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FLAMMABILITY TESTING OF NEW VINYL COMPOUNDS WITH LOW FLAMMABILITY AND LOW SMOKE RELEASE IN CABLES

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ABSTRACT

A set of new vinyl compounds was prepared anticipating the publication of new requirements for limited smoke (.../LS) cables, to provide formulation guidelines. Commercial cables were used as controls and bulletinized compounds were made into TW and THHN tray cables. A new facility built by BFGoodrich to determine full scale fire performance of cables in vertical tray tests (on CSA FT-4) and the cone RHR test apparatus were used on 16 cables. The CSA FT-4 test was used also for measuring continuously heat release, smoke release and mass loss. Some cables had previously been tested at UL. Results in the two facilities showed excellent agreement for clear passes and clear failures. However, a cable rated borderline pass at UL failed in the BFGoodrich facility. Data from the cone correlated so well with cable tray results that the latter could be predicted from the former with reasonable accuracy. The final conclusion was that cables made with bulletinized vinyl compounds or with the other materials tested emitted higher levels of heat and smoke than cables made with the new experimental compounds.

INTRODUCTION

The flammability of cables is often measured in full scale vertical cable tray fire tests. These tests give an indication of real fire performance of cables, in specified scenarios.

It has been well established now that rate of heat release is the most important fire property, because it is a measure of the fire intensity [1,2]. Furthermore, it has been established that fire test results from the cone calorimeter rate of heat release instrument run over a suitable range of incident heat flux correlate well with those from full scale fire tests [3-5].

Most standard cable tray tests, including the one used in this work, tend to measure only the extent of flame spread due to the cables themselves, plus the length of charring of the cables. If cable tray fire tests are run, other fire properties can also be measured, of greater interest for fire hazard assessment [6-11]. The additional properties measured here are heat and smoke release.

A number of vertical cable tray tests had been run at a contract laboratory (Underwriters' Laboratories) in 1989, using three test protocols: CSA FT-4, UL 1581 and ICEA 529-T20. All the same cables had also been tested in the cone calorimeter [12].

A program of work was thus designed with four objectives:

(a) Build a new facility to run vertical cable tray fire tests.
(b) Investigate the full scale fire performance of some advanced vinyl compounds, when made into real cables, and compare them with that of traditional vinyl materials.
(c) Compare the results with several of the same cables previous results obtained using nominally the same test in a different facility.
(d) Test the same cables in the cone calorimeter.

EXPERIMENTAL

Procedures

The test methods used were:

Small scale: Cone calorimeter rate of heat release instrument (exposed area: ca. 0.01 m^2) [13].

Measurements made: The parameters reported from the cone calorimeter tests are: peak rate of heat release (Pk RHR, in kW/m^2), the time to sustained combustion, or time to ignition (TTI, in s), the total heat released (THR, in MJ/m^2), the smoke factor (SmkFct, in MW/m^2), the peak rate of smoke release (Pk RSR, in 1/s), the total smoke released (TSR, non-dimensional), the mass loss rate parameter (MLRP, in g/m^2s^2) and the ratio of time to ignition to peak rate of heat release (TTI/Pk RHR, in s m^2/kW). Some of these variables may not be generally known and they will, thus, all be explained briefly.

Rate of Heat Release: The rate of heat release (RHR) is a measure of the instantaneous amount of heat being released per nominal sample surface area. For each experiment, the maximum RHR value is the most significant one and is recorded here. The RHR values are calculated from the differences between the values of oxygen concentration measured and the background oxygen in the atmosphere.

Total Heat Released: The total heat released in each experiment (THR) per unit nominal sample surface area is determined by integrating the RHR data as a function of time.

Smoke Factor: The smoke factor is a smoke/fire hazard variable used to estimate the potential amount of smoke that a product would generate under full scale fire conditions. It is a realistic approach for such an estimate which takes into account both the potential for smoke obscuration for full sample destruction and the potential to cause other products to burn and release smoke in a real fire. It does so by incorporating the burning rate (as the peak rate of heat release)[14,15]. This takes into account the fact that those products made from materials with low peak RHR will not readily burn up totally in a fire, and will tend to cause less smoke to be generated from the ignition of other products. It is calculated as the product of the ignition of other products. It is calculated as the product of the total smoke released and the peak rate of heat release. The single value presented here is that at 5 minutes. The total smoke released is calculated as the time integral of the rate of smoke release.

Time to Ignition: The time to ignition is the time, expressed in s, until the entire surface of the sample burns with a sustained luminous flame.

Mass loss rate parameter: The MLRP [9,16] is the ratio of (a) the average mass loss rate between the times when the sample loses 10 and 90% of the total mass lost during the test and (b) the time to ignition. It gives an indication of the amount of "smoke" generated in a given amount of time and, thus, of the toxic hazard.

Time to ignition/Peak Rate of Heat Release: This parameter is proportional to the time to flashover, i.e. it may be the best individual indicator of overall fire hazard [17,19].

