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ALUMINIZED COATING STUDY FOR RETROFITTING IN-SERVICE SLIDE MATERIALS

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16. Abstract

This report describes the work performed by the BF Goodrich Company, Akron, Ohio under contract to the FAA Technical Center to develop a thermal resistant reflective coating for the retrofit of in-service slides and slide/rafts. The report includes the experimental evaluation of commercially available reflective coatings and paints, ingredient-modification experiments, methods of application, physical properties tests and retrofit cost estimate. The end product of this study resulted in a new aluminum polyurethane coating, BF Goodrich coating KE7620, suitable for retrofit purposes.

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The report which follows documents this study. Phases of the study are discussed in approximately the order described above, i.e. in the order in which they were performed.

DISCUSSION

I. REFLECTIVE COATING SYSTEMS EVALUATION

In order to improve the thermal radiation resistance of in-service aircraft evacuation slides, radiant heat reflective elastomeric coatings capable of being applied to slides as a retrofit process were investigated. This investigation involved both the evaluation of presently available coatings and the development of new coatings.

For a coating to be considered useable as a retrofit radiant heat resistant coating, it was determined that the following three requirements must be met:

1) The coating must be reflective of infrared radiation in the wavelength range 2.1 - 2.5μ, which according to the literature corresponds to the wavelength range of radiation emitted by JP-4-type aircraft fuel fires;[1]

2) The coating must be heat resistant, i.e. possess adequate heat capacity, at radiant heat intensities as high as 2.2 Btu/ft^2-sec; and,

3) The coating must be "compatible" with all common slide fabric materials, i.e. the coating must neither physically degrade slide materials nor alter the materials' abilities to meet applicable FAA, TSO, and FAR regulations.

Before proceeding into a discussion of the coatings investigated, it should be pointed out that the experimental test methods, which served as the primary means of coatings evaluation, progressed over the time of this study through three distinct phases.

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[1] Schoppee, Skelton, Albot, and Donovan, The Transient Thermomechanical Response of Protective Fabrics to Radiant Heat, Fabric Research Laboratories, Dedham, MA, 1977, (work done for Air Force Materials Laboratory, Wright Patterson AFB, Ohio)

Phase 1 involved the testing of slide materials fabricated into 3-inch diameter tube test specimens, which were inflated to between 2.5 and 3 psig and exposed to a radiant heat flux of 2.5 Btu/ft^2-sec.

Phase 2 also involved the testing of inflated 3-inch diameter slide material tubes at 2.5 to 3 psig, but the heat flux in Phase 2 was reduced to 2.2 Btu/ft^2-sec.

Phase 3 involved the testing of 7-inch diameter flat disks cut from slide materials. During testing, the flat disk would be clamped onto the one open end of a circular metal cylinder, the cylinder pressurized to between 2.5 and 3 psig, and the disk exposed to a radiant heat flux of 2.2 Btu/ft^2-sec.

Phase 1 (and Phase 2)-type testing is described in Section 6.4.6 of BFGoodrich Report No. 79-22-035--the technical proposal submitted for this study. One variance from the test procedure described in Section 6.4.6 is that tests were carried out at 2.5 to 3 psig, rather than at 7.9 psig. Figures 1, 2, and 3 of Report No. 79-22-035, which depict experimental apparatus used in Phase 1 and 2 testing, are reproduced on the following three pages.

Phase 3-type testing differed from Phase 1 and 2-type testing mainly in the type of test specimen and specimen holder employed. The "flat disk" test fixture used in Phase 3-type radiant heat tests, shown in Figure 4 of this report, was modeled after apparatus used at the FAA Technical Center.

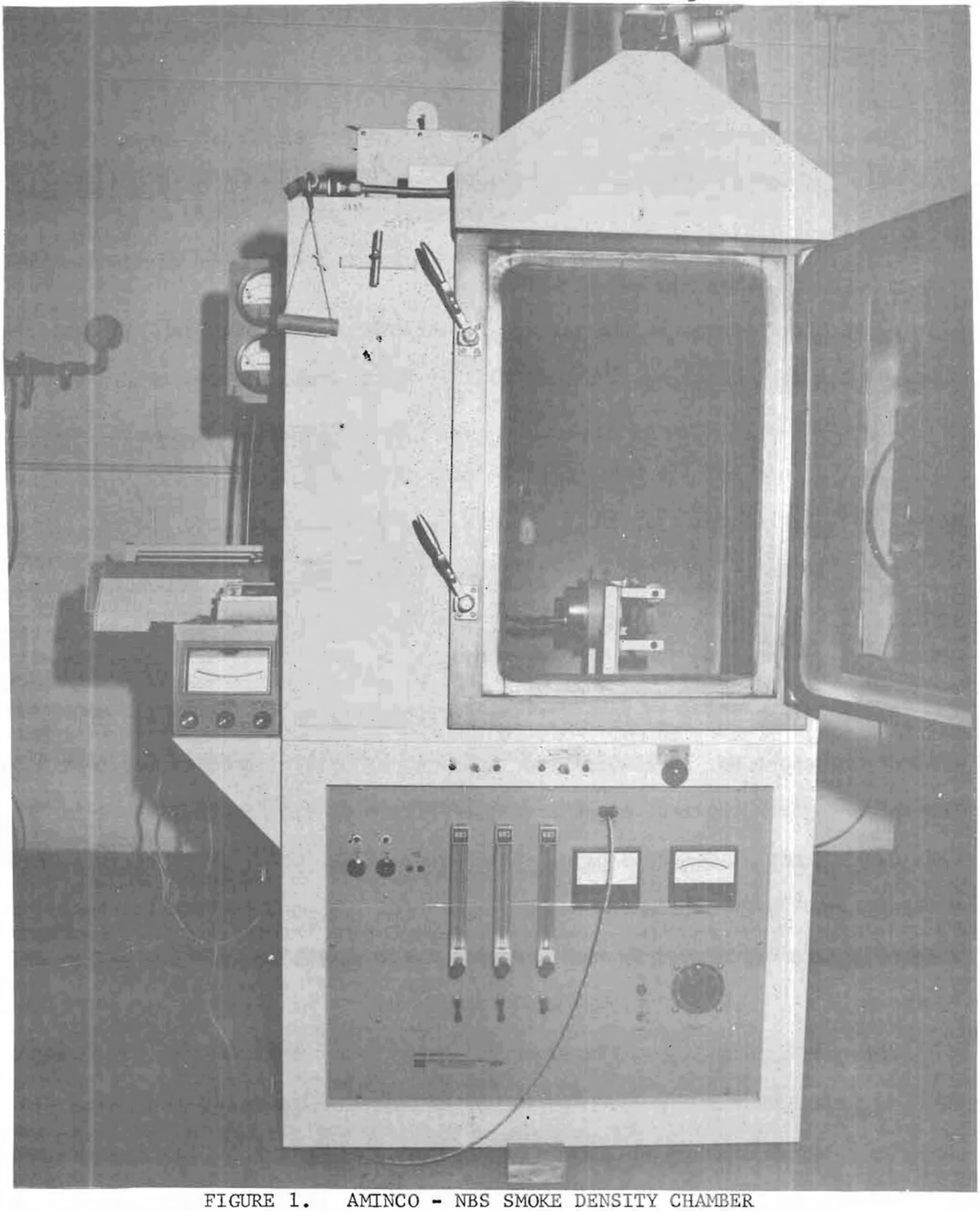
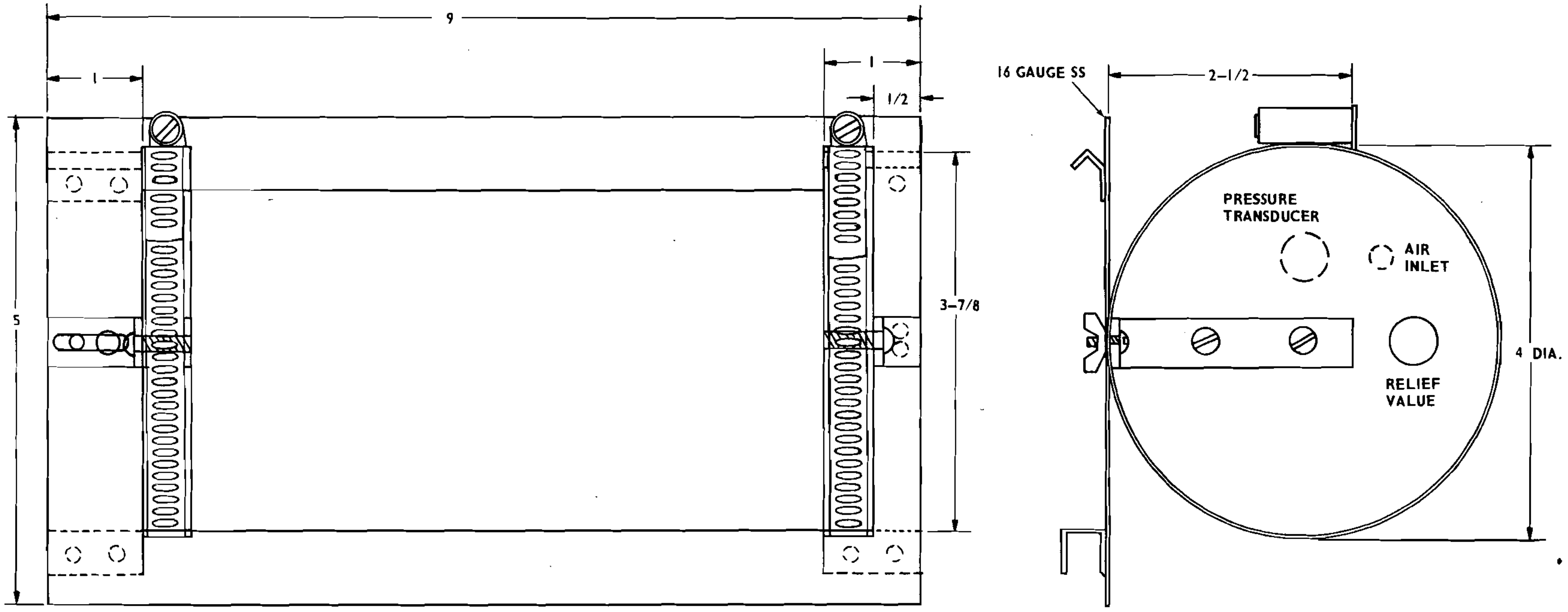
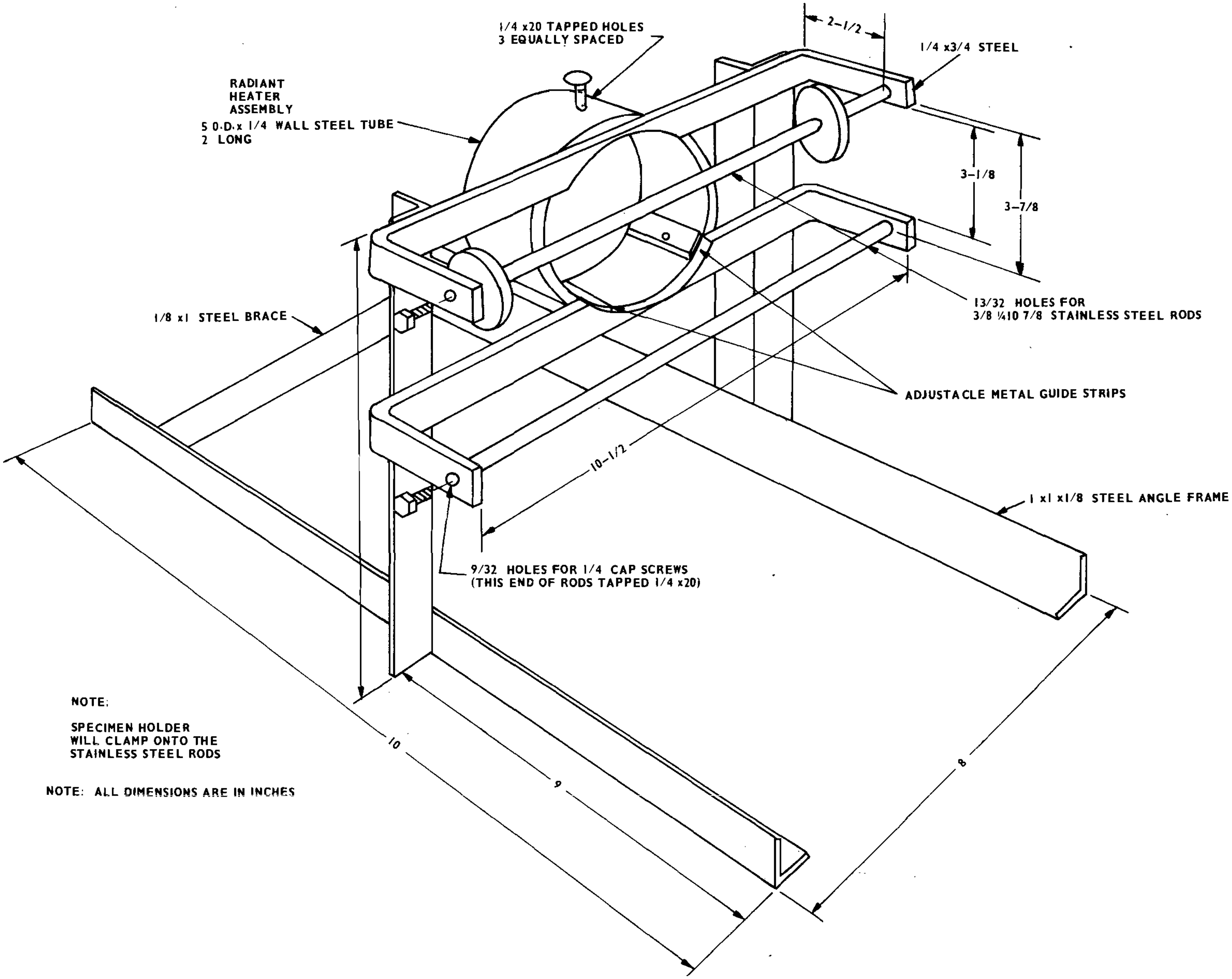


FIGURE 1. AMINCO - NBS SMOKE DENSITY CHAMBER



NOTE: ALL DIMENSIONS ARE IN INCHES

FIGURE 2. SPECIMEN HOLDER FOR RADIANT HEAT TESTING OF SLIDE MATERIALS (PHASE 1 AND 2- TYPE TESTS)

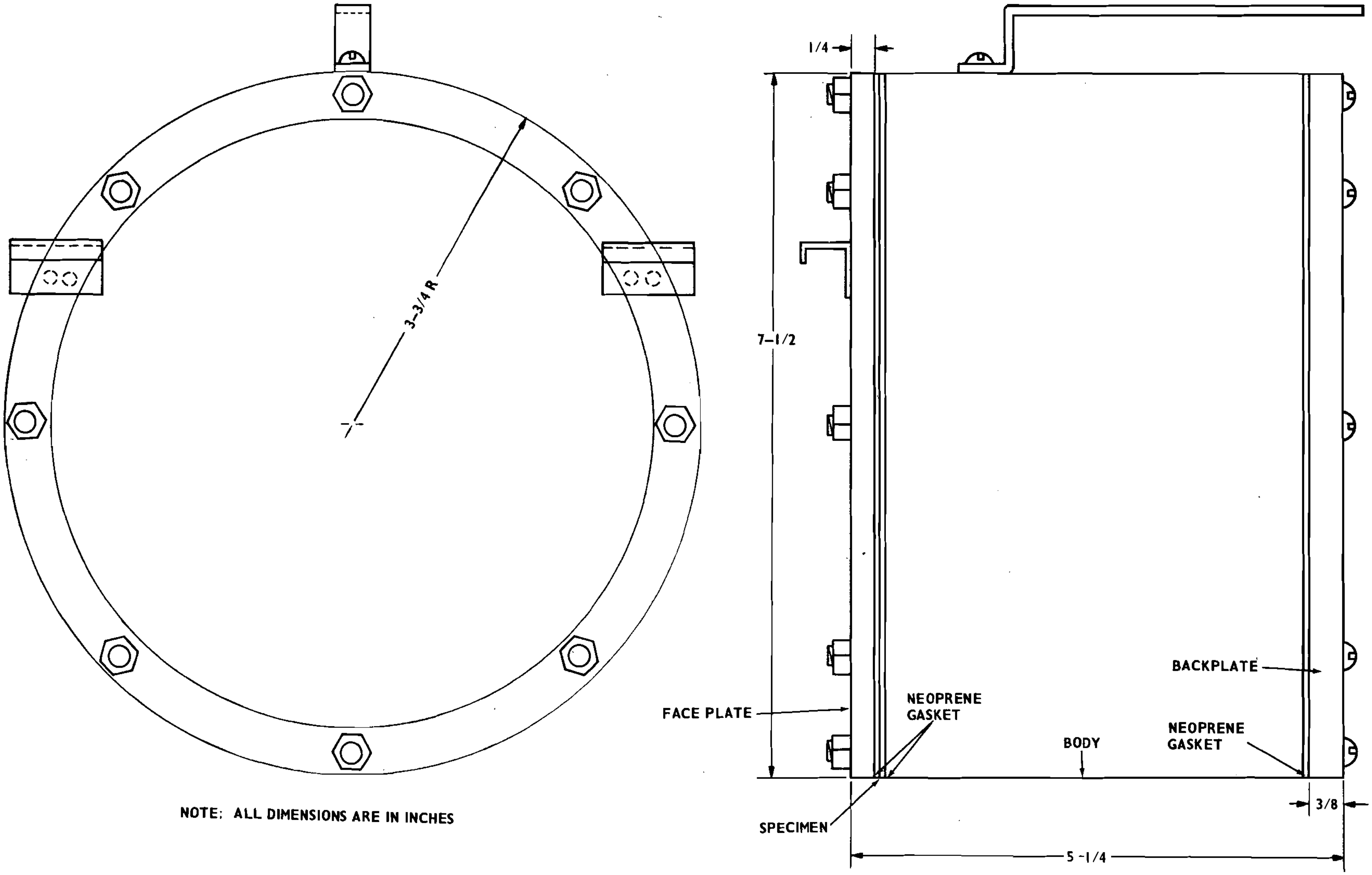


NOTE:

SPECIMEN HOLDER
WILL CLAMP ONTO THE
STAINLESS STEEL RODS

NOTE: ALL DIMENSIONS ARE IN INCHES

FIGURE 3. NBS SMOKE CHAMBER HEATER AND SPECIMEN HOLDER FRAME



NOTE: ALL DIMENSIONS ARE IN INCHES

PRESSURIZED SPECIMEN HOLDER FOR FLAMMABILITY

FIGURE 4. "FLAT DISK" SPECIMEN HOLDER (FOR PHASE 3-TYPE RADIANT HEAT TESTS)

Test data obtained in this study is tabulated in Table 1 ("Master Table"), on the next two pages. The values of "failure time" (elapsed time between initial exposure of a test specimen to radiant heat and initial pressure loss in the specimen) and "temperature rise rate" (time rate of increase of temperature of the air within the test specimen) are average values -- the averages of values measured for multiple runs (usually three runs per each slide material/coating sample).

In addition to "failure time" and "temperature rise rate," Table 1 also lists measured values of radiation reflectivity at wavelengths of 2.0 and 2.5μ for most of the coating samples. Reflectivity was measured separately from the radiation heat resistance tests, using spectrophotometric techniques available at the BFGoodrich Research & Development Center.

Another parameter tabulated in Table 1, which is used in this study as a measure of radiant heat resistance, is the ratio of failure time "T" to the percentage weight increase of the slide material test specimen due to retrofit coating, %Δw. This ratio is referred to as T/%Δw.

TABLE 1. MASTER TABLE

SAMPLE NUMBER	BASE FABRIC BFG. NO.	REFLECTIVE COATING Top Coat (Coating #)	REFLECTIVE COATING Bottom Coat (Coating #)	REFLECTIVITY, ρ @ λ= 2.0-2.5μ		COATING VEHICLE POLYMER	THICKNESS CHANGE (.001 in.)		WEIGHT CHANGE (oz/yd^2)		INFLATED TUBE RADIANT HEAT TEST RESULTS*		FLAT DISK RADIANT HEAT TEST RESULTS** HF=2.2	RATIO OF FAILURE TIME TO PERCENT WEIGHT CHANGE (T/%Δw)		REMARKS
				2.0μ	2.5μ		Δt	% Δt	Δw	%Δw	HF=2.2	HF=2.5		Tube T/%Δw @ HF	Disk T/%Δw @ HF	
1	NS260	Standard Yellow		.72	.37							14.5;80.5	17			Control Sample; NS260=neoprene coated nylon, both sides coated
2	NS397	Standard Yellow		.65	.12							13.0;98.0	10			Control Sample; NS397=polyurethane coated nylon, 1 side only coated
3	NS364	Standard Yellow		.65	.11							14.9;82.0				Control Sample; NS364=polyurethane coated nylon, both sides coated
4	NS260	Alum. (0121GS291A)		.75	.78	Neoprene	2.75	29.7	3.36	38.5		26.7;72.0		0.69 @ 2.5		10 pbv alum. in coating; A13438 curing agent (isocyanate) added to coating, 32/1 pbv; dried too brittle
5	NS260	Alum. (0121GS291B)		.72	.74	Neoprene	2.25	24.3	2.08	23.9		32.0;64.0		1.34 @ 2.5		20 pbv alum. in coating; A13438 curing agent (isocyanate) added to coating, 32/1 pbv; dried too brittle
6	NS260	Alum. (0121GS291C)		.78	.81	Neoprene	2.25	24.3	3.76	43.1		19.7;65.0		0.46 @ 2.5		30 pbv alum. in coating; A13438 curing agent (isocyanate) added to coating, 32/1 pbv; dried too brittle
7	NS397	Alum. (KE7601-1)		.82	.83	Polyurethane	2.00	19.0	2.62	33.7		92.0;59.0		2.73 @ 2.5		A13438 curing agent (isocyanate) added to coating, 32/1 pbv; dried too brittle
8	NS260	Alum. (Reeves V75111)		.64	.66	Neoprene	0.50	5.4	1.48	17.0		22.0;70.0		1.29 @ 2.5		
9	NS397	Alum. (Reeves V75T12)		.72	.73	Polyurethane	2.00	19.0	2.07	26.6		24.0;62.0		0.90 @ 2.5		
10	NS397	Oxide (KE7100)		.71	.41	Polyurethane	4.00	38.0	3.72	47.8		22.5;67.0		0.47 @ 2.5		discolored (off-white)
11	NS260	Oxide (A6258)		.83	.62	Hypalon	1.75	18.9	2.64	30.3		14.5;77.0		0.48 @ 2.5		flat white
12	NS260	Alum. (121GS291C)		.78	.79	Neoprene	1.75	15.9	2.25	25.8		26.0;31.0		1.00 @ 2.5		
13	NS397	Alum. (KE7601-1)		.86	.87	Polyurethane	1.80	14.6	1.55	19.9		18.0;60.0		0.90 @ 2.5		
14	NS397	Oxide (KE7100)		.78	.50	Polyurethane	1.50	12.5	1.38	17.7		8.0;53.0		0.45 @ 2.5		
15	NS260	Alum. (KE7601-1)		.86	.85	Polyurethane	1.05	11.4	1.41	16.2		20.7;56.0		1.28 @ 2.5		
16	NS397	Alum. (Uretek URE1167)		.78	.79	Polyurethane	1.50	12.5	1.50	19.2		16.3;53.0		0.85 @ 2.5		
18	NS397	Yellow (0500BH221-4)		.75	.38	Hypalon	1.00	8.7	1.28	16.5	18.0;36.0			0.48 @ 2.5		
19	NS397	Alum. (KE7601-1)		.88	.88	Polyurethane	1.00	8.7	0.63	8.1	18.3;---			2.26 @ 2.2		
20	NS397	Alum./Intum #1 (KE7601-1-1)		.87	.89	Polyurethane	1.50	12.5	1.11	14.3	24.0;---			1.68 @ 2.2		Intumescent #1 = $CaSO_4 \cdot 2H_2O$
21	NS397	Alum./Intum #2 (KE7601-1-2)		.85	.88	Polyurethane	2.50	19.2	1.52	17.5	17.0;---			0.97 @ 2.2		Intumescent #2 = $Al_2O_3 \cdot 3H_2O$
22	NS397	Alum./Intum #3 (KE7601-1-3)		.87	.88	Polyurethane	1.50	12.5	1.03	11.9	16.8;---			1.41 @ 2.2		Intumescent #3 = $NaHCO_3$
23	NS397	Alum./Intum #4 (KE7601-1-4)		.88	.89	Polyurethane	1.50	12.5	1.00	12.9	14.7;---			1.14 @ 2.2		Intumescent #4 = $CuSO_4 \cdot 5H_2O$
24	NS397	Alum. (KE7601-1)	Oxide (KE7100)	.89	.89	Polyurethane	1.50	12.5	1.08	13.9	15.7;---			1.13 @ 2.2		
25	NS397	Alum. (KE7601-1)	Oxide/Intum #1 (KE7100-1)	.88	.88	Polyurethane	1.50	12.5	1.00	12.9	17.0;---			1.32 @ 2.2		

* Units: Failure Time "T", sec; Temp. Rise Rate, °C/min
@ heat flux (HF), Btu/ft^2-sec; inflation pressure: 2.5-3 psig

** Units: Failure Time "T", sec @ heat flux (HF) = 2.2 Btu/ft^2-sec
inflation pressure: 2.5 - 3 psig

TABLE 1

MASTER TABLE

TABLE 1. MASTER TABLE (Continued)

SAMPLE NUMBER	BASE FABRIC BFG. NO.	REFLECTIVE COATING Top Coat (Coating #)	Bottom Coat (Coating #)	REFLECTIVITY ρ @λ=2.0-2.5 2.0μ	2.5μ	COATING VEHICLE POLYMER	THICKNESS CHANGE (.001 in.) Δt	% Δt	WEIGHT CHANGE (oz/yd²) Δw	% Δw	INFLATED TUBE RADIANT HEAT TEST RESULTS* HF = 2.2 HF = 2.5	FLAT DISK RADIANT HEAT TEST RESULTS** HF = 2.2	RATIO OF FAILURE TIME TO PERCENT WEIGHT CHANGE (T/%Δw) Tube T/%Δw @ HF	Disk T/%Δw @ HF	REMARKS
26	NS397	Alum. (KE7601-1)	Oxide/Intum #2 (KE7100-2)	.89	.90	Polyurethane	1.70	13.9	1.15	18.3	18.2;---		0.99 @ 2.2		
26	NS397	Alum. (KE7601-1)	Oxide/Intum #3 (KE7100-3)	.88	.89	Polyurethane	1.70	13.9	1.20	15.5	15.5;---		1.00 @ 2.2		
29	NS397	Alum. (KE7601-1)	Oxide/Intum #4 (KE7100-4)	.88	.89	Polyurethane	1.50	12.5	1.06	13.7	20.0;---		1.46 @ 2.2		
30	NS397	Alum./Intum #1 (KE7601-1-1)	Oxide/Intum #1 (KE7100-1)	.86	.87	Polyurethane	1.20	10.2	0.94	12.1	15.0;---		1.24 @ 2.2		
31	NS397	Alum./Intum #2 (KE7601-1-2)	Oxide/Intum #2 (KE7100-2)	.82	.85	Polyurethane	2.50	19.2	1.15	14.8	17.0;---		1.15 @ 2.2		
32	NS397	Alum./Intum #3 (KE7601-1-3)	Oxide/Intum #3 (KE7100-3)	.86	.87	Polyurethane	2.50	19.2	1.90	20.4	21.3;---		1.04 @ 2.2		
33	NS397	Alum./Intum #4 (KE7601-1-4)	Oxide/Intum #4 (KE7100-4)	.86	.86	Polyurethane	1.25	11.9	1.41	18.2	20.3;---		1.12 @ 2.2		
34	NS397	Alum. (0165BH169C-5)		.72	.73	Polyurethane	1.50	14.2	1.11	14.3	12.0;---		0.84 @ 2.2		Modified KE7601-1 (Alcoa AL.6578 pigment used)
35	NS397	Alum.		.62	.65	Silicone	2.00	19.0	2.24	28.9	10.0;---		0.34 @ 2.2		Dow Corning 3-5000 silicone with Alcoa Al. 6578 pigment
36	NS397	Alum.		.64	.66	Silicone	1.50	14.3	1.80	23.2	9.5;---		[illegible] @ 2.2		Same as Sample 35 except with Dow Corning 1200 prime coat
37	NS397	Alum.		.75	.77	Polyurethane	1.60	15.2	1.17	14.6	12.3;---		0.84 @ 2.2		Same as Sample 34 except with flame retardant
38	NS397	Alum. (KE7601-1)				Polyurethane	0.50	4.7	0.35	4.7		32		6.81 @ 2.2	1 coat sprayed; diluent = cellosolve (for all spraying)
39	NS397	Alum. (KE7601-1)				Polyurethane	1.10	12.0	0.89	12.0		33		2.75 @ 2.2	2 coats sprayed
40	NS397	Alum. (KE7620)				Polyurethane	0.49	5.6	0.60	6.6		30		4.55 @ 2.2	KE7620 = KE7601-1 with flame retardant and fungicide; 1 coat sprayed
41	NS397	Alum. (KE7620)				Polyurethane	1.30	12.1	1.02	13.7		33		2.41 @ 2.2	2 coats sprayed
42	NS397	Alum. (KE7601-1-C)				Polyurethane	0.80	7.5	0.50	6.7		27		4.02 @ 2.2	KE7601-1-C = KE7620 with Intumescent #1; 1 coat sprayed
43	NS397	Alum. (KE7601-1-C)				Polyurethane	1.60	15.0	1.60	21.6		32		1.48 @ 2.2	2 coats sprayed
44	NS397	Alum. (KE7601-1)				Polyurethane	0.30	2.8	0.18	2.4		26		10.48 @ 2.2	1 "light coat" sprayed
45	NS397	Alum. (KE7602E)				Polyurethane	1.00	9.3	0.82	11.1		41		3.69 @ 2.2	Modified KE7601-1 (high melting point resin used)

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* Units: Failure Time "T", sec; Temp. Rise Rate, °C/min
@ heat flux (HF), Btu/ft²-sec; inflation pressure: 2.5 - 3 psig

** Units: Failure Time "T", sec @ heat flux (HF) = 2.2 Btu/ft²-sec
inflation pressure: 2.5 - 3 psig

TABLE 1

MASTER TABLE

II. REFLECTIVE COATING BASE POLYMER VEHICLE

Three polymer vehicles of the elastomeric type which are known to be compatible with common slide materials were evaluated. These vehicles were polyurethane, neoprene, and Hypalon. In addition to the three elastomer vehicles above, a silicone-based coating was also evaluated.

Initially, "off the shelf" and "in-house" compounded reflective coatings, as well as commercially available reflective elastomer paints, were evaluated. (Paints are distinguished from coatings mainly by being of a more plastic physical nature than are coatings. Coatings are physically more elastomeric (rubbery) than plastic.)

Candidate reflective coatings and paints were applied to three common escape slide fabric materials: neoprene-coated nylon (BFGoodrich Code #NS260) and two polyurethane-coated nylons (BFGoodrich Code #NS397 and #NS364).

(The neoprene and polyurethane coatings on the nylon in the above common slide materials are base coats, applied to seal the fabric against air leakage, as opposed to reflective coatings, which are applied over the base elastomer coats. NS397 is coated with base coat elastomer on one side only, while both NS260 and NS364 are base-coated on both sides.)

In this report's Master Table, (Table 1, page 11), slide materials NS260, NS397, and NS364 are listed as Samples #1, 2, and 3, respectively.

Samples #1, 2, and 3 served as "control samples" in this study. Control samples were samples which were not coated with any reflective coating. Radiant heat test failure times measured for test specimens which were coated with the various reflective coatings were compared to failure times measured for control samples in order to determine relative improvements in radiant heat resistance occurring as the result of the reflective coatings.

Based upon Phase 1-type radiant heat tests, i.e. inflated fabric tubes at 2.5 to 3 psig exposed to a 2.5 Btu/ft^2-sec heat flux, the control samples #1, 2, and 3 were shown to have failure times in the 13 - 15 second range, as shown in the table below:

Sample No.	Reflectivity, ρ @ λ = 2.5μ	Inflated Tube (2.5-3 psig) Failure Time "T" (sec. to pressure drop @ 2.5 Btu/ft^2-sec)
1	.37	14.5
2	.12	13.0
3	.11	14.9

The particular type of base elastomer coating applied to the nylon fabric in these common slide materials (whether neoprene coated both sides, polyurethane coated one side, or polyurethane coated both sides) appears to have no significant influence on radiant heat resistance, judging from the relatively similar failure times measured for Samples 1, 2, and 3.

The above table also shows measured values of radiation reflectivity (ρ) at a wavelength (λ) of 2.5μ for the three control samples. By way of explanation, a reflectivity value of 0.0 indicates zero reflectance, i.e. total absorption, of incident radiation at a given wavelength, while a reflectivity value of 1.0 indicates total reflectance or zero absorption.

The relatively low reflectivity values at $\lambda = 2.5\mu$ for these control samples should be noted. Slide fabrics colored "international yellow," such as Samples 1, 2, and 3, are highly reflective of visible light ($\rho > .8$ at $\lambda = 1\mu$), but are highly absorbent of infrared radiation ($\rho < .4$ at $\lambda = 2.5\mu$).

Infrared radiation is, of course, the fuel fire radiation which poses greatest thermal danger to escape slides.

III. COMMERCIALLY AVAILABLE REFLECTIVE COATINGS/PAINTS

Several commercially available paints were evaluated early in this study. These commercial paints, although based on polyurethane, dried (or cured) at ambient temperatures to a physical state more plastic than elastomeric, which made these paints unsuitable for use on flexible fabrics. In particular, slide material samples coated with these paints exhibited brittleness, and even cracks in the paint, when folded. For these reasons, paints were dropped from consideration as retrofit coatings. No radiant heat tests were performed on samples coated with paints.

Several "off the shelf" reflective elastomer coatings were next evaluated. These elastomer coatings were pigmented with either aluminum or white oxide powders. The polyurethane coatings in Samples #9, 13, 14, and 16 were applied over polyurethane base coat slide material (NS397), while the neoprene coating (Sample #8) and the Hypalon coating (Sample #11) were applied over neoprene base coat material (NS260). One polyurethane coating, Sample #15, was also applied over NS260 neoprene material.

Test results for these "off the shelf" reflective elastomer coatings, based upon Phase 1-type radiant heat tests, are shown in the table below:

Sample Number	REFLECTIVE COATING Elastomer	Color	BASE SLIDE MATERIAL Control Sample	Base Coat Elastomer	Reflectivity, ρ @ λ = 2.5μ	Inflated Tube (2.5 - 3 psig) Failure Time "T" (seconds to pressure drop @ 2.5 Btu/ft^2-sec)	T/%Δw
8	Neoprene	Alum.	1	Neoprene	.66	22.0	1.29
9	Polyurethane	Alum.	2	Polyurethane	.73	24.0	0.90
11	Hypalon	White	1	Neoprene	.62	14.5	0.48
13	Polyurethane	Alum.	2	Polyurethane	.87	18.0	0.90
14	Polyurethane	White	2	Polyurethane	.50	8.0	0.45
15	Polyurethane	Alum.	1	Neoprene	.85	20.7	1.28
16	Polyurethane	Alum.	2	Polyurethane	.79	16.3	0.85

The three different aluminized polyurethane coatings, Samples #9, 13, and 16, showed failure times ranging from 16.3 to 24 seconds. However, when failure times are considered in relation to the percent weight increases due to the coatings, i.e. the ratio T/%Δw, it is seen that the coatings afford about equal protection when equal amounts are applied: T/%Δw = 0.90, 0.90, and 0.85 for Samples #9, 13, and 16, respectively.

A white-colored polyurethane coating, Sample #14, similar to Sample #13 but having white oxide pigment loading instead of aluminum, failed in 8 seconds. The reflectivity of this white coating (Sample #14) was .50 at a wavelength of 2.5μ, while the reflectivity of the corresponding aluminum coating (Sample #13), which lasted 18 seconds,was .87. These results, in conjunction with the reflectivity values and failure times discussed earlier for the yellow-colored control samples #1, 2, and 3, demonstrate that: 1) resistance to fuel fire radiation is directly related to reflectivity in the near infrared radiation range, and 2) aluminum-pigmented reflective coatings demonstrate higher infrared reflectivity (and therefor provide greater radiant heat protection to escape slide material) than do either white oxide-pigmented reflective coatings or yellow-colored slide material base elastomer coatings.

The neoprene base coat slide material, NS260, was coated with aluminized neoprene and polyurethane coatings, Samples #8 and 15, respectively, and also with a white Hypalon coating, Sample #11.

Approximately equal failure times and T/%Δw ratios were obtained with the aluminized neoprene and polyurethane coatings on NS260: Sample #8: 22.0 sec, 1.29; Sample #15: 20.7 sec, 1.28.

Sample #11, the white Hypalon coating on NS260, failed in a relatively short time (14.5 seconds), despite having a rather thick coating, as demonstrated by a T/%Δw ratio of 0.48, which is low compared to the corresponding values for other coatings on NS260 (Samples #8 and 15 above). Sample #11's short failure time is at least partially explained by the low infrared reflectivity of its white Hypalon coating ($\rho = .62$ @ $\lambda = 2.5\mu$).

The radiant heat failure modes for neoprene and Hypalon coatings differed distinctly from those for polyurethane coatings. While the neoprene and Hypalon coatings became brittle and cracked, exposing large areas of the base slide material below, the polyurethane coatings softened and retained elasticity, exposing only "pinholes" of base slide material.

In that one of the prime objectives of this study was to select or formulate a reflective coating capable of being used as a <u>universal</u> retrofit coating for all common slide materials (which from all available information are polyurethane and neoprene-coated nylon), the aluminized polyurethane coating used on polyurethane nylon slide material in Sample #13 was also applied to neoprene nylon slide material in Sample #15. The table below compares failure times for neoprene nylon slide material samples coated with both aluminized neoprene and aluminized polyurethane reflective coatings.

Sample Number	REFLECTIVE COATING Elastomer	REFLECTIVE COATING Color	BASE SLIDE MATERIAL Control Sample	BASE SLIDE MATERIAL Base Coat Elastomer	Reflectivity, ρ @ $\lambda = 2.5\mu$	Inflated Tube (2.5 - 3 psig) Failure Time "T" (seconds to pressure drop @ 2.5 Btu/ft^2-sec)	T/%Δw
8	Neoprene	Alum.	1	Neoprene	.66	22.0	1.29
12	Neoprene	Alum.	1	Neoprene	.79	26.0	1.00
15	Polyurethane	Alum.	1	Neoprene	.85	20.7	1.28

The values of T/%Δw shown above indicate that the aluminized polyurethane reflective coating provides radiant heat protection to the neoprene nylon slide material equivalent to that protection afforded by aluminized neoprene reflective coatings.

The adhesion of the polyurethane reflective coating to the neoprene nylon base slide material was greater than that of either of the neoprene reflective coatings: a peel value in the range of 4.0 - 4.5 lb/inch width, with cohesive failure in the coating, was achieved by the polyurethane reflective coating sample (#15), while peel values of only about 3 lb/inch width, with failure at the coating/material interface, were achieved by the neoprene reflective coating samples (#8 and 12).

The adhesion of Hypalon reflective coatings (Samples #11 and 18) to base slide material was so poor that Hypalon was ruled out as a candidate retrofit coating.

Also because of problems of extremely poor adhesion to base slide material, silicone rubber reflective coatings (Samples #35 and 36) were ruled out of consideration as candidate reflective coatings.

IV. FORMULATION OF REFLECTIVE COATINGS

Based on the polyurethane reflective coatings' higher levels of adhesion to common base slide materials (as compared to neoprene, Hypalon, or silicone rubber coatings), and based upon the higher infrared reflectivity of aluminized coatings as compared to white-colored coatings, it was decided to concentrate all further development work in this study on aluminized polyurethane coatings. It was further decided to concentrate work on only one of the commercially available aluminized coatings -- BFGoodrich KE7601-1.

KE7601-1, which had been investigated earlier in this study in Samples #13 and 15, was chosen for further investigation over such other aluminized polyurethane coatings as Reeves V75112 (Sample #9) and Uretek URE1167 (Sample #16) mainly for reasons of availability and the naturally greater knowledge that BFGoodrich personnel would have regarding an "in-house" product.

KE7601-1 was not chosen for further investigation because of any radiant heat resistance properties superior to those of the two above mentioned coatings. Actually, all three of the commercially available aluminized polyurethane coatings showed similar radiant heat resistances, as measured by $T/\%\Delta w$ ratio, when applied to the same base slide material (polyurethane nylon, NS397) and tested in Phase 1-type tests, i.e. inflated tubes at 2.5 to 3 psig and 2.5 Btu/ft^2-sec, as shown in the table below:

Sample Number	REFLECTIVE COATING Elastomer	Color	Manufacturer	Code No.	T/%ΔW
9	Polyurethane	Alum.	Reeves	V75112	0.90
13	Polyurethane	Alum.	BFGoodrich	KE7601-1	0.90
16	Polyurethane	Alum.	Uretek	URE1167	0.85

Because the radiation heat resistances of the three commercially available aluminized polyurethane coatings were so similar, it was decided that concentration on just a single coating in all further development work was justifiable.

Further development work carried out in this study consisted of modifying the basic KE7601-1 coating in an attempt to improve the coating's infrared reflectivity and heat resistance. This coating modification work is referred to in this report as "formulation" of reflective coatings.

Specific modifications of KE7601-1 attempted included: a) the substitution of different aluminum pigments for the aluminum found in standard KE7601-1; b) the incorporation of intumescent (endothermic) reactants into KE7601-1; c) the substitution of higher melting temperature/higher modulus thermoplastic polyurethane resin for the polyurethane resin used in standard KE7601-1; and d) the incorporation of flame retardant and fungicide into KE7601-1. For the most part, these four specific modifications of KE7601-1 were investigated and evaluated individually, i.e. one modification per coating formulation.

Another area of investigation in this study, which was actually conducted prior to this "coatings formulation" phase of the study but which has not yet been discussed in this report, is the area of curing systems for coatings -- specifically whether to attempt to enhance the chemical cross-linking of the coating polymer vehicle (and thereby to increase the heat capacity of the coating) through the use of curing agents such as isocyanate.

Each of the above listed modifications of KE7601-1, as well as the investigation of curing systems, will now be discussed separately.

Aluminum Pigments

The substitution of a lighter weight, smaller granule ("rhombic") aluminum powder for the heavier aluminum flake used in standard KE7601-1 was made in Sample #34, in order to investigate the effect of aluminum particle size and shape on reflectivity and radiant heat resistance. Coatings containing standard and modified aluminum pigments (Samples #19 and 34, respectively) were applied to the same base slide material (polyurethane coated nylon, NS397) and tested under Phase 2-type tests, i.e. inflated tubes at 2.5 - 3 psig and 2.2 Btu/ft^2-sec. Test results are shown in the table below:

Sample Number	REFLECTIVE COATING Coating Number	Reflectivity, ρ @ $\lambda = 2.5\mu$	Inflated Tube (2.5 - 3 psig) Failure Time "T" (seconds to pressure drop @ 2.2 Btu/ft^2-sec)	T%Δw
19	KE7601-1	.88	18.3	2.26
34	0165BH169C-5	.73	12.0	0.84

As can be seen from the table above, neither infrared reflectivity nor radiant heat resistance, as measured by T/%Δw, were improved by the smaller granule aluminum powder (Sample #34). For this reason, it was decided to retain the larger granule aluminum flakes used in standard KE7601-1 for use in any further coating formulations.

Intumescent Reactants

Even though the greatest percentage of infrared radiation incident upon slide material coated with KE7601-1 is reflected (88% in the case of Sample #19), sufficient radiation is always absorbed to eventually cause coating failure, i.e. burn-through of the reflective coating, which exposes the base slide material below to heat and ultimately leads to slide deflation. Coating failure is thus a function not only of the reflectivity of the coating but also of the heat capacity of the coating, where heat capacity is defined as the amount of absorbed energy required to increase the temperature of the coating by a specified number of degrees.

It was theorized that the heat capacity of KE7601-1 coating could be increased by incorporating intumescent reactants into the coating.

Intumescent (or endothermic) reactants are chemical compounds which decompose when heated to specific temperatures, releasing moisture and gases -- the products of the endothermic reaction. When incorporated into a reflective coating, it was thought that the intumescent reactants might increase the coating's heat capacity by causing some portion of the absorbed radiant heat to be diverted towards the production of endothermic products and away from the burning of the coating.

It was considered preferable that any intumescent reactants incorporated into KE7601-1 would have decomposition temperatures, i.e. temperatures at which endothermic products are released, which would approximate the temperature at which KE7601-1 begins to melt -- approximately 160°C. A literature search revealed three intumescent reactants having decomposition temperatures in the range of 110° to 200°C and a fourth reactant having a decomposition temperature of 327°C. Technical information on these four intumescent reactants is shown in the table below:

Intumescent Reactant No.	Chemical Formula	Decomposition Temperature(s)	Decomposition Products
1	$CaSO_4 \cdot 2H_2O$	160°C, 199°C	H_2O
2	$Al_2O_3 \cdot 3H_2O$	327°C	H_2O
3	$NaHCO_3$	166°C	H_2O, CO_2
4	$CuSO_4 \cdot 5H_2O$	110°C, 138°C, 277°C	H_2O

Where more than one decomposition temperature is listed for a single reactant, this indicates that the reactant releases endothermic products progressively as it is heated through a temperature range.

The intumescent reactants above were incorporated into the aluminized polyurethane coating KE7601-1 and also into the white oxide-loaded coating KE7100. (KE7100 had been used previously in Samples #10 and 14). The reactants were always incorporated into a coating individually, i.e. one reactant per coating modification.

Samples #20 through 23 and #25 through 33 in the Master Table, page   , were polyurethane nylon slide material (NS397) test specimens which were coated with either one or two intumescent-loaded coatings. In the case of two-coat samples, the first coat, or "bottom" coat, was either standard KE7100 or an intumescent modification of KE7100, and the second coat, or "top" coat, was either standard or intumescent-modified KE7601-1. Sample #24 was a completely non-intumescent two-coat specimen, with standard KE7100 on the bottom and standard KE7601-1 on top. Base slide material on Sample #24 was also NS397, polyurethane nylon.

Samples #20 through 23 were one-coat specimens coated with intumescent modifications of KE7601-1, specifically labeled KE7601-1-1, KE7601-1-2, KE7601-1-3, and KE7601-1-4, which contained intumescent reactants #1, 2, 3, and 4, respectively.

Samples #25 through 29 were two-coat specimens coated on the first coat with intumescent modifications of KE7100 (labeled KE7100-1 through KE7100-4, depending upon the intumescent reactant incorporated) and coated on the second coat with standard KE7601-1. (It may be noted that there is no Sample #27 listed in the Master Table. The reason is that Sample #27 was a duplicate of Sample #26.)

