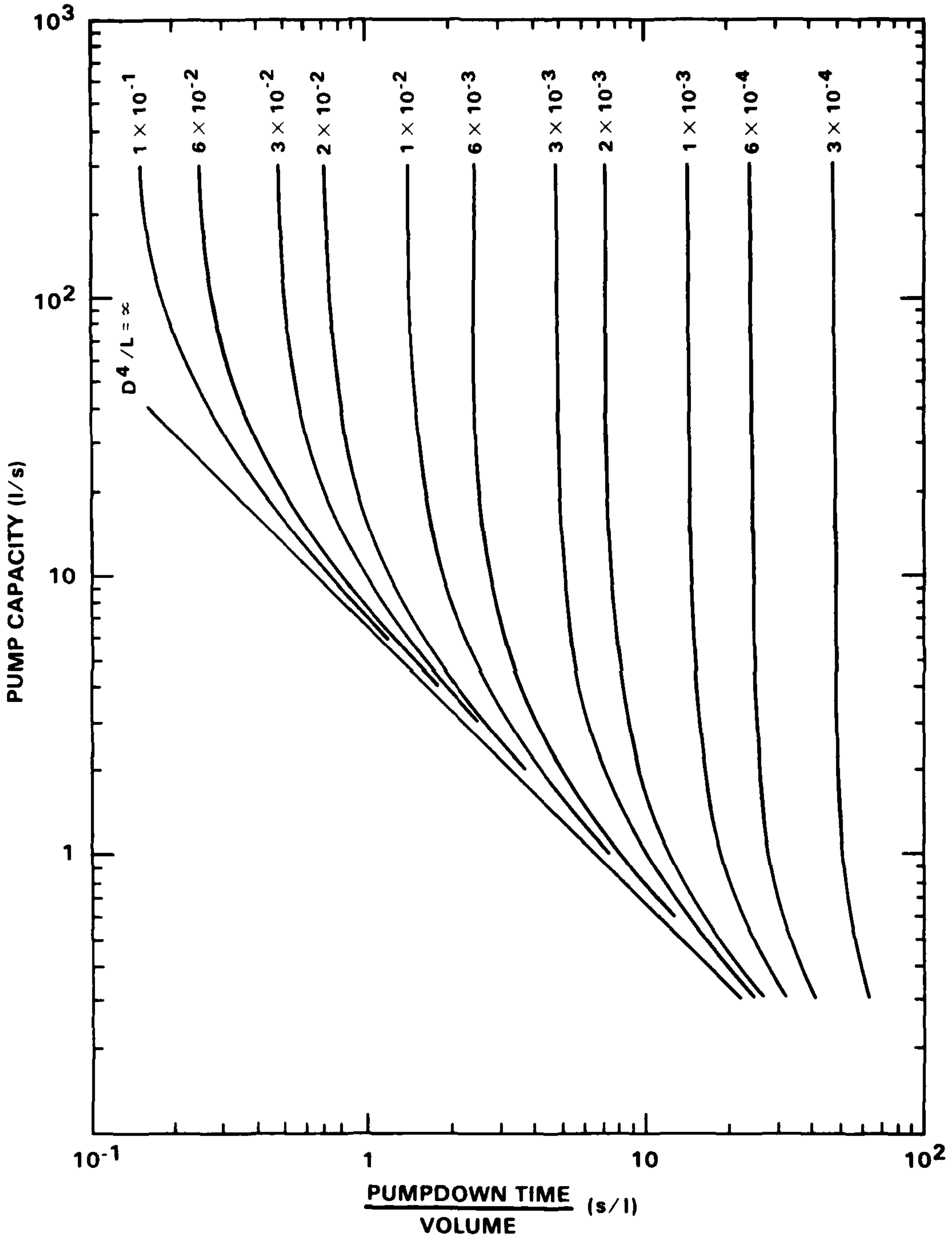

FIGURE B-1. GRAPH FOR ESTIMATING PUMPDOWN TIME FROM SYSTEM VOLUME, PUMP CAPACITY, AND CONNECTING TUBING DIMENSIONS. THE VALUES FOR THIS GRAPH WERE OBTAINED FROM EQUATION B-1 FOR AN INITIAL (AMBIENT) PRESSURE OF 760 TORR (~10^5 PA) AND A FINAL PRESSURE OF 1 TORR (~130 PA).