Full Scale [20,21]: CSA FT-4 cable tray test (70,000 BTU/h: 20.50 kW) [22]

In the full scale tests, measurements taken included: flame height (in cm), heat release (by oxygen consumption [23,24]), smoke release (determined with a laser in the exhaust duct) and mass loss (using a load cell).

Official failure criteria for cable tray tests are based on char length: if the entire cable tray length (UL 1581) or a length over 1.50 m (CSA FT-4) has charred the cable fails.

All cables were tested in the cone calorimeter and the vertical cable tray.

Materials

A total of 16 cables were used, including ten experimental power cables, all based on vinyl compounds, four commercial cables and two experimental communications cables. There were two types for the experimental power cables: THHN and TW. The THHN construction incorporates, of course, a nylon film, as required by the listed construction specifications, extruded over the vinyl insulation, beneath the vinyl jacket. These cables were all made with 9 #12 AWG conductors. The experimental power cables were, in general, made with compounds that contained significant levels of fire retardants, the only exception being those compounds designated "1" (1I, 1J), which contained none or very low levels.

Dimensional requirements for the THHN cables were that the vinyl primary insulation be at least 0.38 mm (0.015") thick on the average, and no thinner than 0.33 mm (0.013") at any point. The extruded nylon film was required to be no thinner than 0.10 mm (0.004") at any point. The primary vinyl insulation in the TW cables was required to be at least 0.76 mm (0.030") thick, on the average, and no thinner than 0.69 mm (0.027")at any point [25]. For either cable construction the overall outside vinyl jacket was required to be at least 1.52 mm (0.060") thick, on the average, and no thinner than 1.2 mm (0.048") at any point [26].

Experimental Vinyl Power Cables:

1I THHN TC/1J THHN TC
3I THHN TC/3J THHN TC
3I THHN TC/1J THHN TC
3I THHN TC/4J THHN TC

1I TW TC/1J TW TC
3I TW TC/3J TW TC
3I TW TC/1J TW TC
1I TW TC/3J TW TC
3I TW TC/2J TW TC
524 TC/3J TW TC

Other Cables:

Commercial:

Plenum:	Western Electric Omaha NEC-800-3D
Tray:	XLP/CU Black Jacket 14 pr #6 Super Flex
Other:	Yellow Ultragard Type SOO 90 deg C Super Trex 14/4,
	Essex THHN 600 V, 4 AWG, Single conductor

Experimental Communications:
IBM Type I
IBM Type II

RESULTS AND DISCUSSION

The main results of the CSA FT-4 full scale vertical cable tray tests carried out at Underwriters' Laboratories (UL) are shown in Tables 1-3. Tables 4 and 5 present the results of the tests run in the new facility at BFGoodrich. The majority of the cables

Table 1.	Main Results of UL cable Tray Tests			
Cable	Flame height [cm]	Char length [cm]	Peak HCl [ppm]	Pass/Fail
1I 1J THHN	> 250	265	> 2332	Fail
1I 1J TW	175	133	547	Pass
1I 1J TW	150	132	587	Pass
31 2J TW	50	60	204	Pass
3I 4J THHN	100	79	578	Pass

Table 2.	Further Results of Cable Tray Tests			
Cable	Mass loss [g]	Mass comb. [g]	% Comb. loss [%]	Pass/Fail
1I 1J THHN	3870	4795	81	Fail
1I 1J TW	1455	6415	23	Pass
1I 1J TW	1350	6350	21	Pass
31 2J TW	780	6775	12	Pass
3I 4J THHN	960	6370	15	Pass

Footnote on abbreviations: Mass comb.: mass of combustible present;
% Comb. loss: percentage of combustible mass lost.

Table 3.	Heat and Smoke Results from UL Cable Tray Tests									
Cable	Total heat release [MJ/m²]				Total smoke release [m²]				Pk RHR [kW/m²]	Pk RSR [m²/s]
	5min	10min	15min	20min	5min	10min	15min	20min		
1I 1J THHN	44.4	105.8	117.3	126.3	121	398	407	411	403.2	1.90
1I 1J TW	12.9	34.7	45.0	53.3	124	264	293	295	81.8	0.68
1I 1J TW	14.1	34.6	46.4	55.1	137	244	274	275	77.1	0.71
3I 2J TW	10.1	21.5	30.3	38.9	100	170	180	183	42.8	0.44
3I 4J THHN	8.7	22.1	33.3	41.9	32	143	194	199	55.1	0.53
BLANK	6.3	12.8	19.3	25.8	0.6	1.8	2.4	3.8	24.7	0.003

tested passed the cable tray tests. This includes cables coated with standard fire-retarded vinyl compounds and those coated with advanced compounds.

Moreover, it was also interesting that the peak amount of HCl released depended on whether the cable passed or failed the test, rather than on the chlorine content of the cable coating materials. The cables that passed released only relatively small amounts of HCl, although they were all based on vinyl compounds. The average peak amount of HCl released by the cables passing the CSA FT-4 tests was 479 ppm. On the other hand, the failing cables reached peak HCl levels exceeding 2330 ppm.