Samples #30 through 33 were two-coat specimens coated on the first coat with intumescent modifications of KE7100 and coated on the second coat with intumescent modifications of KE7601-1. In Samples #30 through 33, the intumescent reactants in the two coats were matched, i.e. intumescent #1 in the bottom coat and in the top coat, etc.

Because the aluminized reflective coating was always the top coat, i.e. the last coat to be applied, the colors of Samples #20 through 33 were all basically aluminum.

The intumescent-loaded coatings (Samples #20 through 23 and #25 through 33), along with Sample #24 (the non-intumescent two-coat specimen) and Sample #19 (Standard KE7601-1), were tested using Phase 2-type radiant heat tests, i.e. inflated tubes at 2.5 to 3 psig and 2.2 Btu/ft^2-sec. Test results are shown in the following table:

Sample Number	REFLECTIVE COATING Top Coat Coating No.	REFLECTIVE COATING Bottom Coat Coating No.	Reflectivity, ρ @ $\lambda = 2.5\mu$	Inflated Tube (2.5 - 3 psig) Failure Time "T" (seconds to initial pressure drop @ 2.2 Btu/ft^2-sec)	T/%Δw
19	KE7601-1	-----------	.88	18.3	2.26
20	KE7601-1-1	-----------	.89	24.0	1.68
21	KE7601-1-2	-----------	.88	17.0	0.97
22	KE7601-1-3	-----------	.88	16.8	1.41
23	KE7601-1-4	-----------	.89	14.7	1.14
24	KE7601-1	KE7100	.89	15.7	1.13
25	KE7601-1	KE7100-1	.88	17.0	1.32
26	KE7601-1	KE7100-2	.90	18.2	0.99
28	KE7601-1	KE7100-3	.89	15.5	1.00
29	KE7601-1	KE7100-4	.89	20.0	1.46
30	KE7601-1-1	KE7100-1	.87	15.0	1.24
31	KE7601-1-2	KE7100-2	.85	17.0	1.15
32	KE7601-1-3	KE7100-3	.87	21.3	1.04
33	KE7601-1-4	KE7100-4	.86	20.3	1.12

From the above test data, it can be seen that infrared reflectivity for all of the samples was fairly equivalent, in the .85 - .90 range. It thus seems fair to say that any differences in radiant heat resistance between the samples would be mainly due to differences in heat capacity of the various coatings or coating combinations applied.

The longest failure time, 24 seconds, was obtained with Sample #20 -- a one-coat aluminized polyurethane coating incorporating intumescent #1. This longest failure time was achieved at some sacrifice in weight, however, as can be seen by comparing T/%Δw ratios. For Sample #20, T/%Δw = 1.68, but for Sample #19 (regular KE7601-1 aluminized polyurethane), which lasted 18.3 seconds, T/%Δw = 2.26. Sample #19's T/%Δw ratio of 2.26 was higher than those ratios obtained by all of Samples #20 through 33. Since T/%Δw is regarded as a more representative measure of radiant heat resistance than failure time "T" alone, it thus appears that the regular non-intumescent aluminized polyurethane coating KE7601-1 (Sample #19) is more resistant to radiant heat than any of the other intumescent coatings or combinations of coatings contained in Samples #20 through 33.

The two-coat systems, in particular, did not generally improve radiant heat resistance, as measured by T/%Δw, beyond what could be obtained using single-coat systems.

To summarize this discussion of intumescent reactants and reflective coatings, it may be stated that the test results do not warrant the incorporation of intumescent reactants in reflective coatings, and that the test results likewise do not warrant two-coat reflective coating systems.

Higher Melting Temperature/Higher Modulus Polyurethane Resin

The substitution of higher melting temperature/higher modulus polyurethane resin for the resin used in standard KE7601-1 was considered a possible way to increase KE7601-1's heat capacity. To investigate this possibility, a new aluminized polyurethane coating, KE7602E (Sample #45), was developed from standard KE7601-1 by the substitution of polyurethane resins as described above.

KE7602E and KE7601-1 (Sample #39) coatings were spray-coated on polyurethane nylon base slide material (NS397) and were tested using Phase 3-type radiant heat tests, i.e. flat disks inflated to between 2.5 and 3 psig subjected to 2.2 Btu/ft^2-sec radiant heat flux. Test results are shown in the table below:

Sample Number	REFLECTIVE COATING Coating Number	Flat Disk (2.5-3 psig) Failure Time "T" (seconds to pressure drop @ 2.2 Btu/ft^2·sec)	T/%Δw
39	KE7601-1	33	2.75
45	KE7602E	41	3.69

The above results show that an approximate 25% improvement in radiant heat resistance, as measured by T/%Δw, could be obtained by using higher melting temperature/higher modulus polyurethane resin (as in Sample #45) instead of the standard KE7601-1 resin (as in Sample #39).

It was decided, however, not to recommend the use of higher melting temperature/higher modulus resin in reflective coatings because of certain shortcomings in the coating developed with such resin (KE7602E) -- shortcomings which were not present in the coating developed with standard resin (KE7601-1). These shortcomings were:

1) Samples coated with KE7602E were stiffer than samples coated with KE7601-1, which would mean that an escape slide coated with KE7602E would be more difficult to fold and pack than a slide coated with KE7601-1; and

2) A coating made with higher melting temperature/higher modulus resin, such as KE7602E, would, in order to be applied to slide material, have to be in solution with a chemically stronger solvent than would a standard resin coating, such as KE7601-1; the danger with a strong solvent would be that such a solvent could tend to attack and "swell" (lift) the base elastomer coating from slide material, i.e. the coating which actually seals the slide material fabric against air leakage.

Because of the shortcomings described above for coatings containing higher melting temperature/higher modulus resin, it was decided to retain the standard polyurethane resin used in KE7601-1 in any further coating formulations developed in this study.

Flame Retardant and Fungicide

The final modification of coating KE7601-1 was coating KE7620. KE7620 was the same as KE7601-1, i.e. an aluminized polyurethane coating, except for the addition of flame retardant and fungicide.

Flame retardant and fungicide were added in KE7620 in order to assure compliance of escape slide material with TSO and FAR requirements regarding flame propagation and fungus growth after retrofit coating with KE7620.

The effects of flame retardant and fungicide on radiant heat resistance were investigated in Samples #38 through 41. Samples #38 and 39 were regular KE7601-1, while #40 and 41 were KE7620.

Reflective coatings in Samples #38 through 41, as well as in #42 through 45, were spray-coated. (All previous samples, #4 though 37, had been brush-coated.) Spraying allowed relatively more control over the amount of coating applied than did brushing. Thus Samples #38 through 41 also allowed investigation of the effect of varying coating weight on radiant heat resistance: specifically, Samples #38 and

40 were sprayed with one coat of coating, while #39 and 41 were sprayed with two coats.

Base slide material in Samples #38 through 41 was polyurethane-coated nylon, NS397. Phase 3-type radiant heat tests, i.e. flat disks inflated from 2.5 - 3 psig and subjected to 2.2 Btu/ft -sec, produced the following test results for Samples #38 through 41, as well as for Sample #2 (NS397 base slide material without any reflective coating):

Sample Number	REFLECTIVE COATING Coating Number	Number of Coats Applied	Percentage Weight Increase Due To Coating (%Δw)	Flat Disk (2.5 - 3 psig) Failure Time "T" (seconds to pressure drop @ 2.2 Btu/ft^2-sec)	T/%Δw
38	KE7601-1	1	4.7	32	6.8
39	KE7601-1	2	12.0	33	2.75
40	KE7620	1	6.6	30	4.55
41	KE7620	2	13.7	33	2.41
2	----	-	----	10	----

The above test results lead to the following conclusions:

1) Radiant heat resistance of aluminized polyurethane reflective coating with flame retardant and fungicide (KE7620) is slightly lower than that for similar coating without retardant and fungicide (KE7601-1), judging from T/%Δw values;

2) Despite the slight reduction in radiation heat resistance noted above for the coating containing fungicide and flame retardant (which may or may not have been due to the addition of fungicide and flame retardant), this coating -- KE7620 -- still possesses radiant heat resistance far superior to base slide material, as can be seen by comparing failure time "T" for Samples #40 and 41 with that for Sample 2; and

3) Approximately equivalent radiant heat resistance for a given type of coating can be obtained by the application of a single coat as can be obtained by application of dual coats, as can be seen by comparing failure time "T" for Samples #38 and 39 and Samples #40 and 41.

Because KE7620 aluminized polyurethane reflective coating still managed to provide adequate radiant heat resistance even after flame retardant and fungicide necessary to meet FAR and TSO requirements were added, and because slide material coated with KE7620 remained flexible enough to allow slide packing, KE7620 was chosen as the single reflective coating recommended by this study for retrofit coating of escape slides.

Curing Systems for Coatings

It is a known fact that the heat capacity of some elastomers can be increased by the process of vulcanization or "curing." Curing refers to the chemical action within an elastomer of curing agents -- chemical compounds which, when incorporated in the elastomer, react at elevated or ambient temperatures to produce an enhanced chemical cross-linking network, i.e. primary chemical bonds, in the elastomer. Increased heat capacity is related to enhanced chemical cross-linking.

The effect of curing agents on heat capacity of reflective coatings was investigated early in this study with two BFGoodrich-developed coatings -- coating #0121GS291C, an aluminized neoprene coating, and coating #KE7601-1, an aluminized polyurethane coating.

Coating #0121GS291C, the neoprene coating, was compounded both with and without the curing agent "isocyanate" (BFGoodrich code #A1343B) in Samples #6 and 12, respectively. The curing process in Sample #6 was at ambient temperature. Base slide material in both Samples #6 and 12 was neoprene-coated nylon (NS260). Phase 1-type radiant heat tests, i.e. inflated tubes at 2.5 to 3 psig and 2.5 Btu/ft^2-sec, were performed on Samples #6 and 12 with the following test results:

Sample Number	REFLECTIVE COATING Coating Number	Curing Agent	Reflectivity, ρ @ $\lambda = 2.5\mu$	Inflated Tube (2.5 - 3 psig) Failure Time "T" (seconds to pressure drop @ 2.5 Btu/ft^2-sec)	T/%Δw
6	0121GS291C	isocyanate	.81	19.7	0.46
12	0121GS291C	------	.79	26.0	1.00

As can be seen from the above test results, radiant heat resistance (and thereby heat capacity), as measured by T/%Δw, appears to have actually been decreased by the incorporation of the curing agent isocyanate into the neoprene in Coating #0121GS291C.

In the case of the aluminized polyurethane reflective coating, KE7601-1, the reverse effect of isocyanate incorporation was observed, i.e. coating heat capacity appeared to have been increased by the curing agent, as described below.

The polyurethane coating KE7601-1 was compounded both with and without isocyanate in Samples #7 and 13, respectively. The curing process in Sample #7 was at ambient temperature. Base slide material in Samples #7 and 13 was polyurethane-coated nylon (NS397). Samples #7 and 13 were tested in Phase 1-type radiant heat tests, producing the following test results:

Sample Number	REFLECTIVE COATING Coating Number	Curing Agent	Reflectivity, ρ @ $\lambda = 2.5\mu$	Inflated Tube (2.5 - 3 psig) Failure Time "T" (seconds to pressure drop @ 2.5 Btu/ft^2-sec)	T/%Δw
7	KE7601-1	isocyanate	.83	92.0	2.73
13	KE7601-1	---	.87	18.0	0.90

The test results above show that radiant heat resistance (and thereby heat capacity), as measured by T/%Δw, for the polyurethane coating KE7601-1 indeed appeared to have been increased by the incorporation of isocyanate into the polyurethane.

The explanation for these opposite-appearing effects of isocyanate on neoprene and polyurethane-based coatings lies in the characteristics of the elastomers themselves. Basically, polyurethane is an elastomer which <u>does</u> contain functional chemical groups which react at ambient temperature with the isocyanate curing agent to produce strong primary chemical bonds and therefore increased heat capacity, while neoprene is an elastomer which does <u>not</u> contain such functional groups.