APPENDIX C

SCHEMATICS OF THE PROJECTILE TEST FIXTURE AND VACUUM PUMP HOSE ADAPTER

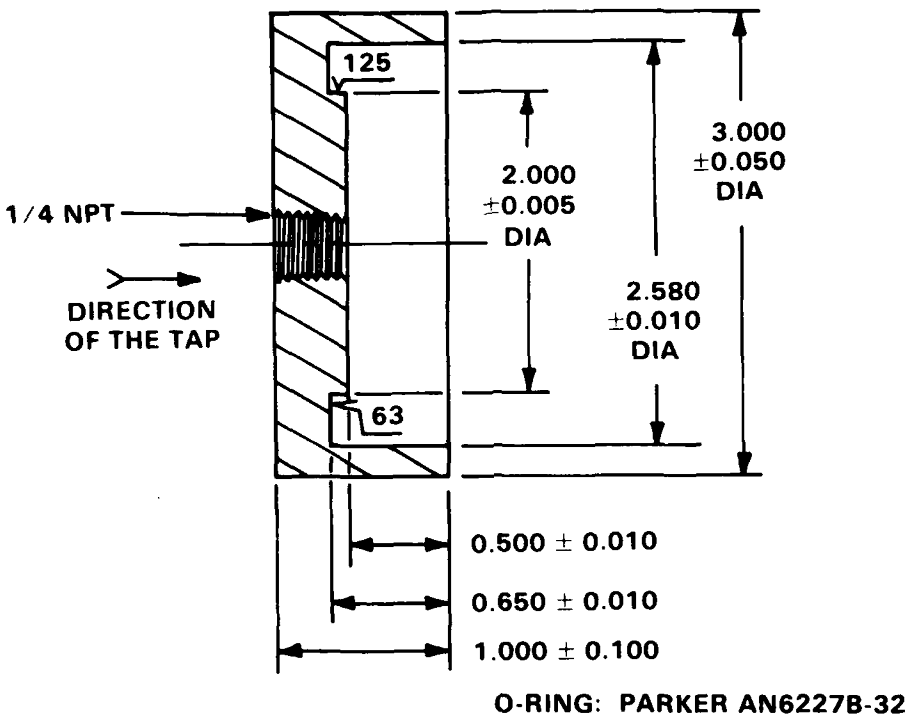

FIGURE C-1. SCHEMATIC OF BRASS TEST FIXTURE THAT FITS ONTO THE NOSE OF THE PROJECTILE.

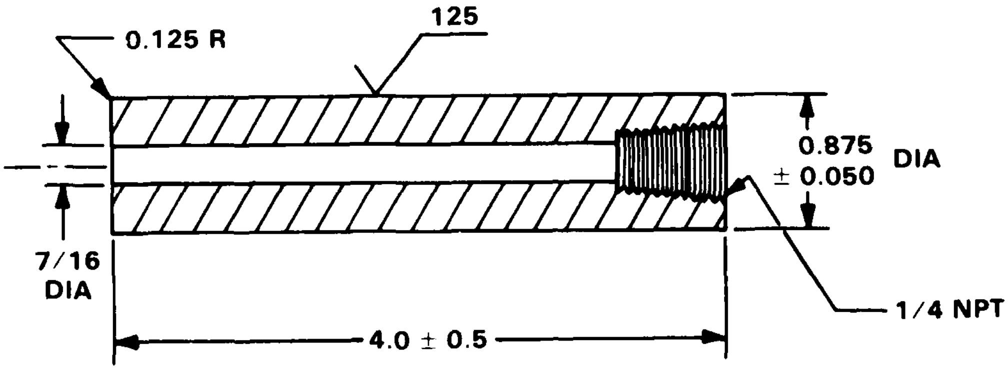

FIGURE C-2. SCHEMATIC OF BRASS ADAPTER FOR CONNECTING THE VALVE MANIFOLD TO THE VACUUM PUMP HOSE.

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