The other standard results shown in Table 1, char lengths and peak flame heights, are of limited importance in yielding information of use for fire hazard assessment. Table 2 has data on mass of cables and mass loss. This is interesting because the fraction of combustible mass lost is under 50% for the cables that passed and over 50% for those that failed.

Table 3 shows some fundamental fire properties: information on heat and smoke released. It is clear from these data that the cables failing the test release more heat and more smoke than those passing the test. Furthermore, the rate at which the heat and smoke is released is also significantly higher for failing cables. Moreover, the peak rate of heat release also indicates which cables passed the test marginally. This was the case with the 1I 1J TW cable.

Table 4. Main Cable Tray Test Results for BFGoodrich Tests

Cable	Pk RHR [kW]	Time [min]	Pk RSR [m^2/s]	Time [min]	Mass Loss [g]	Comb. Loss [%]	Flame Ht.** [cm]	Pass/ Fail
Essex THHN	387.9	4.60	0.913	5.2	2221	66.79	275	Fail
1I 1J THHN	383.7	5.75	1.602	6.2	3743	75.96	300	Fail
Ultragard SOO	370.2	9.00	1.547	6.9	3942	62.29	275	Fail
3I 1J THHN	355.7	5.60	1.518	5.2	3502	71.35	275	Fail
1I 1J TW	131.2	12.90	0.970	11.6	*	*	275	Fail
1I 1J TW	129.9	15.55	1.050	4.7	3615	56.51	275	Fail
1I 1J TW	123.5	10.80	1.107	5.0	3285	52.63	300	Fail
XLPE CU	101.5	7.95	1.848	6.6	1380	23.60	175	Pass
XLPE CU	92.9	7.25	1.729	6.0	1773	30.30	205	Pass
3I 1J TW	65.5	7.45	0.885	4.6	985	15.32	160	Pass
3I 4J THHN	52.9	12.75	0.580	10.3	769	12.52	110	Pass
3I 3J THHN	48.2	8.15	0.545	6.5	709	13.39	125	Pass
1I 3J TW	46.9	8.35	0.501	7.2	817	13.59	110	Pass
3I 3J THHN	45.8	7.30	0.523	6.9	651	12.56	120	Pass
1I 3J TW	44.9	8.80	0.477	6.5	864	13.07	125	Pass
3I 2J TW	44.3	6.70	0.770	6.7	760	11.19	105	Pass
3I 3J TW	38.7	6.90	0.516	6.2	746	9.62	100	Pass
524 3J TW	36.3	11.80	0.384	6.9	759	9.78	85	Pass
3I 3J TW	34.0	8.00	0.500	4.7	798	10.85	105	Pass
IBM TYPE II	33.7	4.35	0.398	4.1	505	11.90	85	Pass
IBM TYPE I	32.1	5.60	0.225	2.8	342	10.49	85	Pass
Plenum	31.0	1.75	0.037	1.8	340	10.05	80	Pass
Blank	20.5	3.10	0.012	12.8	--	--	65	--

* the load cell was malfunctioning in this test.
** measured from the bottom edge of the tray

The earlier work also indicated that the peak rate of heat release measured in the cone calorimeter was a significantly good indicator of pass/fail criterion. Moreover, there was good correlation between the peak RHR in the cone and in the cable tray test (Table 6).

The ratios between the total heat and total smoke released and percent combustible mass lost by failing and passing cables in the test was:

	Failing/passing
THR	4.7
TSR	2.8
% Mass Loss	4.6

This indicates that there is, generally, a clear distinction, although sometimes there may be borderline cases.

The smoke and the HCl results would appear to give an important message: the amount of smoke or HCl released in a fire is heavily dependent on the severity of the fire, or on the fire performance of the product tested. It is worth restating thus once more a fact often misunderstood. The level of smoke released is a primary function of the amount of material burnt, and depends only somewhat on the smoke-producing characteristics of the material or product itself. Thus, less smoke and gas is released in a full scale fire if the material burns less readily, and is only partly consumed.

The peak concentrations of carbon monoxide and carbon dioxide were also much higher for the cables that failed the tests than for those that passed, reflecting the larger amount of material burnt. However, the CO/CO_2 ratios were virtually the same for all tests: high at levels above 0.13. This is of particular interest

Cable	Total heat release [MJ]				Total smoke release [m^2]			
	5 min	10 min	15 min	20 min	5 min	10 min	15 min	20 min
Essex THHN	39	60	61	61	86	160	165	168.6
1I 1J THHN	27	82	85	86	125	402	413	415.9
Ultragard SOO	8	76	110	120	105	403	455	459.5
3I 1J THHN	43	89	98	125	176	396	413	435.8
1I 1J TW	5	26	50	68	131	346	541	616.9
1I 1J TW	5	24	49	70	163	382	569	639.2
1I 1J TW	5	25	52	80	150	379	549	609.0
XLPE CU	2	16	25	31	40	281	343	404.5
XLPE CU	1	13	23	35	34	223	307	402.4
3I 1J TW	6	15	16	17	150	277	283	287.9
3I 4J THHN	2	5	12	16	17	58	149	181.4
3I 3J THHN	2	7	9	11	55	155	164	169.3
1I 3J TW	2	6	9	10	56	158	185	195.4
3I 3J THHN	1	7	8	11	32	134	142	144.0
1I 3J TW	2	8	10	12	51	157	189	197.4
3I 2J TW	1	5	5	8	114	219	227	237.2
3I 3J TW	2	6	7	9	61	151	164	172.4
524 3J TW	2	5	8	10	51	129	168	181.5
3I 3J TW	1	4	6	8	58	144	158	167.7
IBM TYPE II	2	4	5	6	42	69	74	79.1
IBM TYPE I	2	4	5	8	34	47	51	56.2
Plenum	1	3	4	5	4	6	8	10.2
Blank	7	13	19	26	0.026	0.039	0.068	0.091

