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ALUMINIZED CODING 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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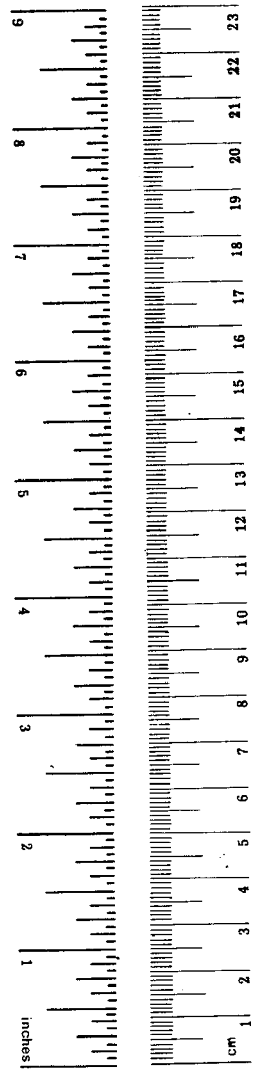
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

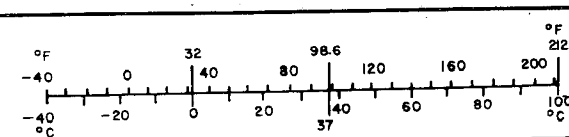
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

This report is submitted to the FAA Technical Center in fulfillment of Government Contract No. DOT-FA79NA-6065, the objective of which was to "study the feasability of a retrofit program for in-service commercial transport carrier emergency evacuation slides and slide/rafts," to quote from the contract. A more specific objective of the contract was to develop radiant heat-resistant ("reflective") coating(s) capable of being applied to in-service slides and slide/rafts as a retrofit process.

This study began with an experimental evaluation of commercially available reflective coatings, out of which a single coating -- BFGoodrich Coating KE7601-1, an aluminum-loaded polyurethane coating -- was selected for further experimentation.

Coating KE7601-1 was then subjected to a series of "ingredient-modification" experiments, in an attempt to improve the coating's radiation reflectivity and heat capacity.

These ingredient-modification experiments ultimately resulted in a new aluminized polyurethane coating, BFGoodrich Coating KE7620, which was eventually chosen as the single coating recommended by this study for slide retrofit purposes.

This study concluded with an experimental evaluation of possible methods for applying KE7620 coating to escape slides (as well as for preparing the escape slide surfaces <u>prior</u> to coating), finally culminating with the actual retrofit coating (and eventual full scale fire testing by the FAA) of a Lockheed L1011 single-lane escape slide.

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.

