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Fire Resistance Tests of Intumescent-Coated Self-Sealing Fuel Lines

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Technical Center
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Tests were conducted on self-sealing fuel lines whose exterior surface was covered with one of several intumescent coatings. These tests included subjecting coated lines to simulated in-flight fires and to .50 Cal AP and API gunfire. The self-sealing material was flammable, and these tests have shown that the destructive intrusion of a severe fire can be significantly delayed by using an intumescent coating. During this test program, the intumescent coatings had no apparent affect on self-sealing capability of the protected fuel lines when subjected to .50 Cal AP gunfire.

PREFACE

This final report was prepared by the Federal Aviation Administration (FAA) Technical Center, Atlantic City Airport, New Jersey. The effort was initiated by ASD/ENFEF and sponsored by JTCG/AS and AFWAL/POSH. The work was conducted under Aero Propulsion Laboratory, MIPR Number FY 1455-82-N0601 for the period January 1979 to May 1981. The work herein was accomplished under Project 3048, Task 304807, Work Unit Number 30480783, with G. T. Beery, AFWAL/POSH, as Program Monitor and J. Cinelli, ASD/ENFEF, as Project Engineer. FAA Technical Center personnel were: G. Chamberlain, Program Manager; P. Boris, Project Manager; J. Dailey and A. Spezio, Aerospace Technicians.

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Both the Federal Aviation Administration and the military have similar requirements for the resistance of fuel lines within a designated fire zone. The military services, however, have an additional requirement for self-sealing fuel lines in aircraft whose missions so dictate. When these lines are involved in a fire, the self-sealing properties are degraded.

This report documents the results of a test program conducted to determine the effect of intumescent coatings on the fire-resistance and ballistic penetration characteristics of self-sealing fuel lines.

A number of candidate manufacturer's intumescent coatings were screened and tested in the first phase of this program, and those deemed most promising were applied to prepared self-sealing fuel lines and subjected to additional testing. Separate specimens were subjected to simulated in-flight fires using an FAA standard burner and a dry bay test fixture. Specimens were also subjected to .50 Cal gunfire.

The results of the test program indicated that selected intumescent coatings can significantly delay the destructive intrusion of a severe fire into an underlying self-sealing fuel line, and these coatings had no apparent effect on the self-sealing capability of the protected fuel lines when subjected to impact by .50 Cal armor piercing ammunition.

SECTION I

INTRODUCTION

1.1 PURPOSE

The purpose of this test program was to demonstrate the need, feasibility, and practicality of intumescent coatings on self-sealing fuel lines; to assess the degree of fire resistance provided by such coatings; to identify suitable candidate coatings for possible future use; and to determine the reaction of intumescent coated self-sealing fuel lines to .50 Cal armor piercing (AP) and armor piercing incendiary (API) gunfire.

1.2 BACKGROUND

Both the Federal Aviation Administration (FAA) and the military have similar requirements for the fire resistance of fuel lines within a designated fire zone. According to the Federal Air Regulations (FAR) Part 1, fire resistance with respect to fluid-carrying lines means ".....the capacity to perform the intended function under heat and other conditions likely to occur when there is a fire in the place concerned." FAR Parts 23, 25, 27, 29, and 33 state that "lines carrying flammable fluids within a fire zone must be fire resistant." Military Standardization Handbook, MIL-HDBK-221 (WP) entitled "Fire Protection Design Handbook for U.S. Navy Aircraft Powered by Turbine Engines" states that for flammable fluid lines in potential fire zones, "Tubes carrying flammable fluids in or close to a potential fire zone shall be made of stainless steel or equivalent."

With regard to hoses, this handbook states, "Hoses carrying flammable fluids in or close to a potential fire zone shall withstand a flame of 2000° F for at least 5 minutes without leakage at the lowest fluid flow rate and highest fluid temperature and under vibration of operation." Civil Aeronautics Administration Safety Regulation Release No. 259, dated August 26, 1947, states with regard to fire resistant materials, "the flame temperature shall be 2000° ±50° F as measured within one-fourth inch of the surface of the hose and end connection at the point nearest the flame." It further states that, "The hose and end fittings shall be subject to flame.....for not less than 5 minutes without evidence of failure or leakage sufficient to aggravate an existing fire."

The FAR's are not specific with regard to test requirements for rigid fluid carrying lines within a designated fire zone and, therefore, such requirements have been derived from FAR 37 which refers to Technical Standard Order (TSO) c53a. This TSO pertains, however, to the testing of fuel and engine oil hose assemblies (rubber or tetrafluoroethylene tube and wire braid construction). This document, in turn, refers to FAA Powerplant Engineering Report No. 3, entitled "Standard Fire Test Apparatus and Procedure (For Flexible Hose Assemblies)," dated March 1961. It has since been revised to Powerplant Engineering Report No. 3A, dated March 1978. This report describes the FAA standard burner and its use in the fire testing of hose assemblies. It is this burner that was used for some of the tests described herein and when it was used, the test specimen was subjected to its flame for 5 minutes.

The Air Force, as well as other military services, require self-sealing fuel lines in aircraft whose design missions so dictate. When these lines are involved in a fire, self-sealing properties are degraded. For this program a number of intumescent coatings were tested in an attempt to ascertain which, if any, could offer fire protection to the self-seal material for a 5-minute duration. The method pursued in accomplishing this objective consisted essentially of two individual efforts which are described in detail as Part A and Part B in Paragraph 1.3.

Basically, Part A involved the screening of potential intumescent coating candidates, and the selection of those with the most promise. Part B consisted of the application of the selected coatings to the self-sealing fuel lines and additional testing of the intumescent/self-seal combination. As an adjunct to Part B, coated self-sealing lines were subjected to .50 Cal AP and API gunfire. The gunfire testing was conducted to determine if an intumescent coating would be drawn into the projectile created wound and adversely affect self-sealing properties.

The specification governing the acceptance of self-sealing fuel lines which are subjected to gunfire is MIL-C-83291. Since the object of the gunfire portion of this test program was not to specifically judge the performance of self-sealing fuel lines, but rather to determine the effect of intumescent coatings on self-sealing properties, the aforementioned military specification was used only as a guide, and strict adherence to its provisions was not a deciding factor. Examples of specific provisions of the specifications that were not incorporated were high- and low-temperature (bulk fluid) gunfire tests, oblique rounds, 50-foot gun-to-target distance, and leakage evaluation. Further, while MIL-C-83291 specifies that AP rounds will be used, this test program used both AP and API rounds.

1.3 METHOD OF APPROACH

1.3.1 Part A - Screening Tests. The screening tests were designed to select the intumescent coating or coatings that showed the most promise in offering extended fire protection for self-sealing fuel lines. This selection process was accomplished by testing a number of intumescent coatings applied to bare 3-inch diameter x 0.035-inch wall 6061-T6 aluminum alloy tubes. The testing involved subjecting each of the samples to the flame environment of a simulated dry bay test fixture and the FAA standard burner. The simulated dry bay test fixture was provided to the FAA Technical Center by Wright-Patterson Air Force Base (WPAFB) for use in this test program. The coatings were evaluated on the basis of relative heat transfer, char strength and adhesion to the aluminum tube, and intumescent action. Data parameters included tube internal wall temperatures in the test section and fluid temperature at the entrance and exit of the test section.

For all screening tests, fuel flow was simulated by circulating water through the test line at a flow rate of 0.25 gallons per minute (gpm) and a pressure of 30 pounds per square inch gage (psig). Water was chosen as the test fluid for safety purposes. The pressure of 30 psig was specified in MIL-C-83291 and was considered typical of that in actual fuel line installations.

The 0.25 gpm water flow rate was selected after a number of preliminary tests on uncoated aluminum tubes of the same alloy and size as those which were later coated. A wide variety of flow rates were investigated, the pressure always being maintained at 30 psig. Higher flow rates resulted in little or negligible rise in temperature of either the tube wall or the water through the test sections, and therefore provided no significant data on which to base comparisons. Lower flow rates produced a situation which was characterized by extremely high localized wall temperatures that were attributed to isolated water vapor pockets. This condition was also deemed unacceptable since it was unstable and did not provide data continuity. The 0.25 gpm water flow rate was thus experimentally determined as the best possible compromise. As low a flow rate as practicable was desired to yield the highest temperature rise possible and still provide stable flow conditions. The values recorded as inside wall temperature were probably somewhat less than actual because of some heat carried away by the circulating water. These are relative values and since the flow and test conditions were the same from test to test, it was a reasonable basis for comparison.

Test duration using the simulated dry bay test fixture was 10 minutes, and test duration using the FAA standard burner was 5 minutes.

The intumescent coatings which were tested under Part A are listed in Table 1. Three-foot lengths of aluminum tubing were provided by the FAA Technical Center to the intumescent coating manufacturers who applied their respective intumescent coatings to the central 2 feet.

The most promising intumescent coatings selected under Part A were applied to self-sealing fuel lines and tested under Part B.

1.3.2 Part B - Fire Tests. The Part B fire tests were designed to determine which of those intumescent coatings selected under Part A offered the highest degree of fire protection to the self-seal material. The major difference between Parts A and B testing was that in Part A the intumescent was applied to bare aluminum tubes, whereas in Part B the coating was applied to self-sealing lines.

The basic test conditions were the same as in Part A. Water was circulated through the test specimen at 0.25 gpm and 30 psig. The test duration using the simulated dry bay test fixture was 10 minutes, and the duration using the FAA standard burner was 5 minutes.

The Part B test schedule is given in Table 2. This table indicates the self-sealing fuel line type, the coatings, and the number of each type of test.

The criteria for determining the intumescent coating which offered the highest degree of fire protection to the self-sealing fuel lines was largely judgmental. As will be explained in Section 2.2, the parameters used to evaluate the coatings in part A did not lend themselves to an accurate evaluation when applied to self-sealing fuel lines tested in Part B. Assessing the degree of fire protection imparted to the self-sealing fuel line test samples by the various intumescents was based on visual observation during the test, reviewing video tapes and films and a post-test examination of the test sample. This task was simplified, since one intumescent product considerably outperformed the others under the test conditions stated herein.

As an adjunct to Part B, intumescent coated self-sealing fuel lines were subjected to AP and API .50 Cal gunfire. Also, previously tested (i.e., prior exposure to fire) fuel lines were selected and subjected to AP gunfire only.

For these tests there was no circulating fluid, but the test samples were pressurized to 30 psig with JP-4 turbine fuel. The intent of the tests with new samples was to determine if the intumescent coating would have an adverse effect on

TABLE 1. INTUMESCENT COATING DATA (1)

Coating	(2) Thickness Range (in)	(3) Thickness Avg. (in)	(2) Wgt. Area Density Range (lb/ft^2)	(3) Wgt. Area Density Avg. (lb/ft^2)	(4) Coating Wgt. Difference (lb)
AVCO 1400	0.017-0.025	0.023	0.123-0.175	0.151	0.07
AVCO 1600	0.021-0.028	0.023	0.154-0.187	0.164	0.05
3M (2mm)(5)	0.081-0.094	0.087	0.331-0.455	0.368	0.08
3M (3mm)(5)	0.111-0.143	0.133	0.652-0.672	0.667	0.04
Ocean 47135	0.042-0.099	0.072	0.383-0.610	0.445	0.54
Ocean 1-112D	0.094-0.150	0.116	0.426-1.311	0.995	1.38

Notes:

(1) Data obtained on manufacturer-prepared coated aluminum tubes only. Self-sealing lines not included.
(2) Range indicates the minimum and maximum measurements.
(3) Average is the arithmetic mean of all tubes measured.
(4) Difference between the minimum and maximum coated tube weights.
(5) Same formulation. Difference is in thickness only: 2 and 3 mm nominal.

TABLE 2. PART B TEST SCHEDULE

Fuel Line	Uncoated		-Dry Bay- Coating		-Std. Burner- Coating		
	Dry Bay	Std Burner	3M	1400	3M	1400	1600
McAir Standard	2	1	3	3	3	3	3
Uniroyal	2	1	3	3	3	3	3
Aeroquip	2	1	2	2	2	2	-
McAir Chem-Milled	1	1	1	1	1	1	2

the self-sealing properties of the fuel lines. It had been speculated that portions of the intumescent coating could be drawn into the gunfire wound, thus adversely affecting the ability of the self-seal material to close the wound. Those samples which were previously tested under Part B were subjected to AP gunfire in an effort to determine what effect prior exposure to heat would have on self-sealing properties. The list of samples exposed to AP and API gunfire is shown in Table 3.

1.4 TEST EQUIPMENT DESCRIPTION

1.4.1 Test Fixtures and Instrumentation. The heat sources for both Part A and B fire tests were a simulated dry bay test fixture, a device designed and fabricated by the United States Air Force (see Figures 1 and 2), and the FAA standard burner. The FAA standard burner is a modified Model 200 CRD Carlin conversion oil burner described in Federal Aviation Administration report FAA-RD-76-213. This burner is shown in Figure 3. The simulated dry bay test fixture is intended to be representative of an aircraft dry bay area. This fixture is essentially a stainless steel box, open at the top, with provisions to install a test specimen. The fixture also has provisions to allow air in through the bottom for combustion. The outside dimensions of this fixture are 18 inches long by 12 inches wide by 18 inches high. The width was adjustable from 4 to 12 inches to allow for varying clearances between the sides of the fixture and the test sample. All tests were conducted with the widest wall spacing. Located in the fixture under the test sample was a 12-inch long by 3-inch wide by 3-inch high stainless steel container which was filled with 1 pint of JP-4. This provided a rather quiescent flame which was much less severe than that of the FAA standard burner.

For Parts A and B tests, measurement of the inside wall temperature was accomplished using the device shown in Figure 4. Copper-constantan thermocouple wire was threaded through small-diameter aluminum tubes and terminated at an aluminum rivet secured to a split ring made of a section of 3-inch diameter aluminum tubing. The rivets were drilled out to accept the thermocouples, and, additionally the rivets were insulated from the split ring with rubber washers. The tubes through which the thermocouple wire was passed were potted to prevent leakage. This fixture allowed for positive contact of the thermocouple bead to the inside tube wall. The temperature measurement fixture was used for all tests (except gunfire) where the test specimen had an inner aluminum tube. Due to its construction, this device was not used in tests with Aeroquip hoses. The completely rubberized construction and smaller inside diameters precluded insertion of the fixture into these test specimens.

TABLE 3. LISTING OF GUNFIRE TEST SAMPLES

Tube No.	Fuel Line	Coating	New	Prior Exposure to Fire
85	McAir Standard	3M	-	
86	McAir Standard	3M	-	
89	McAir Chem-Milled	3M	-	
96	Uniroyal	3M	-	
97	Uniroyal	3M	-	
102	Aeroquip	3M	-	
103	Aeroquip	3M	-	
110	McAir Standard	1400	-	
111	McAir Standard	1400	-	
114	McAir Chem-Milled	1400	-	
121	Uniroyal	1400	-	
122	Uniroyal	1400	-	
127	Aeroquip	1400	-	
128	Aeroquip	1400	-	
80	McAir Standard	3M		Dry-Bay
90	Uniroyal	3M		Dry-Bay
99	Aeroquip	3M		Dry-Bay
106	McAir Standard	1400		Dry-Bay
117	Uniroyal	1400		Dry-Bay
123	Aeroquip	1400		Dry-Bay
82	McAir Standard	3M		FAA-Burner
95	Uniroyal	3M		FAA-Burner
100	Aeroquip	3M		FAA-Burner

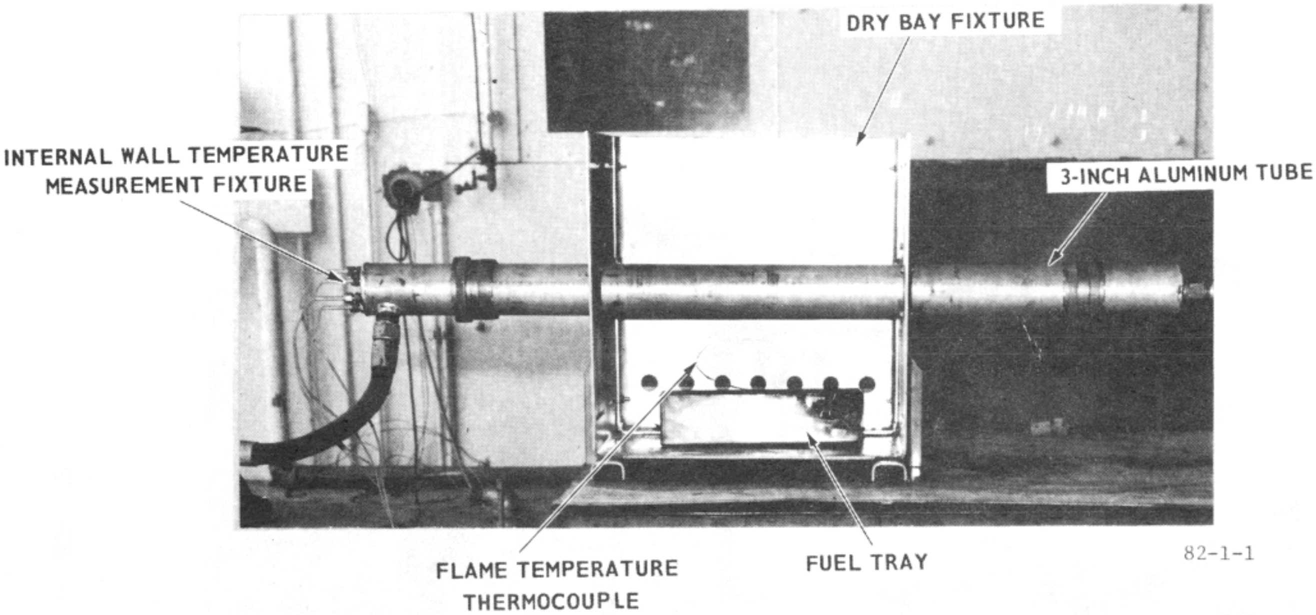


FIGURE 1. SIMULATED DRY BAY TEST FIXTURE SHOWING UNCOATED ALUMINUM TUBE SAMPLE

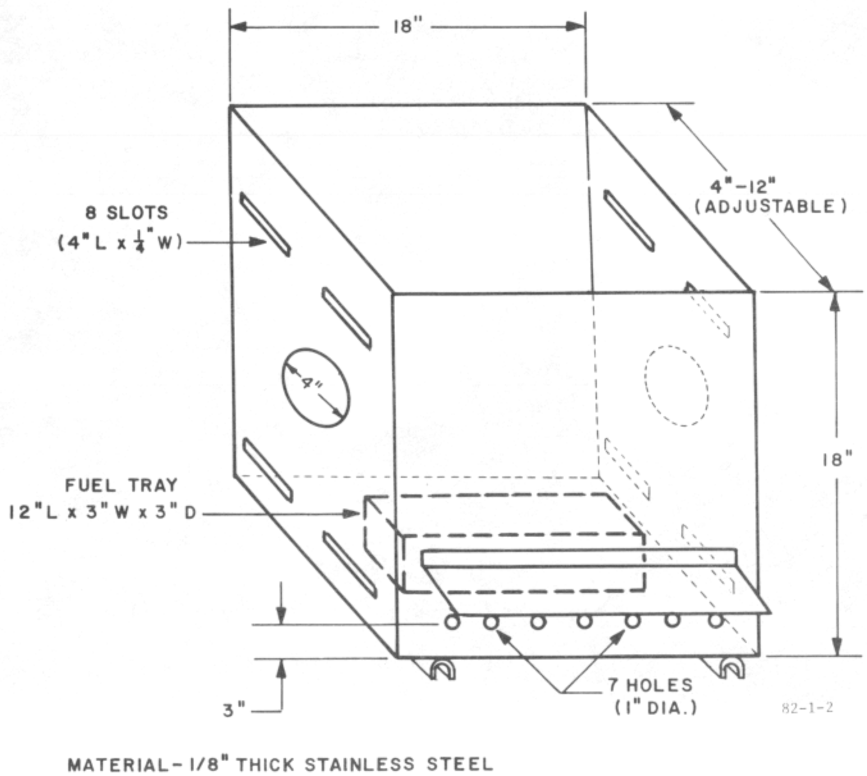


FIGURE 2. SKETCH OF SIMULATED DRY BAY TEST FIXTURE

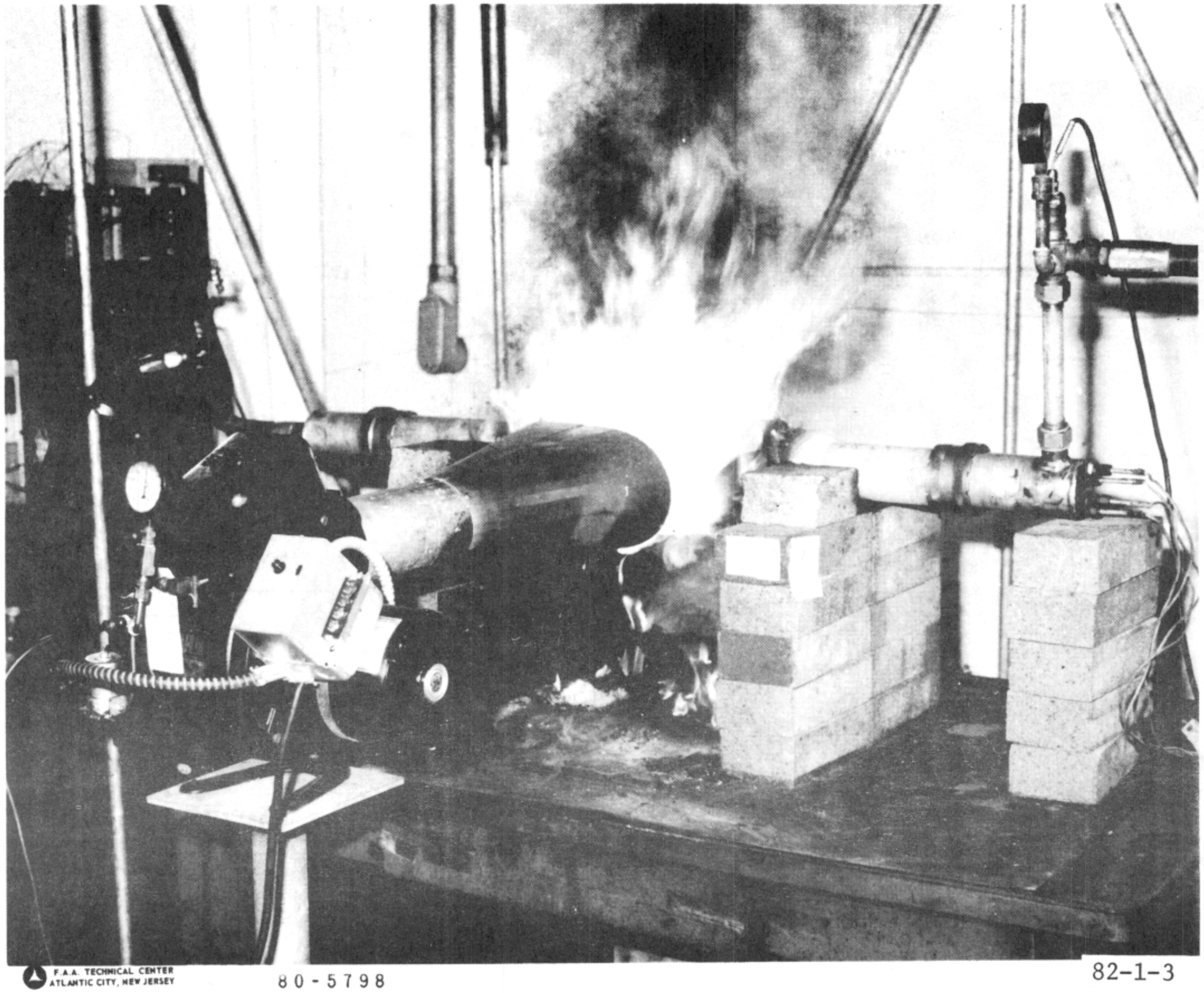


FIGURE 3. TYPICAL TEST SHOWING FAA STANDARD BURNER

The circulating water flow was monitored using a Cox AN8-4 flowmeter and a Potter Model 43-4M4 digital readout system. Fluid in and fluid out temperatures were measured using a Thermoelectric Ceramocouple,™ Type T (copper-constantan). Fluid and tube wall temperatures were recorded with an Esterline Angus D-2020 data logger. Additionally, all tests were recorded on video tape.

For the gunfire portion of this test program, the device used for firing the .50 Cal ammunition was a single-shot weapon provided to the FAA Technical Center by Wright-Patterson AFB. The ammunition, standard AP and API rounds, was also provided by the Air Force for these tests. A typical test setup is shown in Figure 5. A schematic of the gunfire test setup is shown in Figure 6. The API rounds were fired at the test specimens through a striker plate consisting of two 1/8-inch thick plates of aluminum (alloy 2024T3) which were secured so that the flat faces were in contact. The test articles were mounted in a steel fixture that securely restrained the test article in supports 27 inches apart. The muzzle of the single shot weapon was 13 feet 8 inches from the test specimen. A pressure relief valve was installed in the fuel supply line to obtain the required pressure. A remotely-operated shutoff valve was also installed in the line. Either a hand valve or end-cap at the free end of the test line served to purge the test line of air and assure that it was filled with JP-4 fuel.

1.4.2 Description of Test Specimens - Part A. For the Part A tests, all intumescent products were applied to 3-foot sections of 6061-T6 aluminum alloy tubing The tubing was 3 inches in diameter and had a wall thickness of 0.035 inches. Only the central 2 feet of each test sample was coated.

Typical test specimens for Part A tests are shown in Figures 7 through 11. Of all the coatings tested, only the 3M products were applied as wraps. The AVCO products were sprayed and the Ocean Chemical Company products were applied manually with a brush or trowel. AVCO 1400 became available as a wrap, but it was not included in this test program since its availability became known after Part A had been completed.