Table 5. Additional Cable Tray Test Results from the BFGoodrich Tests

The THR data has had the blank heat value (caused by the burner itself) subtracted.
The TSR values are as measured, because the blank TSR is negligible.

Table 6. Correlation Between the Cone Calorimeter and the Cable Tray Test

Property	Flux	Corr. Coeff R^2/Adj R^2	Slope	Intercept	CV [%]	p
THR @ 15	20	0.98/0.97	0.99±0.08	12.4± 3.3	17	0.001
THR @ 15	40	0.43/0.24	0.46±0.31	- 11.5± 34.2	89	0.232
Pk RHR	20	0.91/0.88	4.21±0.76	-334.3± 83.0	49	0.011
PK RHR	40	0.65/0.53	1.76±0.75	-223.3±148.1	97	0.100
Pk RSR	20	0.68/0.57	0.26±0.10	- 1.2± 0.8	46	0.088
Pk RSR	40	0.19/0.00	0.05±0.06	0.1± 1.0	72	0.457
TSR @ 15	20	0.86/0.81	0.10±0.02	94.6± 45.3	15	0.025
SmkFct	20	0.93/0.91	1.53±0.24	182.4± 18.7	10	0.008
TSR @ 15	40	0.75/0.67	0.05±0.02	- 26.5±104.1	19	0.057
SmkFct	40	0.71/0.62	0.32±0.12	234.1± 53.3	21	0.071

in view of the fact that these were very intense fires, where low CO/CO_2 ratios might have been expected. The instantaneous CO/CO_2 ratios were also of the same order, until the cables stopped burning and no more carbon oxides were emitted from them.

Tables 4 and 5, organized in decreasing peak RHR order, show that the cables can be subdivided into three categories:

(i) Cables that are clear failures
(ii) Cables that are borderline in passing or failing the test
(iii) Cables performing better than needed to pass the test

Category (i) consists of 4 cables: two commercial ones (Essex THHN and Ultragard SOO) and two experimental (1I 1J THHN and 3I 1J THHN, both with a non fire retarded jacket and nylon).

Category (ii) consists of two cables: one commercial (XLP/CU) and one experimental (1I 1J TW).

All the category (i) and category (ii) cables are not only high in heat release but also high in smoke release.

Category (iii) consists of all other cables.

Thus, it would be useful to subdivide these category (iii) cables into two or three classes depending on the amount and rate of smoke generated. This is particularly important in view of the requirement in the National Electrical Code for a category of "limited smoke," as yet undefined. Class (a) could be used for those cables that have total smoke released values of over 240 m^2 but under 400 m^2 which separates typical class (ii) from class (iii) cables, and peak RSR values of over 0.85 m^2/s. Class (b) could be for those cables with TSR between 200 and 240 m^2 and peak RSR between 0.70 and 0.85 m^2/s and class (c) would be those cables with TSR < 200 m^2 and peak RSR $<$ 0.70 m^2/s. The choice of the criteria for the top class is based on the fact that tightly specified communications cables (which require much better fire performance than power cables normally) seem to give TSR values of up to 168 m^2 and peak RSR values of up to 0.40 m^2/s.

Under these criteria, cable 3I 1J TW is class (ii)(a), cable 3I 2J TW is class (iii)(b) and the others are class (iii)(c). This indicates that a number of the experimental cables have good enough fire performance that they clearly emit low amounts of heat and of smoke.

Figures 1 and 2 show indications of the rate of heat release and rate of smoke release, respectively, for an example of a cable from each class in the tray test. The trends are clearly the same as was observed in the earlier series of tests: passing cables and failing cables are normally clearly distinguished.

Figures 3-6 show comparisons, for the four main properties measured, RHR, THR, RSR and TSR, between the tests carried out at UL and at BFGoodrich on the same cables.

It is interesting to notice that the results for the tests that were clear passes and clear fails were very similar for both laboratories. The only case that showed a distinct difference was that of 1I 1J TW, which is a borderline product. This shows that the new facility is very close to reproducing the results of the tests in the established (UL) facility.

The cable that failed the test at BFGoodrich and passed at UL is an example of the inconsistencies of fire tests, due to very small differences in test construc-

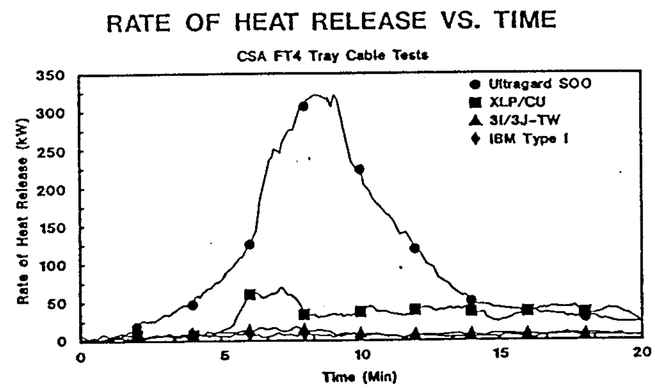

Fig. 1. Rate of Heat Release vs. Time: CSA FT-4 Cable Tray Tests.

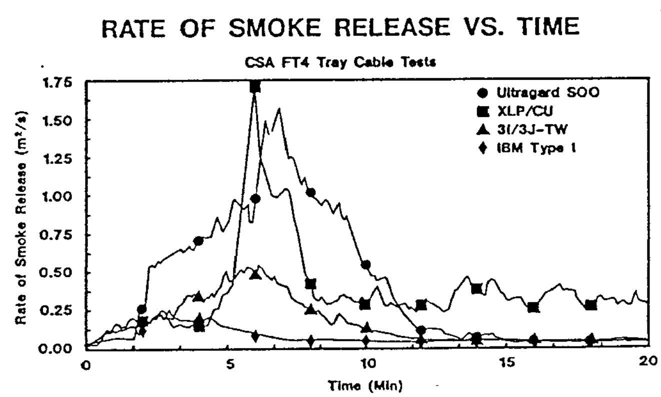

Fig. 2. Rate of Smoke Release vs. Time: CSA FT-4 Cable Tray Tests.

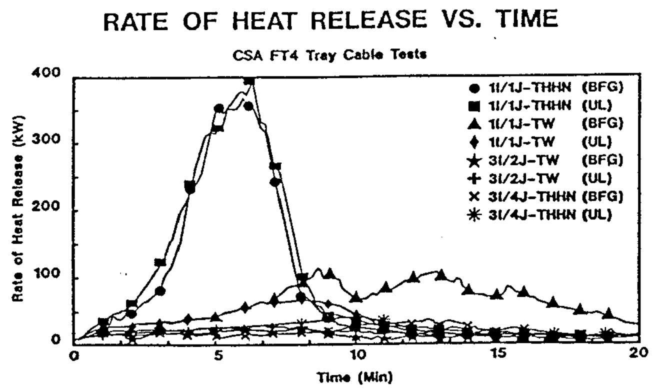

Fig. 3. Rate of Heat Release vs. Time: Comparison between BFG and UL results.

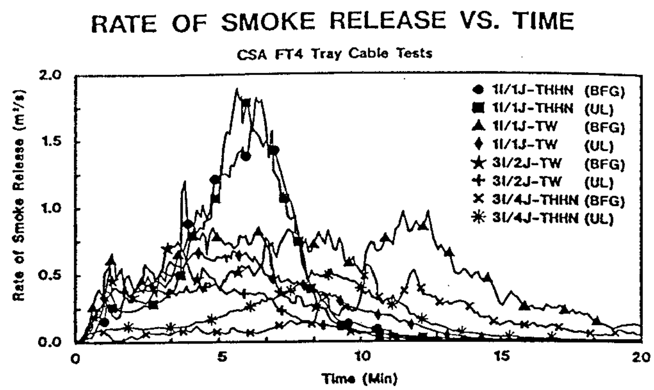

Fig 5. Rate of Smoke Released vs Time: Comparison between BFG and UL Results.

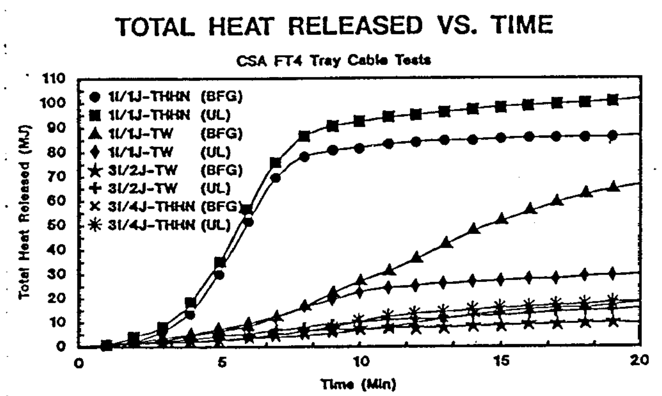

Fig. 4. Total Heat Released vs. Time: Comparison between BFG and UL Results.

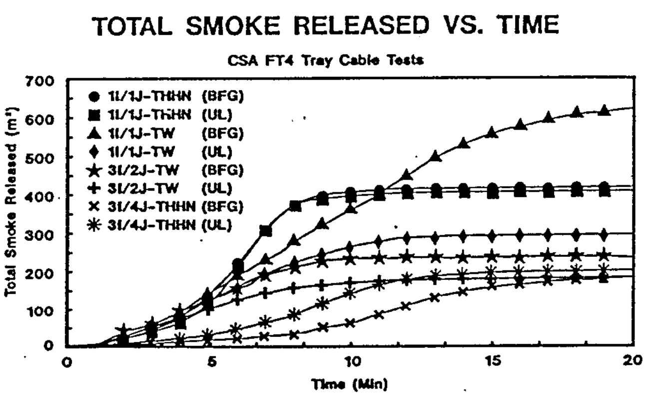

Fig. 6. Total Smoke Released vs Time: Comparison between BFG and UL results.

tion. The cable released slightly more heat at the BFGoodrich facility, partially through reradiation from the walls and ceilings and it, thus, continued burning to the top of the tray, while it stopped burning before the end at UL.

Figures 7-10 show that the old equations used for carrying out linear correlations between the cone and the cable tray test tend to give reasonably good correlations with the new test results too. The two exceptions appear to be the 1I 1J TW and the XLP/CU, viz. the class (ii) cables.

All the cables were also tested in the horizontal mode, in the cone calorimeter, at 20 and 40 kW/m^2 incident flux (Table 7). The cone calorimeter (heat and smoke) data are very consistent with the cable tray data, with the possible exception of the data for the two class (ii) cables. All the class (i) cables give the highest RHR and THR values at 20 kW/m^2, followed by the class (ii) cables. However, at 40 kW/m^2 one of the class (ii) cables (XLP/CU) is indistinguishable from the class (i) cables while the 1I 1J TW cable is significantly better, although the latter failed one of the tray tests and the former passed!

In terms of the most indicative fire index, TTI/Pk RHR, several cables stand out at 40 kW/m^2: the communications cables, 3I 3J THHN, 1I 3J TW, 3I 3J TW and 524 3J TW, all of which are (iii)(c) cables.

This suggests, clearly, that the cone calorimeter is capable of giving a good "a priori" indication of whether a cable will pass or fail the cable tray tests

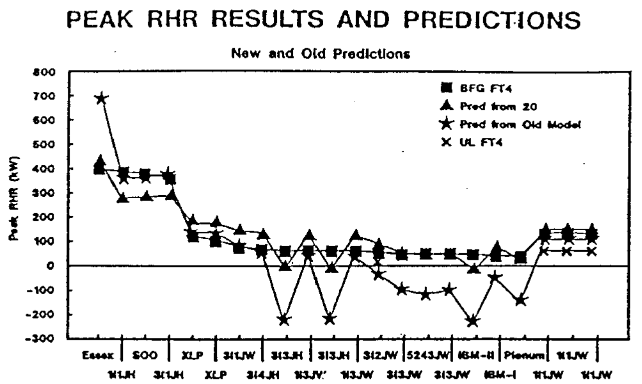

Fig. 7. Peak RHR results and predictions.

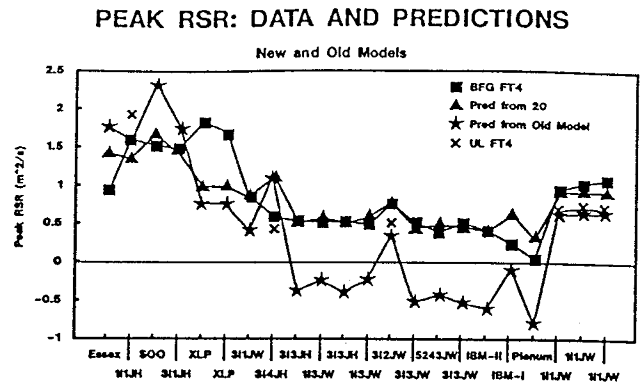

Fig. 9. Peak RSR data and predictions.

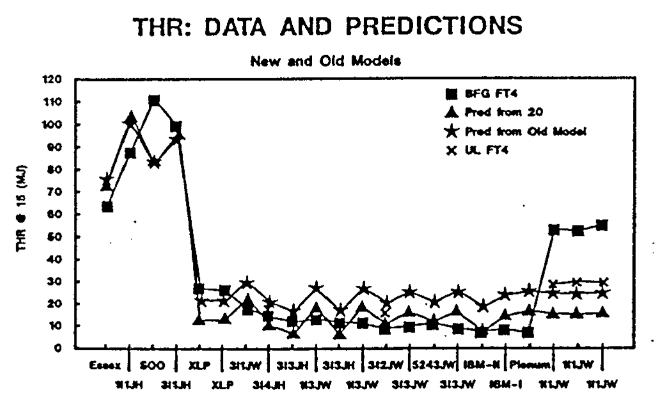

Fig. 8. THR data and predictions.

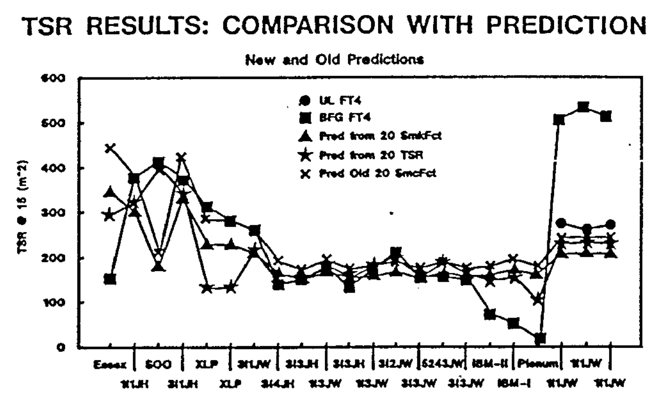

Fig. 10. TSR results: Comparison with predictions.

studied (CSA FT-4, UL 1581 or ICEA 529 T-20). It appears, for example, that if the peak RHR is significantly over 100 kW/m^2, at an incident flux of 20 kW/m^2, the cable will fail a cable tray test. When the cone calorimeter test is carried out at higher incident fluxes the peak RHR cut off point is higher: it appears to be near 200 kW/m^2 at 40 kW/m^2. However, borderline cases, i.e. class (ii) cables are still a problem.

New linear correlations have also been made, using the data obtained in the new series of tests, and the predicted cable tray results, also shown in Figures 7-10, are indicative of the reasonable degree of agreement found between the two full scale test facilities. This is a very important finding, because it has long been thought that exact replication of every minute detail of a full scale facility is essential to be able to replicate the data. Although the facility used at BFGoodrich is very similar, in most respects, to the one at UL, it differs in a few details. However, the results of the tests are clearly comparable.

It is of interest to recall that the compounds used in the experimental cables were also tested in the cone and Ohio State University (OSU) calorimeters [12]. The jacket compound test results were found to be very useful indicators of full scale cable tray test results. Moreover, cone and OSU test results were found to correlate well with each other [12,27], indicating that both are excellent techniques for predicting full scale fire performance of products, in a manner relevant to fire hazard assessment.

Table 7.	Main Results from the Cone Calorimeter on Cables							
Cable	Pk RHR [kW/m²]	THR@15 [MJ/m²]	TTI [s]	SmkFct [MW/m²]	TSR@15	Pk RSR [1/s]	MLRP [g/(sm)²]	TTI/Pk RHR [s m²/kW]
				20 kW/m²				
Essex THHN	241	60	201	199	2611	11.6	1.2	0.8
1I 1J THHN	162	87	96	155	2950	10.8	2.7	0.6
Ultragard SOO	163	68	318	29	3891	13.9	0.6	2.0
3I 1J THHN	167	80	81	186	3127	11.6	2.9	0.5
1I 1J TW	102	9	199	50	1702	7.1	0.8	2.0
XLPE/CU	108	7	958	83	601	7.6	0.3	8.9
3I 1J TW	96	15	114	63	1607	6.2	1.6	1.2
3I 4J THHN	90	5	950	15	702	9.0	0.1	10.6
3I 3J THHN	20	1	620	2	832	3.0	0.2	31.0
1I 3J TW	86	12	780	18	1172	3.6	0.3	9.1
3I 2J TW	69	5	551	15	1396	6.0	0.3	8.0
3I 3J TW	52	10	576	6	901	2.4		11.1
524 3J TW	48	6	252	11	1235	2.8	0.7	5.3
IBM TYPE II	19	3	6909	4	723	2.1	0.04	363.6
IBM TYPE I	66	8	483	16	796	4.2	0.2	7.3
PLENUM	41	10	142	3	138	1.3	0.9	3.5
				40 kW/m²				
ESSEX THHN	318	64	32	846	3454	16.0	6.6	0.1
1I 1J THHN	285	154	21	754	8119	20.3	23.2	0.1
Ultragard SOO	283	134	36	518	5747	21.3	7.2	0.1
3I 1J THHN	269	136	24	707	6981	20.0	16.9	0.1
1I 1J TW	195	122	27	394	6033	16.3	10.5	0.1
XLPE CU	278	83	32	159	2925	14.2	8.4	0.1
3I 1J TW	205	114	30	407	5298	15.4	9.7	0.1
3I 4J THHN	89	18	69	76	3804	7.2	4.2	0.8
3I 3J THHN	158	54	41	239	5767	11.9	7.7	0.3
1I 3J TW	156	37	44	164	2518	8.1	7.0	0.3
3I 2J TW	176	97	30	388	5702	20.0	12.4	0.2
3I 3J TW	131	28	54	149	2366	7.8	10.4	0.4
524 3J TW	132	29	51	142	2737	7.8	6.9	0.4
IBM TYPE II	81	20	206	61	1551	7.2	1.1	2.5
IBM TYPE I	81	17	41	115	1528	12.8	3.2	0.5
PLENUM	84	25	75	33	503	4.9	2.0	0.9

CONCLUSIONS

A facility was built to carry out full scale vertical cable tray fire tests. The results of a series of fire tests carried out in this facility look very similar to those carried out in an established facility. This facility can be used to develop materials for /LS cables.

Vinyl wire and cable compounds have been developed which offer improved fire performance over that of traditional materials. These materials have been made into cables which perform well in small scale testing and pass full scale fire tests measuring rate of heat release. The better materials give off very little heat or smoke. These test results will form the basis for the development of new vinyl materials for use in /LS cables.

The cables tested that did not burn extensively, in the full scale tests, released very little smoke. The earlier work on UL-1581, CSA FT-4, and ICEA 529-T20 tests showed that those cables which did not burn beyond the failure points released an order of magnitude less of combustion gases, notably HCl, than the cables which failed.

Cone calorimeter test results on the cables tested could be correlated well with full scale test results, both in terms of heat and smoke release. This was particularly true for the cone calorimeter, at 20 kW/m^2 incident flux. These results could be, roughly, used to predict the results of full scale tests.

REFERENCES

1. Thomas, P.H., Int. Conf "FIRE: Control the Heat - Reduce the Hazard", Fire Research Station, October 24-25, 1988, London, paper 1.

2. Babrauskas, V., Int. Conf. "FIRE: Control the Heat -Reduce the Hazard", Fire Research Station, October 24-25, 1988, London, paper 4.

3. Babrauskas, V., J. Fire Sci. 2, 5 (1984).

4. Babrauskas, V. and Krasny, J., in "Fire Safety. Science and Engineering, ASTM STP 882" (Ed. T.Z. Harmathy), p. 268, Am. Soc. Test. Mats, Philadelphia, 1985.

5. Mulholland, G.W., Henzel, V. and Babrauskas, V., in Proc. 2nd. Int. Fire Safety Science Symp., (Ed. T. Wakamats, et al.), Hemisphere, Washington, D.C., p. 347, 1989.

6. Babrauskas, V., Fire Mats 8, 81 (1984).

7. Babrauskas, V., "Bench-Scale Methods for Prediction of Full-Scale Fire Behavior of Furnishings and Wall Linings", Soc. Fire Prot. Eng., Technology Report 84-10, Boston 1984.

8. Fowell, A.J., Fire Technol. 21(3), 199-212 (1985).

9. Hirschler, M.M., J. Fire Sciences 5, 289 (1987).

10. Tewarson, A., in Handbook Society Fire Prevention Engineers (Ed. P. di Nenno), Chapter 1/13, p. 1-179, NFPA, 1988.

11. Hirschler, M.M., 31st. IUPAC Microsymp. on Macromolecules Poly(Vinyl Chloride)", Prague, July 18-21, 1988, Makromol. Chem., Macromol. Symp. 29, 133-53 (1989).

12. Coaker, A.W., Hirschler, M.M. and Shoemaker, C.L., Fire Safety J., (in the press).

13. Babrauskas, V., "Development of the Cone Calorimeter. A Bench-Scale Heat Release Rate Apparatus Based on Oxygen Consumption", Nat. Bur. Stands, NBSIR 82-2611 (1982).

14. Babrauskas, V., J. Fire Flammability 12, 51 (1981).

15. Hirschler, M.M. and Smith G.F., in "Fire Safety Progress in Regulations, Technology and New Products", Fire Retardant Chemicals Assoc. Fall Conf., Monterey (CA), 1987, p. 133.

16. Babrauskas, V., Int. Conf. "FIRE: Control the Heat -Reduce the Hazard", Fire Research Station, October 24-25, 1988, London, paper 8.

17. Wickstrom, U. and Goransson, U., J. Testing Evaluation, 15(6), 346, 1987.

18. Hirschler, M.M., Int. Conf. Fire in Buildings (Interscience), Toronto, Canada, Sept. 25-26, 1989, Technomic, Lancaster, PA, p. 57.

19. Hirschler, M.M. and Poletti, R.A., J. Coated Fabrics, 19, 94 (1989).

20. Ebert, T.R., "Preliminary Modified Vertical Tray Flame Tests," E41877, 89NK14704, Underwriters' Laboratories, Inc., Northbrook, IL August 30, 1989.

21. UL letter for release of publication of results, Underwriters' Laboratories, Inc., Northbrook, IL, 1989.

22. Canadian Standards Association, C22.2 No. 0.3-M1985 (updated August 1988), Section 4.11.4, Vertical Flame Test: Cables in Cable Trays.

23. Parker, W.J., "Calculations of the Heat Release Rate by Oxygen Consumption for Various Applications," NBSIR 81-2407, February 1982.

24. Huggett, C., Fire Mats 4, 61 (1980).

25. UL 83, Thermoplastic Insulated Wires and Cables, 9th Ed., September 1983 (periodically updated), Tables 15.3, 15.5, Underwriters' Laboratories, Inc., Northbrook, IL.

26. UL 1277, Electrical Power and Control Tray Cables with Optional Optical Fiber Members, 1st Ed., January 1986 (updated October 1988), Table 10.24, Underwriters' Laboratories, Inc., Northbrook, IL.

27. Hirschler, M.M., Int. Conf. "FIRE: Control the Heat - Reduce the Hazard", Fire Research Station, October 24-25, 1988, London, paper 9.

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