The increased heat capacity of KE7601-1 resulting from isocyanate notwithstanding, it was decided <u>not</u> to incorporate curing agents in any further coatings developed in this study, for reasons explained below.

In all of the coatings developed which incorporated isocyanate in the coating elastomer (Samples #4 and 5, as well as the aforementioned #6 and 7), the resulting reflective coating was, upon drying, very stiff and brittle, which made the coated slide material very inflexible. An escape slide coated with any of these coatings containing isocyanate would have been virtually unpackable. In contrast, the coatings developed <u>without</u> isocyanate, Samples #12 and 13, which differed from their respective corresponding coatings Samples #6 and 7 only by the absence of isocyanate, were fully flexible.

Thus because of the extreme inflexibility which was found in slide material samples coated with coatings containing isocyanate, it was decided not to incorporate curing agents into any further reflective coatings developed in this study.

Summary

To summarize this discussion of "formulation of reflective coatings," it may be stated that:

1) neither lighter weight aluminum powder nor intumescent reactants were able to improve the radiant heat resistance of basic KE7601-1 aluminized polyurethane coating; and

2) the incorporation of flame retardant and fungicide necessary to meet FAR and TSO requirements into basic KE7601-1 coating (in the form of a new coating, KE7620) did not seriously reduce the radiant heat resistance of the resulting new coating, KE7620, from that of basic KE7601-1.

For these reasons, KE7620 was chosen as the single reflective coating recommended by this study for retrofit coating of in-service aircraft escape slides.

V. PHYSICAL PROPERTIES TESTS FOR RETROFIT-COATED SLIDE MATERIALS

Physical properties tests were performed on slide material test specimens coated with the reflective coating recommended in this study -- KE7620, an aluminized polyurethane coating containing fungicide and flame retardant. For comparison, these same tests were performed on "control" specimens cut from base slide material without reflective coating -- NS397 (polyurethane-coated nylon), NS364 (polyurethane-coated nylon), and NS260 (neoprene-coated nylon).

The attached physical properties test report, which begins on the following page, demonstrates that commonly used slide materials, even after retrofit coating with KE7620, still meet all pertinent physical properties requirements specified in FAA Technical Standard Order Part 514, "Emergency Evacuation Slides," TSO-C69.

RETROFIT-COATED AND BASE SLIDE MATERIAL PHYSICAL PROPERTIES TESTS

1.0 Scope

This document reports physical properties test results obtained on retrofit-coated and base slide materials per FAA Technical Standard Order Part 514, "Emergency Evacuation Slides," TSO-C69.

2.0 Material Designation

2.0.1	NS397	base slide material (polyurethane-coated nylon)
2.0.2	NS364	base slide material (polyurethane-coated nylon)
2.0.3	NS260	base slide material (neoprene-coated nylon)
2.0.4	NS397-r.c.	NS397 slide material retrofit-coated with KE7620 reflective coating
2.0.5	NS364-r.c.	NS364 slide material retrofit-coated with KE7620 reflective coating
2.0.6	NS260-r.c.	NS260 slide material retrofit-coated with KE7620 reflective coating

3.0 Test Procedures

3.0.1	Weight Change	Method 5040, Fed. Test Method Std. 191
3.0.2	Thickness Change	Method 5030, Fed. Test Method Std. 191
3.0.3	Tensile Strength	Method 5100, Fed. Test Method Std. 191
3.0.4	Trapezoidal Tear Strength	Method 5136, Fed. Test Method Std. 191
3.0.5	Crease	Method 5874, Fed. Test Method Std. 191 (10 lb. roller @ room temp. and @ -40°C)
3.0.6	Cold Fold	Method 5874, Fed. Test Method Std. 191 (@ -40°C)
3.0.7	Blocking	Method 5872, Fed. Test Method Std. 191 (4 lb. weight for 30 min. @ 70°C)

3.0.8	Flammability (vertical)	Method 5903, Fed. Test Method Std. 191 and Appendix F, para. (b), FAR Part 25, para. 25.853(b)
3.0.9	Fungus Resistance	Military Standard MIL-STD-810C, Method 508.1, Procedure I
3.0.10	Accelerated Aging	Method 5850, Fed. Test Method Std. 191 (168 hrs. @ 70°C)
3.0.11	Accelerated Weathering	Method 5804, Fed. Test Method Std. 191 (25 hrs., all filters)

4.0 Material Physical Properties Test Results

4.0.1 Weight Change

Weight change tests performed per Method 5040, Fed. Test Method Std. 191 at the BFGoodrich Physical Testing Laboratory.

Test values:

Material	Weight (oz/yd^2)	% Weight Change
NS397	7.42	----
NS397-r.c.	8.44	13.7

4.0.2 Thickness Change

Thickness change tests performed per Method 5030, Fed. Test Method Std. 191 at the BFGoodrich Physical Testing Laboratory

Test values:

Material	Thickness (in.)	% Thickness Change
NS397	.0107	-----
NS397-r.c.	.0120	12.1

4.0.3 Tensile Strength

Tensile tests performed per Method 5100, Fed. Test Method Std. 191 at the BFGoodrich Physical Testing Laboratory

Test values:

	Material	Tensile Strength (lb/in) Warp	Tensile Strength (lb/in) Fill
Original material:	NS397	392	265
	NS397-r.c.	380	277
	Passing values	190	190
After accel. aging: (per Method 5850, FTMS 191; 168 hrs. @ 70°C)	NS397	397	270
	NS397-r.c.	383	262
After accel. weathering: (per Method 5804, FTMS 191; 25 hrs., all filters)	NS397	360	255
	NS397-r.c.	390	277

4.0.4 Trapezoidal Tear Strength

Trapezoidal tear tests performed per Method 5136, Fed. Test Method Std. 191 at the BFGoodrich Physical Testing Laboratory

Test values:

Material	Tear Strength (lb) Warp	Tear Strength (lb) Fill
NS397	18.7	13.5
NS397-r.c.	18.8	14.8
Passing values	13.0	13.0

4.0.5 Crease

Crease tests performed per Method 5874, Fed. Test Method Std. 191 (10 lb. roller @ room temperature and @ -40°C) at the BFGoodrich Physical Testing Laboratory

	Material	Crease Test Result
Original Material:		
@ room temperature	NS397	passed
	NS397-r.c.	passed
@ -40°C	NS397	passed
	NS397-r.c.	passed
After accel.aging: (per Method 5850, FTMS 191; 168 hrs. @ 70°C) @ room temperature:	NS397	passed
	NS397-r.c.	passed
After accel. weathering: (per Method 5804, FTMS 191; 25 hrs., all filters) @ room temperature:	NS397	passed
	NS397-r.c.	passed

4.0.6 Cold Fold

Cold Fold tests performed per Method 5874, Fed. Test Method Std. 191 (@ -40°C) at the BFGoodrich Physical Testing Laboratory

Material	Cold Fold Test Result
NS397	passed
NS397-r.c.	passed

4.0.7 Blocking

Blocking tests performed per Method 5872, Fed. Test Method Std. 191 (4 lb. weight for 30 min. @ 70°C) at the BFGoodrich Physical Testing Laboratory

Material	Blocking Test Result
NS397	passed
NS397-r.c.	passed

4.0.8 Flammability (Vertical)

Flammability (vertical) tests performed per Method 5903, Fed. Test Method Std. 191 and Appendix F, para. (b), FAR Part 25, para. 25.853 (b) at the BFGoodrich Physical Testing Laboratory

Test values:

Material	Self-Extinguishing time (sec)		Char Length (in)	
	Warp	Fill	Warp	Fill
NS364	0	.42	2.9	3.3
NS364-r.c.	0	.36	2.9	3.3
NS260	1.54	10.37	4.8	6.3
NS260-r.c.	7.64	11.51	6.9	6.1
Passing values	15	15	8	8

4.0.9 Fungus Resistance

Fungus resistance tests performed per Military Standard MIL-STD-810C, Method 508.1, Procedure I; tests performed for BFGoodrich by Herron Testing Laboratories, Inc., Cleveland, Ohio

Material	Fungus Resistance Test Result
NS397	No fungus growth
NS397-r.c.	No fungus growth

VI. RADIANT HEAT RESISTANCE OF RETROFIT-COATED SLIDE MATERIALS AFTER EXPOSURE TO ACCELERATED AGING AND WEATHERING

In order to investigate the effects of aging and weathering on radiant heat resistance of slide material retrofit-coated with reflective coating, Phase 3-type radiant heat tests, i.e. slide material disks inflated to between 2.5 and 3 psig subjected to 2.2 Btu/ft^2-sec heat flux, were performed on samples of NS397 polyurethane nylon slide material which had been spray-coated with KE7601-1 and KE7620 aluminized polyurethane reflective coatings and which had been subjected to (on separate samples) accelerated aging per Method 5850, FTMS 191 and accelerated weathering per Method 5804, FTMS 191. For comparison, tests were also performed on retrofit-coated NS397 material not subjected to accelerated aging and weathering, as well as on NS397 material not retrofit-coated, i.e. base slide material.

Test results are shown in Table 2 on the following page. These test results show that radiant heat resistance for retrofit-coated NS397 slide material (as well as for NS397 material not retrofit-coated) is not adversely affected by either aging or weathering.

TABLE 2

RESULTS OF FLAT DISK RADIANT HEAT TESTS

(inflation pressure = 2.5 - 3 psig, radiant heat flux = 2.2 Btu/ft^2-sec)

Sample Number	Base Slide Material No.	Reflective Coating No.	Sample Conditioning	Flat Disk (2.5 - 3 psig) Failure Time "T" (seconds to pressure drop @ 2.2 Btu/ft^2-sec)
2	NS397	------	-------	15
2	NS397	------	Accelerated aging*	15
2	NS397	-----	Accelerated weathering**	14
19	NS397	KE7601-1	--------	33
19	NS397	KE7601-1	Accelerated aging	31
19	NS397	KE7601-1	Accelerated weathering	32
38	NS397	KE7620	-------	33
38	NS397	KE7620	Accelerated aging	31
38	NS397	KE7620	Accelerated weathering	36

* accelerated aging per Method 5850, FTMS 191

** accelerated weathering per Method 5804, FTMS 191

VII. EFFECT OF RETROFIT REFLECTIVE COATING ON ESCAPE SLIDE CONSPICUITY

The work statement issued by NAFEC for this study (NAFEC RFP NA00-9-50, July 5, 1979) contained the following sentence: "The contractor will investigate any detrimental effects that the retrofit coating would have on the ICAO conspicuity requirements of slide/rafts for rescue purposes."

Early in this study, the author contacted ICAO (International Civil Aviation Organization) to inquire as to conspicuity requirements set by ICAO for escape slides. Mr. Richard Hill, of the ICAO Operations and Air Worthiness Technical Office, stated at that time that ICAO established no specific conspicuity requirements for slide/rafts other than a general requirement that "the slide shall be conspicuous," or words to that effect. Mr. Hill stated that ICAO specifically did not specify minimum distances at which slide/rafts afloat at sea should be visible to search planes, etc.

Given this rather general ICAO requirement for escape slide conspicuity, it may be stated that a slide retrofit-coated with aluminum-colored KE7620 reflective coating would probably be, by ICAO standards, somewhat less conspicuous against a blue sea/sky background than would a non-retrofit-coated "international yellow"-colored slide.

However, it may be assumed that any aircraft which regularly makes trans-oceanic flights would be equipped with slide/rafts containing "canopies" -- fabric roofs which are attached to the slide/rafts after deplaning has been completed.

(The escape slide/rafts manufactured by BFGoodrich for the Boeing 747 airliner have such canopies.)

Since a canopy is not an integral part of the slide/raft inflatable stucture used in deplaning, and since the canopy is not even mounted until deplaning is completed, a canopy would not need to be retrofit-coated and could thus be left in its original "international orange" color. When mounted atop an aluminum-colored retrofit-coated slide/raft, an "international orange"-colored canopy should provide adequate slide/raft conspicuity for rescue purposes.