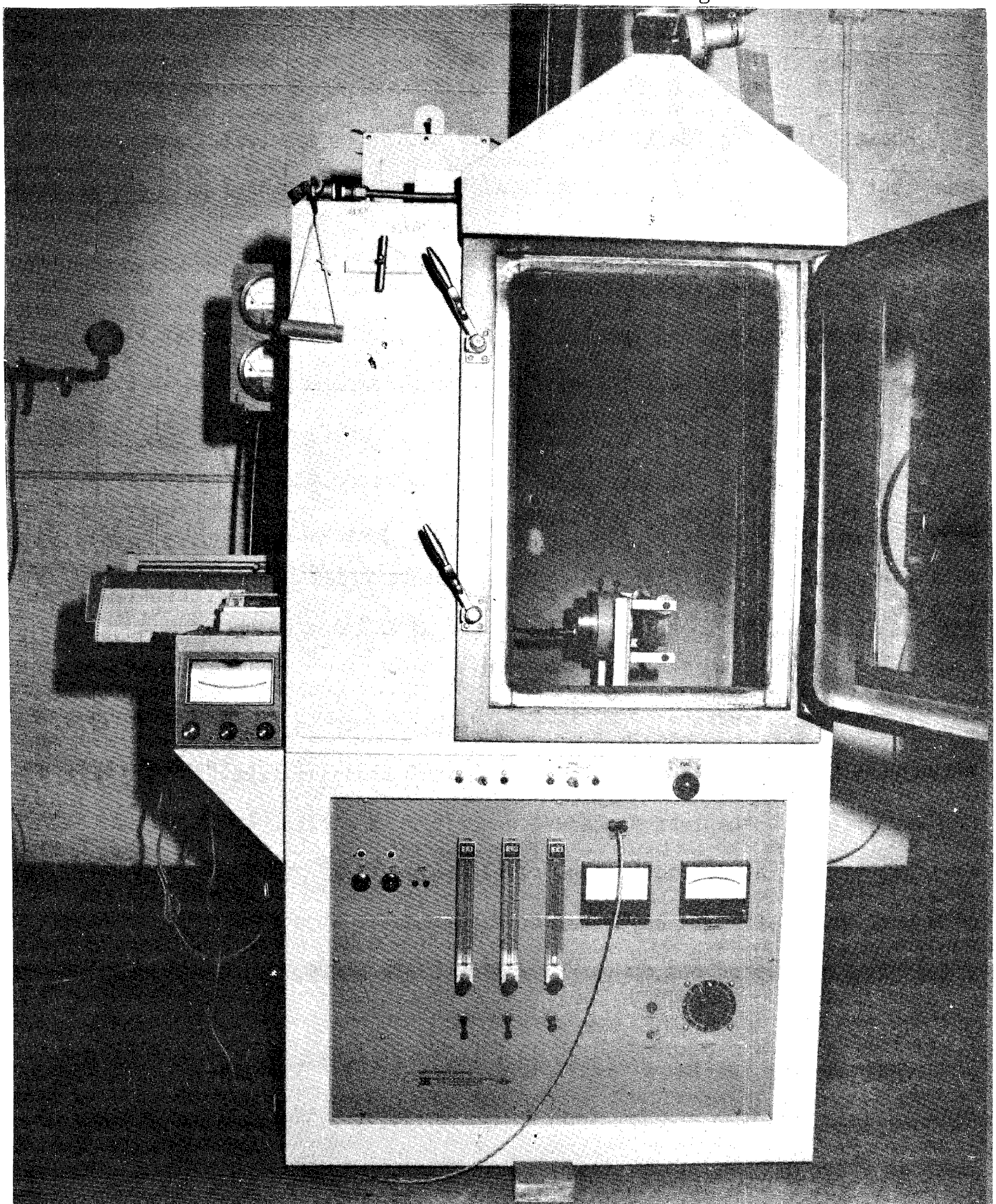
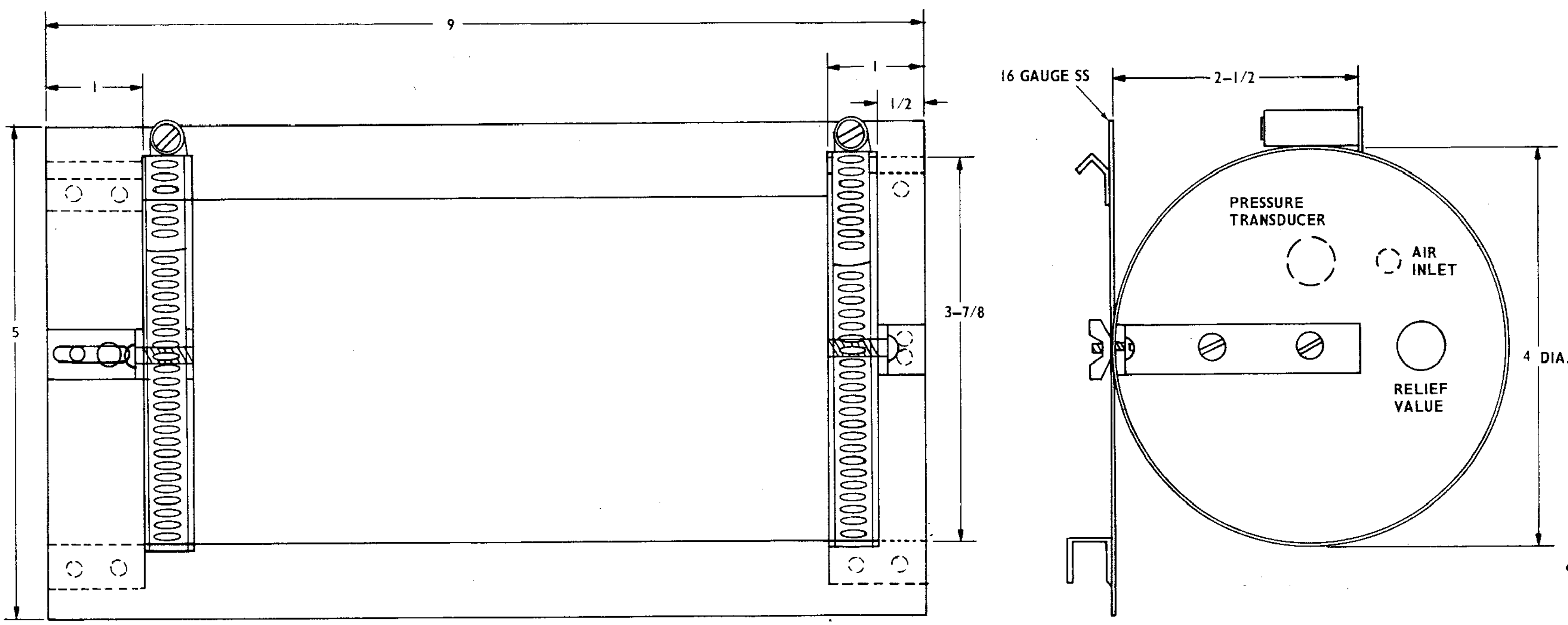