The aluminum tubes were provided to the manufacturers of the intumescent products who applied their respective coatings. The specific details of application were not provided by the manufacturers. Only Ocean Chemical requested any preconditioning of the tubes before applying their coatings. The FAA Technical Center complied with their request, which involved sandblasting followed by a treatment with an Alodine Chemical Kit No. 12 (brush) per MIL-C-5541. With the exception of the 3M products, the coatings textures were smooth to the touch, although the overall surface appearance of some was very uneven. The 3M intumescent wrap had a rough surface texture (not abrasive) and was rubber-like in appearance and touch. Its color was reddish brown. Small granules, about the size and color of large salt crystals, appeared on the surface and could be rubbed off by hand. There was no lack of adhesion of the intumescent wrap to the underlying aluminum tube, and there were no surface discontinuities in any of the 3M coated samples. Although the Ocean Chemical coatings textures were smooth, there was a considerable variation in thickness. The supplier informed the FAA Technical Center that this was due to the fact that they were applied with a brush and trowel. It is for this reason that the thicknesses shown in Table 1 for coatings 47135 and 1-112D are rough approximations only. The 47135 coating color can be described as light beige or cream, while the 1-112D was white. There was no lack of adhesion and there were no surface discontinuities on these Ocean Chemical products. For the AVCO coatings,

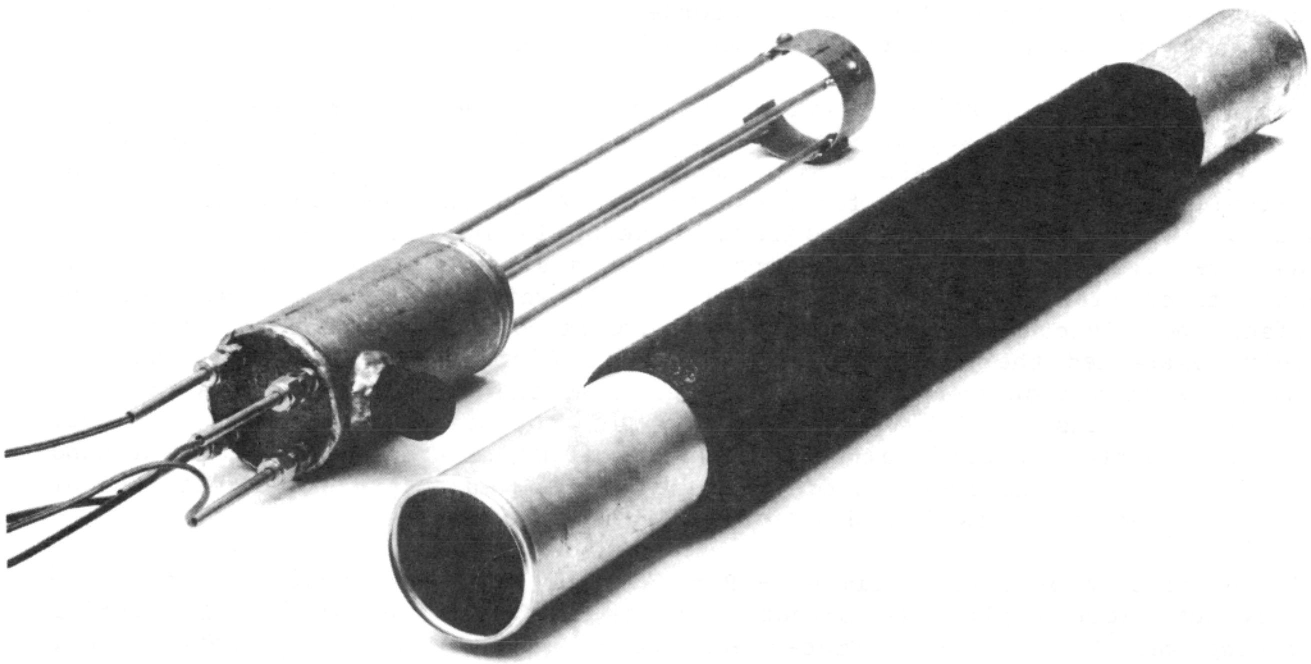


FIGURE 4. INTERNAL WALL TEMPERATURE MEASUREMENT FIXTURE SHOWN WITH SELF-SEALING ALUMINUM FUEL LINE

FIGURE 5. TYPICAL TEST SETUP FOR GUNFIRE TESTS

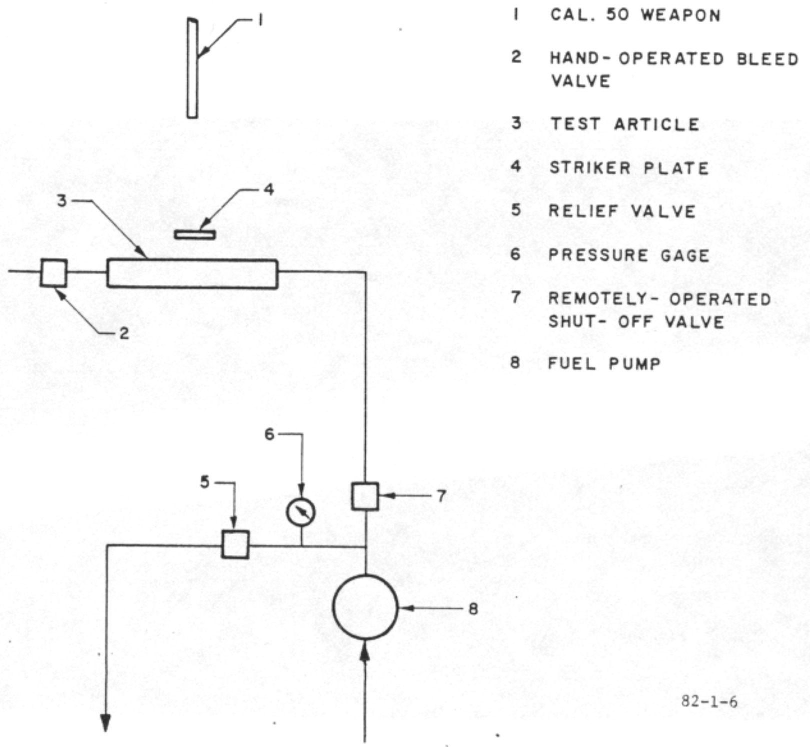


FIGURE 6. SCHEMATIC OF GUNFIRE TEST SETUP

there was, likewise, no lack of adhesion and there were no surface discontinuities. The color of the AVCO 1400 was yellow, and the 1600 was white.

Micrometer readings of the tube diameters were taken with and without a coating to determine coating thickness. This was accomplished by taking the measurements at four different locations along the central 2 feet of the tube sample. These measurements were taken 90 degrees apart to minimize error due to uneven coating thickness and any possible out-of-round condition. For the Ocean Chemical samples, the thickness shown in Table 1 was the result of measurements taken where the coating was relatively even. The thickness in some lumpy areas exceeded 0.5 inch.

Some of the test sample descriptive information is given in Table 1. In the columns identified as THICKNESS RANGE and WEIGHT AREA DENSITY RANGE, the minimum and maximum measured values are given. In those columns identified as THICKNESS AVERAGE and WEIGHT AREA DENSITY AVERAGE, the value shown is the arithmetic mean of all the tube samples measured. Note that the values in Table 1 were obtained from aluminum tube coated test samples and not the coated self-sealing fuel lines. The column identified as COATING WEIGHT DIFFERENCE is an indication of the control the manufacturer had on his application process. The values shown are the difference between the heaviest and lightest weight of the fuel line samples. The AVCO and 3M coatings revealed less of a variability in measured parameter than did the Ocean Chemical coatings. The two 3M coatings listed in Table 1 were identical. The 2 millimeters (mm) and 3 mm denote the nominal coating thickness applied, i.e. 2 mm and 3 mm, respectively. This product was identified by 3M Company as 3M Brand Fire Barrier FS-195.

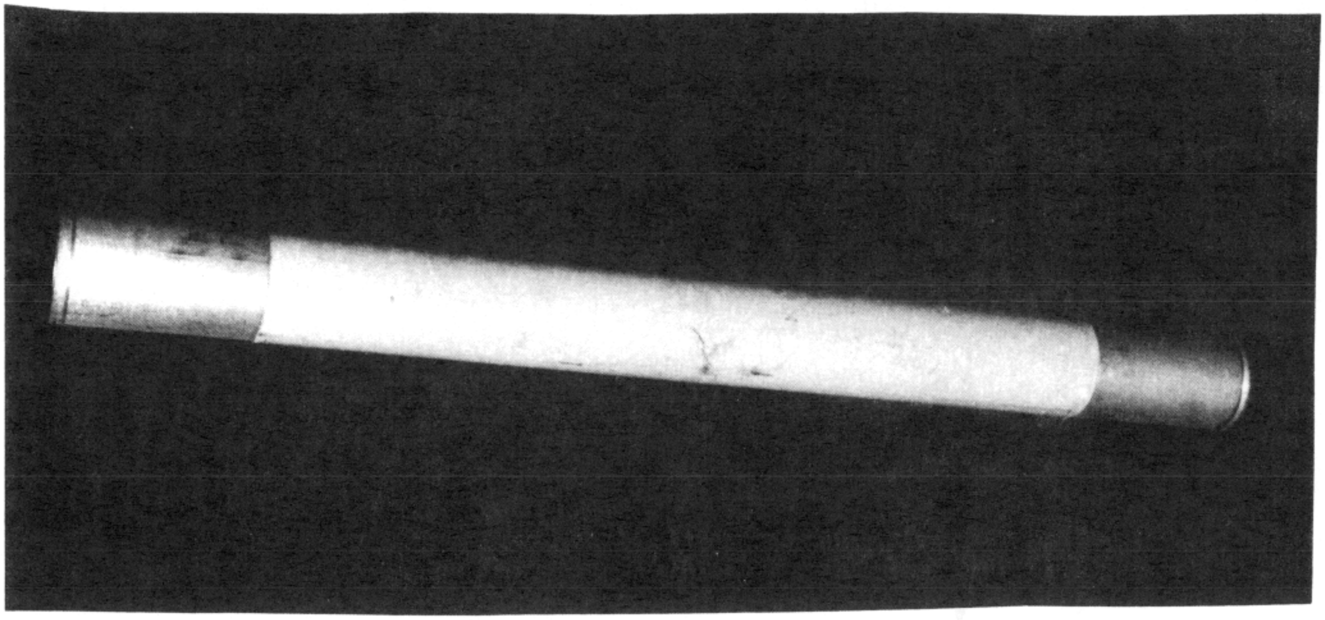


FIGURE 7. TYPICAL AVCO 1600 COATED ALUMINUM TUBE BEFORE TEST

1.4.3 Description of Test Specimens - Part B. The intumescent coatings selected for testing in Part B were the 3M (2mm), AVCO 1400, and AVCO 1600. The selection rationale is discussed in Paragraphs 2.1.1 and 2.1.2.

The self-seal fuel lines to which the intumescent coatings were applied were provided to the FAA Technical Center by the USAF. Photographs of typical coated and uncoated test samples are shown in Figures 12 through 17.

The fuel lines were of four types, namely: McAir standard, McAir chem-milled, Uniroyal, and Aeroquip. All but the Aeroquip lines were constructed with a 3-inch-outside diameter (o.d.) 6061-T6 aluminum tube over which was bonded a self-seal cover. The aluminum tube wall thickness of the McAir standard and Uniroyal lines was 0.028 inches; the McAir chem-milled was 0.008 inches. The McAir standard and Uniroyal lines both had overall diameters of 4 inches, which included the self-seal cover; the McAir chem-milled was 3 1/2 inches o.d. The Aeroquip line differed in that it was completely rubberized with no inner aluminum tube. Its o.d. and inside diameter (i.d.) were 3 inches and 2 inches, respectively. All self-sealing material was black in color. Of the three types of self-seal tubes, only the Aeroquip lines were standard production items. The Uniroyal lines were manufactured for these tests using production materials and techniques. A description of the McAir test lines is contained in Report AFML-TR-73-176 (contract no. F33615-72-C-1391) prepared by the McDonnell Aircraft Company. These test specimens were manufactured and delivered to the United States Air Force (USAF) under the aforementioned contract. The McAir standard lines were selected by WPAFB from the 25 fuel lines manufactured under the contract. The McAir chem-milled specimens were also manufactured under the same contract.

The intumescent coatings were applied by the supplier, as in Part A, to the self-sealing fuel line samples. Each of the test specimens was coated with either an AVCO 1400, AVCO 1600, or 3M Fire Barrier intumescent coating as noted in Table 2.

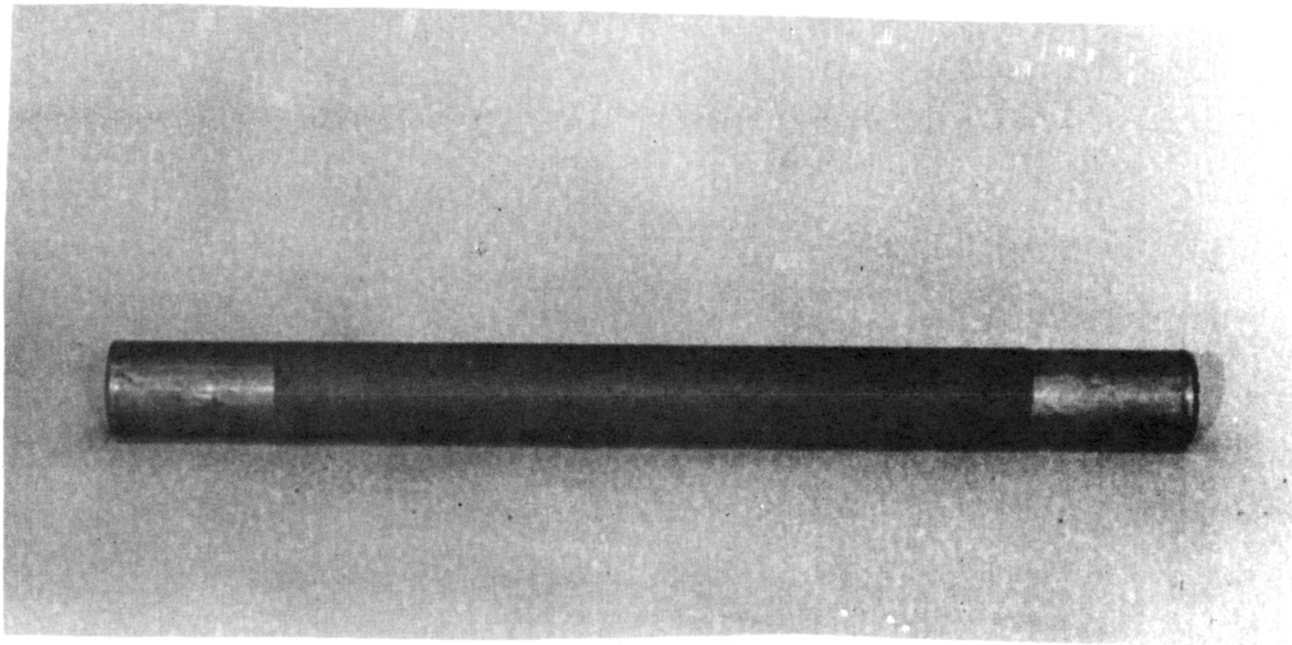


FIGURE 8. TYPICAL AVCO 1400 COATED ALUMINUM TUBE BEFORE TEST

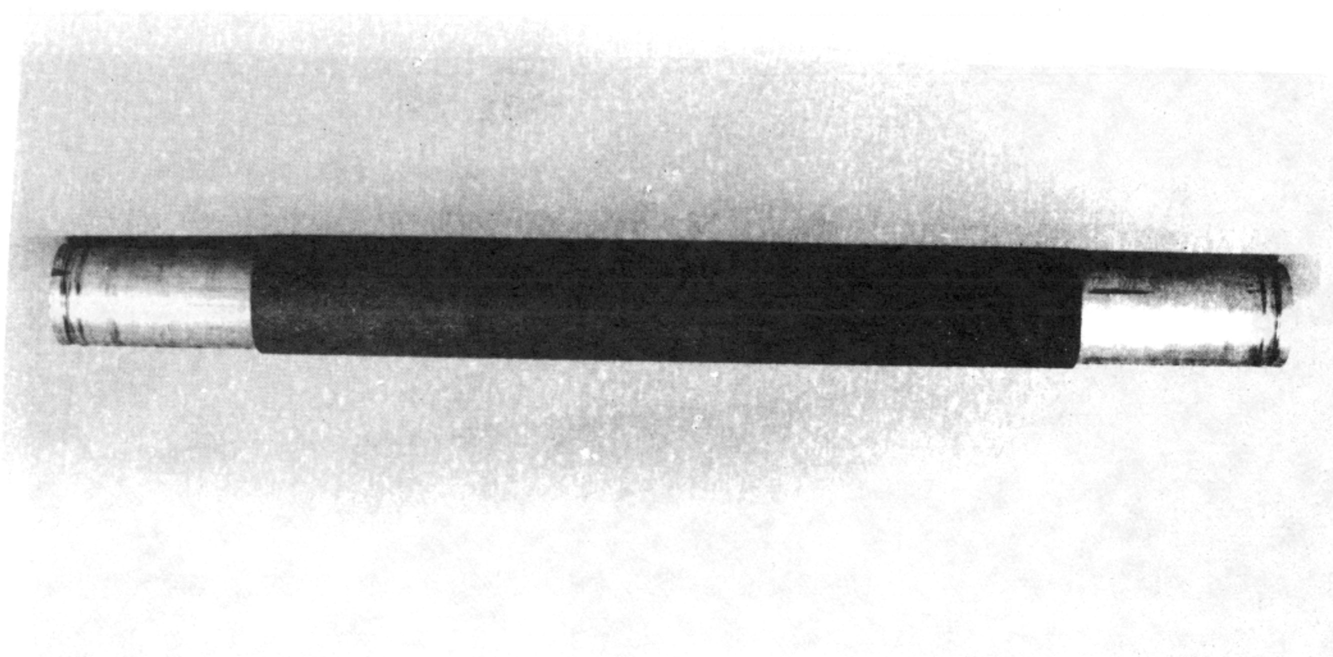


FIGURE 9. TYPICAL 3M COATED ALUMINUM TUBE BEFORE TEST

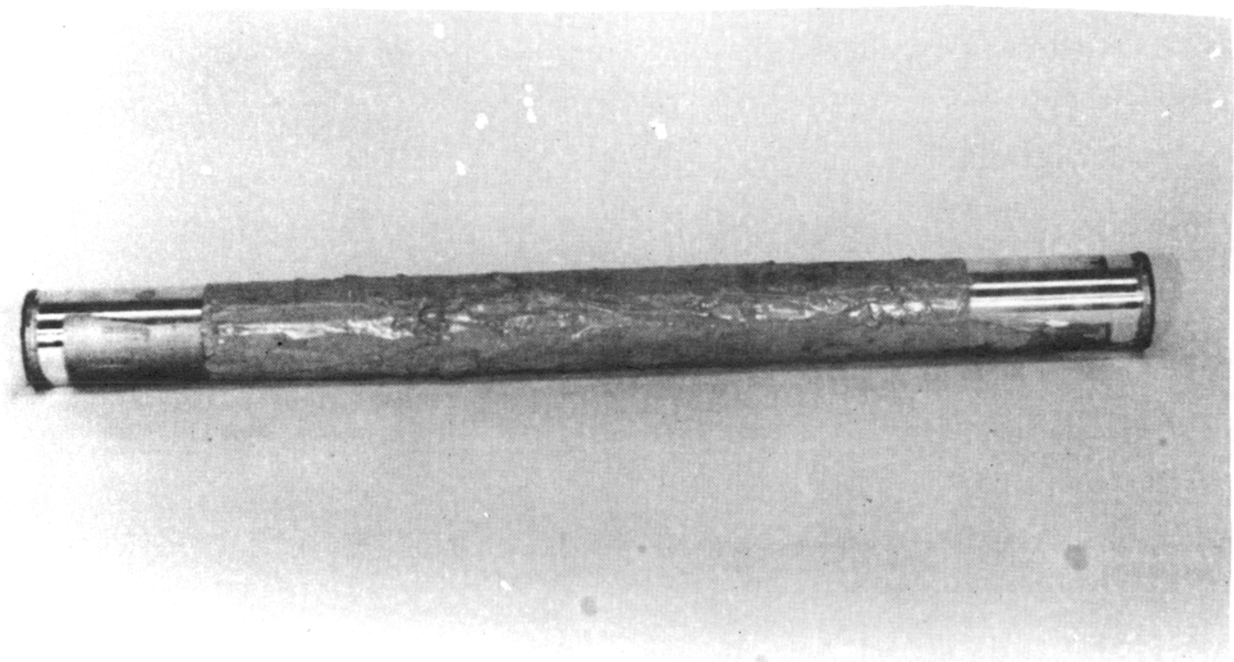


FIGURE 10. TYPICAL OCEAN 47135 COATED ALUMINUM TUBE BEFORE TEST

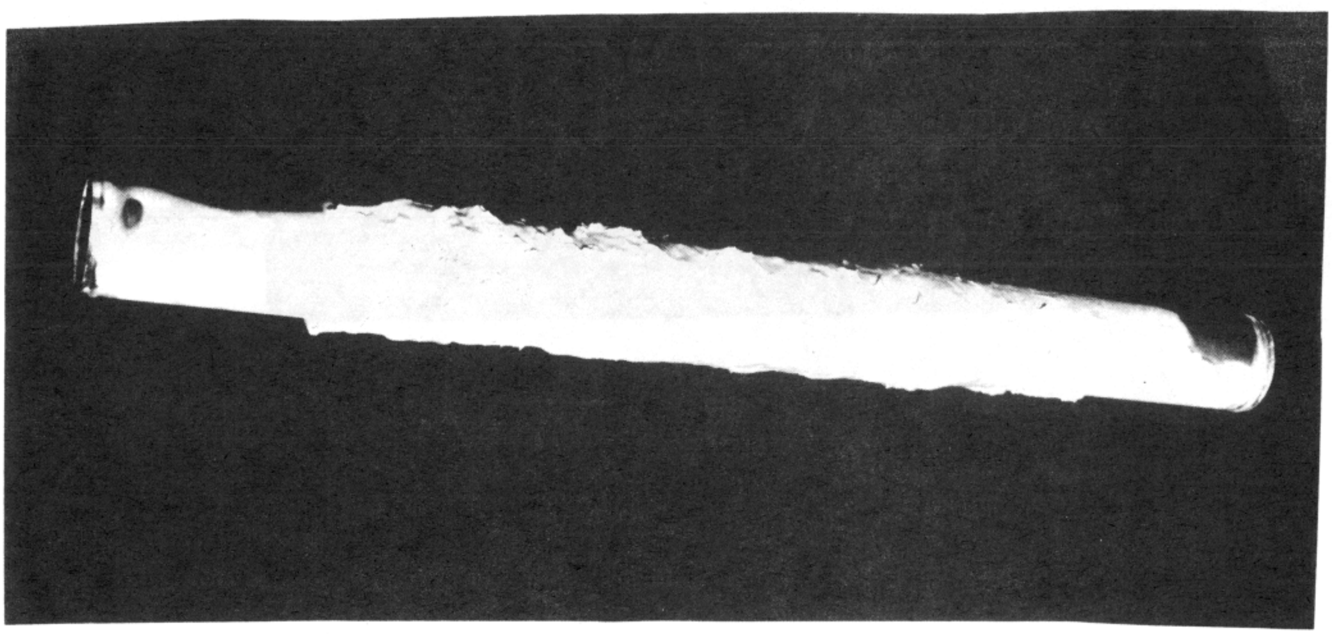


FIGURE 11. TYPICAL OCEAN 1-112D COATED ALUMINUM TUBE BEFORE TEST

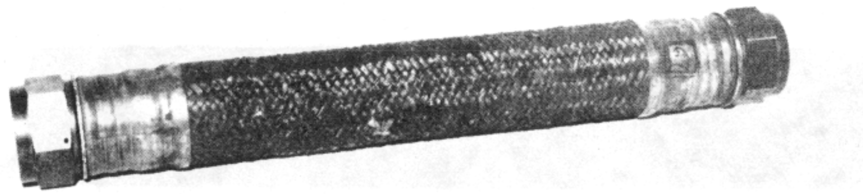


FIGURE 12. UNCOATED AEROQUIP SELF-SEALING FUEL LINE WITH END FITTINGS

Some descriptive information for these coatings is given in Table 1. It should be noted that this descriptive data was obtained by measurements taken only of coated aluminum tubes, and not of coated self-sealing fuel lines. This is because the irregularity of the surface and varying coated lengths of the self-seal material made it difficult to determine an accurate coating thickness and weight area density. On the other hand, since the surface of the coated aluminum tubes was even, and in all cases the coated length precisely 2 feet, it allowed coating thickness and weight area density to be determined more accurately. It was assumed that there was no significant difference between thickness and weight area density of the coatings applied to the aluminum tubes of Part A and the self-sealing lines of Part B.

All coatings had the same appearance as described in Paragraph 1.4.2. The only exception noted pertained to the 3M wrap. There were small surface discontinuities on three samples. These discontinuities were manifested as holes through the coating, such that the underlying self-seal was visible (Figure 15). The discontinuities ranged in size from approximately 1/16 inch to 1/4 inch in diameter. They were by no means numerous, and, as will be noted in a subsequent section of this report, had no apparent affect on the performance of the product. On one Aeroquip test sample there were discontinuities along the butted seam of the 3M wrap (Figure 15). The largest of these manifested itself as an elongated hole 3/16-inch long and less than 1/16-inch wide, while the smallest was less than 1/16-inch long and 1/16-inch wide. The total length of the discontinuities was approximately 5/8 inch, noting, however, that they were not contiguous. This particular test sample was used during the gunfire test. One other irregularity noted was the lack of wrap adhesion on one sample. The 3M intumescent wrap was not completely bonded to the self-seal over an area of approximately 10 square

FIGURE 13. TYPICAL UNCOATED UNIROYAL SELF-SEALING FUEL LINE

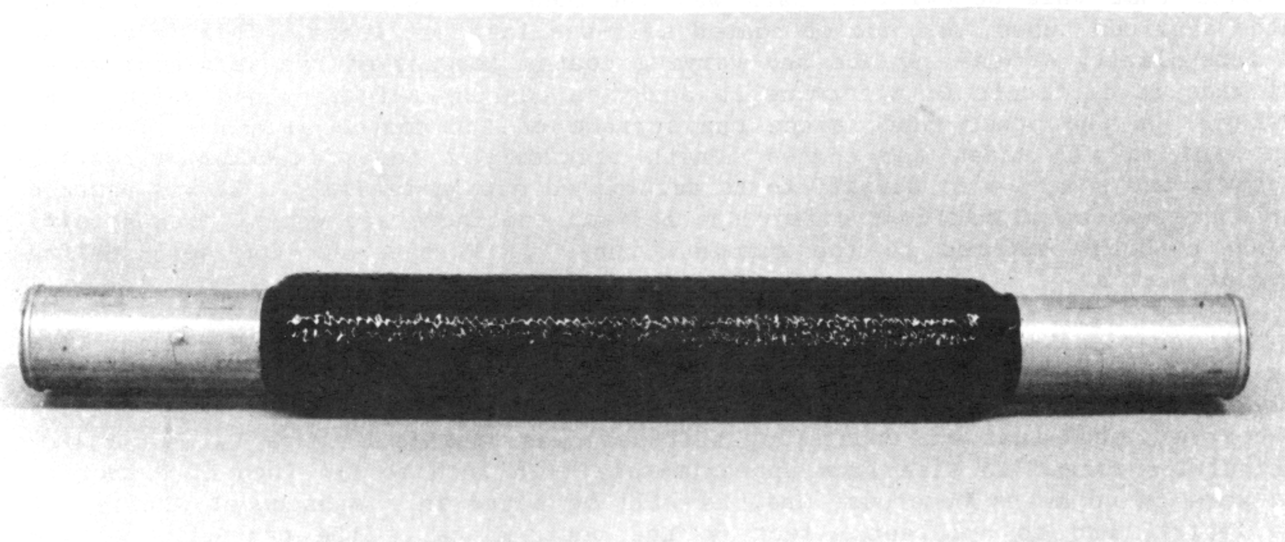


FIGURE 14. TYPICAL UNCOATED McAIR STANDARD SELF-SEALING FUEL LINE

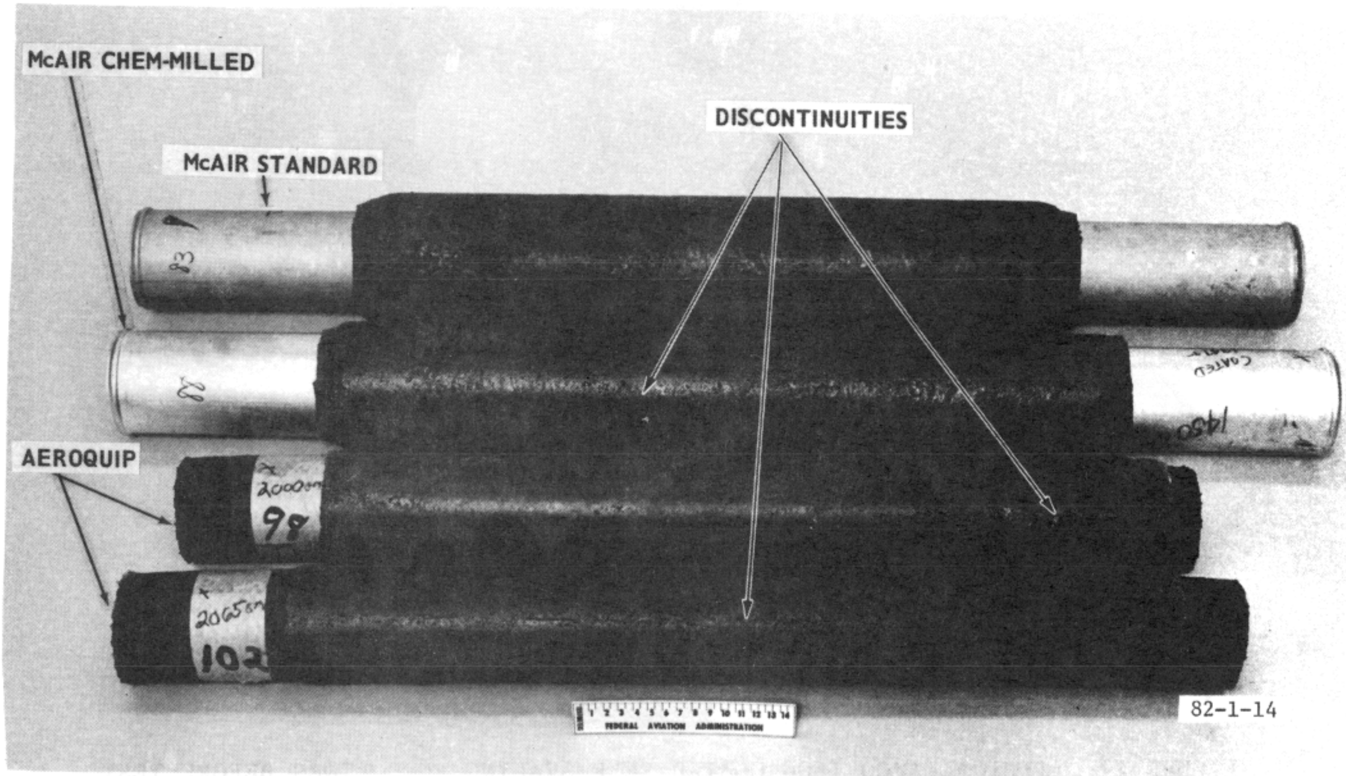


FIGURE 15. TYPICAL 3M COATED SELF-SEALING FUEL LINES BEFORE TEST

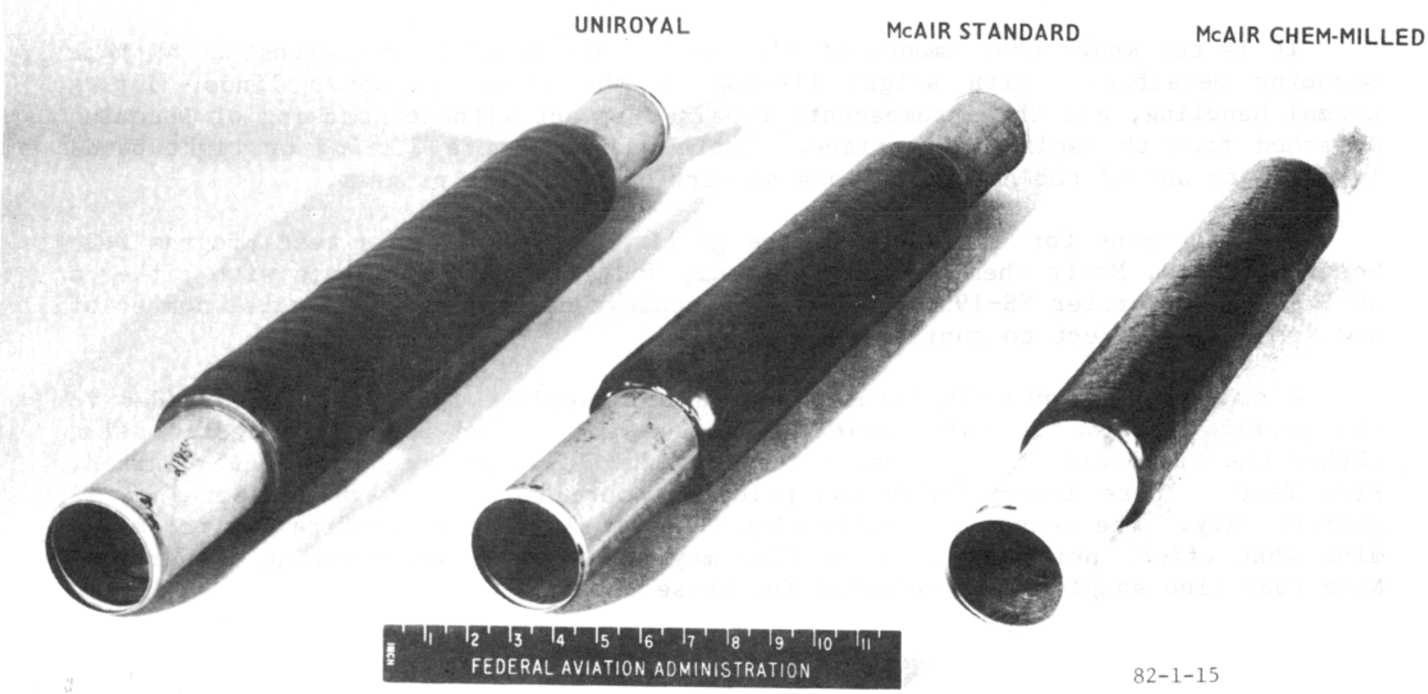


FIGURE 16. TYPICAL AVCO 1400 COATED SELF-SEALING FUEL LINES BEFORE TEST

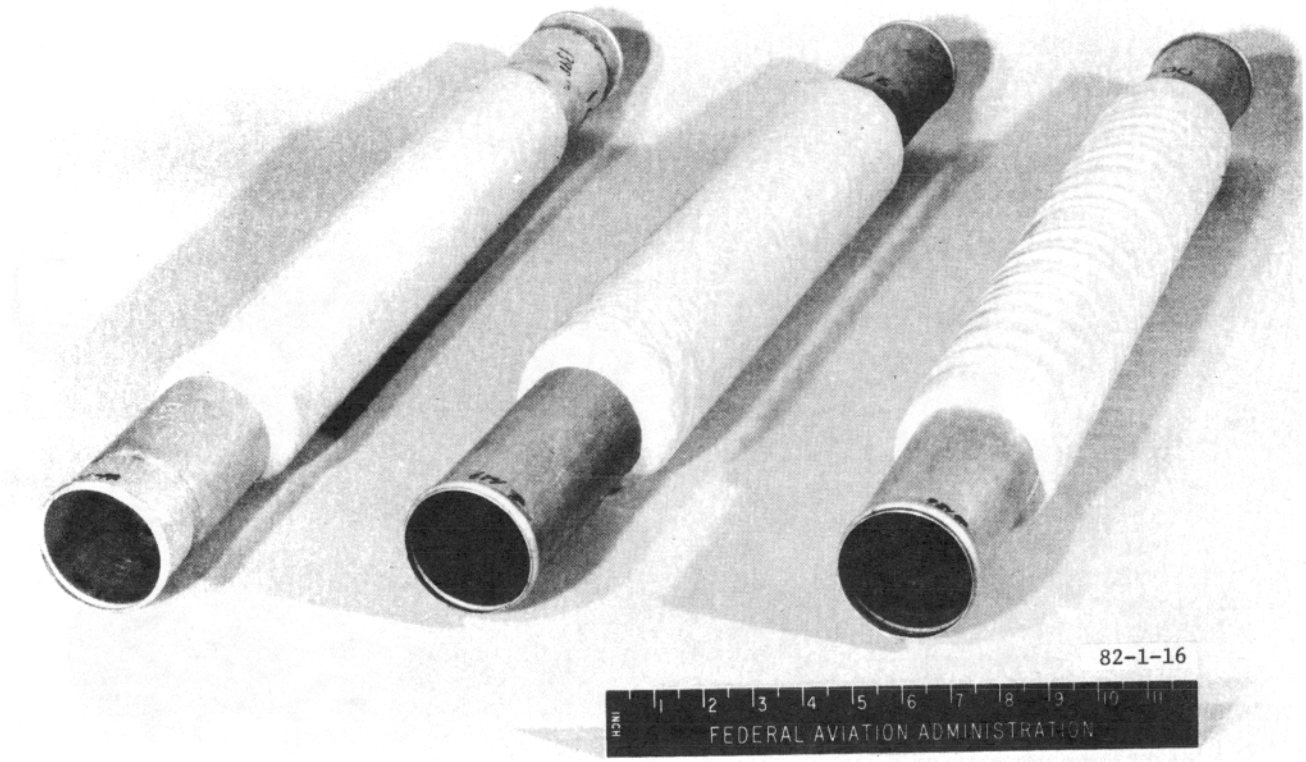


FIGURE 17. TYPICAL AVCO 1600 COATED SELF-SEALING FUEL LINES BEFORE TEST

inches. It was obvious that there was an air pocket between the wrap and the self-seal. This had no apparent effect on its performance under fire test.

It is not known what amount of flexing the intumescents can withstand without becoming detached. With slight flexing of the coated Aeroquip lines, during normal handling, all the intumescents remained intact without cracking or becoming detached from the self-seal surface. There was no severe flexing or tight bends imparted to any of the Aeroquip lines as part of this test program.

The specimens for all tests in the gunfire portion of this test program were McAir Standard, McAir Chem-Milled, Uniroyal, and Aeroquip fuel lines with either a 3M Brand Fire Barrier FS-195 or AVCO 1400 intumescent coating. The total number of new specimens subject to gunfire was 14.

A number of previously burned, coated self-sealing fuel lines were added to the gunfire portion of this project. These samples had been fire tested using either the simulated dry bay test fixture or the FAA standard burner under Part B, Fire Test. These lines, which had prior exposure to heat, were subjected to AP gunfire only. The reason for subjecting these fuel lines to gunfire was to determine what effect prior exposure to fire may have had on self-sealing properties. Nine fuel line samples were selected for these tests.

SECTION II

DISCUSSION

2.1 TEST RESULTS - PART A

2.1.1 Screening Tests. A baseline was established, using uncoated tube specimens, for both test methods, i.e. the simulated dry bay test fixture and the FAA standard burner. The baseline consisted of establishing both a water temperature rise and inside wall temperature rise. Using the dry bay test fixture with the uncoated tube in place, the fuel tray was filled with 1 pint of JP-4 and ignited. Water was circulated through the tube at 0.25 gpm at a pressure of 30 psig. Inside wall temperature and water in and out temperatures were recorded. A similar approach was used to establish a baseline using the FAA standard burner. The fire tests of the coated samples were conducted in a like manner. The flame temperatures recorded using the dry bay test fixture varied generally between 500° and 800° F with some excursions above and below. The recorded flame temperature of the FAA standard burner generally was between 1800° and 2000° F.

The results of the baseline tests were compared to those using the specimens with the intumescent coatings. These results are shown in Tables 4 and 5. The water temperature rise was the most repeatable parameter for comparing the intumescents as insulators. For all tests, the maximum water temperature was attained at the end of the test and was compared with the temperature of the water entering the test article. Likewise, the maximum wall temperature rise was attained at the end of the test and was compared with that at the start of the test. The rate of water temperature rise was determined starting at a point one minute after exposure to the flame and was determined by a least-squares linear regression.

Due to the relatively low intensity of the test flame using the simulated dry bay test fixture, there were only minor differences in measured parameters among the various intumescents. Using the FAA standard burner, these differences became more pronounced. The coatings offering the greatest resistance to heat transfer were the 3M (3 mm) and Ocean 1-112D identified by Footnote 2 in Table 5. The reader must be made aware, however, why the same Ocean Chemical product was divided into two separate groupings. As noted previously, there was little consistency in coating thickness of the Ocean intumescents. In this particular instance a distinction was made according to applied coating weight. That grouping identified by Footnote 2 had an average weight area density of 1.03 lb/ft^2, whereas that identified by Footnote 3 had an average weight area density 0.50 lb/ft^2. The two AVCO products performed nearly equally, with the data indicating that the 1400 provided slightly better insulation.

When comparing the same product, there was little difference in the char developed by either the dry bay fixture or the FAA standard burner. Typical results are shown in Figures 18 through 23. It is surmised that the underlying aluminum tube, cooled by the circulating water, affected the intumescing action by limiting its growth. As described in a following section of this report, when the intumescent product was applied over an insulating sublayer, namely the self seal, the intumescing action increased. Figures 7 through 11 show the intumescent products as applied to the aluminum tubes prior to testing. Figures 18 through 22 show specimens after testing in the dry bay test fixture, and Figure 23 shows a typical result of exposure of the coated aluminum tubes to the FAA burner. The

TABLE 4. SUMMARY OF TEST RESULTS USING THE SIMULATED DRY BAY TEST FIXTURE - PART A(1)

(Test Duration - 10 minutes)

Coating	Water Temp. Rise (°F)	Wall Temp. Rise (°F)	Rate of Water Temp. Rise (°F/min.)
None	57.1	105.5	6.6
AVCO 1600	10.4	34.6	1.2
AVCO 1400	12.2	34.0	1.2
3M (2mm)	9.0	31.0	1.1
3M (3mm)	7.9	28.7	0.9
Ocean 47135	10.2	29.3	1.4
Ocean 1-112D	6.7	25.1	0.8

Notes:

(1) Average of four tests

TABLE 5. SUMMARY OF TEST RESULTS USING THE FAA STANDARD BURNER - PART A(1)

(Test Duration - 5 minutes)

Coating	Water Temp. Rise (°F)	Wall Temp. Rise (°F)	Rate of Water Temp. Rise (°F/min.)
None	52.0	150 (approx.)	11.1
AVCO 1600	40.2	139.9	8.6
AVCO 1400	38.9	137.1	8.2
3M (2mm)	15.3	66.8	3.4
3M (3mm)	11.1	52.0	2.7
Ocean 47135	29.1	107.2	6.2
Ocean 1-112D(2)	12.3	71.9	2.3
Ocean 1-112D(3)	29.0	122.5	6.2

Notes:

(1) Average of four tests except as noted in (2) and (3)
(2) Average of two tests
(3) Average of two tests

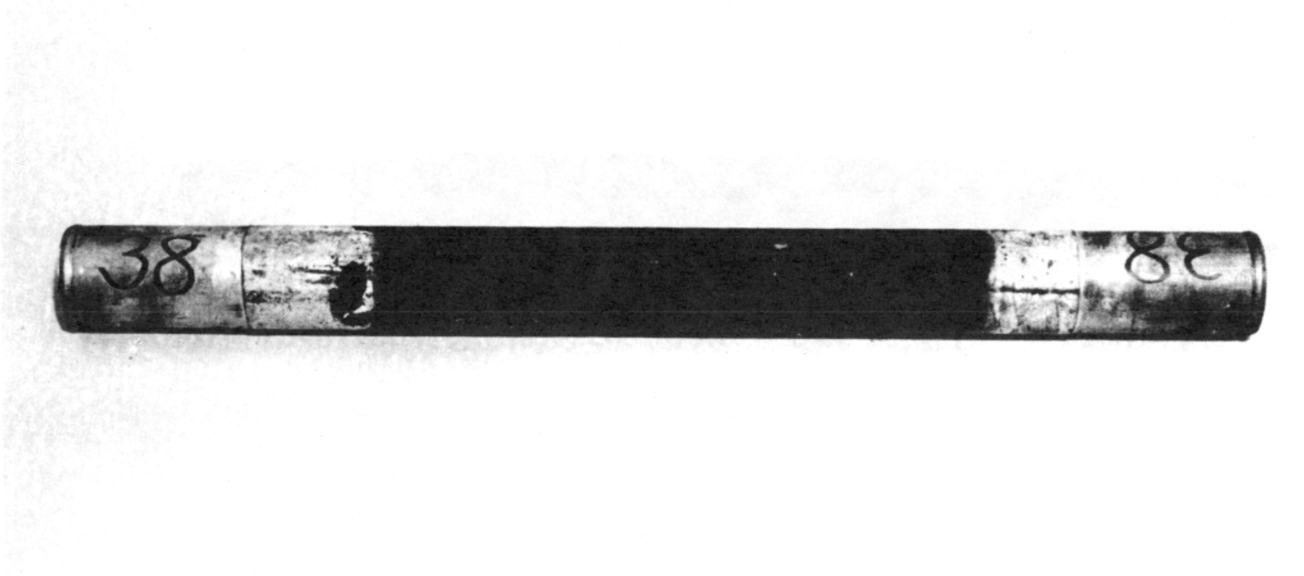


FIGURE 18. TYPICAL AVCO 1600 COATED ALUMINUM TUBE AFTER TEST IN DRY BAY FIXTURE

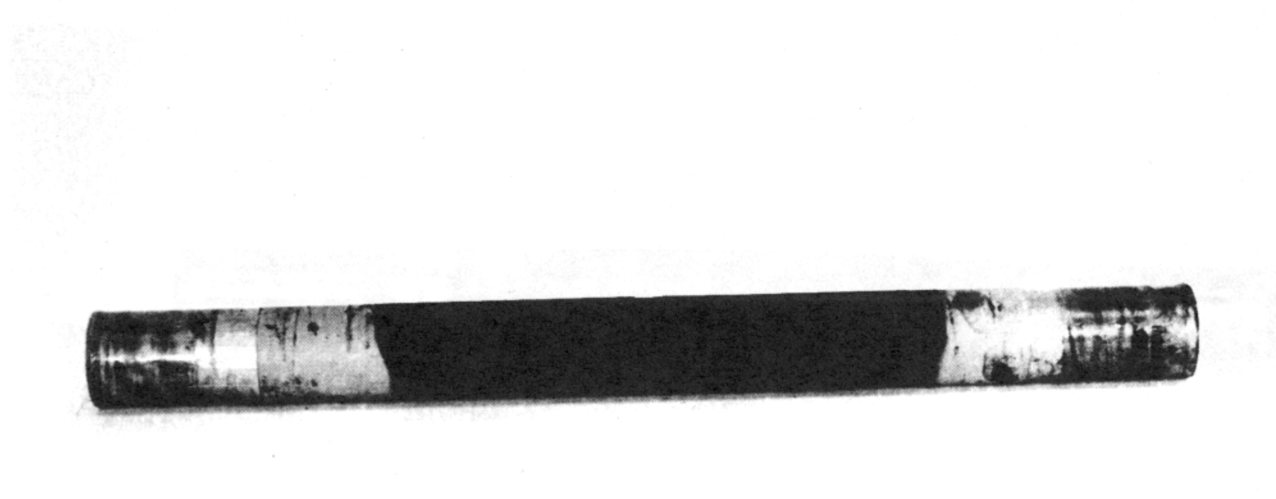


FIGURE 19. TYPICAL AVCO 1400 COATED ALUMINUM TUBE AFTER TEST IN DRY BAY FIXTURE

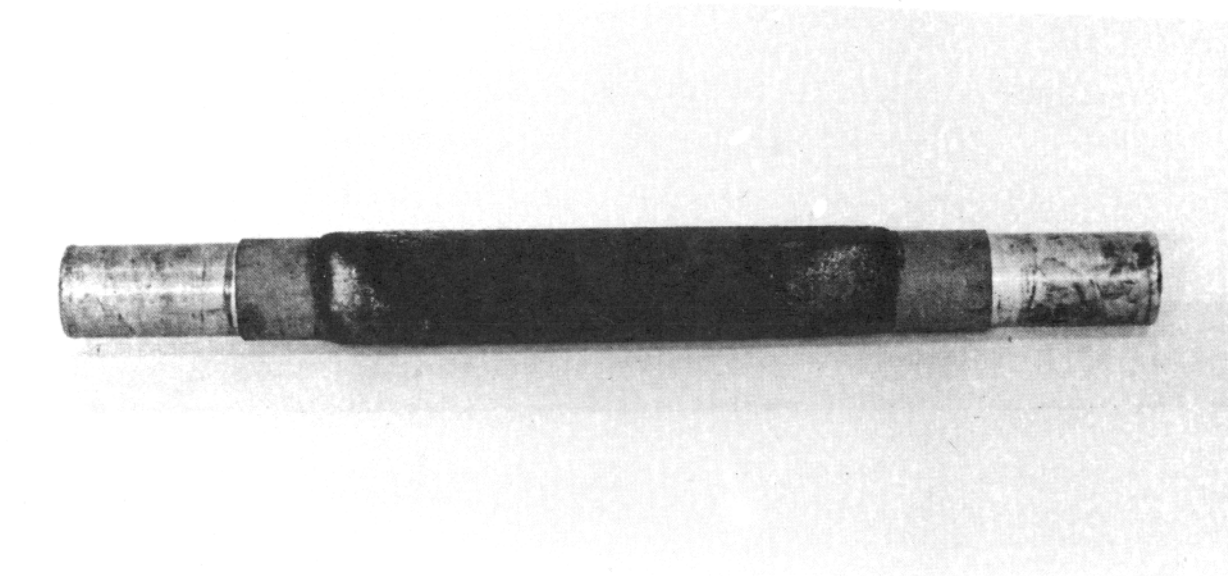


FIGURE 20. TYPICAL 3M COATED ALUMINUM TUBE AFTER TEST IN DRY BAY FIXTURE

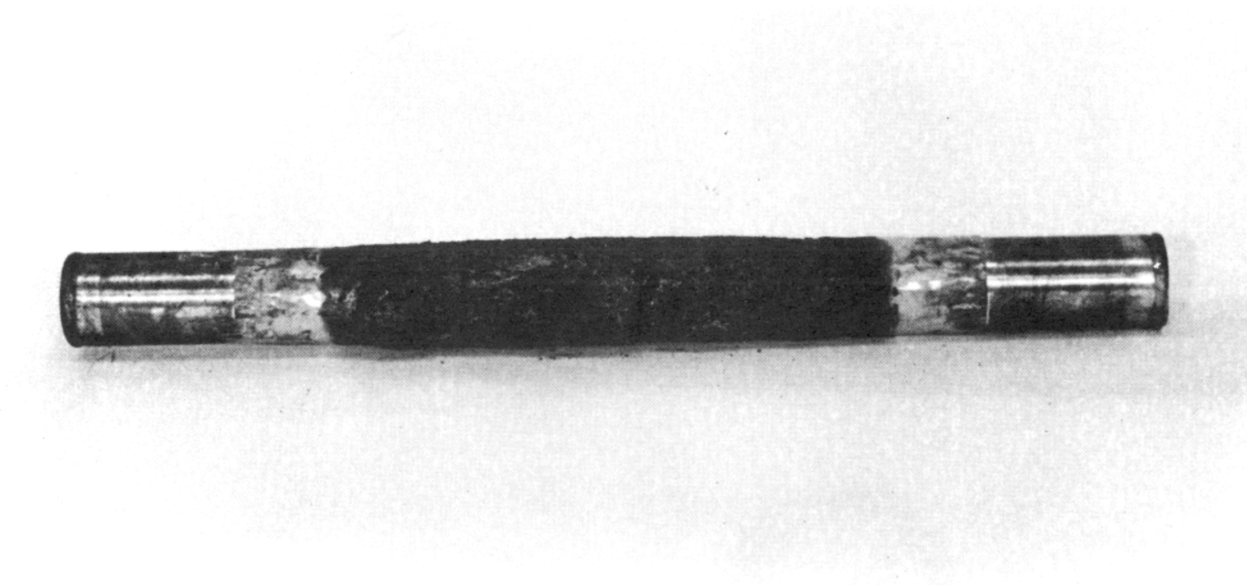


FIGURE 21. TYPICAL OCEAN 47135 COATED ALUMINUM TUBE AFTER TEST IN DRY BAY FIXTURE

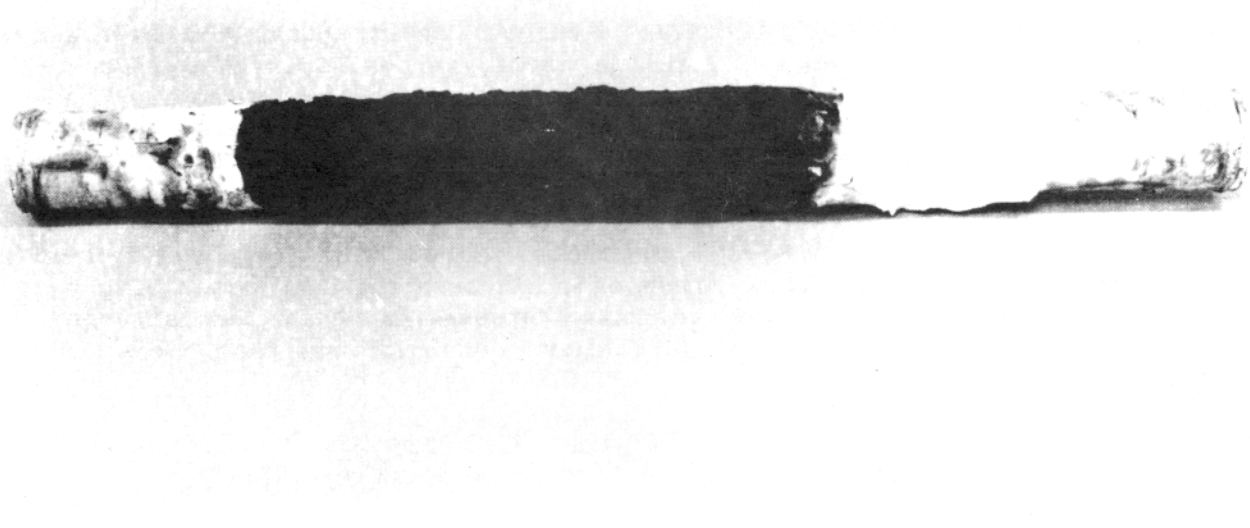


FIGURE 22. TYPICAL OCEAN 1-112D COATED ALUMINUM TUBE AFTER TEST IN DRY BAY FIXTURE

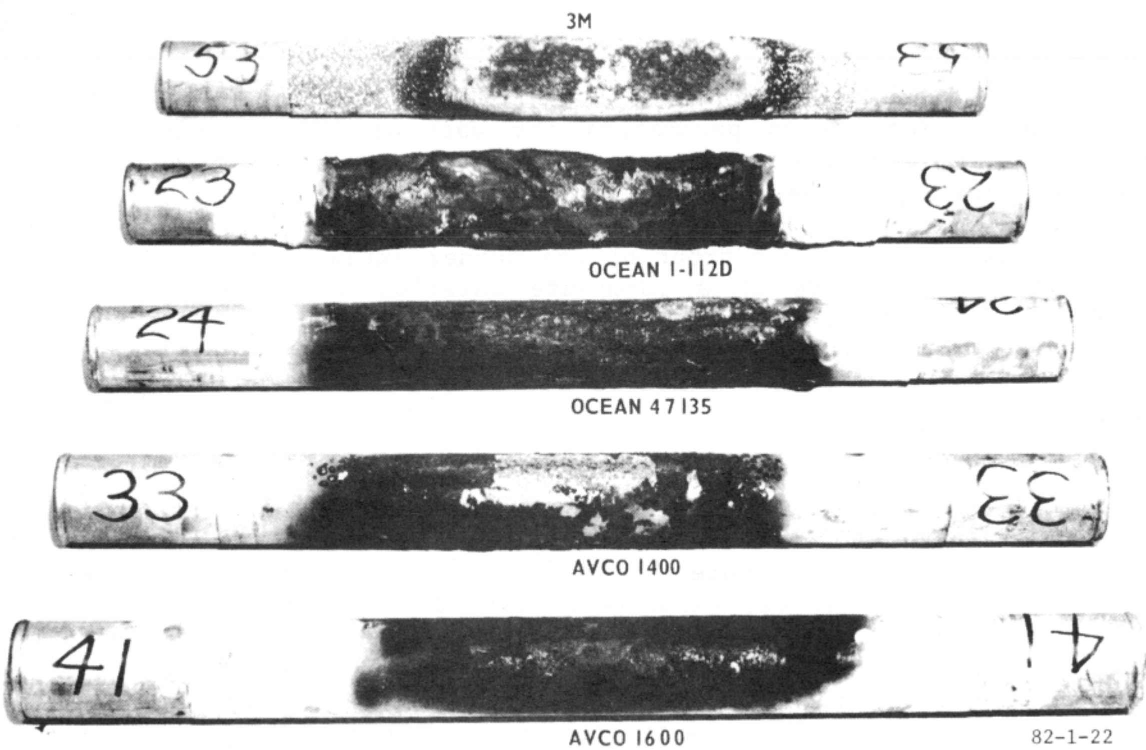


FIGURE 23. TYPICAL COATED ALUMINUM TUBES AFTER TEST WITH FAA STANDARD BURNER

fragile char of the AVCO and Ocean products was damaged in handling, and hence the tubes shown in Figures 18 through 23 do not truly indicate the condition of the tubes immediately following the tests. The lighter colored area visible on the AVCO 1400 coated tube in Figure 23 most readily depict this damage and indicates an area where the char was almost completely jarred loose in handling.

2.1.2 Candidate Selection. The AVCO products, 1400 and 1600, performed very nearly equally. The parameters that were indicative of heat transfer to the aluminum tube and circulating water, as noted in Tables 4 and 5, did not show significant differences. Thus, selection only on that basis was difficult. By mutual agreement between WPAFB and the FAA Technical Center, both AVCO 1400 and 1600 were selected for Part B testing with the primary emphasis on AVCO 1400 because of its slightly tougher char strength. AVCO 1600 coated fuel line specimens were tested using the FAA standard burner only. No Part B tests were conducted in the simulated dry bay fixture with this product, nor were any samples subjected to gunfire.

Of the two 3M Fire Barrier FS-195 products tested, the 2 mm thick wrap was selected over the 3 mm as a weight trade off, although the 3 mm was a slightly better insulator. Neither demonstrated any other properties, e.g. char strength, which would make it superior to the other. Weight consideration then became the deciding factor.

Neither of the Ocean Chemical products, the 47135 nor 1-112D, were selected for Part B testing. The relatively high weight area density (Table 1) and the apparent lack of a suitable application technique of the coating by the supplier were factors in their elimination.

2.2 TEST RESULTS - PART B

2.2.1 Fire Tests (General)

As in Part A, Part B fire testing was conducted in two phases. One phase was conducted with the simulated dry bay test fixture and the other with the FAA standard burner. The common parameters for both of these phases were the pressure and the water flow rate through the test specimens. These were 30 psig and 0.25 gpm, respectively. The positioning of the test specimen in the dry bay fixture is shown in Figure 1. For tests using the FAA standard burner the test specimen was positioned 4 inches in front of the burner extension horn. The tests using the dry bay fixture were of a 10-minute duration while those using the standard burner were 5 minutes in duration. An exception to the specified test duration was that a test would be terminated if a leakage failure occurred before the scheduled end of the test. The schedule of Part B tests (except gunfire) is shown in Table 2.

Since the self-sealing aspect was not a factor during the fire tests, the decision as to whether a particular test specimen failed was tentative and based on arbitrary criteria. Prior to testing, the criteria for failure were established as fulfilling one or more of the following conditions: (1) obvious water leakage in the burn area, (2) exposure of the aluminum tube (not applicable to Aeroquip lines), and (3) sustained burning of the self-seal material at the end of the test. Evidence of conditions (1) and/or (2) would leave little doubt that the fuel line could not function in its self-sealing capacity, since there would already be leakage or the self-seal material had been burned away exposing the underlying aluminum tube. Sustained burning at the termination of the test (condition 3) was an indication that combustion of the self-seal material was taking place and its ability to function as a self-seal would be questionable. At the termination of the tests using the FAA standard burner, no attempt was made to extinguish any posttest burning for several minutes. If appearances were that burning would continue unabated, the fire was extinguished with CO_2. For those tests using the dry bay test fixture, the procedure followed was somewhat different in that the test fire was extinguished with CO_2 at the end of the 10-minute test duration. Since this test method involved a small pan fire, the only convenient means to terminate was to flood the dry bay cavity with CO_2. This procedure also resulted in the extinguishment of any burning of the self-sealing material that may have been taking place. Consequently, only the first two criteria for failure of the test specimen could be applied with certainty.

2.2.2 Fire Tests (Dry Bay). The tests conducted using the simulated dry bay test fixture were for the most part uneventful. The summary of results are shown in Table 6 for coated samples. The wall spacing using the dry bay test fixture was at its maximum separation of 12 inches for all tests. The self-seal material on all uncoated fuel lines was completely burned away. Of itself, the self-seal has no resistance to fire. Typical examples are shown in Figures 24 through 26. It was difficult to ascertain visually if any burning of the self-seal material was taking place during the test, since the specimen was hidden by the test fixture. At the end of the 10-minute duration test, the pan fire was extinguished. This also resulted in the extinguishment of any burning of the self-seal material that might be taking place. It was for this reason that the third of the three criteria for failure was not applied.

Flame temperatures at the surface of the test sample during these tests varied between 500° and 800° F with occasional excursions above and below. The test flame was rather quiescent and consequently there was no erosion of the char due to the action of the flame.

Due to the design of the dry bay test fixture, the test samples could not be readily removed without destroying the char. Consequently close examination of the test sample was difficult, since the examination could only be accomplished while the sample was still mounted in the fixture. The char of the 3M intumescent was very tougn and adhered tightly to the self seal. The only way some of the larger diameter samples (McAir Standard and Uniroyal) could be removed from the test fixture was to peel off the intumescent/char layer from the test sample. The other samples were similarly withdrawn but without removing any material. The char of the AVCO products was not nearly as tougn and broke off as the sample was passed through the circular opening.

As stated, both sidewalls of the dry bay fixture were in place and set at the maximum wall spacing of 12 inches. In no case did the char fill the gap between the test sample and the fixture wall. From the condition of the char it would appear that if the narrowest wall spacing had been used (4 inches), the char would have contacted the sidewalls of the fixture.

Tests using the dry bay fixture were representative of only milder fire environments to which the intumescent protected self-seal line could be exposed. This fixture did not provide suitable means to fully investigate the fire resistance imparted to self-sealing fuel lines by intumescent coatings.

TABLE 6. FUEL LINE DATA SUMMARY USING THE SIMULATED DRY BAY TEST FIXTURE - PART B

Test No.	Max ΔT Water (°F)	Time min:sec	Max ΔT Tube (°F)	Time min:sec	Fuel Line Type	Coating
69	5.7	9:40	-	-	Aeroquip	None
70	4.4	8:00*	-	-	Aeroquip	None
71	29.6	10:00	109.2	10:00	Uniroyal	None
72	33.1	10:00	83.6	9:40	Uniroyal	None
73	33.8	8:40	88.7	8:00	McAir Std.	None
74	33.2	10:00	82.5	9:20	McAir Std.	None
75	34.1	10:00	92.2	10:00	McAir Chem-Milled	None
79	0.9	9:20	2.9	9:40	McAir Std.	3M (2mm)
80	1.3	9:40	2.2	9:40	McAir Std.	3M (2mm)
81	1.3	9:20	2.5	10:00	McAir Std.	3M (2mm)
87	2.9	9:40	9.5	8:40	McAir Chem-Milled	3M (2mm)
90	-	-	5.3	9:40	Uniroyal	3M (2mm)
91	0.5	8:00	8.5	10:00	Uniroyal	3M (2mm)
92	-	-	6.2	9:40	Uniroyal	3M (2mm)
98	2.7	8:40	-	-	Aeroquip	3M (2mm)
99	2.3	8:20	-	-	Aeroquip	3M (2mm)
104	1.4	9:20	3.0	9:40	McAir Std.	1400
105	1.2	9:40	3.8	9:20	McAir Std.	1400
106	1.4	9:20	6.9	9:40	McAir Std.	1400
112	0.8	9:40	12	9:20	McAir Chem-Milled	1400
115	1.2	9:20	7.6	9:40	Uniroyal	1400
116	1.6	9:40	6.4	10.00	Uniroyal	1400
117	1.4	9:20	9.7	10:00	Uniroyal	1400
123	2.4	8:20	-	-	Aeroquip	1400
124	5.2	10:00*	-	-	Aeroquip	1400

* Tube ruptured

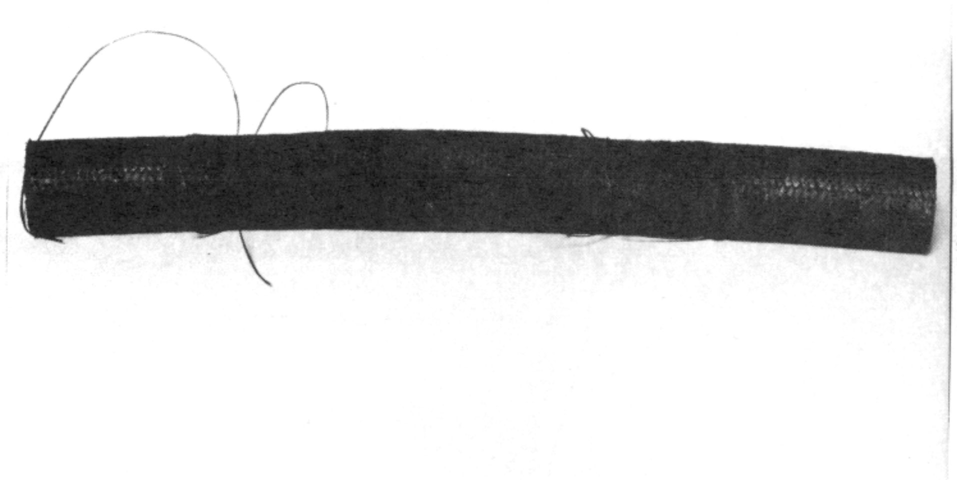


FIGURE 24. TYPICAL UNCOATED AEROQUIP SELF-SEALING FUEL LINE AFTER TEST IN DRY BAY FIXTURE

A summary of the test data for the tests using the dry bay fixture is given in Table 6. The times noted in the third and fifth columns are the times when the maximum rise in water and tube wall temperatures were attained. Where no figure is entered, the data were not available or was suspect. The data does not show any significant differences or trends when comparing the various coatings. Test Sample No. 70, an uncoated Aeroquip hose, ruptured 8 minutes into the test and was the only uncoated sample to do so during testing with the dry bay test fixture. Test Sample No. 124, an Aeroquip line coated with AVCO 1400, ruptured at the very end of the test. Test Samples 104, 105, 106, and 115 did show some evidence of burning of the self-seal upon posttest examination, although again, it was not readily visible during the actual test.

The condition of the coated tubes after testing in the dry bay fixture varied, but in most cases damage was minimal. In no instance was there a failure manifested by the exposure of the underlying aluminum tube and only one line ruptured at the very end of a test. Tube No. 87 (McAir Chem-Milled/3M coating) had some blisters, most of which were broken during the removal of the tube from the fixture. Blistering was a characteristic of the 3M coatings, but did not occur during all tests. Figure 27 shows a blisterd 3M coated tube mounted in the dry bay test fixture. The blisters generally remained intact when not disturbed. One of the blisters on Tube No. 87 did break open at some time prior to the end of the 10-minute test, but it was impossible to determine when the event occurred.

There was some evidence of melting of the self-seal under this blister. The melting most probably occurred after the blister had broken. Another characteristic of the 3M coatings was that cracks appeared in the char parallel to the

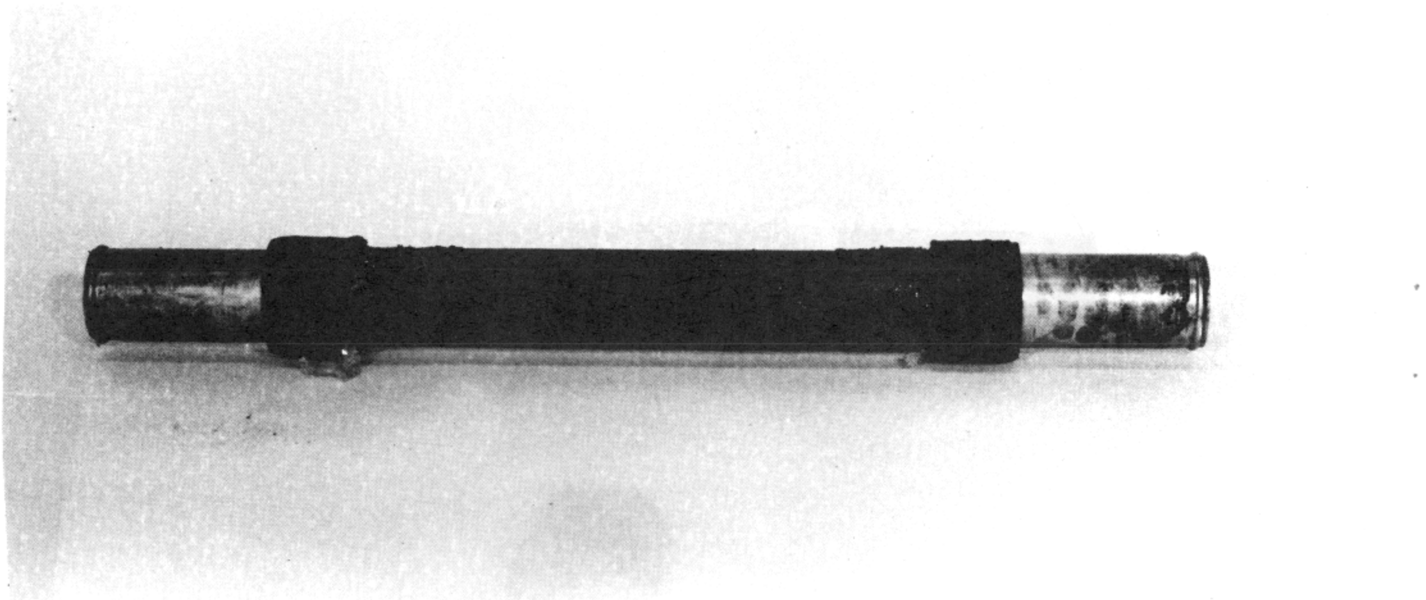


FIGURE 25. TYPICAL UNCOATED UNIROYAL SELF-SEALING FUEL LINE AFTER TEST IN DRY BAY FIXTURE

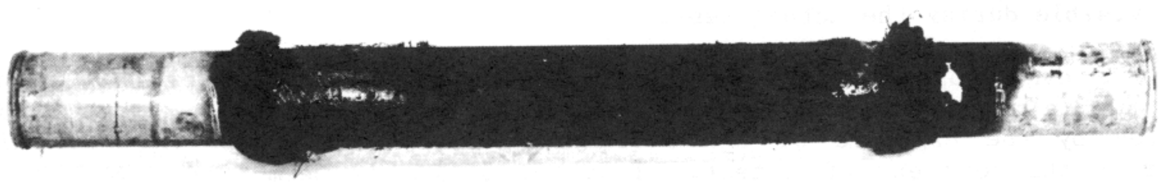


FIGURE 26. TYPICAL UNCOATED McAIR STANDARD SELF-SEALING FUEL LINE AFTER TEST IN DRY BAY FIXTURE

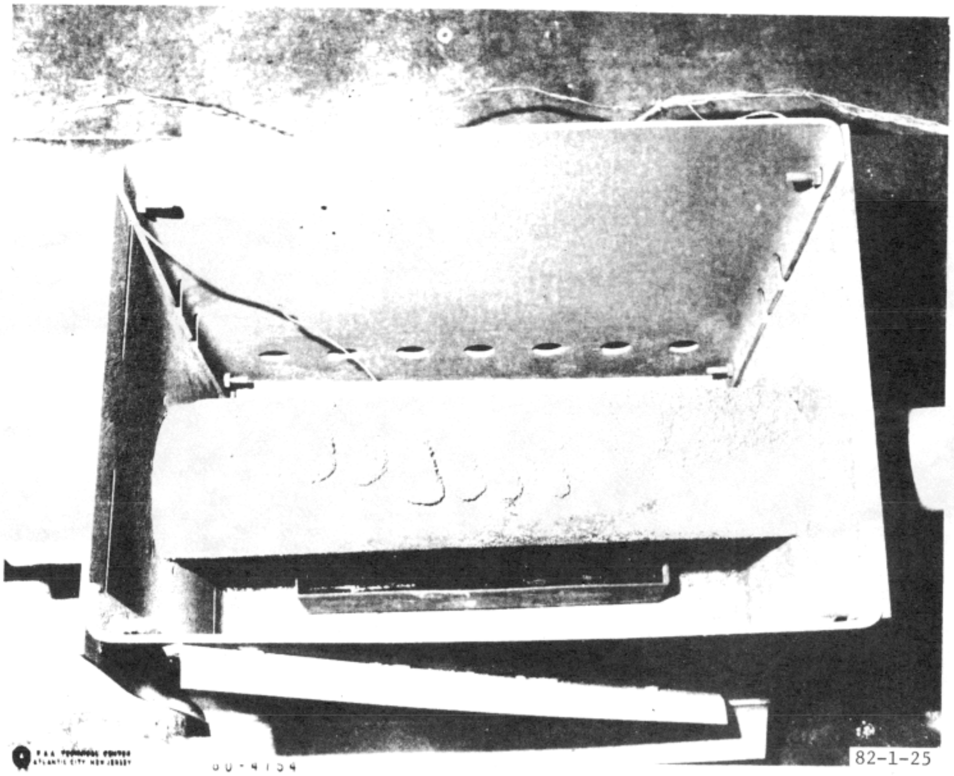


FIGURE 27. 3M COATED SELF-SEALING FUEL LINE SHOWING BLISTERS AFTER TEST IN DRY BAY FIXTURE

centerline of the test specimen. These cracks did not seem to have any detrimental effect during the tests with the dry bay test fixture. Examination of Tube No. 105 (McAir Standard/AVCO 1400) did reveal that some of the self seal had melted away, thus laying bare some of the reinforcing fibers of the self-seal material. Again, it was impossible to determine whether burning actually took place because the specimen was hidden by the test fixture. As will be noted for some tests using the FAA standard burner, where the test article was completely observable, visual evidence indicated that melting of the self-seal material occurred before burning.

Figures 28 through 31 show the condition of coated self-sealing fuel lines after testing in the dry bay test fixture. Figure 29 shows typical Uniroyal fuel lines coated with the 3M and AVCO 1400 intumescents. The 3M intumescent/char was removed prior to withdrawal of the line removal from the test fixture, and then replaced loosely for this figure. Note the blisters and the undamaged self-seal sublayer. In Figure 29, the still readable information placed on the tube by the manufacturer is evidence of the protection afforded by the 3M coating. Most of the loose char on the AVCO 1400 coated tube was knocked off during removal from the fixture, as was the case with all other AVCO 1400 test specimens. For Figure 28, the 3M coating/char was not replaced. Note the virtually undamaged self-seal layer. The fuel line coated with AVCO 1400 shows evidence of melting and possible burning and exposure of the self-seal reinforcing fiber. For the 3M test specimens shown in Figures 30 and 31, the coatings did not have to be removed to separate the specimens from the dry bay test fixture because of their smaller overall diameter. It should be noted that the blisters on the 3M coated specimens were broken upon removal. The AVCO 1400 coated Aeroquip hose, shown in Figure 30, ruptured during testing and a rather long split is evident.

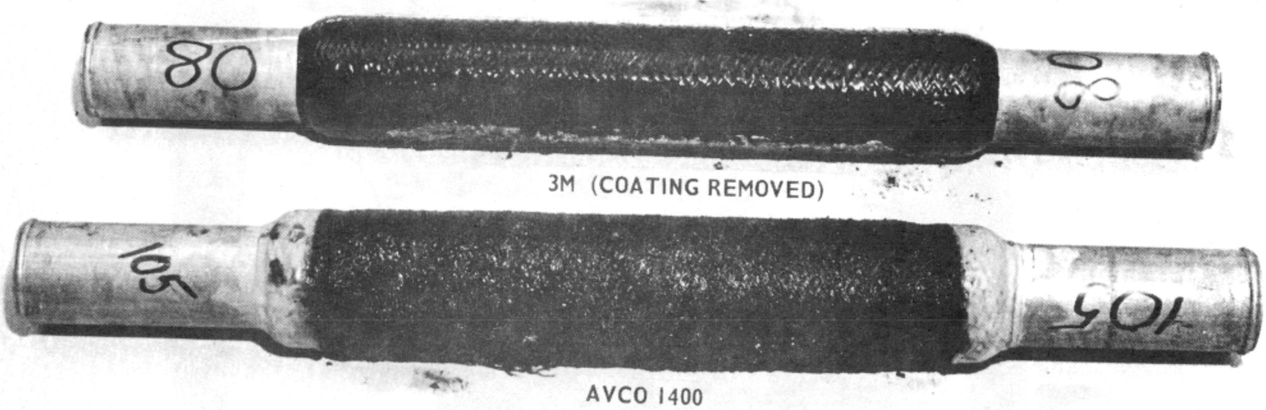


FIGURE 28. TYPICAL COATED McAIR STANDARD SELF-SEALING FUEL LINES AFTER TEST IN DRY BAY FIXTURE

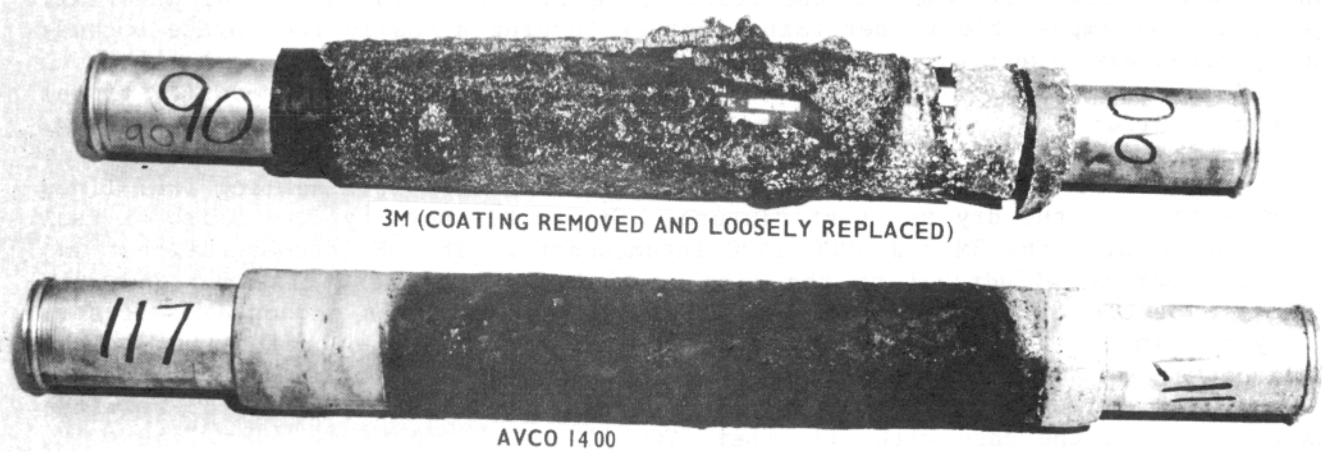


FIGURE 29. TYPICAL COATED UNIROYAL SELF-SEALING FUEL LINES AFTER TEST IN DRY BAY FIXTURE

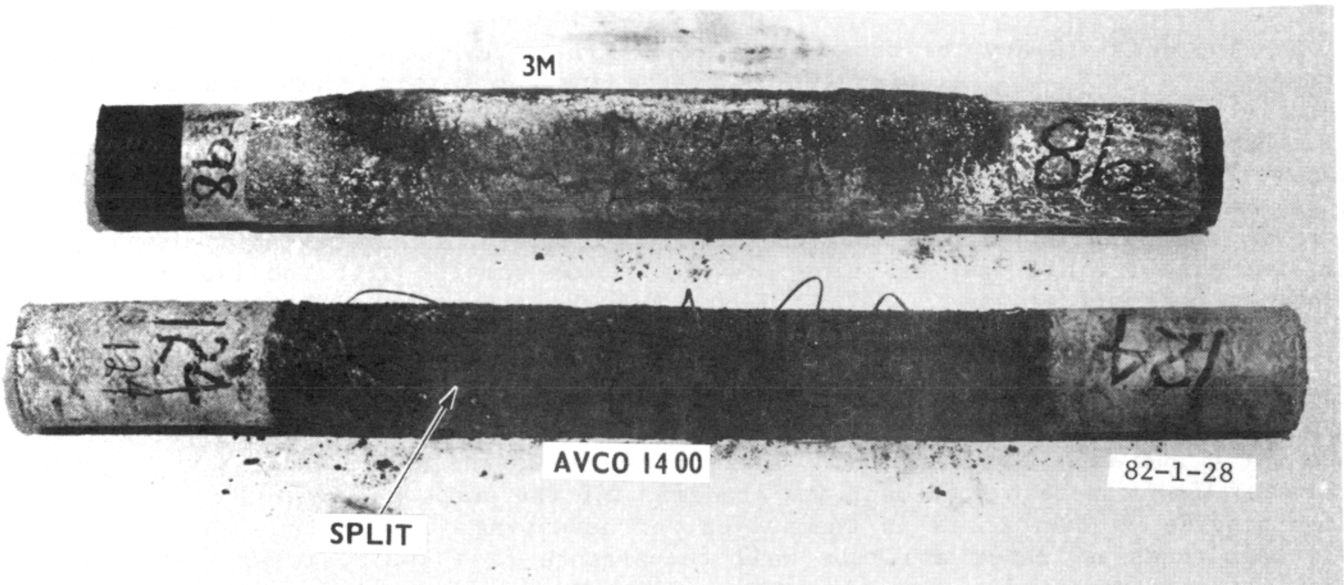


FIGURE 30. TYPICAL COATED AEROQUIP SELF-SEALING FUEL LINES AFTER TEST IN DRY BAY FIXTURE

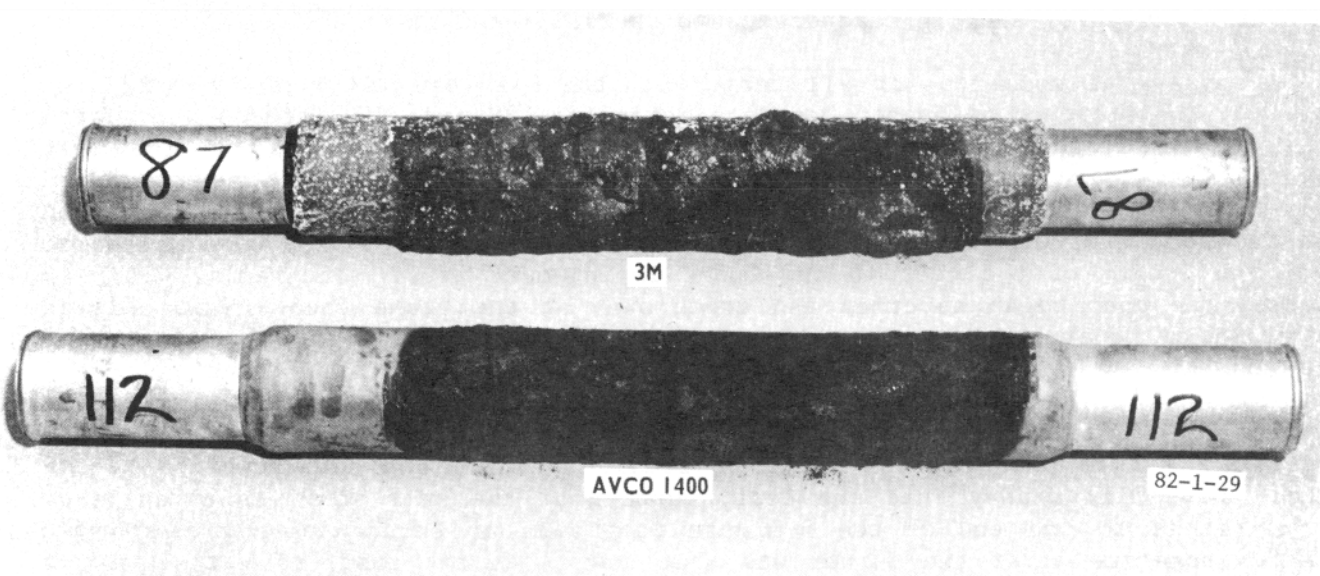


FIGURE 31. TYPICAL COATED McAIR CHEM-MILLED SELF-SEALING FUEL LINES AFTER TEST IN DRY BAY FIXTURE

2.2.3 Fire Tests (FAA Standard Burner). Tests using the FAA standard burner were by far more revealing since these tests provided a more severe environment for assessing the fire protection afforded to the self-sealing fuel lines by intumescent coatings. Thermocouple measured temperatures at the surface of the test article varied between 1800° and 2000° F.

The data summary for those tests conducted using the FAA standard burner is presented in Table 7. As with the simulated dry bay test fixture, the self-seal material on all uncoated fuel lines was completely burned away, thus exposing the aluminum line. The Aeroquip hose burned until a leakage occurred. When comparing the water temperature rise through the various test samples with different coatings, there were measured differences, but not of significant magnitude. The samples with the 3M coating had the smallest temperature differential, with the average rise for all samples being 1.3° F. Those samples with the 1400 and 1600 coatings had average rises of 2.2° F and 4.5° F, respectively. The inside tube wall temperature rise showed greater differences; those with the 3M wrap being the least with an average rise of 5.7° F. The samples coated with the 1400 and 1600 intumescents averaged 14.7° F and 51.2° F, respectively. The burning self-seal material contributed to the overall fire intensity and probably had an effect on the water and wall temperatures. These parameters, which are indicative of heat transfer into the test specimen, are academic for the purpose of these tests, since they provide no firm basis in themselves for assessing intumescent effectiveness. The magnitudes of water and tube wall temperature rise would appear to indicate that all performed well, with one coating, the 3M providing slightly better resistance to heat transfer than the others. Although the coatings undoubtedly do provide a measure of resistance to heat transfer to the fuel line, depending on the condition and effectiveness of the char, a more significant role that the coating plays is its ability to delay the onset of destructive intrusion of the test flame. This delay would allow the self-seal material to maintain its integrity and provide additional resistance to heat transfer. In this regard, the 3M coating displayed the greatest resistance to flame penetration of the coatings tested and therefore offered the greatest protection to the self-seal material. This was largely due to the char's integrity and tight adherence to the self-seal material.

A summary of comments for all tests with the FAA standard burner is given in Table 8. The sequence of events when subjecting the 3M and AVCO intumescent coated lines to the standard burner had some similarities initially, but as the test progressed the similarities ended. During the test of an AVCO intumescent coated line, intumescing began almost immediately after the flames of the burner impinged upon the test sample. Within 1 minute small flames appeared which were scattered along the length of the tube in the flame impingement area. Generally, within 2 minutes, the char began to crack and erode away at the flame face. This allowed the flame to penetrate the char which caused the self-seal material to begin to melt and burn. Frequently large pieces of char or pieces of softened self-seal material with char still attached fell off exposing yet more of the self-seal material to the test flame. As the self seal softened, the intumescent layer no longer had a firm substrate on which to remain attached and deterioration became rapid. Generally midway into the test, burning of the self seal was established and continued to the end of the 5-minute test and was subsequently extinguished with CO_2 sometime after the burner was shut down. At the onset of a test with a 3M coated line, white spots appeared on the surface of the intumescent wrap at the

TABLE 7. FUEL LINE DATA SUMMARY USING FAA STANDARD BURNER - PART B

Test No.	Max. ΔT Water (°F)	Time (min:sec)	Max. ΔT Tube (°F)	Time (min:sec)	Fuel Line Type	Coating	Remarks
76	37.9	5:00	>300	5:00	McAir Std.	None	Leakage failure @ 5:00
77	35.9	5:00	102.5	5:00	McAir Chem-Milled	None	
78	1.2	2:17	-	-	Aeroquip	None	Leakage failure @ 2:17
82	1.4	5:00	3.9	5:00	McAir Std.	3M	
83	1.6	5:00	3.8	5:00	McAir Std.	3M	
84	0	5:00	4.9	5:00	McAir Std.	3M	
88	1.7	5:00	11.5	5:00	McAir Chem-Milled	3M	
93	0.4	5:00	6.1	5:00	Uniroyal	3M	
94	1.3	5:00	4.8	5:00	Uniroyal	3M	
95	1.3	5:00	5.2	5:00	Uniroyal	3M	
100	1.8	5:00	-	-	Aeroquip	3M	
101	2.2	5:00	-	-	Aeroquip	3M	
107	0	5:00	6.3	5:00	McAir Std.	1400S	
108	-	-	8.5	5:00	McAir Std.	1400S	
109	1.5	5:00	8.0	5:00	McAir Std.	1400S	
113	3.1	5:00	21.2	5:00	McAir Chem-Milled	1400S	
118	1.7	5:00	13.7	5:00	Uniroyal	1400S	
119	2.8	5:00	21.8	5:00	Uniroyal	1400S	
120	-	-	24.0	5:00	Uniroyal	1400S	
125	2.1	3:20	-	-	Aeroquip	1400S	Leakage failure @ 3:20
126	4.2	4:20	-	-	Aeroquip	1400S	Leakage failure @ 4:20
129	2.8	5:00	41.5	5:00	McAir Std.	1600	
130	3.7	5:00	71.5	5:00	McAir Std.	1600	
131	4.3	5:00	96.6	5:00	McAir Std.	1600	
132	5.6	5:00	44.5	5:00	McAir Chem-Milled	1600	
133	6.3	5:00	60.0	5:00	McAir Chem-Milled	1600	
134	4.4	5:00	45.7	5:00	Uniroyal	1600	
135	4.7	5:00	24.6	5:00	Uniroyal	1600	
136	-	-	25.8	5:00	Uniroyal	1600	
138	9.0	5:00	105.3	5:00	Uniroyal	None	

TABLE 8. COMMENT SUMMARY: TESTS USING FAA BURNER - PART B

Sample No.	Hose Type	Coating	Remarks (Time min:sec)
76	McAir Standard	None	<:15 self-seal (ss) dripping 3:00 large piece of ss fell off 5:00 water leakage through tub burning continuous, SS destroyed (failure)
77	McAir Chem-Milled	None	<1:00 ss dripping 2:05 Aluminum tube exposed <4:00 water oozing through tube at center, burning continuous, ss destroyed (failure)
78	Aeroquip	None	2:17 hose ruptured (failure)
138	Uniroyal	None	<1:00 ss burning <2:00 ss dripping 2:40 ss dripping and burning continuous, ss destroyed (failure)
107	McAir Standard	1400	<1:00 ss burning 3:15 ss dripping 5:00 burning continuous (failure)
108	McAir Standard	1400	<:05 intumescing begins <1:00 small pockets of flame along tube <2:00 ss burning <4:00 burning drops of ss 5:00 burning continuous (failure)
109	McAir Standard	1400	<:05 intumescing begins 1:30 sample smoking <2:00 ss burning 3:20 burning drops of ss 5:00 burning continuous (failure)
118	Uniroyal	1400	<:05 intumescing begins 1:15 ss burning 1:30 char lifts up at top 2:30 ss melting and dripping through char 5:00 burning continuous (failure)

Note: ss is self-seal

TABLE 8. COMMENT SUMMARY: TESTS USING FAA BURNER - PART B (Continued)

Sample No.	Hose Type	Coating	Remarks (Time min:sec)
119	Uniroyal	1400	<:05 intumescing begins 1:20 flame pockets along tube 2:30 burning drops of ss 4:15 char destroyed at flame face 5:00 burning continuous (failure)
120	Uniroyal	1400	<:05 intumescing begins 1:30 char cracking 1:45 char eroding at flame face 2:15 burning drops of ss 3:00 dripping increasing and burning on table 3:30 aluminum tube exposed 4:00 large piece of char fell off 5:00 burning continuous, aluminum tube exposed, ss and char destroyed (failure)
125	Aeroquip	1400	<2:00 ss burning 3:20 hose ruptures (failure)
126	Aeroquip	1400	1:00 burning drops of ss 3:00 hose burning 4:20 hose ruptures (failure)
113	McAir Chem-Milled	1400	<:05 intumescing begins 1:15 ss burning through char 4:20 ss dripping but not burning 5:00 burning continuous
129	Standard	1600	<:05 intumescing begins 3:00 ss dripping 3:15 aluminum tube exposed 5:00 burning continuous (failure)
130	McAir Standard	1600	<:05 intumescing begins <1:00 ss burning <2:00 char sagging at bottom, burning drops 2:15 large piece of char fell off 5:00 burning continuous, aluminum tube exposed, char and ss destroyed (failure)

Note: ss is self-seal

TABLE 8. COMMENT SUMMARY: TESTS USING FAA BURNER - PART B (Continued)

Sample No.	Hose Type	Coating	Remarks (Time min:sec)
131	McAir Standard	1600	<:05 intumescing begins :40 flame pockets along tube 1:00 tube burning 1:40 char and ss fell off, tube exposed 5:00 burning continuous (failure)
134	Uniroyal	1600	<:05 intumescing begins 1:00 ss burning through char 1:30 char peels up at top 2:30 char flaking off in small pieces, erosion at flame face 5:00 burning continuous, aluminum tube exposed ss destroyed (failure)
135	Uniroyal	1600	<:05 intumescing begins <1:00 flame pockets along tube, erosion of char at flame face <2:00 burner flame penetrates char <3:00 burning drops of ss, tube burning 5:00 burning continuous, aluminum tube exposed (failure)
136	Uniroyal	1600	<:05 intumescing begins <1:00 ss burning, erosion of char at flame face 2:15 char falling off, burning drops of ss 4:40 large piece of char falls off, aluminum tube exposed 5:00 burning continuous, ss and char destroyed, aluminum tube exposed (failure)

Note: ss is self-seal

TABLE 8. COMMENT SUMMARY: TESTS USING FAA BURNER - PART B (Continued)

Sample No.	Hose Type	Coating	Remarks (Time min:sec)
132	McAir Chem-Milled	1600	<:05 intumescing begins <1:00 flame pockets along tube 1:20 ss dripping through char but not burning <2:00 burning drops of ss erosion of char at flame face 5:00 burning continuous (failure)
133	McAir Chem-Milled	1600	<:05 intumescing begins <1:00 flame pockets along tube <2:00 burner flame penetrates char 2:15 burning drops of ss <3:00 large piece of char falls off, ss melting and burning 5:00 burning continuous, ss and char destroyed (failure)
82	McAir Standard	3M	<5:00 some cracks in char 5:00 tube smoking briefly after test
83	McAir Standard	3M	<:20 white spots followed by dark char 3:00 cracks in char 5:00 some smoking, no burning
84	McAir Standard	3M	<:20 white spots followed by dark char 2:30 cracks in char 3:30 some flame pockets along tube 5:00 smoking, small flame out in 35 sec (failure)
93	Uniroyal	3M	<:20 white spots followed by dark char <3:00 char cracking 4:15 burner malfunction 7:15 (approx) burner relit for 45 sec. 8:00 no smoking, no burning
94	Uniroyal	3M	5:00 cracks in char, smoking, no burning

Note: ss is self-seal

TABLE 8. COMMENT SUMMARY: TESTS USING FAA BURNER - PART B (Continued)

Sample No.	Hose Type	Coating	Remarks (Time min:sec)
95	Uniroyal	3M	2:00 char blister opens, ss probably exposed 5:00 burning continuous at open char area, self-extinguished in approx. 2 min. (failure)
100	Aeroquip	3M	5:00 smoking, no burning
101	Aeroquip	3M	5:00 small flame out in 30 sec, smoking, hose did not leak (failure)
88	McAir Chem-Milled	3M	<:20 white spots followed by dark char <3:00 char cracking 5:00 smoking, no burning

Note: ss is self seal

flame impingement area almost immediately, followed by a dark char. Within 1 to 3 minutes, small flames, noted as flame pockets in Table 8, appeared along the tube in the flame impingement area similar to those in tests with the AVCO coated lines. Blisters appeared within 2 minutes if they appeared at all, followed by longitudinal cracks in the char. At the end of the 5-minute test there was smoke emanating from the tube, which in some cases was accompanied by a short-lived and very localized burning. The origin of the smoking is not known. It could have been some volatile product from the intumescent char or from the self seal itself. When there was no burning at the end of the test, the self seal was generally firm with minor heat damage and the 3M char was still firmly attached. This casts some doubt as the self-seal material being the origin of the smoking.

With regard to Table 8, the first noteworthy input of this table is that all test specimens coated with AVCO 1400 and 1600 satisfied the pre-established criteria for failure described in Paragraph 2.2.1. Additionally, Test Samples 84, 95, and 101, which were coated with the 3M intumescent wrap displayed some burning at the end of the 5-minute test duration and therefore were noted as failures. However, the burning that was taking place at the end of the test of these samples was much less intense than that which occured with those samples not coated with the 3M wrap. Of Samples 84, 95, and 101, the one that most fit the failure criteria was Sample No. 95. A blister opened on Sample No. 95 which exposed the self-seal material, and posttest burning continued for about 2 minutes. For these three samples, the resultant burning at the end of the test could be described as a small flickering flame, whereas the posttest fire of those samples not coated with the 3M intumescent was by far more severe. In no instance was it necessary to extinguish a posttest fire with CO_2 when the 3M intumescent was tested, since the small flame soon self extinguished.

The char thickness of the 3M product was fairly consistent at approximately 1 inch in the burn area. The char thickness of the AVCO products generally grew to slightly more than 2 inches in the area facing the burner. Some of this char eroded away as the test progressed. In some instances, the char of the AVCO products fell away allowing a more rapid destructive intrusion of the test flame, e.g. Test Nos. 130 and 131. In other instances, the char opened or lifted away from the test sample without initially falling off, thus, also exposing the self-seal to the test flame, as in Test No. 118. There were also tests with AVCO products where the char remained relatively intact, yet flames or dripping, melted, self-seal material emerged through rents in the char as in Test Nos. 113, 134, and 133. Although there were cracks in the char of the 3M intumescent wrap, no detrimental effect was evident. When the cracks in the 3M char opened widely (e.g. Tube Nos. 84 and 101) there was a short-lived flickering flame at the end of the test. Of the three 3M coated samples with surface discontinuities, noted in Paragraph 1.4.3, only Sample No. 88 was used with the standard burner. The surface discontinuities on Sample No. 88 had no apparent detrimental effect. These small openings closed as the coatings intumesced. In no instance did the char of the 3M intumescent wrap fall away from the test specimen during testing.

Uncoated Samples 76 and 77, in addition to having the self-seal largely destroyed, failed by leaking water through the tube wall in the flame impingement area. These were the only aluminum tube core samples, coated or uncoated, which failed in this manner. In both samples, relatively large areas of aluminum tube became directly exposed to the burner flame early in the test because of the self-seal material falling away. Of the two samples, the leakage from Sample No. 76 could be described as a drip whereas that from Sample No. 77 appeared to be more of an oozing or seeping of water.

Figures 32 through 35 show typical coated self-sealing fuel lines after testing with the FAA standard burner. Note the obvious damage to the AVCO 1400 and 1600 coated fuel lines. All failed because of posttest burning. Figure 36 shows the posttest burning and Figure 37 shows the results of the posttest burning. Although these figures depict a McAir Standard self-sealing fuel line coated with AVCO 1600, the results are typical of all coated self-sealing lines except those protected with 3M Fire Barrier. In Figure 33, note the blister in the 3M coated Uniroyal sample that had opened some time during testing. This was a sample that was termed a failure because of posttest burning. In Figure 34, half of the 3M coating was removed to show the relatively minor amount of damage to the self-seal. This specimen was also termed a failure in accordance with the previously established criteria for failure. The posttest burning was slight, however, and the small flickering flame self-extinguished 30 seconds after the burner was shut down. In Figure 35 a portion of the 3M char/intumescent layer was removed from the flame impingement area on the McAir Chem-Milled sample. Note the relatively undamaged self-seal.

Figures 38 and 39 are presented to depict typical trends of the inside aluminum tube wall and water temperature rise with time. Presenting all the data in this manner would have offered no additional insight in assessing intumescent effectiveness. As stated previously, the aspect deemed more significant was the ability of the coating/char to delay destructive intrusion of the test flame.

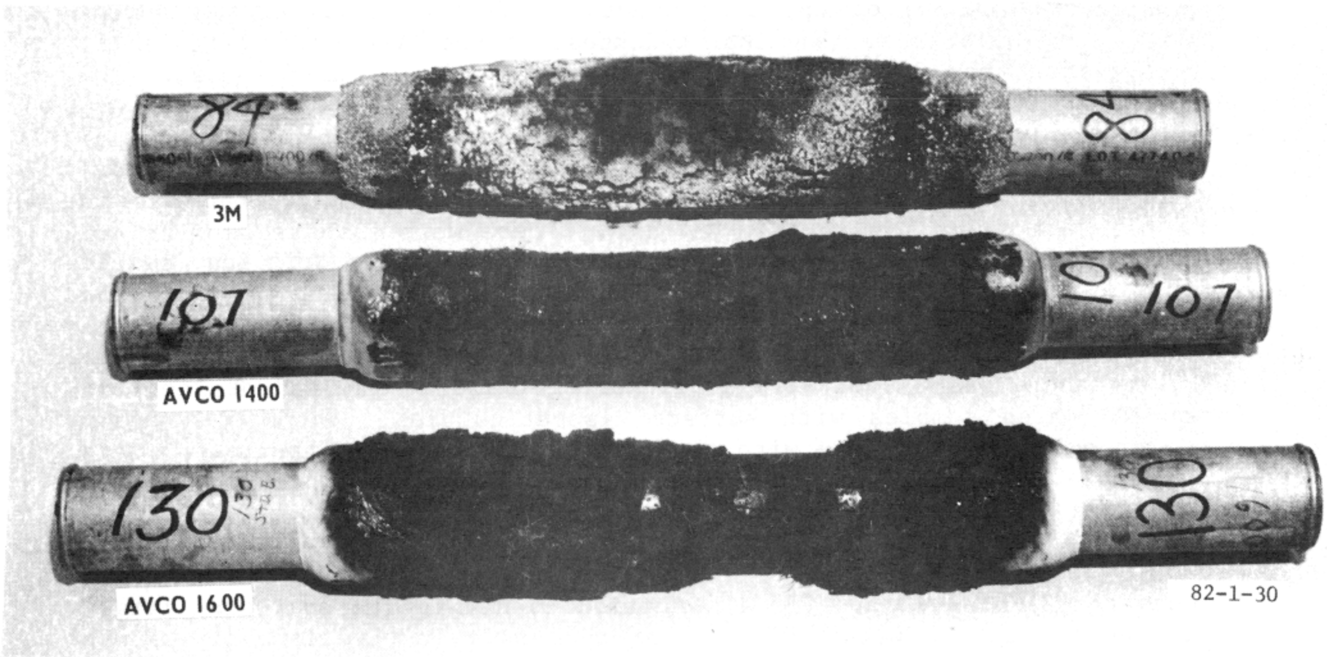


FIGURE 32. TYPICAL COATED McAIR STANDARD SELF-SEALING FUEL LINES AFTER TEST WITH FAA STANDARD BURNER

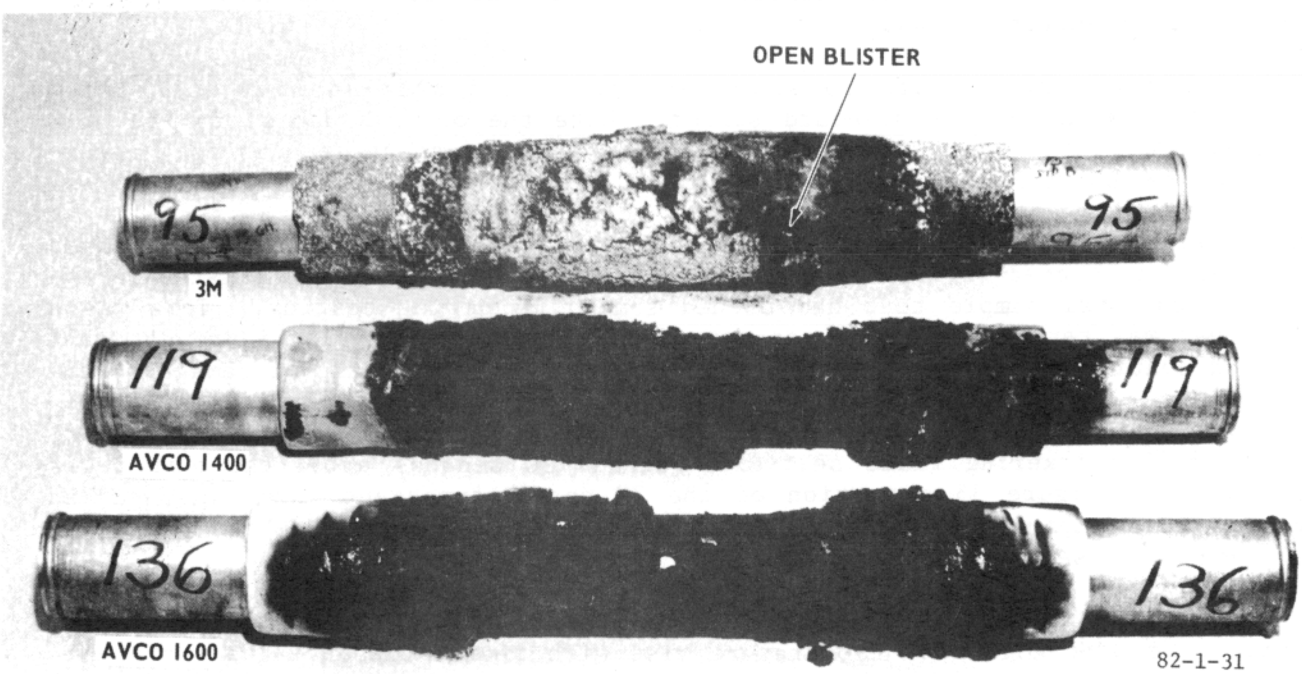


FIGURE 33. TYPICAL COATED UNIROYAL SELF-SEALING FUEL LINES AFTER TEST WITH FAA STANDARD BURNER

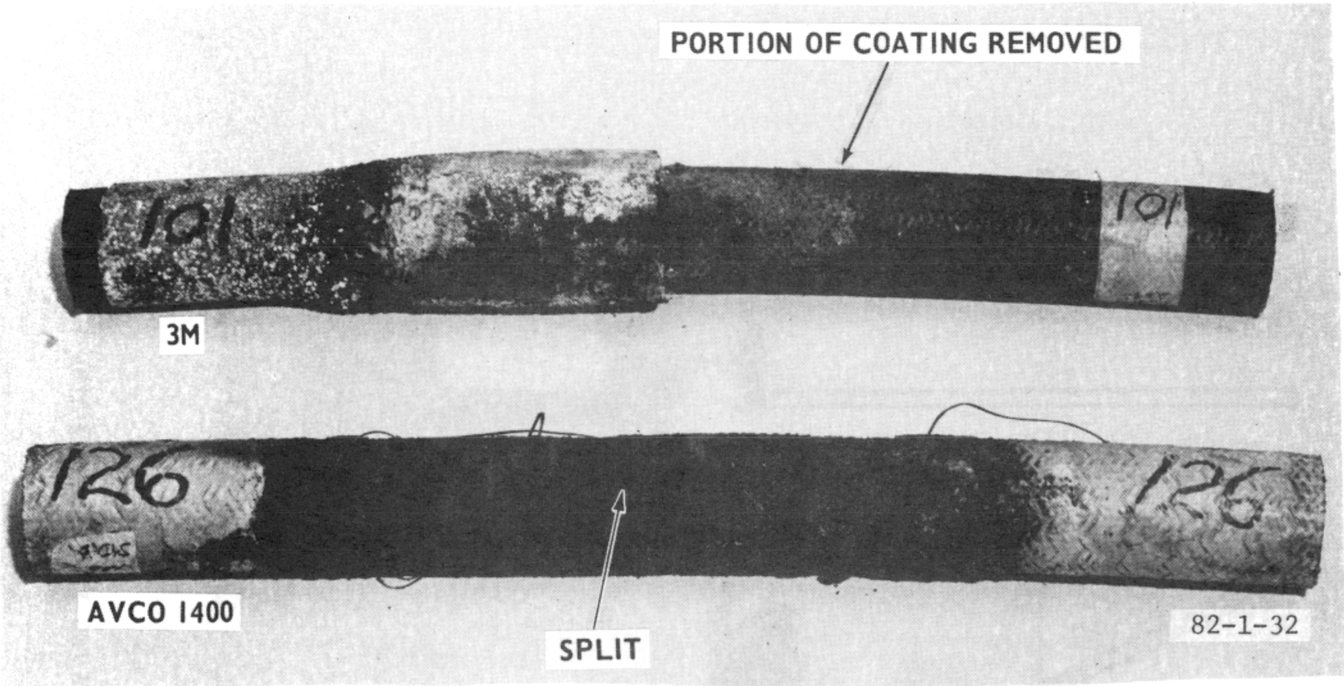


FIGURE 34. TYPICAL COATED AEROQUIP SELF-SEALING FUEL LINES AFTER TEST WITH FAA STANDARD BURNER

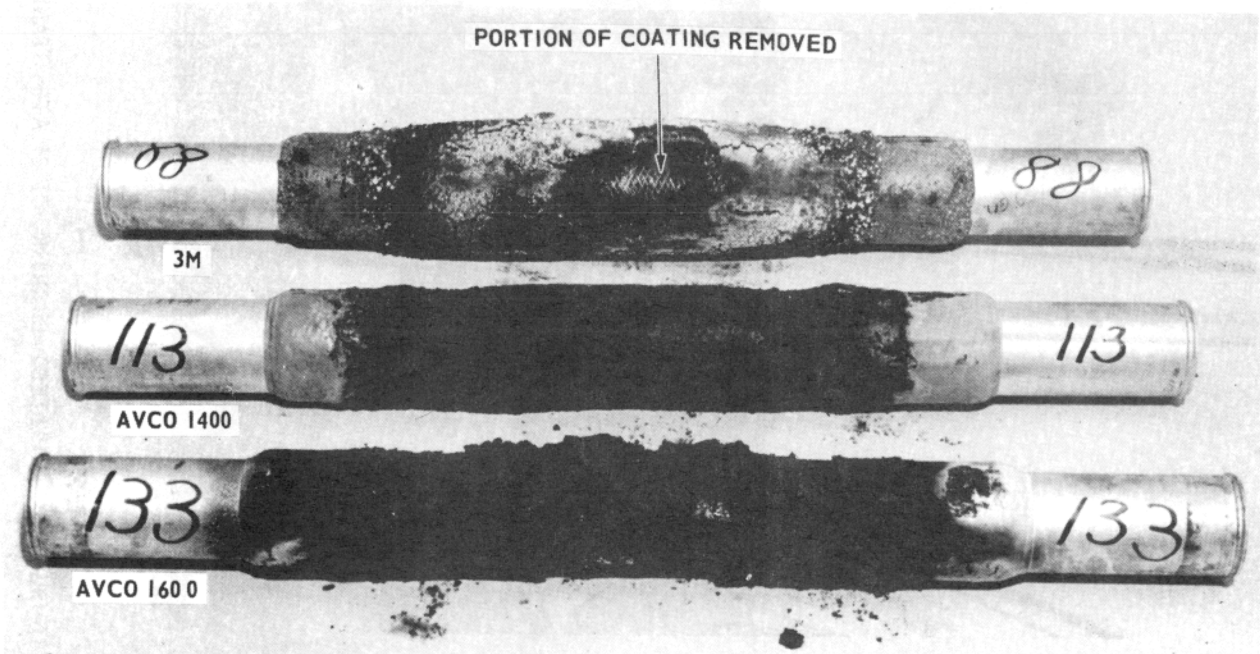


FIGURE 35. TYPICAL COATED McAIR CHEM-MILLED SELF-SEALING TEST WITH FAA STANDARD BURNER

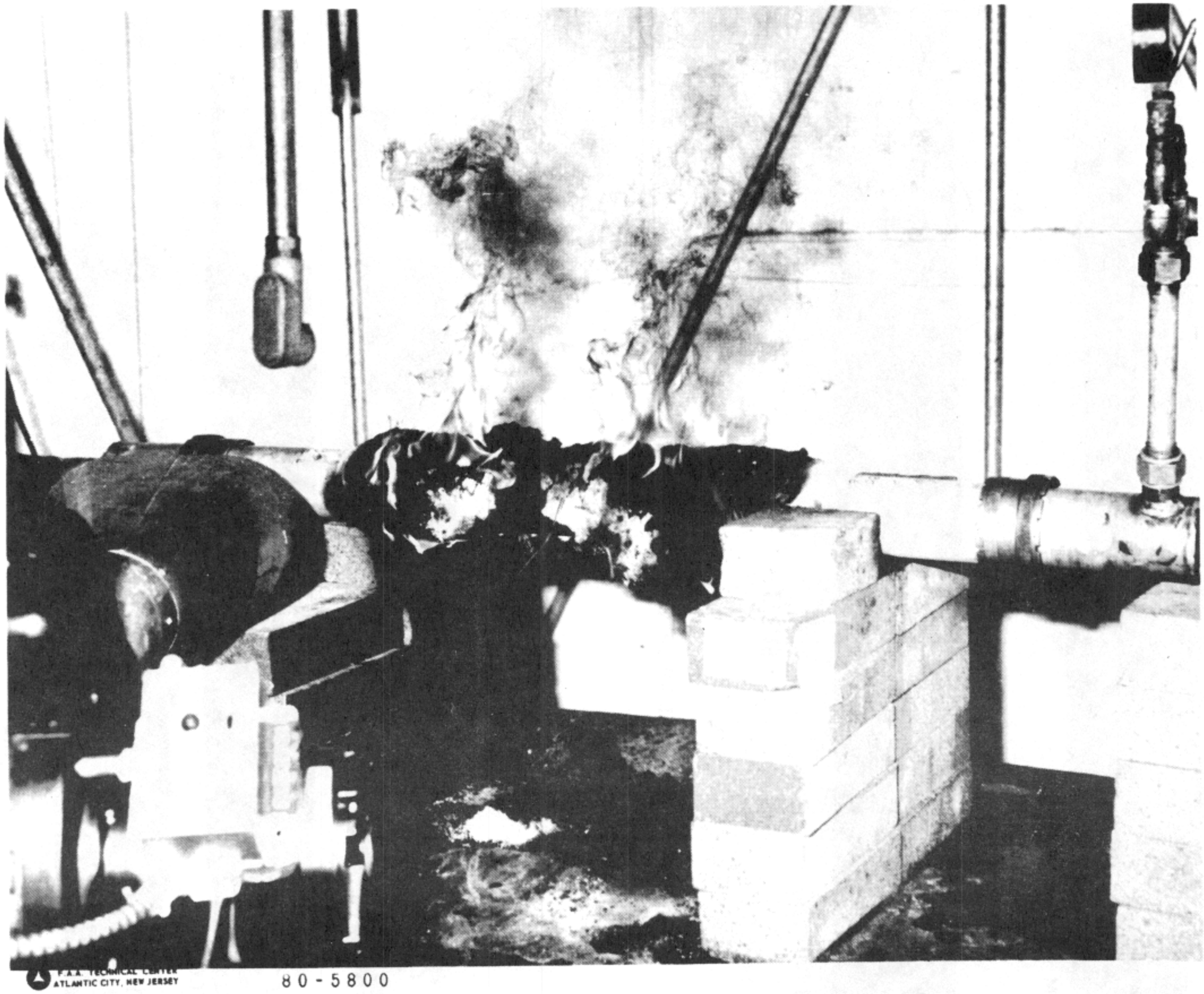


FIGURE 36. POSTTEST BURNING OF McAIR STANDARD SELF-SEALING FUEL LINE COATED WITH AVCO 1600

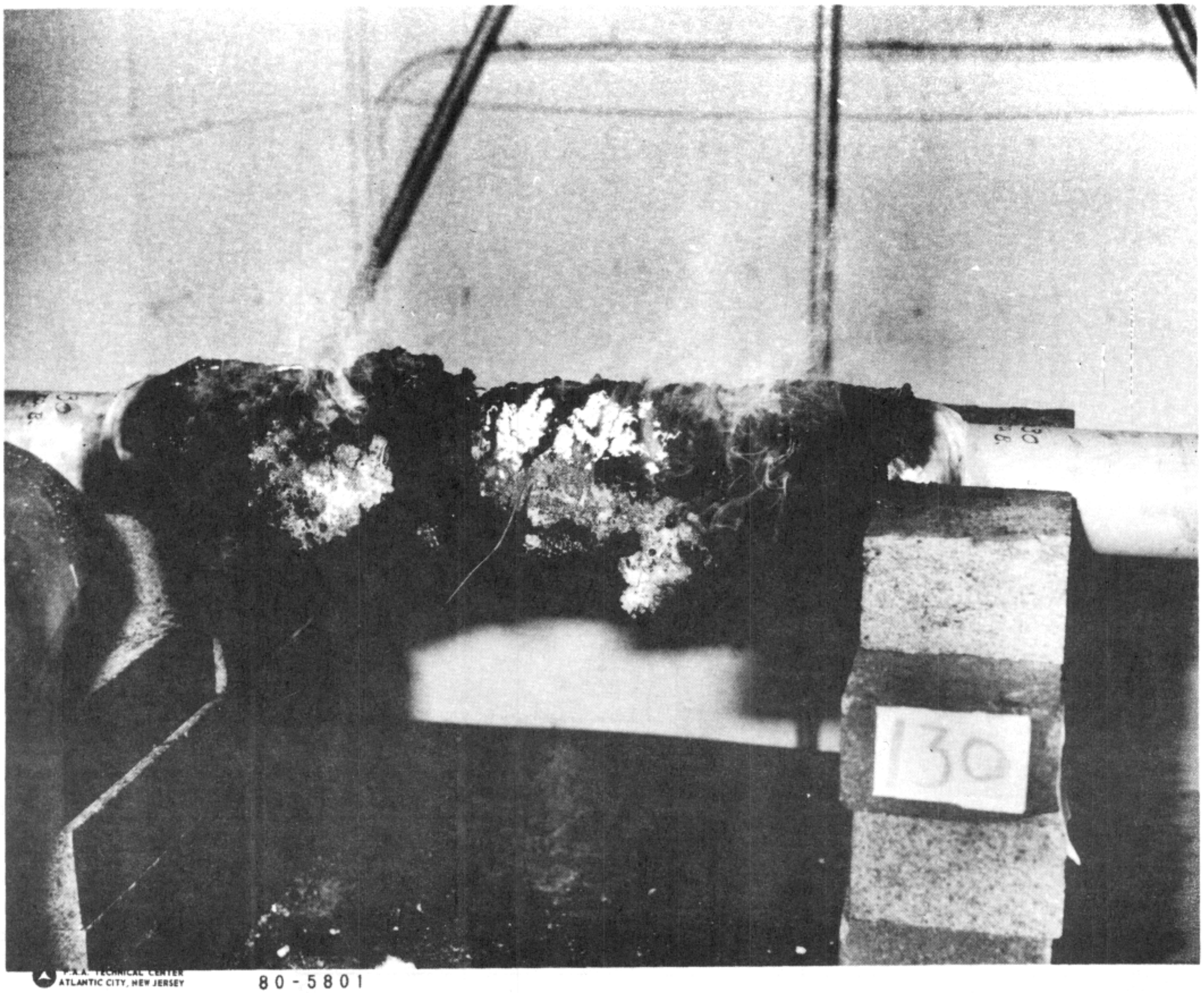


FIGURE 37. RESULT OF POSTTEST BURNING OF McAIR STANDARD SELF-SEALING FUEL LINE COATED WITH AVCO 1600

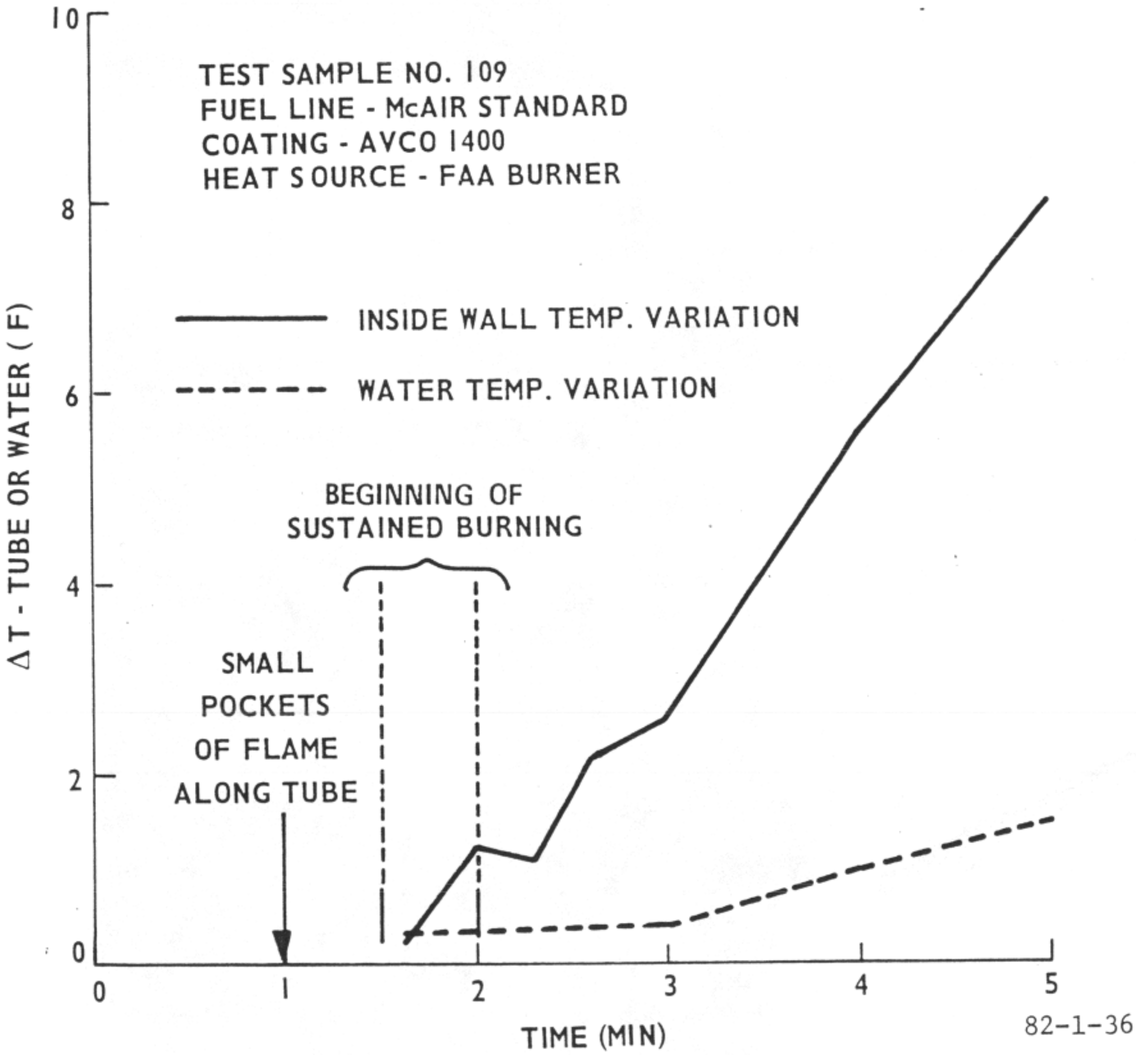


FIGURE 38. INSIDE WALL AND WATER TEMPERATURE VARIATION FOR TEST No. 109

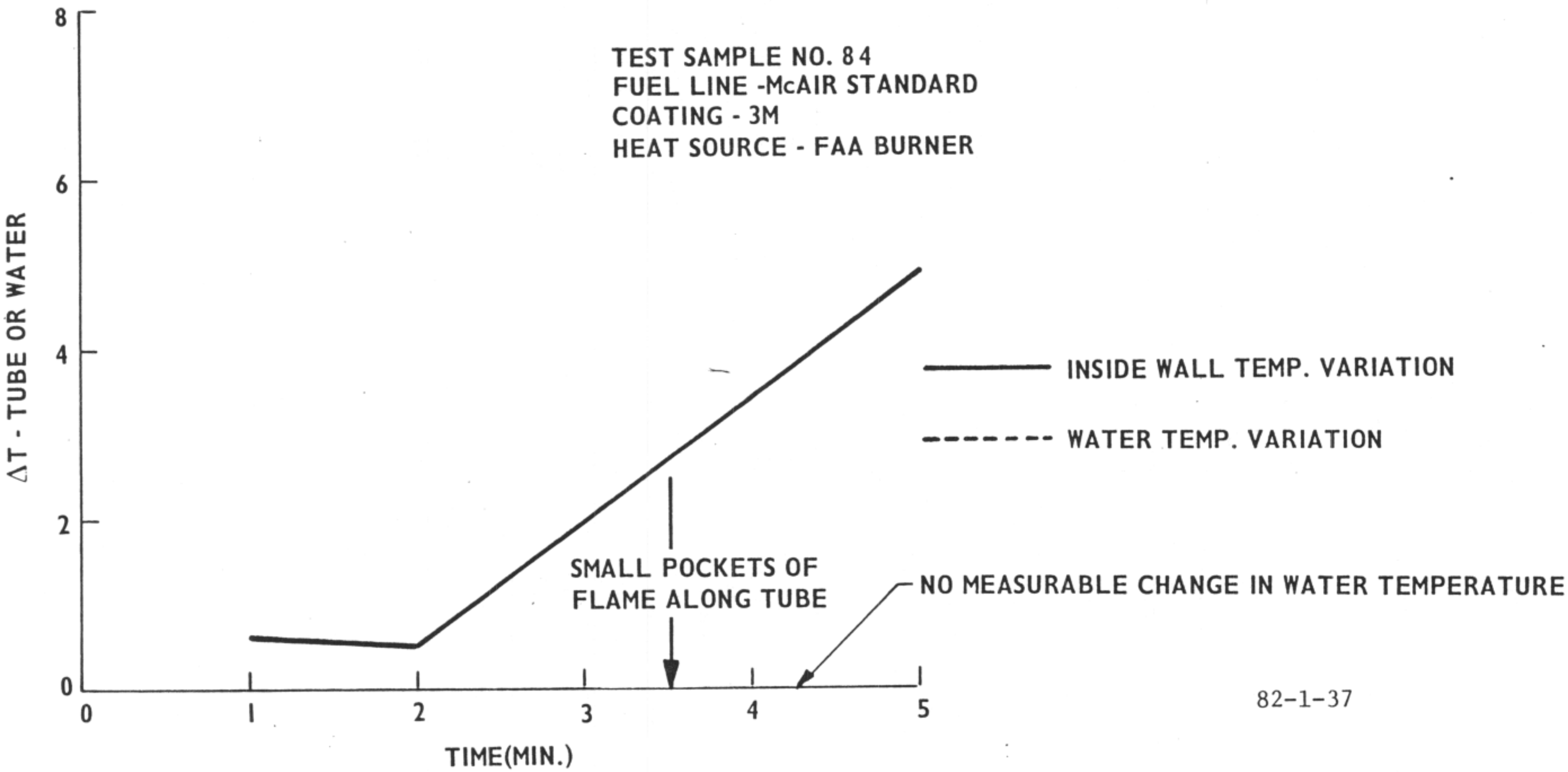


FIGURE 39. INSIDE WALL AND WATER TEMPERATURE RISE FOR TEST No. 84

Also, the underlying self-seal material, provides an extra insulating factor which masks the effectiveness of the intumescent char as an insulator. Figure 38 shows the rise in tube wall and water temperature of an AVCO coated specimen as the intumescent began to deteriorate, losing its fire protection properties and the self seal started to burn. Note that the water temperature rise is the difference between the water temperature out and the water temperature in at any given time, while the inside tube wall temperature rise is the difference between the wall temperature at the start of the test and the wall temperature at any given time during the test. Figure 39 is similar and was chosen because test Sample No. 84 was one of those 3M coated samples that was termed a failure due to a brief period of posttest burning. The tube wall temperature began to rise before the small flickering pockets of flame appeared along the tube in the flame impingement area. The flame pockets noted in this report were characterized as a dispersion of small candle-like flames along portions of the tube in the burner impingement area. It was impossible to determine whether these small flames were the burning of flammable vapors from the self-seal material or the intumescent coating, or the diffusion of the burner flame. There was no measurable increase in the temperature of the circulating water in this particular test.

2.2.4 Gunfire Tests. The test setup is depicted in Figures 5 and 6. A test specimen was securely mounted in the holding fixture. This fixture was positioned so that the path of the .50 Cal projectile was normal to the longitudinal centerline of the test specimen. When API rounds were fired, the striker plate was also normal to the path of the projectile.

Each test was conducted in a similar manner. First the fuel supply pump was turned on and the pressure relief valve was set for 30 psig. The bleed valve (or end cap) at the free end of the test article was cracked briefly to allow all air to escape and to completely fill the line with JP-4 fuel. While there was no fuel flow through the test article during these tests, the pressure was maintained at 30 psig. Next, a single AP round was fired into the test specimen. The fuel pressure was maintained for 15 seconds, the leakage noted, and then the pressurizing pump was turned off. A visual inspection was made of the entrance and exit wounds and of the general condition of the test article. The fuel pressure pump was again turned on after about 5 minutes, and any change in leakage noted. In no test was the actual leakage rate determined. The entrance and exit wounds then were patched, and the striker plate was positioned 8 inches in front of the test article. The fuel pressure pump was turned on and a single API round was fired through the striker plate into the test article. The fuel pressure pump was immediately turned off, and the ensuing ground fuel spill fire was extinguished. Any burning at the test specimen itself was allowed to continue for 5-minutes. This burning was extinguished with CO_2 after 5-minutes if there was no indication that it would self extinguish. A visual inspection of the test article was again performed.

For tests using fuel line samples which had prior exposure to fire, only AP rounds were used. Lines selected for these tests were those with minimal fire damage. Samples selected from those previously tested in the simulated dry bay test fixture were McAir Standard, Uniroyal, and Aeroquip with a 3M or 1400 coating. For those previously tested using the FAA standard burner, the same manufacturer lines were selected, but only those which were coated with the 3M intumescent. The fire damage to the 1400-coated lines was extensive and included such severe degradation of the self-seal material that any self-sealing after penetration by an AP projectile was considered virtually impossible. No previously exposed McAir

Chem-Milled line was selected, since its performance was marginal when even new lines were subjected to AP gunfire.

A brief summary of the gunfire test results for new samples is given in Table 9. A similar summary for fuel line samples with prior exposure to fire is given in Table 10.

TABLE 9. GUNFIRE TEST RESULTS - NEW SAMPLES

Tube No.	Fuel Line	Coating	Leakage AP	Leakage API	Remarks (Pertains to AP Shots Only)
85	McAir Standard	3M	Yes	Yes	Large exit wound leak
86	McAir Standard	3M	Yes	Yes	Entrance wound-small leak; exit wound-massive leak
89	McAir Chem-Milled	3M	Yes	Yes	Same as 86
96	Uniroyal	3M	No	Yes	
97	Uniroyal	3M	No	Yes	
102	Aeroquip	3M	Yes	Yes	Oozing at entrance and exit wounds
103	Aeroquip	3M	Yes	Yes	Massive leak exit wound only
110	McAir Standard	1400	No	Yes	
111	McAir Standard	1400	Yes	Yes	Massive leak exit wound only
114	McAir Chem-Milled	1400	Yes	Yes	Spray from exit wound only
121	Uniroyal	1400	Yes	Yes	Massive leak exit wound only
122	Uniroyal	1400	No	Yes	
127	Aeroquip	1400	No	Yes	
128	Aeroquip	1400	Yes	Yes	Fuel oozing from entrance wound only

TABLE 10. AP GUNFIRE TEST RESULTS - SAMPLE WITH PRIOR EXPOSURE TO FIRE (1)

Tube No.	Fuel Line	Coating	Leakage(2) Ent.	Leakage(2) Exit	Remarks
80	McAir Standard	3M	small	large	All intumescent coating removed
90	Uniroyal	3M	none	large	All intumescent coating removed
99	Aeroquip	3M	dribble	none	
106	McAir Standard	1400	large	large	
117	Uniroyal	1400	none	large	
123	Aeroquip	1400	small	large	
(3) 82(AP#1)	McAir Standard	3M	large	large	Intumescent coating removed
(3) 82(AP#2)	McAir Standard	3M	none	large	Intumescent coating in place
95	Uniroyal	3M	none	large	
100	Aeroquip	3M	large	large	

Notes:

(1) Refer to table 3 for type of prior fire exposure, i.e., Dry Bay Fixture or Standard Burner.
(2) Leakage from entrance (ent.) and exit wounds
(3) Half of the intumescent/char layer was removed so that on 1/2 of sample No. 82 the self-seal was exposed.

One of the more important aspects of these gunfire tests was that in no case, when using AP ammunition, was there evidence of the intumescent coating being drawn into the wound. It would appear from the AP tests that the intumescent coating had no adverse effect on self-sealing properties.

After the penetration of an AP round, the condition of the entrance and exit wounds was such that the intumescent coating was broken away from the projectile impact and exit areas. In most instances, the intumescent was broken away in a small circular pattern around the wounds. Figure 40 shows an AVCO 1400 coated Aeroquip fuel line with a typical entrance wound. Figure 41 shows the exit wound of the same test sample. The sample depicted in these figures did not leak after AP penetration. Sealing of the wound was dependent upon the damage sustained by the self-seal material and/or the petaling of the aluminum tube. The petaling effect was not relevant to the Aeroquip lines.

As noted in Table 9, for AP round tests, Tube Numbers 96, 97, 110, 122, and 127 did not leak. In those cases, the seal was virtually instantaneous. Upon close examination an area damp with fuel was noted around the exit wound, but there was no evidence of fuel seeping out. Some of the video tapes revealed an instantaneous misting as the projectile exited, which undoubtedly contributed to the fuel damp area. For tubes other than those cited, where there was an initial leakage, there was no subsequent self seal when the line was repressurized. As described previously, the fuel pressure pump was turned off 15 seconds after projectile impact and remained off for approximately 5 minutes, after which time the line was repressurized. If the line did not seal within the 15-second period, it did not seal at all. Although there was no attempt to catch and quantify the leaking fuel, visual observation indicated no significant lessening of the leakage that occurred during the 15 seconds before the pump was turned off and that which occurred 5 minutes later when the line was repressurized.

For those test specimens noted in Table 9 which did not leak after being impacted by an AP round, the entrance and exit wounds were fairly "clean" with only a few fibers protruding from the wounds. Since the type of intumescent coating did not appear to have any bearing on whether or not a line sealed, the intumescent/self-seal interaction aspect can be eliminated from further discussion herein. Of the four Uniroyal lines tested, three self sealed. The Uniroyal line that did not seal (No. 121) had a massive leak resulting from a large exit wound. In five other test shots, large gaping exit wounds resulted which made it impossible for a self seal to be effected. Tube Numbers 102, 114, and 128 were also noted as leaking, but these leaks can be described as relatively minor with only a small spray or dribble. The size of the entrance and exit wounds did vary, with the most variation occurring in the exit wounds. In some cases exit wounds were "clean," and in others a large ragged hole resulted which was characterized by an opening up or petaling of the inner metal tube. The Aeroquip lines did not have an inner aluminum tube and, consequently, did not fail in this manner. Although three of four Aeroquip lines did not seal, the leakage was small in all except No. 103. Table 9 indicates that when entrance wound leaks resulted they were small, whereas exit wound leakage varied. The cause of the variability of the exit wounds was not determined, but some possible causes could have been the onset of projectile tumbling or the deviation of the projectile from a straight line as the projectile passed through the fluid-filled line. Deformation of the AP projectile was not considered a factor, since several were recovered from the dirt mound backstop and no deformation was noted. In any case, where entrance and exit wounds were "clean" there was little or no leakage.

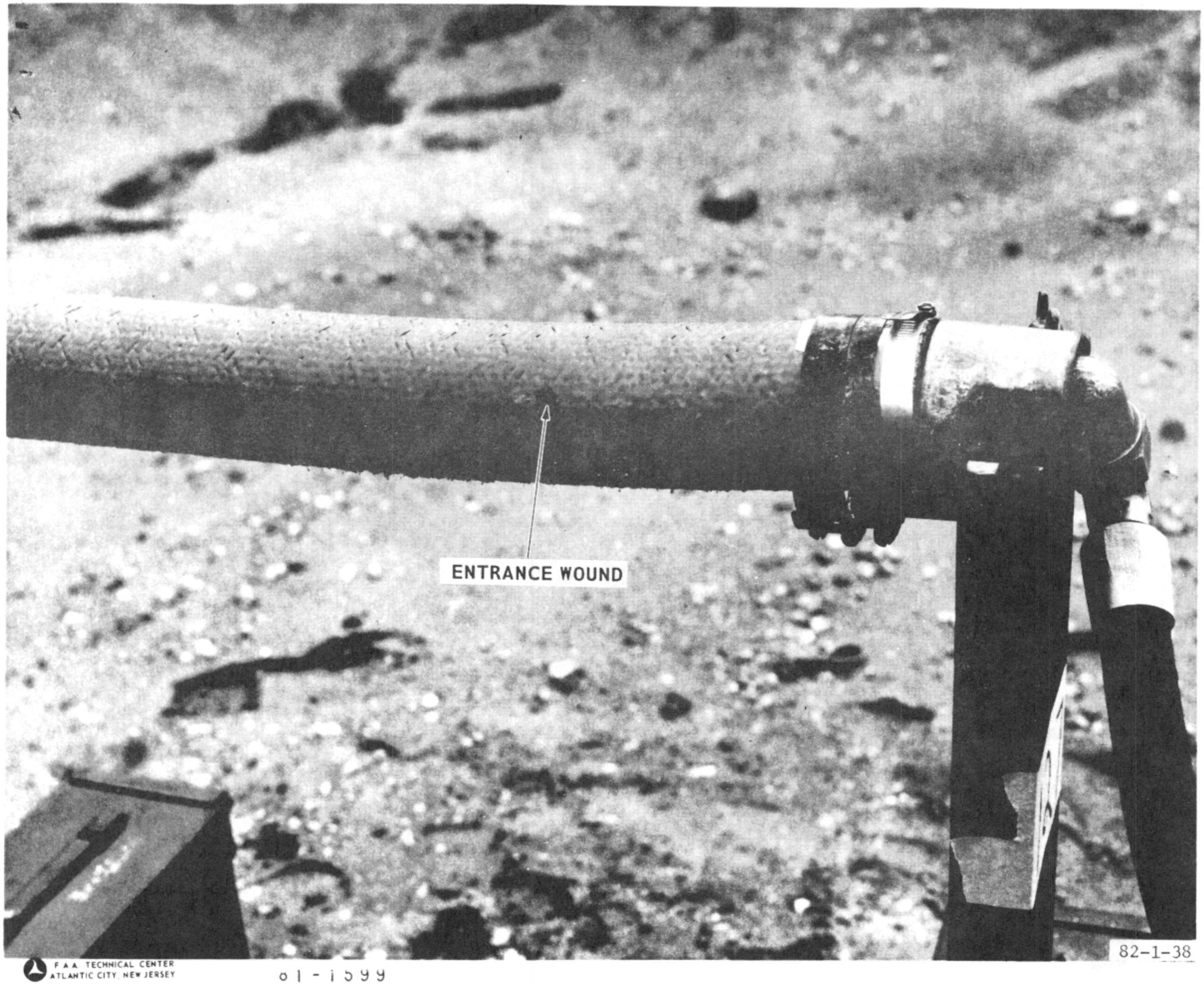
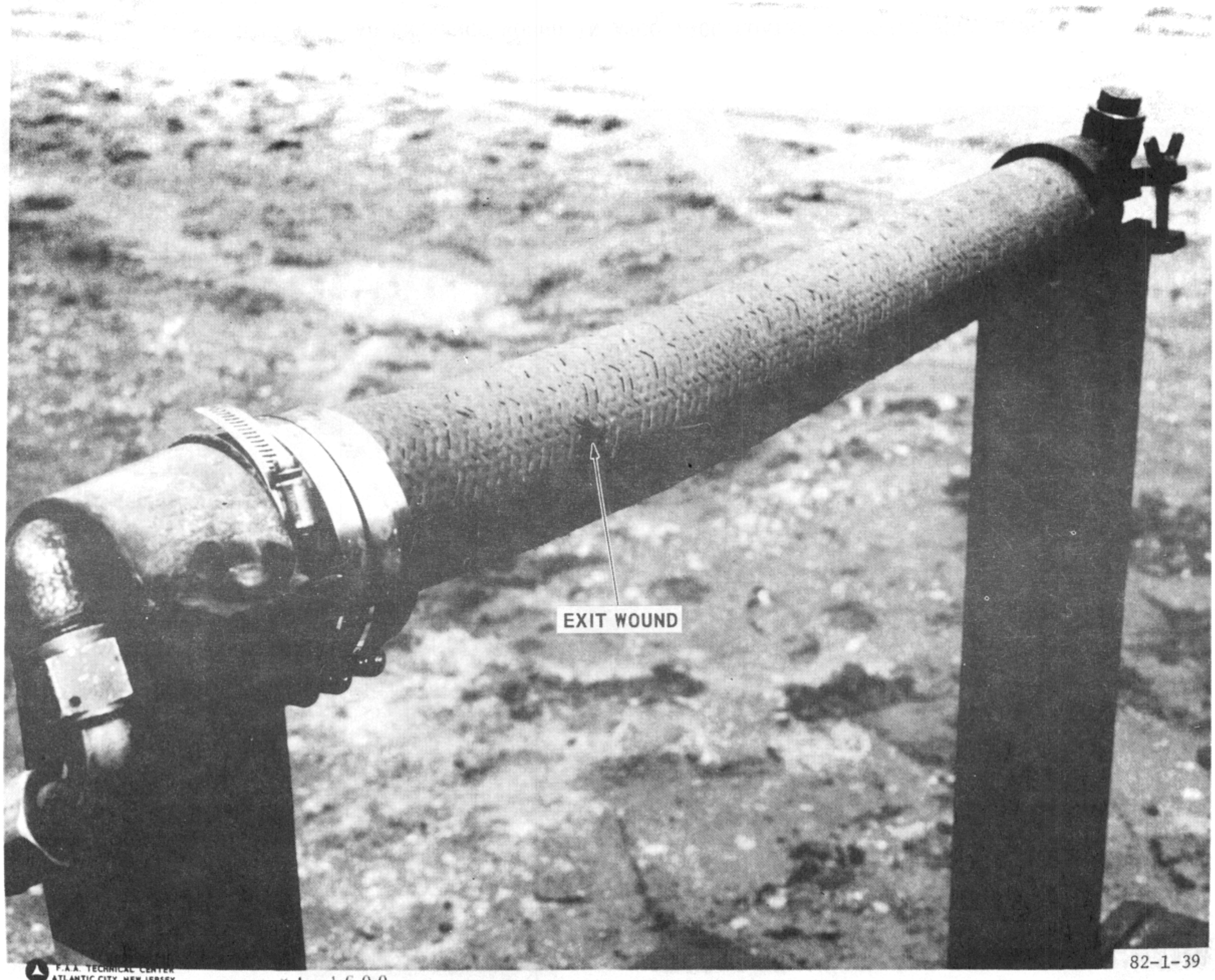


FIGURE 40. AP ENTRANCE WOUND IN AVCO 1400 COATED AEROQUIP FUEL LINE



81-1600

FIGURE 41. AP EXIT WOUND IN AVCO 1400 COATED AEROQUIP FUEL LINE

In no instance did a fuel line self-seal after an API shot. In all cases there was a large gaping exit wound which made it impossible for the self-seal material to close around the wound, and thus, any effect the intumescent coating may have had on self-sealing performance was incidental. Figure 42 shows an AVCO 1400 coated Aeroquip line with a typical exit wound. The figure also illustrates a typical test setup for an API test shot. All API shots resulted in tube and ground fires. The ground fire was extinguished immediately, but the fire at the fuel line was allowed to burn. The fire at the fuel line was initially caused by the JP-4 which remained in the tube, but eventually the self seal became involved. The self-seal involvement was evidenced by a darkening of the smoke and a pungent smell. In no instance was there an indication that the tube fires would self extinguish, and they were, therefore, extinguished with CO_2 after 5 minutes. The tube fire was a "lazy" type of flame comparable to that of the dry bay test fixture. However, the scenario was somewhat different in that with the dry bay test fixture heat was applied to the outside of an intact line, whereas following an API shot heat was applied both inside and outside the test line in a concentrated area at the wounds.

Fire damage on the tube outer surface tended to spread outwardly away from the burning wounds as the self-seal became more involved. The 3M intumescent did offer more resistance to this spreading fire damage on the exterior of the line. This additional resistance was somewhat academic, since the tube was damaged beyond its ability to self-seal. However, this characteristic is important from the standpoint of protection for a fuel line whose integrity has not been compromised.

Figures 43 through 56 show the entrance and exit wounds of the test articles not previously exposed to fire. The API wounds are obvious in these figures. The instantaneous peak pressure (value not measured) developed as the API round passed through the test article undoubtedly contributed to the extensive damage. This effect is particularly evident in the lower tube in Figure 56 which shows a split in the McAir Chem-Milled line in an area not covered by the self-seal material and outside the projectile penetration area. Bulges in the aluminum line at the end of the self-seal cover are also evident in Figure 55. Particularly noticeable is the bulge on the right in the bottom tube (McAir Chem-Milled with the 1400 coating) whose sharp outline was caused by a steel restraining strap. The thin-wall design of the McAir Chem-Milled samples was most probably the reason for this deformation, since no such permanent set was observed in the other aluminum tube core samples. The AP entrance and exit wounds in these figures are not as obvious. These wounds are located within the lighter shaded area, evident on most test lines, which was caused by the patch used to cover the AP entrance and exit wounds. The wrinkled 3M wrap shown in Figures 47 and 48 was not the result of any unusual intumescent action. It was rather, the result of a fire extinguishment with a high-pressure water stream directed from the side on the burning tube after an API shot. The extinguishment procedure was subsequently revised to use CO_2. Figures 45, 46, and 49 through 54 show those test lines which self-sealed after penetration by an AP round. These lines are Nos. 96, 97, 110, 122, and 127. In Figures 43 through 56, the arrows indicate the general area of entry and exit of the AP round, since it is not readily apparent in all these figures.

Table 10 gives a brief summary of the results of AP gunfire tests which were conducted on fuel lines selected from Part B. These fuel lines had prior exposure to fire in either the standard burner or the dry bay fixture. Note that fuel lines Nos. 80 and 90 had all the intumescent coating removed prior to being

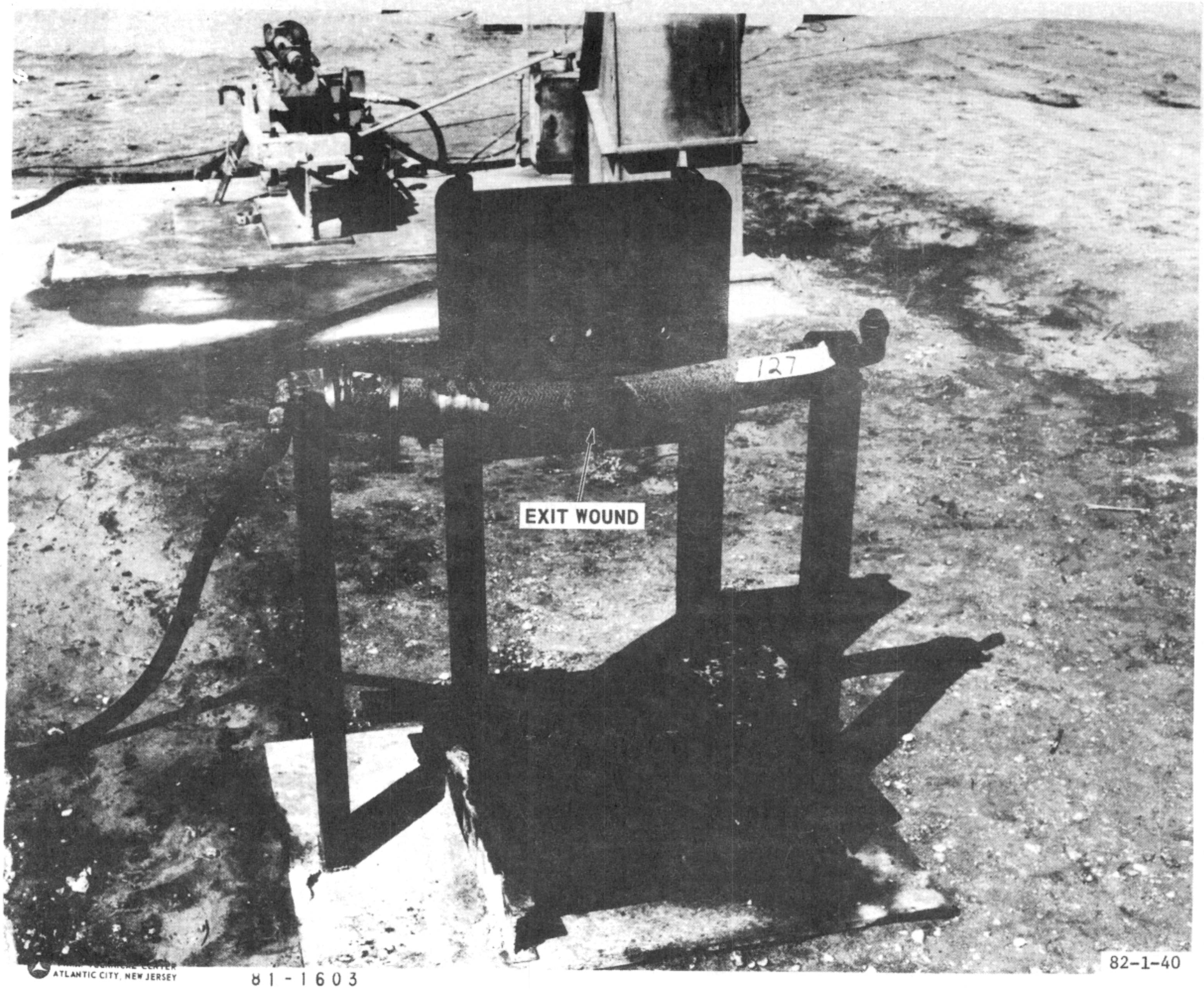


FIGURE 42. API EXIT WOUND ON AVCO 1400 COATED AEROQUIP FUEL LINE

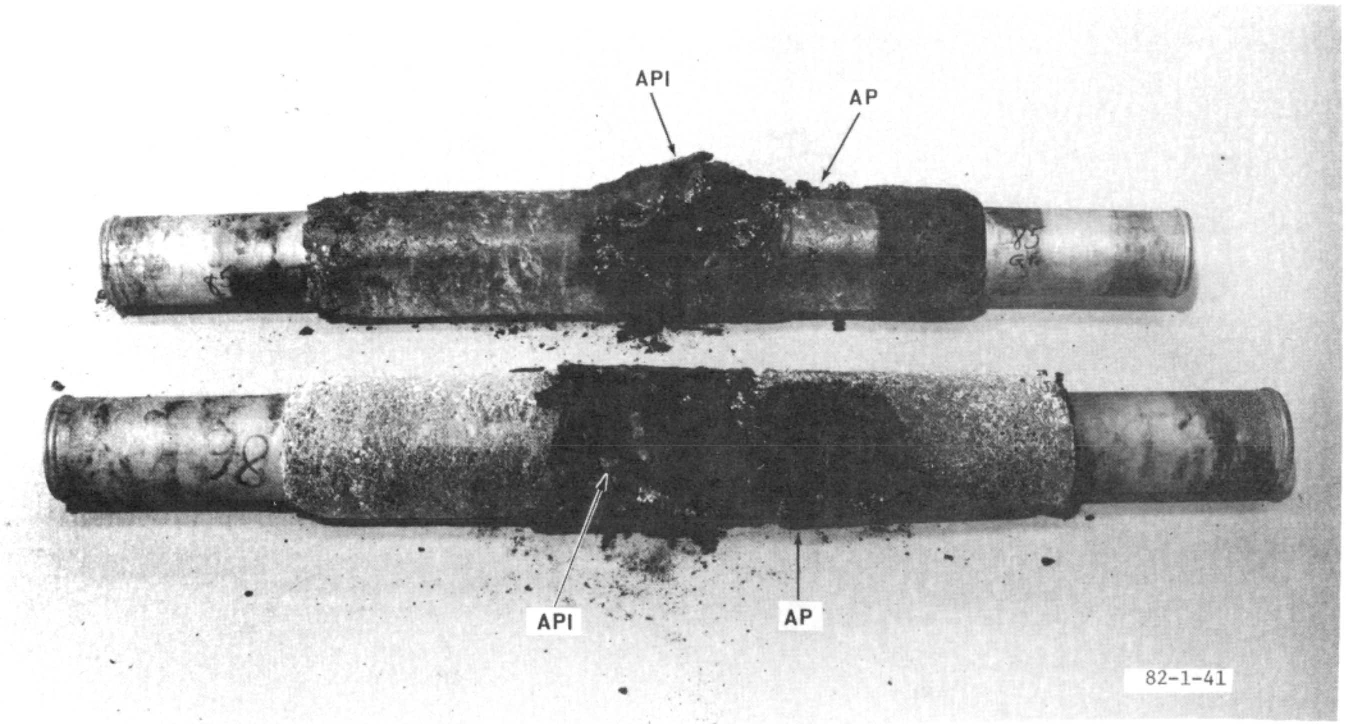


FIGURE 43. ENTRANCE WOUNDS IN McAIR STANDARD FUEL LINES WITH 3M COATING

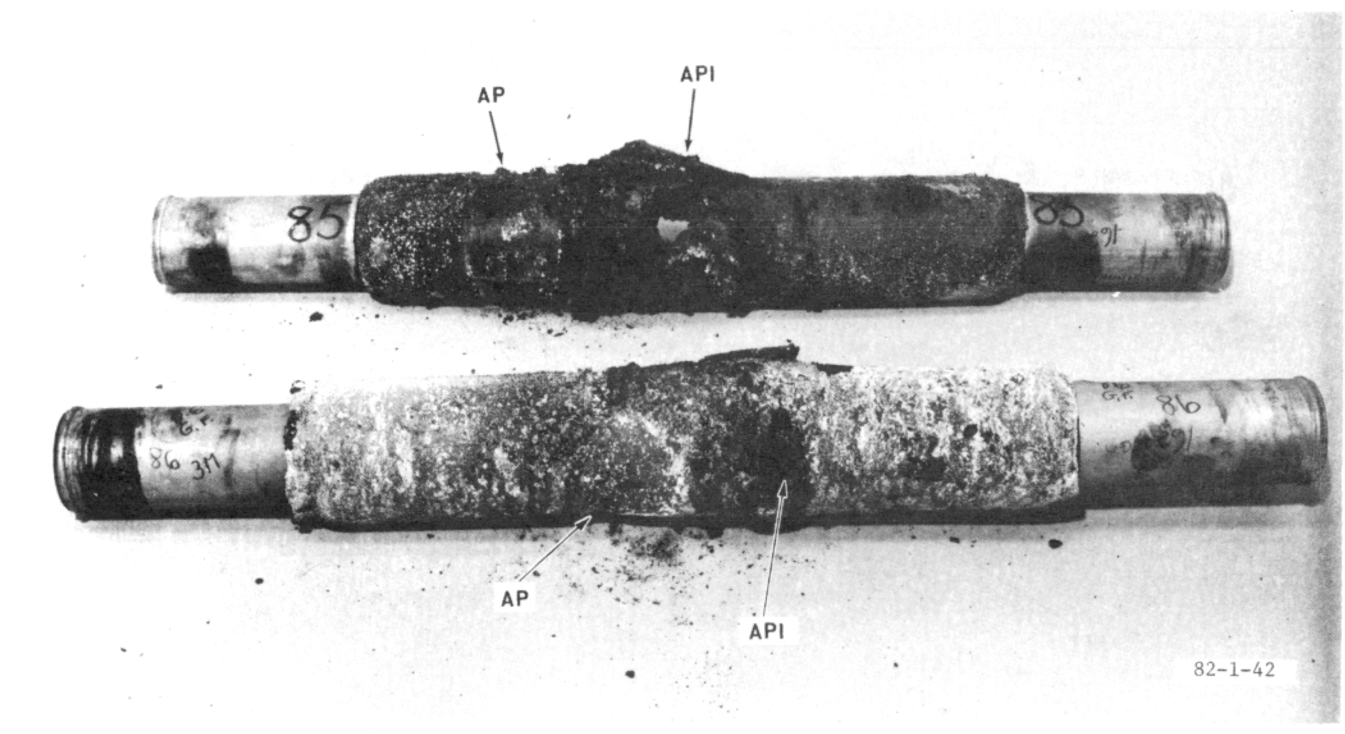


FIGURE 44. EXIT WOUNDS IN McAIR STANDARD FUEL LINES WITH 3M COATING

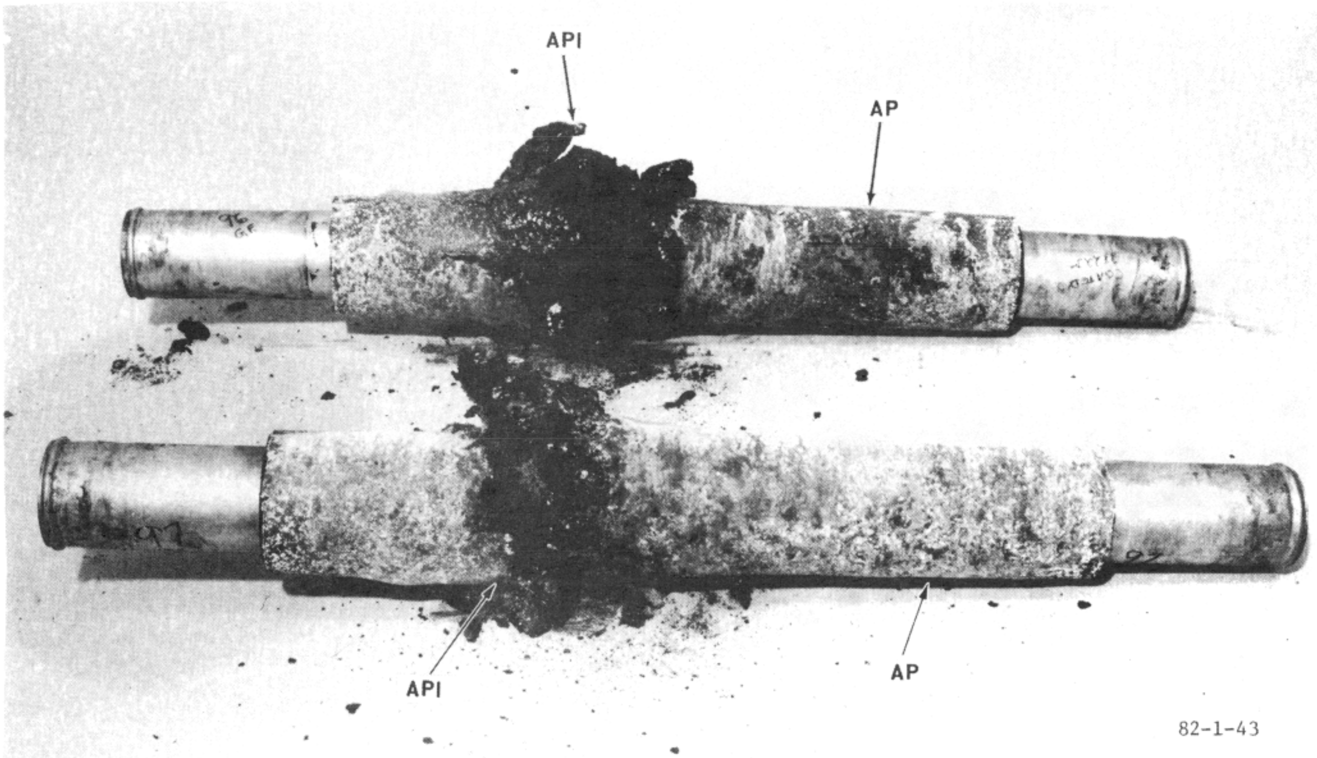


FIGURE 45. ENTRANCE WOUNDS IN UNIROYAL FUEL LINES WITH 3M COATING

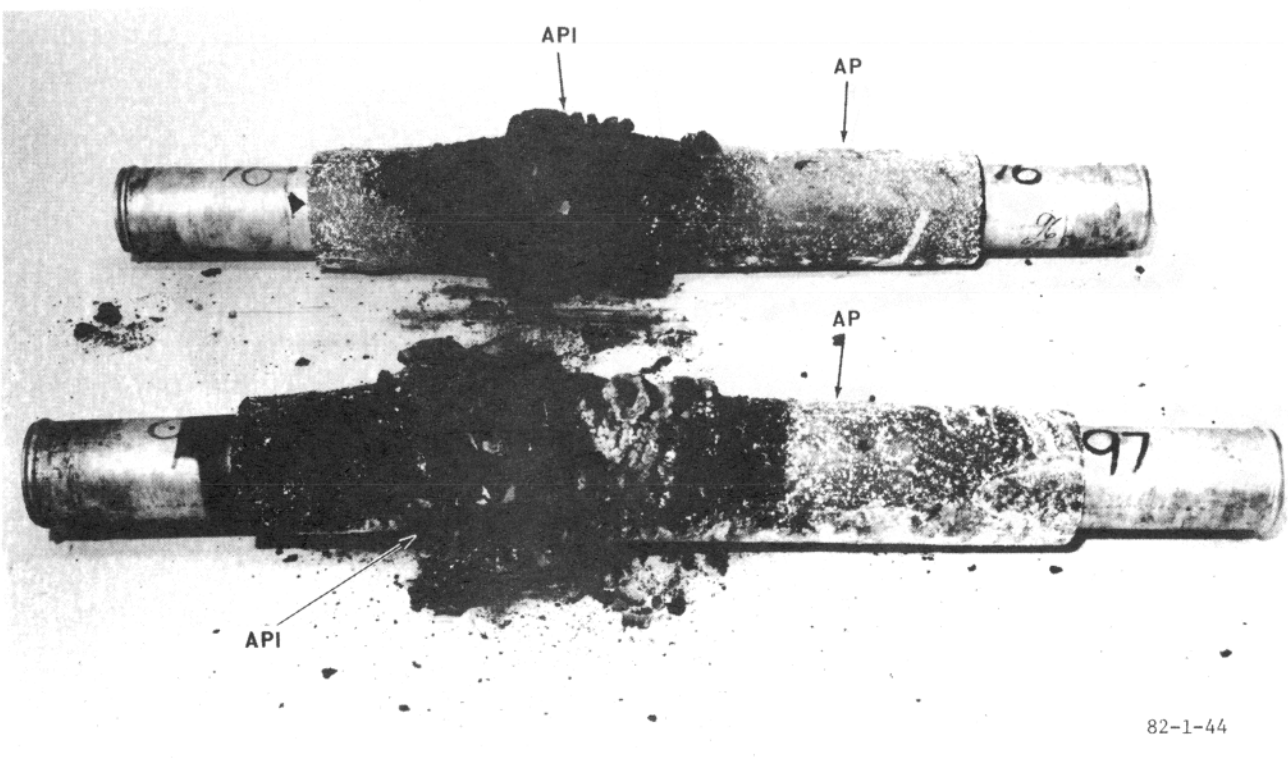


FIGURE 46. EXIT WOUNDS IN UNIROYAL FUEL LINES WITH 3M COATING

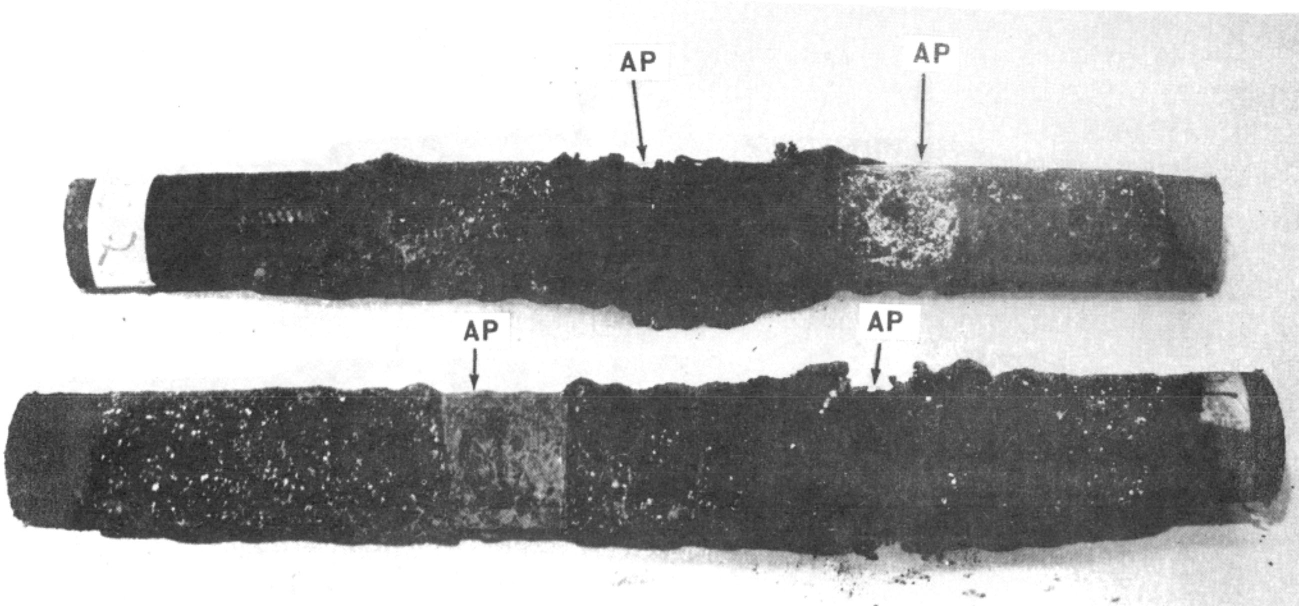


FIGURE 47. ENTRANCE WOUNDS IN AEROQUIP FUEL LINES WITH 3M COATING

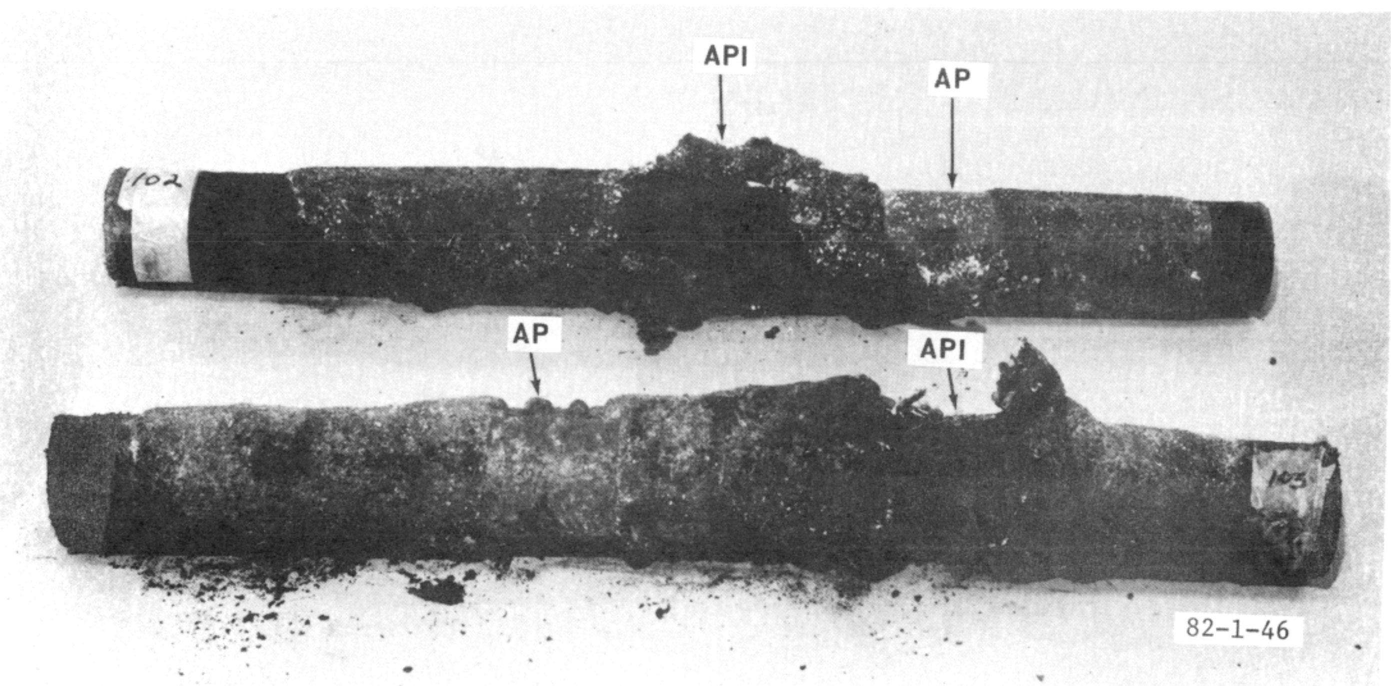


FIGURE 48. EXIT WOUNDS IN AEROQUIP FUEL LINES WITH 3M COATING

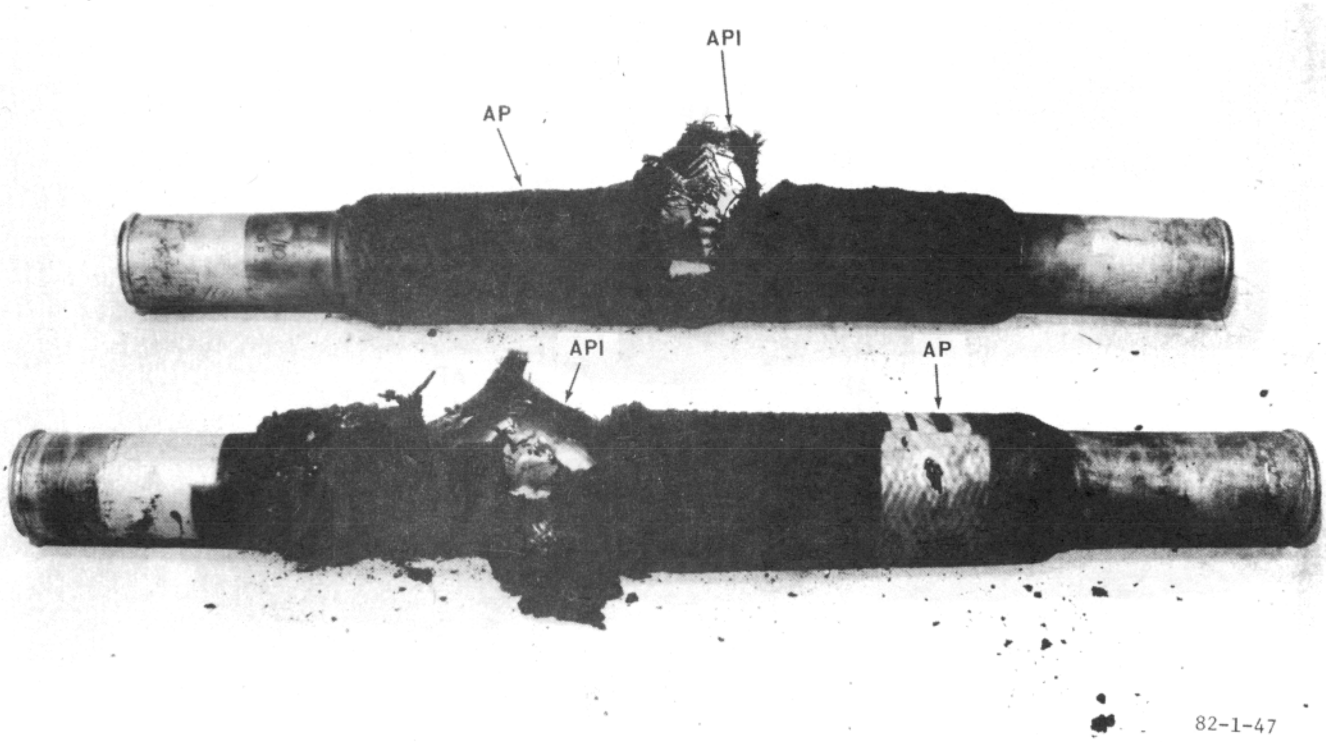


FIGURE 49. ENTRANCE WOUNDS IN McAIR STANDARD FUEL LINES WITH AVCO 1400 COATING

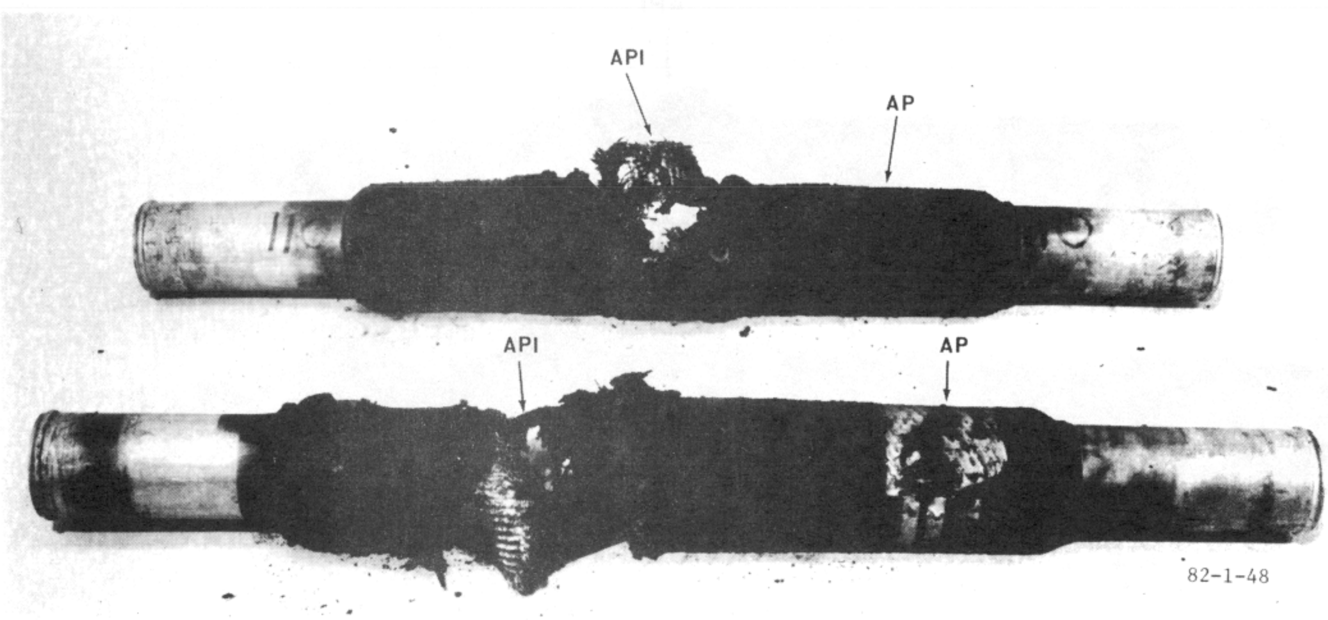


FIGURE 50. EXIT WOUNDS IN McAIR STANDARD FUEL LINES WITH AVCO 1400 COATING

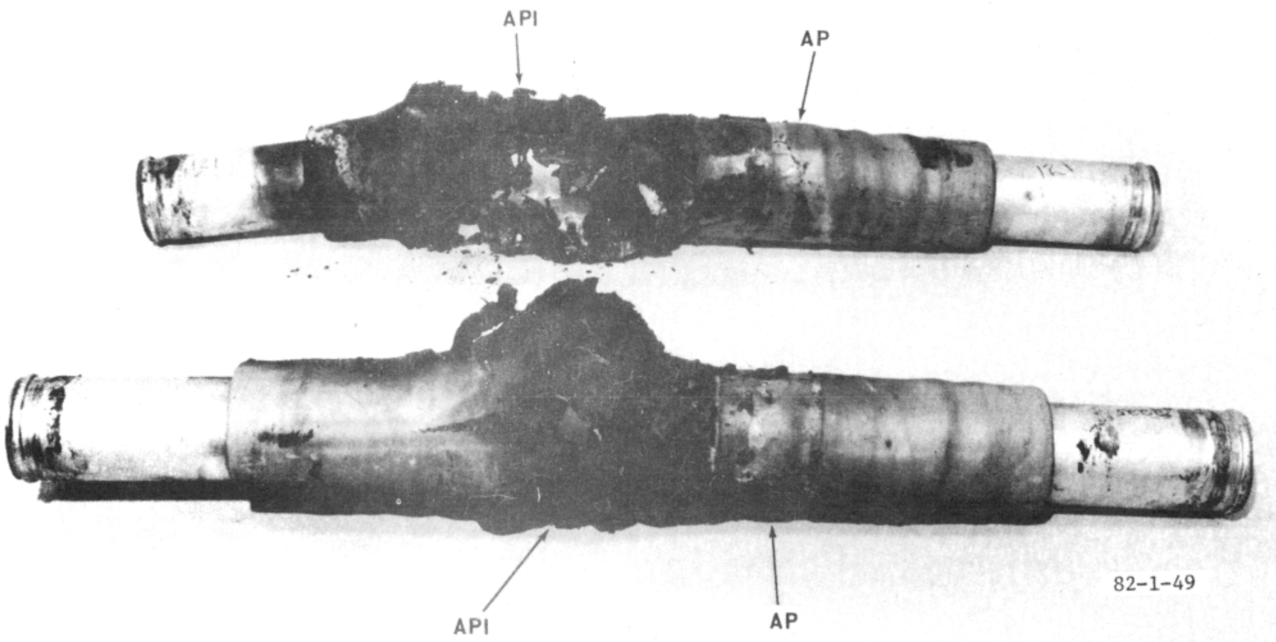


FIGURE 51. ENTRANCE WOUNDS IN UNIROYAL FUEL LINES WITH AVCO 1400 COATING

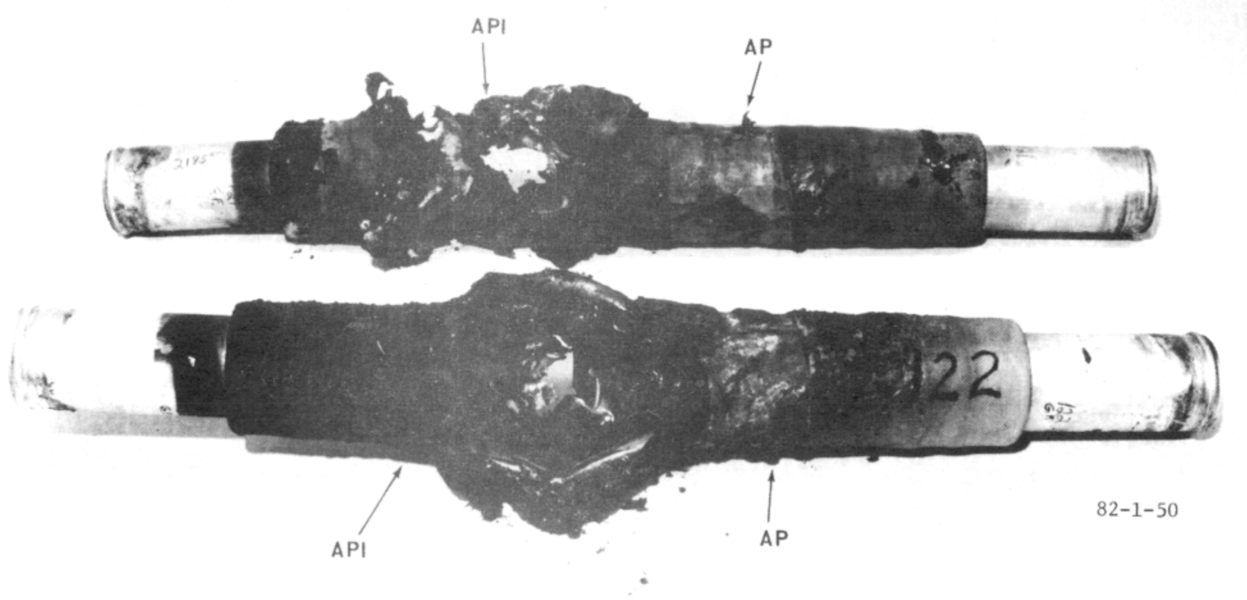


FIGURE 52. EXIT WOUNDS IN UNIROYAL FUEL LINES WITH AVCO 1400 COATING

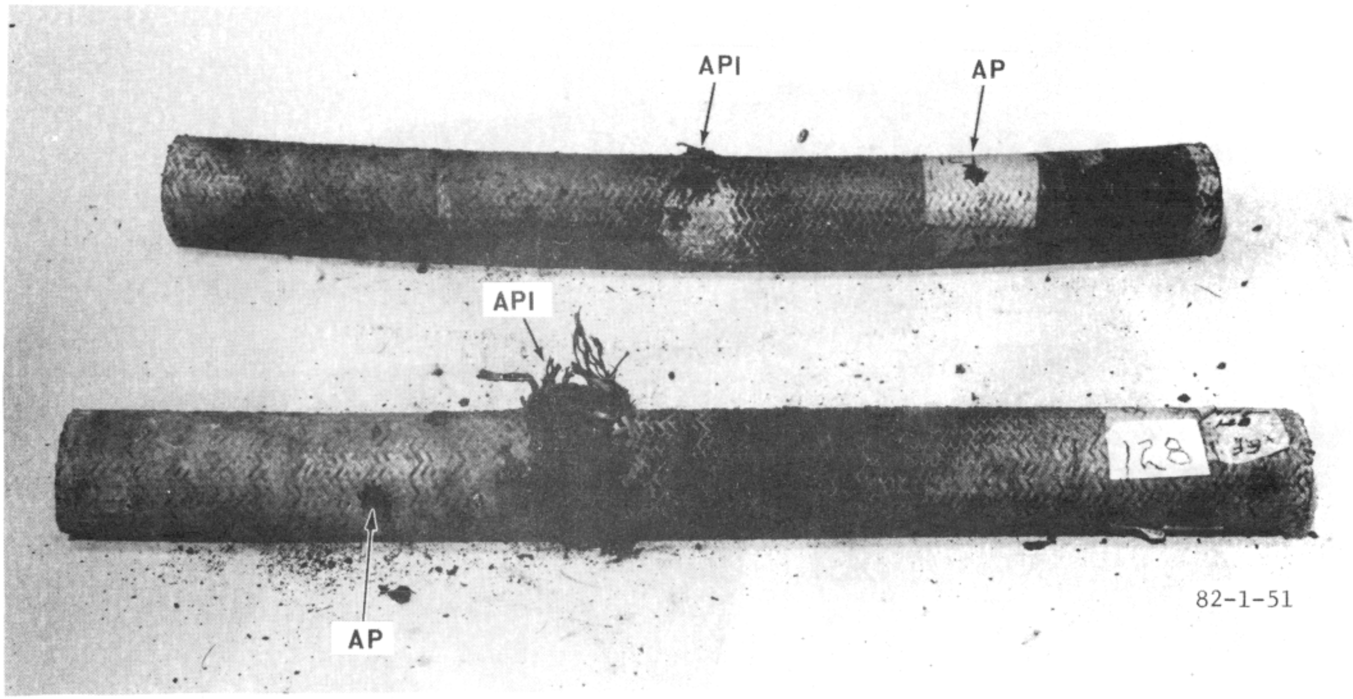


FIGURE 53. ENTRANCE WOUNDS IN AEROQUIP FUEL LINES WITH AVCO 1400 COATING

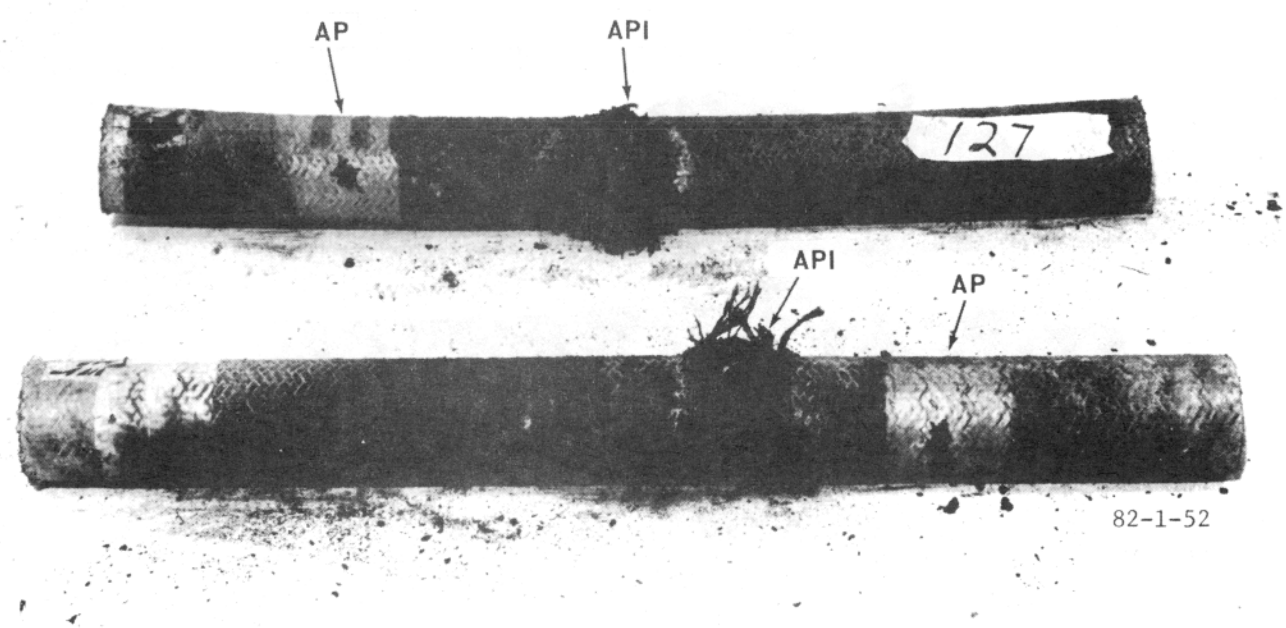


FIGURE 54. EXIT WOUNDS IN AEROQUIP FUEL LINES WITH AVCO 1400 COATING

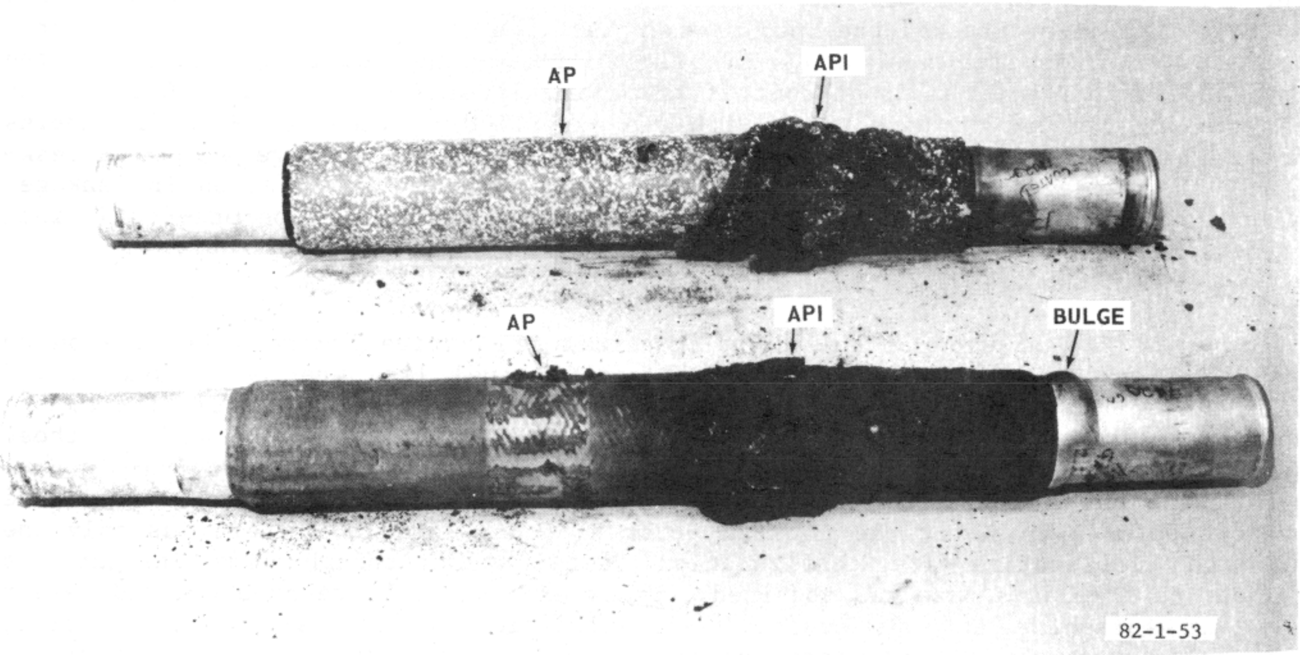


FIGURE 55. ENTRANCE WOUNDS IN McAIR CHEM-MILLED FUEL LINE WITH 3M COATING (TOP) AND AVCO 1400 COATING (BOTTOM)

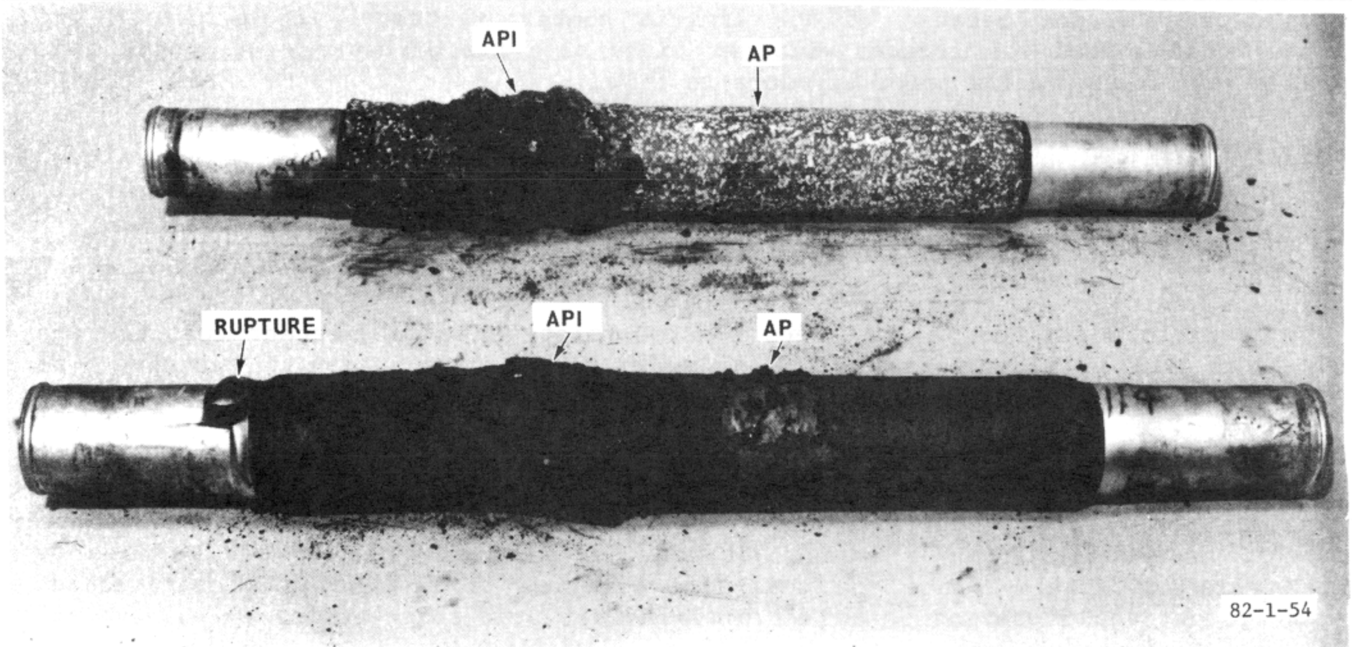


FIGURE 56. EXIT WOUNDS IN McAIR CHEM-MILLED FUEL LINE WITH 3M COATING AND AVCO 1400 COATING (BOTTOM)

subjected to gunfire. These lines had been tested in the dry bay fixture, and and the 3M intumescent/char layer had to be peeled off in order to remove them from the fixture. Fuel Line No. 82 had half of the intumescent/char layer removed for examination of the underlying self seal after testing with the FAA standard burner. Sample No. 82 was the only line into which two AP rounds were fired: one into the area that had the intumescent/char layer removed and one into the area where the intumescent was still in place. All of the remaining lines had the intumescent in place, although some of the char, especially that of AVCO 1400, was unavoidably damaged in handling. With the exception of Tube No. 99, all samples noted in Table 10 had a large exit wound and consequently, a large amount of leakage. The entrance wounds also varied with a corresponding variation in leakage. A leak was described as small when the stream was estimated to be one-fourth inch or less in diameter.

It is not known precisely what effect prior fire damage will have on an otherwise intact intumescent coated self-sealing fuel line when subjected to .50 Cal AP gunfire. The limited number of tests make firm conclusions difficult. In no instance was there a complete seal of both the entrance and exit wounds of those samples listed in Table 10. However, with the exception of Sample No. 99, in each case there was a large exit wound and the line's ability to self-seal would have been doubtful even if it had not had prior exposure to fire. There was only one of each line/coating/fire configuration tested and although some insight was gained, no firm data base was obtained. Prior exposure to fire probably did result in some softening and subsequent resolidification of the self-seal material, especially when the FAA standard burner was used. There was, however, no visual deformation noted in the self-seal/intumescent layer of the specimens selected from Part B for the gunfire tests. Prior exposure to fire may have degraded self-sealing properties, but this should not have contributed to the larger exit wounds, particularly in those lines with an aluminum tube core. Other than for Sample No. 99, there were no "clean" exit wounds but had there been, the results may have been more closely aligned with those where new tubes were used. Although not statistically significant because of the limited number of tests, the percentage of wounds that sealed was greater with new lines than the percentage of wounds that sealed with lines having prior exposure to fire.

SECTION III

CONCLUDING STATEMENT

The tests described in this report substantiate that intumescent coatings are available that will significantly delay the destructive intrusion of a severe fire into the underlying self-sealing material.

The use of the FAA standard burner, which is intended to simulate an in-flight fire, is considered a severe but suitable test. The 5-minute test duration, although not generally representative of the time a fire would go undetected in flight, nevertheless adds a measure of confidence in a product which is able to meet this criteria. Since the self-seal material is flammable, an intumescent product that would prevent or delay the self-seal from contributing to the overall fire scenario is desirable.

Based on a limited number of tests, it appears that neither the AVCO 1400 nor the 3M intumescent coatings adversely affected the ability of the self-seal sleeve to seal when subjected to AP gunfire. Prior exposure to fire casts some doubt on the self-sealing performance of intumescent coated self-sealing lines. However, the absence of an intumescent coating in the presence of fire will result in the virtual destruction of the self-seal material.

SECTION IV

CONCLUSIONS

a. The simulated dry bay test fixture used for this project was not a suitable means for fully investigating intumescent coating effectiveness on self-sealing fuel lines. The dry bay tests did however, reveal that even quiescent fires may result in destruction of the self-seal provisions.

b. The FAA standard burner provided a severe but suitable test for evaluating the effectiveness of intumescent coatings on self-sealing fuel lines.

c. A suitable criterion and desirable goal for an effective intumescent coating would be to delay the destructive intrusion of a test flame and thus prevent the self-sealing material from burning for at least 5 minutes.

d. Since intumescing action of an intumescent coating appears to be affected by the thermal characteristics of the material to which it is bonded, testing must be conducted using the actual material on which the coating is to be applied.

e. Uncoated self-sealing fuel lines have no fire resistance, thus demonstrating the need to be protected.

f. Since self-sealing fuel lines have no fire resistance, a properly functioning intumescent coating can increase line survival time in a fire environment.

g. Because self-sealing material is flammable, it can contribute to the intensity of an existing fire if not protected.

h. Char thickness and rapidity of growth should not be used as the sole deciding criteria for evaluating intumescent effectiveness.

i. Necessary characteristics for an intumescent coating are a tough and tightly adhering char layer after exposure to fire.

j. The AVCO 1400 and AVCO 1600 intumescent coatings were not able to protect the self-seal material from a fire as severe as that resulting from the FAA standard burner.

k. Of the coatings tested with the FAA standard burner, the 3M (2mm) intumescent coating provided the best resistance to the destructive intrusion of the test flame into the underlying self-sealing fuel line.

l. Prior exposure to fire casts some doubt on the performance of intumescent coated self-sealing fuel lines when subjected to .50 Cal AP gunfire.

m. There was no evidence to indicate that the intumescent coating was drawn into an AP gunfire wound.

SECTION V

RECOMMENDATIONS

a. The FAA standard burner, or equivalent, should be used to demonstrate the effectiveness of intumescent coatings on self-sealing fuel lines.

b. The pass/failure criteria for intumescent coatings should be the coating's ability to delay the destructive intrusion of the test flame, the formation of a tough and tightly adhering char layer, and the prevention of the self-seal material from burning for 5 minutes.

c. A prerequisite for the testing of intumescent coatings should be the application of the coating to the actual material which is to be protected.

d. For future testing, consideration should be given to include vibration and airflow if the line is intended to function in such a environment.

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