VIII. ESCAPE SLIDE SURFACE PREPARATION PRIOR TO RETROFIT COATING

The thorough removal of contaminants (grease, hydraulic fluid, etc.) from the surface of an escape slide prior to retrofit coating is necessary in order to assure optimum adhesion of the reflective coating to the slide surface. Failure to achieve adequate adhesion could result in the reflective coating peeling away from the slide during heating, which would result in premature slide failure.

In order to devise recommended techniques for slide surface preparation prior to coating, samples of two common base slide materials, polyurethane nylon (NS397) and neoprene nylon (NS260), were contaminated with the following five contaminants common to commercial aircraft:

Contaminant

1) grease (type MIL-G-23827)
2) hydraulic fluid (type MIL-G-5606)
3) fuel (type MIL-T-5624)
4) coffee
5) accelerated aging (per Method 5850, FTMS 191: 168 hrs. @ 70°C)

(Accelerated aging is not itself a contaminant, but is rather a producer of contaminants, such as coating compound ingredient bloom and oxidation and reaction products.)

A number of contaminated slide material samples were then scrubbed with the following four candidate cleaning agents:

Cleaning Agent

1) methylethyl ketone (industrial solvent)
2) toluene (industrial solvent)
3) 1,1,1 trichloroethane (industrial solvent)
4) "Fantastik" (household cleaner)

Finally, the contaminated and contaminated/cleaned samples, as well as some completely uncontaminated samples, were coated with KE7620 aluminized polyurethane coating.

The effectiveness of the four candidate cleaning agents in removing the various contaminants from the surfaces of slide materials was determined by means of peel adhesion tests (Method 8011, FTMS 191) and attenuated total reflectance (ATR) scans.

A peel adhesion test consists of bonding two pieces of fabric together with adhesive and then pulling the pieces apart, measuring the force necessary to separate the pieces. Two pieces of slide material contaminated with grease on both touching surfaces could be expected to require relatively low force to separate, whereas two pieces from which grease had been removed by a cleaning agent could be expected to require higher force to separate.

An attenuated total reflectance (ATR) scan is a test performed using infrared spectroscopy techniques. An ATR scan provides a visual display of the infrared (IR) radiation absorption spectrum (IR spectrum) of the material being tested. An IR spectrum is a peculiar characteristic of an individual material, and as such an IR spectrum can be used to differentiate one material from another.

In the case of the slide materials tested in this study, ATR scans were used to determine the relative degrees of surface cleanliness produced by the various cleaning agents. Specifically, IR spectrums produced by ATR scans of contaminated/cleaned materials were compared to IR spectrums produced for uncontaminated specimens of the same materials. The degrees to which IR spectrums of contaminated/cleaned materials resembled IR spectrums of their uncontaminated counterparts then determined the degrees of surface cleanliness achieved by the various cleaning agents on the variously contaminated slide material surfaces.

Peel adhesion tests and attenuated total reflectance scans were performed on slide material samples which had been: a) contaminated but not cleaned, then retrofit-coated; b) contaminated and cleaned, then retrofit-coated; and c) not contaminated, then retrofit-coated.

Peel adhesion test specimens were two pieces of common slide material retrofit-coated with KE7620 reflective coating and bonded on the retrofit-coated side with polyurethane adhesive. By "common" slide material, it is meant that NS397 was bonded to NS397, and that NS260 was bonded to NS260, but the NS397 was not bonded to NS260.

Peel adhesion test results are tabulated in Table 3 on the following page.

TABLE 3

PEEL ADHESION TEST RESULTS

Base Slide Material	Contaminant Number	Cleaning Agent Number	Reflective Coating	Peel Adhesion (lb/in width)
NS397	none	none	KE7620	5.0
NS397	1	none	KE7620	0.0
NS397	1	1	KE7620	4.0
NS397	1	2	KE7620	5.0
NS397	1	3	KE7620	5.0
NS397	1	4	KE7620	1.5
NS397	2	none	KE7620	0.0
NS397	2	1	KE7620	5.0
NS397	2	2	KE7620	5.0
NS397	2	3	KE7620	4.5
NS397	2	4	KE7620	2.5
NS397	3	none	KE7620	4.0
NS397	3	1	KE7620	5.5
NS397	3	2	KE7620	5.5
NS397	3	3	KE7620	6.5
NS397	3	4	KE7620	5.0
NS397	4	none	KE7620	4.0
NS397	4	1	KE7620	4.3
NS397	4	2	KE7620	5.0
NS397	4	3	KE7620	5.0
NS397	4	4	KE7620	5.0
NS397	5	none	KE7620	4.5
NS397	5	3	KE7620	4.5
NS260	none	none	KE7620	4.0
NS260	1	none	KE7620	0.0
NS260	1	1	KE7620	2.5
NS260	1	2	KE7620	2.5
NS260	1	3	KE7620	3.5
NS260	1	4	KE7620	2.0
NS260	2	none	KE7620	0.0
NS260	2	1	KE7620	3.0
NS260	2	2	KE7620	2.5
NS260	2	3	KE7620	3.0
NS260	2	4	KE7620	1.0
NS260	3	none	KE7620	3.0
NS260	3	1	KE7620	3.0
NS260	3	2	KE7620	3.0
NS260	3	3	KE7620	3.0
NS260	3	4	KE7620	3.0
NS260	4	none	KE7620	3.5
NS260	4	1	KE7620	3.5
NS260	4	2	KE7620	3.5
NS260	4	3	KE7620	3.5
NS260	4	4	KE7620	3.0
NS260	5	none	KE7620	4.5
NS260	5	3	KE7620	4.0

(Key to Table 3 on next page)

TABLE 3 KEY

Contaminant Numbers:

1) grease
2) hydraulic fluid
3) fuel
4) coffee
5) accelerated aging

Cleaning Agent Number:

1) methylethyl ketone
2) toluene
3) 1,1,1 trichloroethane
4) "Fantastik"

Slide Materials:

NS397, polyurethane-coated nylon
NS260, neoprene-coated nylon

Reflective Coating: KE7620, aluminized polyurethane coating

Table 3 shows peel adhesion values of uncontaminated retrofit-coated slide materials, both NS397 and NS260, to be in the 4 - 5 lb/in width range. Table 3 also shows that contamination with grease and hydraulic fluid reduces the levels of adhesion of these slide materials virtually to zero, while contamination with fuel, coffee, and contaminants due to accelerated aging reduces adhesion to levels only slightly below the 4 - 5 lb/in width range.

In regard to the effectiveness of the candidate cleaning agents on removing the various contaminants, the peel adhesion test results in Table 3 show that the household cleaner "Fantastik" is ineffective in cleaning hydraulic fluid and grease, the two contaminants most detrimental to adhesion, although it is fairly effective on coffee. The three industrial solvents (methylethyl ketone, toluene, and 1,1,1 trichloroethane) appear to be relatively equivalent in their abilities to remove contaminants, and all three solvents do a creditable job on grease and hydraulic fluid -- the two contaminants most difficult to remove.

The attenuated total reflectance (ATR) scans led to similar observations regarding slide material contaminants and cleaning agents: i.e. grease and hydraulic fluids were the contaminants most difficult to remove, contaminants were removed fairly thoroughly by the three industrial solvents but not by "Fantastik" etc. One additional observation which the ATR scans did provide was that, even after scrubbing with the industrial solvents, some residual grease always remained on grease-contaminated slide material surfaces.

Given the fairly equivalent capabilities of the three industrial solvents in removing slide surface contaminants, 1,1,1 trichloroethane is recommended over methylethyl ketone and toulene for the following reasons: 1) 1,1,1 trichloroethane is nonflammable, whereas both methylethyl ketone and toluene are flammable; and 2) methylethyl ketone vigorously attacks slide material base coat elastomers (particulary polyurethane), which could lead to air retention problems for a slide scrubbed excessively with methylethyl ketone, whereas 1,1,1, trichloroethane only slightly activates base coat elastomers (both polyurethane and neoprene), which actually works to improve adhesion of retrofit reflective coatings to slide material surfaces.

It should be pointed out that the slide materials tested for contamination/ cleaning in this study (polyurethane and neoprene-coated nylon) were standard BFGoodrich slide materials. It is possible that slide materials used by other escape slide manufacturers might require somewhat different surface cleaning agents than did the BFGoodrich materials, depending upon the effects of the various cleaning agents on the base coat elastomers of the particular slides being cleaned. However, at this time it is felt that for BFGoodrich polyurethane and neoprene-coated nylon slides(and for slides of other manufacturers made of similar materials), a light scrubbing with 1,1,1 trichloroethane prior to retrofit coating will effectively remove common escape slide surface contaminants and will also activate slide surfaces so as to improve adhesion of retrofit reflective coatings.

IX. RECOMMENDED METHOD FOR RETROFIT COATING OF IN-SERVICE AIRCRAFT ESCAPE SLIDE/RAFTS

The retrofit coating method recommended by this study for use on in-service aircraft escape slide/rafts was described in a July 14, 1980, letter from the author to Mr. Louis J. Brown, Jr. of the FAA Technical Center. This letter, which deals with the experimental retrofit coating of a Lockheed L1011 single-lane slide performed by BFGoodrich, is reproduced beginning on the following page. Also reproduced is a letter from Mr. Paul A. Wilkinson of BFGoodrich to Mr. Brown.

The only additional comments which need be made regarding the L1011 retrofit, beyond the information contained in the two letters, are the following:

1) Base slide material in the Air Cruisers - manufactured L1011 slide was polyurethane-coated nylon with both sides base-coated, which is similar to BFGoodrich slide material Code #NS364;

2) Weight added to the L1011 slide by the spraying of one and one-half gallons of KE7620-cellosolve solution was approximately 1.5 pounds, compared to an original (pre-retrofit coating) slide weight of 39 pounds; and

3) In a full-scale fire test conducted at the FAA Technical Center on June 25, 1980, the L1011 slide retrofit-coated by BFGoodrich with KE7620 reflective coating lasted between 60 and 70 seconds at a heat flux of 1.5 to 1.8 Btu/ft^2-sec before experiencing initial pressure loss. Failure time at this heat flux for a similar L1011 slide <u>not</u> retrofit-coated was 27 seconds.

BFGoodrich

The BFGoodrich Company
Research and Development Center
9921 Brecksville Road
Brecksville, Ohio 44141
216-526-4311

July 14, 1980

Mr. Louis J. Brown, Jr.
Department of Transportation
FAA Technical Center
ACT-350, Bldg.203
Atlantic City, NJ 08405

Dear Mr. Brown,

In answer to your question regarding estimated costs for slide retrofit coating and a recommended coating and coating method, I will make reference to the L-1011 slide coated by BFGoodrich which was recently fire tested by you.

Paul Wilkinson and I spray painted the slide ourselves, outdoors, using a Binks Model 18 spray gun (Figure 1 attached). Details of this gun were contained in Paul's letter of May 19 to you. Figure 2 shows the spraying method.

Before we sprayed, we masked off all areas of the slide which we did not want coated -- sliding surface, aspirators, stenciled serial numbers, etc. Figure 3 shows the slide before and after masking and also after spraying.

The protective coating used (which we recommend for retrofit purposes) is an aluminum loaded urethane coating manufactured by Goodrich, BFGoodrich Code #KE7620. This coating contains both fungicide and flame retardant. The coating sent to you on May 19 for testing, identified as 7601-B, was actually KE7620.

The total sprayed area on the L-1011 slide was approximately 850 square feet. To cover this area, one and one-half gallons of KE7620-Cellosolve solvent solution (in a 1:1 dilution ratio) was required. Our goal in spraying was simply to cover the surface with just enough coating so that no yellow showed through. The amount sprayed was thus dependent on the judgement of the painter.

Paul and I spent approximately 3 hours masking and 5 hours spraying. One task which we did not do, but which we nevertheless recommend for future retrofits, would be to lightly scrub the slide surface prior to painting with 1,1,1 trichloroethane solvent, to remove grease and other contaminants and to promote paint adhesion. Stan Sims estimates that one quart of trichloroethane would be sufficient for an L-1011 slide. This scrubbing could probably be accomplished by two workers in an hour.

Costs for materials used in the retrofit of the L-1011 are as follows:

MATERIAL	BASE COAT	X	AMOUNT USED	=	TOTAL COST
BFGoodrich KE7620 Coating	$22.00/gallon		3/4 gallon		$ 16.50
Union Carbide Cellosolve Solvent	$ 3.80/gallon		3/4 gallon		2.85
Dow 1,1,1 Trichloroethane Solvent	$ 4.44/gallon		1/4 gallon		1.11
TOTAL MATERIALS COST					$ 20.46

Costs for labor, assuming a $10/hr. wage rate, are as follows:

2 workers at $10/hr. x (1 hr. scrubbing + 3 hrs. masking + 5 hrs. spraying)
$180.00

Summing these cost figures for materials and labor produces a total cost of about $200 for retrofit coating of the L-1011 slide.

Whether or not the wage rate assumed is exactly correct, it appears that labor costs will far outweigh material costs for most retrofits.

It is our recommendation that retrofits of existing in-service slides be conducted as described above for the L-1011, i.e. scrubbing, masking, and spraying, and that these retrofits be conducted in the field, in or outside the airlines' hangars. Spray painting, we feel, will be the method most convenient for airline service crews to use.

The 1:1 dilution ratio of KE7620 to Cellosolve solvent is not an absolute fixed requirement. Airline service crews should experiment with dilution ratios to find a ratio which, in their judgement, produces complete coverage of the yellow slide color with minimum percentage of KE7620 in the coating solution. This should be done to keep slide weight gain to a minimum. In particular, a more diluted coating solution, i.e. more Cellosolve solvent than KE7620, should be used when spraying outdoors than when spraying indoors, due to the effect of the sun on solvent evaporization rate.

Reducing the percentage of KE7620 in the coating solution to the minimum necessary for complete coverage will probably not save a great deal of money in slide retrofitting, given the low cost of materials relative to labor, but it will result in slides with adequate radiant heat protection and with minimum increases in weight.

If you have any further questions on the slide retrofit process, coatings, etc., please call me at the number below.

Very truly yours,

The BFGoodrich Company
ENGINEERED PRODUCTS GROUP

Richard J. Cole

Richard J. Cole
Advanced R & D Engineer
(216) 526-4311, Ext. 384

fmh

Enc.

cc: J. S. Lee
O. J. Mifsud
G. S. Sims
R. S. Varga
P. A. Wilkinson
R & D Files (3AI01F6)

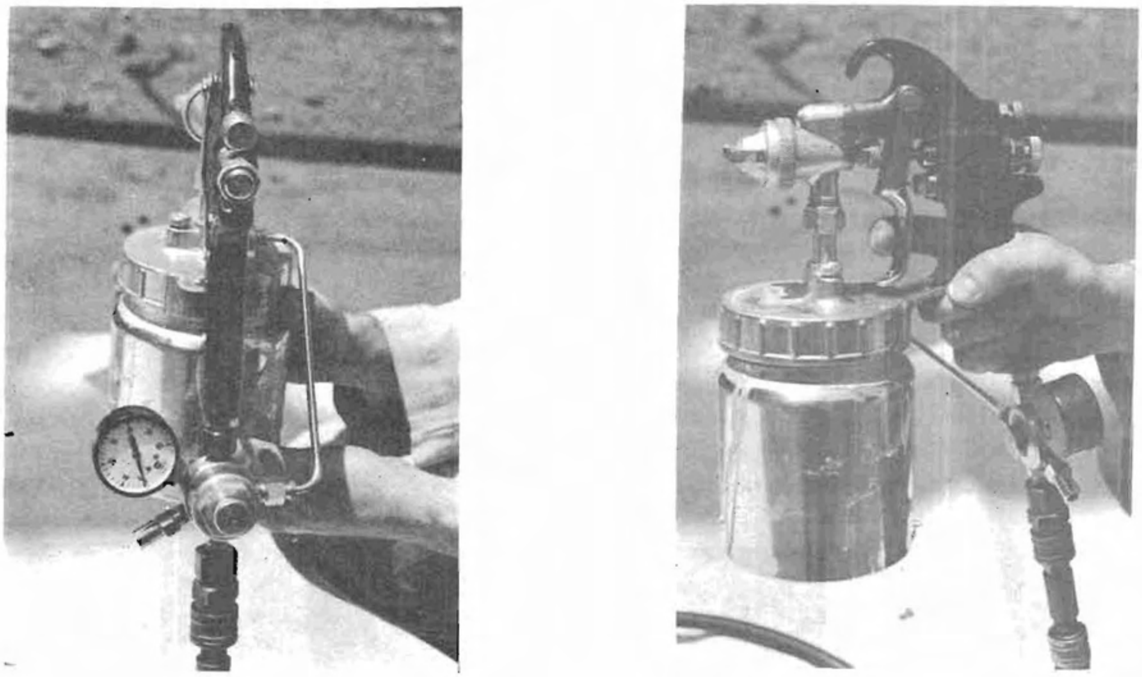

FIGURE 5. BINKS MODEL 18 SPRAY GUN

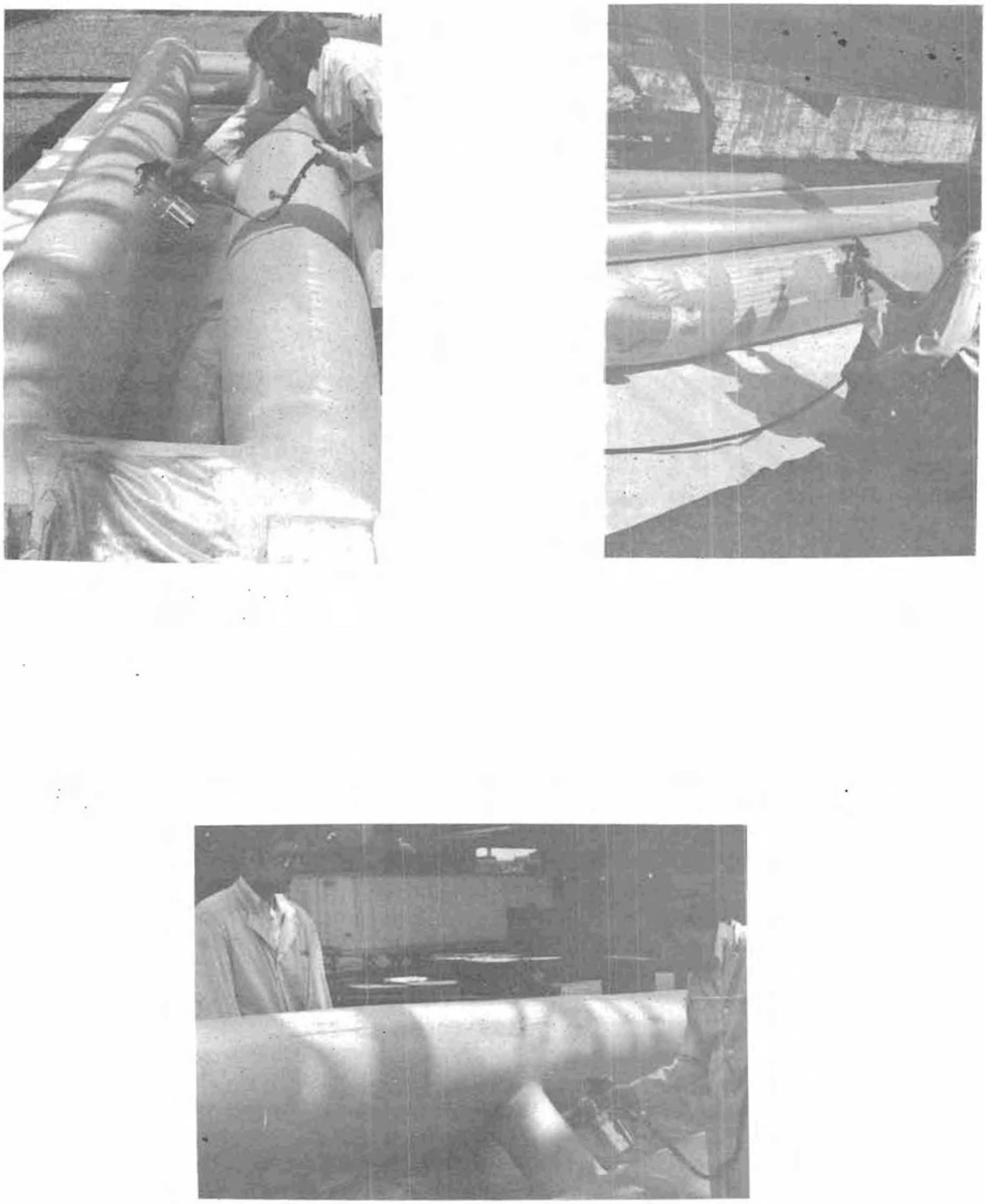

FIGURE 6. SPRAYING METHOD

FIGURE 7. BEFORE MASKING, AFTER MASKING, AFTER SPRAYING

The BFGoodrich Company
500 South Main Street
Akron, Ohio 44318

Address Reply To:
Dept. 1831
Bldg. 41-B

May 19, 1980

Mr. Lou Brown
FAA-NAFEC
ANA-350
Bldg. 203
Atlantic City, NJ 08405

Dear Mr. Brown:

Please find enclosed one (1) gallon of BFGoodrich 7601-B, an aluminum-filled thermal reflective spray coating that we have had some success with. Satisfactory spraying was achieved with a 1:1 dilution of the 7601-B with Cellosolve solvent (Union Carbide) and using a Binks Model 18 spray gun, fluid nozzle no. 67, air nozzle no. 67PB, needle size no. 67. We used a line (atomization) pressure of 40 psi and pressurized the fluid cup to 25 psi. This produced a uniform coating without excessive webbing.

The spray gun can be cleaned with methyl ethyl ketone. Should you have any questions, feel free to contact either Stan Sims or myself.

Yours truly,

Paul A. Wilkinson
216/379-2666

ik
enclosure
cc: G. S. Sims
R. J. Cole

CONCLUSIONS AND RECOMMENDATIONS

The main conclusions of this study are:

1) There is a direct relationship between the infrared radiation reflectivity of a slide material and the radiant heat resistance of that material: specifically, slide materials coated with coatings possessing high values of reflectivity in the near infrared wavelength range (2.1 - 2.5μ) demonstrate the greatest resistance to damage from radiant heat due to fuel fires;

2) Aluminized elastomer retrofit coatings are more reflective in the near infrared range (and thus provide greater protection to slides from fuel fire radiant heat) than either white oxide-pigmented elastomer retrofit coatings or standard "international yellow" slide material base elastomer coatings;

3) Of those aluminized retrofit coatings evaluated, polyurethane-based coatings adhere better to common slide materials (both polyurethane and neoprene-coated nylon) than do either neoprene-based coatings or Hypalon-based coatings; and

4) The reflective coating recommended by this study for slide retrofit purposes, BFGoodrich Coating KE7620, an aluminized polyurethane coating,

    a) provides considerable radiant heat protection to slides to which it is applied (an approximate 100% improvement in slide failure time over an equivalent slide <u>not</u> retrofit-coated with KE7620 according to full scale burn tests conducted by the FAA);

    b) does not adversely affect the physical properties of slide materials to which it is applied;

    c) is resistant to fungus growth and flame propagation;

    d) adheres well to common slide materials; and

    e) is easily applied to escape slides using common spray-painting equipment.

Based on the conclusions above, the recommendations of this study are:

1) that BFGoodrich Coating KE7620 be used for the retrofit-coating of in-service aircraft escape slides and slide/rafts; and

2) that the retrofit coatings be performed "in the field", i.e. by airline service crews, using the slide surface preparation methods and coating application methods described in this report.