FIGURE 1. AMINCO - NBS SMOKE DENSITY CHAMBER



NOTE: ALL DIMENSIONS ARE IN INCHES

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

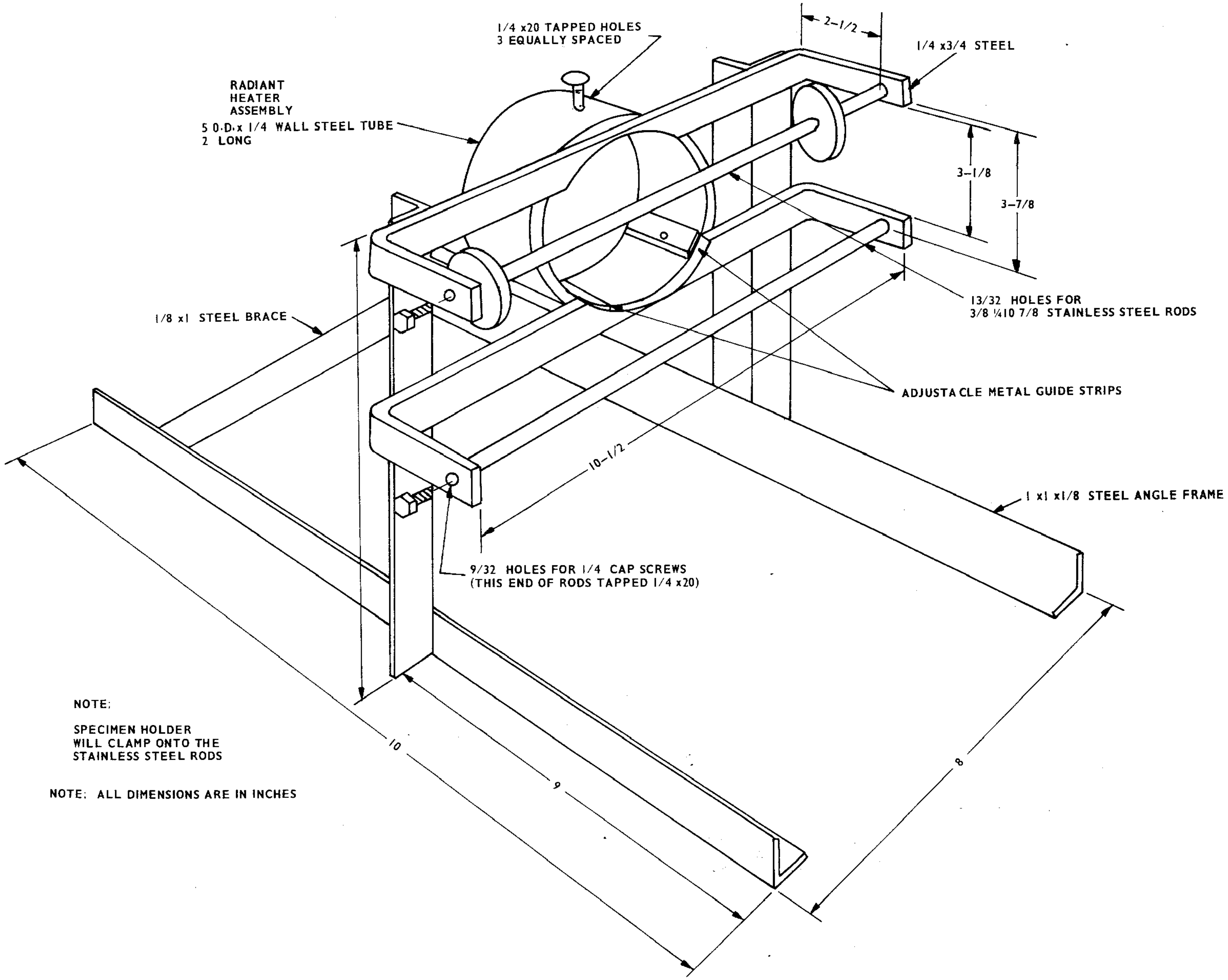
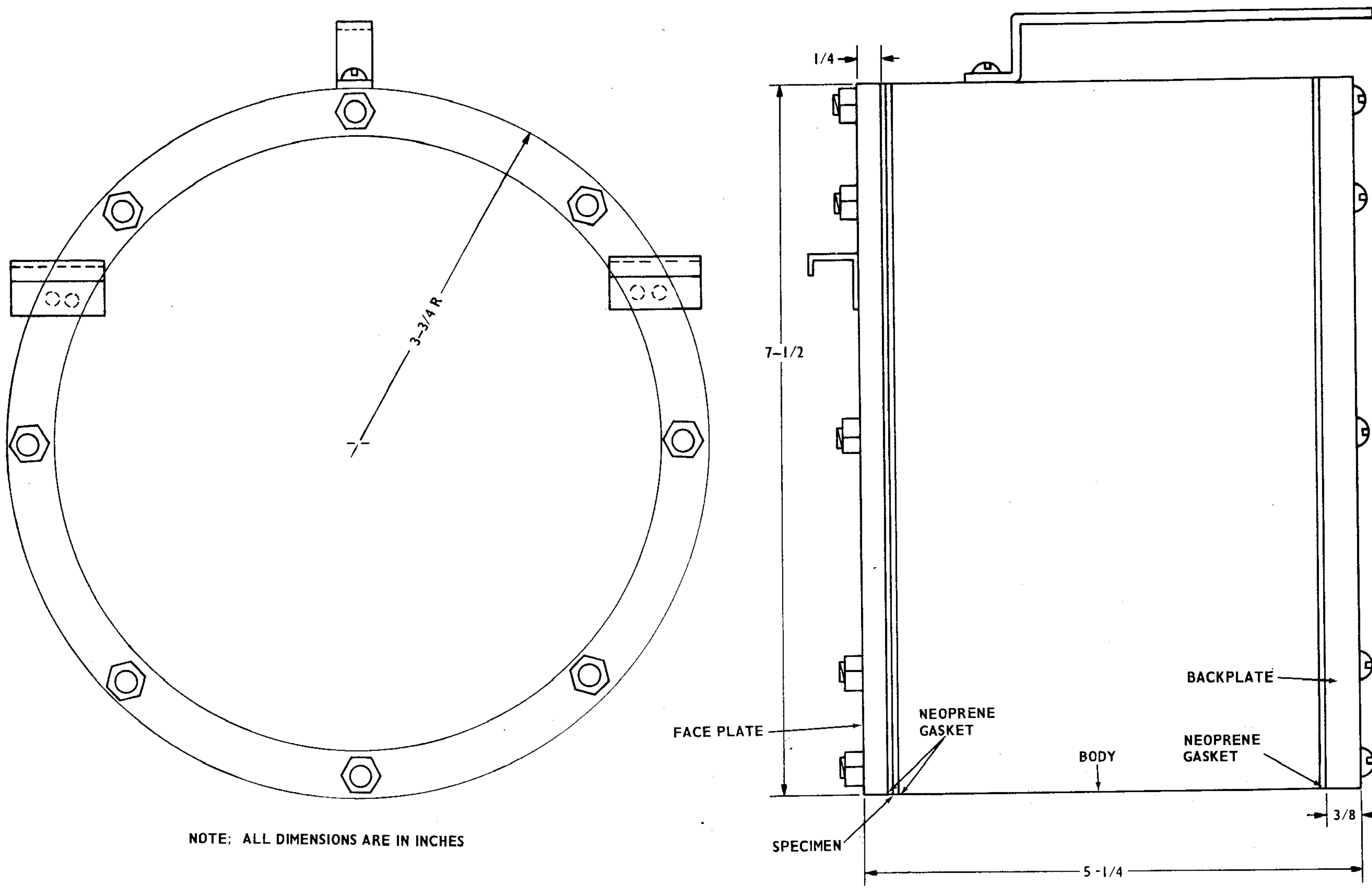


FIGURE 3. NBS SMOKE CHAMBER HEATER AND SPECIMEN HOLDER FRAME



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, $\%\Delta w$. This ratio is referred to as $T/\%\Delta w$.

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 2.0μ	REFLECTIVITY 2.5μ	COATING VEHICLE POLYMER	THICKNESS CHANGE (.001 in.) Δt	THICKNESS CHANGE % Δt	WEIGHT CHANGE (oz/yd²) Δw	WEIGHT CHANGE %Δw	INFLATED TUBE RADIANT HEAT TEST RESULTS* HF=2.2	INFLATED TUBE RADIANT HEAT TEST RESULTS* 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	RATIO Disk T/%Δw @ HF	REMARKS
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; A1343B 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; A1343B 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; A1343B 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		A1343B 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 V75112)		.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. (1216S291C)		.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/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

TABLE 1. MASTER TABLE (Continued)

SAMPLE NUMBER	BASE FABRIC BFG. NO.	REFLECTIVE COATING Top Coat (Coating #)	REFLECTIVE 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;---		..41 @ 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)

* 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 @ $\lambda = 2.5\mu$	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: