FIRE TESTING OF ELECTRICAL CABLES FOR PUBLIC TRANSPORTATION

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In recent years electrical wire or cable insulation has been, once more, identified by NFPA statistics as a major material first ignited in both residential fires (where it represents 7.6% of fires and 4.0% of fire fatalities, between 1993 and 1997, and the cause of 13% of catastrophic fires, between 1993 and 1996) and transportation fires (where it represents between 11.4 and 25.6% of the first source of ignition between 1992 and 1996, depending on the type of transport, with11.8% for aircraft). This highlights the need for renewed emphasis on fire testing of wires, cables and electrical materials.

Cables can be used for power, for control or for communications; in the case of communications cables, the transmission can be effected by means of metal conductors or optical fibers. With the large increase in communications, the amount of cables used in public transportation is a large, and growing, part of the fuel load, but the fire performance of electric cables has traditionally been based on semi-mandatory guidelines, of relatively low severity. Furthermore, in many vehicles, cables constitute a very large proportion of the combustibles contained in concealed spaces, not easily accessible to passengers.

Recently, the Federal Railroad Administration, the International Maritime Organization, and the US Coast Guard all investigated cable fire performance requirements, to decide whether changes are needed. The Federal Aviation Administration has now embarked in a project to investigate the fire performance requirements for aircraft electrical wiring.

Cable fire tests can be subdivided into 5 categories:

(a) Old fashioned small scale tests, generally addressing ignitability or flame spread, with results often not predictive of real fire performance;
(b) Vertical cable tray tests, ranging in heat input from 20 kW up to 154 kW, addressing flame spread, and sometimes also smoke and heat release;
(c) The Steiner tunnel test (NFPA 262), assessing wind aided horizontal flame spread, and smoke release, with very high heat input (ca. 90 kW);
(d) Small scale cable tests, often originally designed for materials, measuring fundamental fire properties, such as heat release, critical flux for ignition or flame spread; and
(e) Tests for other cable fire properties, typically smoke: obscuration, toxicity, or corrosivity.

This paper surveys the types of tests available and makes some recommendations for future courses of action.

INTRODUCTION

There were a significant number of fires in the 1950's and early 1960's, in the USA, where serious losses resulted from propagation by electrical cables [1], which led to the realization that cable fire tests involving only single cables are inappropriate to assess the fire hazard of cables. Specific problems with tests on single cables include: lack of radiation to and from adjacent burning conductors, so that NFPA recommended, probably for the first time, that tests should be conducted on "bunched" cables because "grouped" cables can spread flame much faster than single cables. Therefore, even if single cables appear adequately fire retarded, they may not be safe when put in groups, due, at least partly, to radiation effects. Three of the few prominent major electrical cable fires since the 1970s and 1980s in the US have been in telephone central offices, and have been addressed by changes in the requirements for communications cables.

Telephone Central Office	Manhattan, New York City	New York State	2/27/1975
Telephone Central Office	Brooklyn, New York City	New York State	2/18/1987
Telephone Central Office	Hinsdale	Illinois State	5/8/1988

Transportation fires are a critical fraction of the overall US fire problem and aircraft are a small but significant fraction of the fires and fire fatalities.

Fire Statistics: 1994-1998 Averages [2]

	% Fires	% Fire Fatalities	% Fire Injuries
Residential Structures	22	82	75
Non Residential Structures	8	4	10
Vehicles	21	13	9
Others	49	1	6

	# Fires	# Fire Fatalities	# Fire Injuries
Residential Structures	418,500	3,575	18,669
Non Residential Structures	148,600	119	2.485
Vehicles	399,900	586	2,346
Aircraft (part of vehicles)	300	10	14
Others	856,000	49	139

An assessment was made by adding all the catastrophic residential fires which occurred between 1993 and 1997 (i.e. those fires which killed at least 5 people each): a total of 230 fires, of which approximately 13% were started by electrical causes. This is not surprising, since electrical wire or cable insulation, as the item first ignited, corresponds to of the four deadliest causes of fires, both in homes and in transportation fires. Curiously, electrical fires are often ignored, principally perhaps because it used to be common-place to ascribe electrical causes to all fires which did not have a well understood cause. Such misreporting has now ceased, but a re-evaluation of electrical causes of fires has not yet started in earnest.

Fire Statistics: 1993-1997 Averages - Item First Ignited in Home Fires
(in Descending Fraction of Fatality Order) [3]

	% Fires	% Fire Fatalities	% Fire Injuries
Upholstered Furniture	3.1	18.2	8.8
Mattress or Bedding	6.2	15.3	14.5
Interior Wall Covering	3.9	5.6	3.0
Electrical Wire or Cable Insulation	7.6	4.0	3.9
Cooking Materials	19.0	3.5	19.8
Clothing on a Person	0.2	3.5	1.1
Clothing Not on a Person	3.6	2.7	4.3

Vehicle Fire Statistics: 1992-1996 Averages
Electrical Wire or Cable Insulation as Item First Ignited [4]

	% Electrical Fires	Total # Fires by Type of Vehicle
Passenger Road Vehicle	25.6	298,570
Freight Road Transport Vehicle	22.0	38,050
Heavy Equipment Vehicle	20.3	5,870
Water Transport Vehicle	13.3	1,670
Rail Transport Vehicle	11.4	630
Air Transport Vehicle	11.8	230
Special Vehicle	13.9	2,000

None of the very early cable fire tests are sufficiently adequate to predict fire hazard in a real full scale fire environment, whether in a building or in a transportation vehicle. This work will discuss briefly some of the early tests, and then concentrate on those in use today, and on the needs of the transportation world, with emphasis on aircraft.

Initial Fire Tests for Cables

Category a tests: the earliest approach for fire test requirements for electrical cables were tests intended to assess the properties of the plastic materials used as coatings. All the tests also involve small scale specimens and low intensity simple laboratory burners, and are intended to address individual types of materials (and sometimes single cables). In reality, these can now be seen to be nothing more than quality assurance tests, rather than fire safety test methods. Examples of these standards are the fire tests in: ASTM D 229[1], ASTM D 350, ASTM D 470, ASTM D 876 ASTM D 1000, ASTM D 2633, ASTM D 2671 and ASTM D 3032, and the hot wire ignition test in ASTM D 3874. Interestingly, Test Method B in section 18.11 of ASTM D 3032 is the 60° angle test used by the FAA and originally described in ASTM F 777. On the other hand, Test Method A in section 18.5 of ASTM D 3032 is one of the test

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[1] The bibliography has full references for a large number of fire test standards, including all of those discussed in the text.

methods most widely used for acceptance of cables in the National Electrical Code [NFPA 70]: the UL 1581, section 1080, known as the VW1 test. The VW1 test is used for the lowest level of fire performance permitted for use in the National Electrical Code.

Many of these small scale tests on materials are very similar. In particular some of them are versions of the famous UL 94 series of tests for plastic plaques. An effort has been underway, at ASTM, IEC and ISO, to coordinate the profusion of these standards, administered by different bodies. Thus, ASTM D 635, ASTM D 3801, ASTM D 4804 and ASTM D 5048, like UL 94, are all basic flammability/dripping tests, ASTM D 5025 is a specification of the corresponding burner (of the Bunsen or Tirrill type) and ASTM D 5207 describes how to calibrate the burner. There have been projects to develop more repeatable burners, with work still in progress. Internationally, responsibility is divided in a similar fashion to the way it is within ASTM. IEC (International Electrotechnical Commission) addresses the electrical world (with fire tests in IEC TC20 and IEC TC89) while ISO (International Organization for Standardization) is responsible for both plastics (technical committee ISO TC61) and building product fire standards (ISO TC 92). This has been reviewed in reference [5].

ISO has three material fire standards relevant to the electrical industry: ISO 1210 (for horizontal and vertical plastics flammability, with a 20 mm flame; combining ASTM D 635 and ASTM D 3801, i.e UL 94 HB and V-0 tests), ISO 9773 (the corresponding vertical test for flexible plastics; ASTM D 4804) and ISO 10351 (the test for the 125 mm flame; i.e. UL 94 5V or ASTM D 5048). ISO 1210 and ISO 10351 have been withdrawn now and the subjects are covered in IEC 60695-11-10 and IEC 60695-11-20. All the tests use the premixed burner specified in ASTM D 5025, which is also one of the standard sources of ignition described in ISO 10093 (P/PF2). Tests corresponding to the ISO ones also exist at IEC. The new set of standards is: IEC 60695-11-3 and IEC 60695-11-4, representing the specification and calibration of the 500 W and 50 W premixed burners respectively (even if the same burner can be used for both 50 W and 500 W tests). They differ from the ASTM and ISO burner specifications, because there are more options. IEC 60695-11-10 is the test method corresponding to UL 94 HB & V-0 (or ISO 1210, or ASTM D 635 and ASTM D 3801) and IEC 60695-11-20 is the one corresponding to UL 94 5-V (or to ISO 10351 or ASTM D 5048). A joint ISO/IEC task group has successfully combined ISO 1210 and ISO 10351 with the pertinent parts of IEC 60707 to create IEC 60695-11-10 and IEC 60695-11-20, with responsibility being assigned to IEC. IEC 60707 includes the classification system, being harmonized with the UL one.

There are three tests that are similar, albeit not identical, and that are used to regulate wires and cables: UL VW1, CSA FT1(Canadian Standards Association) and IEC 60332-2. All of them basically apply a small flame (500 W) to a vertical cable sample, and assess flame spread (pass/fail criterion for the VW1 test is < 10 in vertical flame spread) but the differences are sufficient that a manufacturer needs to conduct all tests to be sure of qualifying for the corresponding market, whether for the US, Canada or Europe. The most notable small scale materials test is, of course, UL 94, with HB, V-0 and 5V parts. The Canadian equivalent, CSA C22.2 No. 0.17, has the same parts.

Vertical Cable Tray Fire Tests for Grouped Cables

Category b tests: As explained above, testing of individual cables with small burners cannot predict the potential fire hazard inherent in the use of grouped (or bunched) cables. This is critical, since cables are only rarely isolated from other cables, but rather normally present in trays or just simply laid out in concealed spaces (such as in concealed spaces, including air handling spaces, overheads, underfloors, computer rooms, cable cabinets, etc.). This issue becomes a more severe problem as a facility becomes older, since excess cables, once installed, are rarely removed ("mined") when replaced, and serve as an additional source of combustible mass. This is the reason why fire testing of grouped cables has now been shown to be essential.

This resulted in the development of all the now common vertical cable tray tests. The first one is the most famous one: IEEE 383, later to become UL 1581-1160, first standardized in 1974, using a 70,000 BTU/h (20.3 kW) gas ribbon burner. In Canada, the Canadian Standards Association adopted CSA FT4, a vertical cable tray test has is different from IEEE 383 (more details later). The IEEE 383 test requires, basically, that cables don't burn up completely under the exposure conditions (20 min, at 70,000 BTU/h; actual requirements are a char length of less than 8 ft (ca. 2.44 m)). IEEE also later developed its own version of the CSA FT4 test, which it standardized as IEEE 1202. The IEEE 383 test became the first tray cable test adopted as a North American standard for measuring flammability of grouped cables. Specifications for shipboard cable (in IEEE 45), nuclear power industry power cable and trains (NFPA 130) also refer to the IEEE 383 test for flame propagation. Table 1 presents the differences between the various standard vertical cable tray tests and Table 2 shows the magnitudes that are actually measured in each test (and the criteria, if applicable). Several studies have compared the severity of various cable tray tests, in particular Coaker et al. [6-11] and Barnes et al. [12-13]. There are some aspects that are worth highlighting on differences, as follows.

The Canadian FT4 standard differs from UL 1581-1160 in a few main aspects, as follows (which is the reason that it is a part of UL 1581, in section 1164):

The burner is at an angle of 20° from the horizontal, rather than vertical, and it is sited 1 ft from the floor rather than 18 in from the floor;
The burner is sited in front of cable tray rather than at the back;
Cable loadings are different, the CSA FT4 test having significantly more cable, particularly for smaller diameters;
Tray length is 3 m (10 ft) and not 8 ft (2.4 m); minimum cable length is 2.3 m;
Failure criterion is a char length of 1.5 m, rather than 8 ft (2.4 m);
In summary, the CSA FT4 test is substantially more severe than UL 1581-1160.

Internationally, the IEC 60332-3 standard is substantially similar to the UL 1581 test, but it has some significant differences. The differences include [5]:

The cable tray is mounted against a wall, rather than free standing, so that mass loss cannot be measured continuously;

#	The tray and cable lengths are both 3.5 m;
#	The cable loading and flame duration (20 or 40 min) depends on the category of cables to be tested, with unspecified category criteria (see Table 3);
#	The burner, horizontal, is at a height of 2 ft from the floor;
#	Failure criterion is char length of 2.50 m from the bottom edge of the burner;
#	The air inlet and outlet are not symmetrical within the chamber.
#	In summary, the IEC 60332-3 test is less severe than the CSA FT4 test.

Recently, internationally, a European community research project developed a variation of IEC 60332-3, known as the FIPEC test [14-15], which is significantly more severe and can distinguish between various degrees of cable fire performance. In the test method, cables are tested in a thermally insulated vertical test chamber (1 m x 2 m x 4 m), with floor air inflow and ceiling air and smoke outlet. The test chamber also has an observation door (to view the tests), and is connected to a hood and duct system, where heat and smoke release information is determined and assessed. The cables are mounted on a cable tray attached to the rear wall of the test chamber, with multiple 3.5 m lengths of electrical or optical fiber cable as test specimens. The lower part of the cables extends 0.2 m below the lower edge of the burner, and the normal distance between the burner and the cables is 75 mm. The cables are centered along the width of the cable tray, with each cable attached individually to each rung of the tray, by means of a metal wire. The cables are exposed for a period of 40 min to a 20 kW flame (Protocol 1) or a 30 kW flame (Protocol 2), from a gas burner. The two protocols also differ in the presence of a non combustible board, made of calcium silicate behind the cables, at the back of the cable tray in Protocol 2. Protocol 1 is applied to all cables, but Protocol 2 is not applied to those cables that perform poorly when tested in Protocol 1. Measurements are cable char length (damage), and all relevant heat and smoke release parameters.

In 1991, a group of cable materials manufacturers and cable manufacturers worked with UL to develop a standard "limited smoke" (/LS) marking for cables. The resulting standard, UL 1685, has two versions: UL 1581-1160 and CSA FT4. The test includes pass/fail criteria, which requires the char length criterion of the original test (i.e. 8 ft for UL 1581-1160 and 1.5 m for CSA FT4), as well as requirements for maximum rate of smoke release (Pk RSR) and total smoke release (TSR). UL 1685 Pk RSR and TSR criteria are based on optical density rather than the more technically correct extinction coefficient as used in CSA FT4 (differing by a factor of 2.3). The corresponding pass-fail criteria for the two UL 1685 versions are: CSA FT4 TSR # 345 m^2 (compared to # 150 m^2 in the UL 1685 version of CSA FT4) and Pk RSR # 0.92 m^2/s (versus # 0.40 m^2/s in UL 1685) and are used in that way in the corresponding CSA requirements, with the cable being marked as FT4-ST1 (flame tested level 4, smoke tested level 1).

There are two ASTM standards based on UL 1685, with all the needed information: they are ASTM D5424 (with smoke obscuration as the mandatory measurement, and heat release, mass loss, toxic gases and char length as optional measurements) and ASTM D5537 (with heat release, mass loss and char length as requirements and smoke and toxic gas release as optional measurements). Both standards can be satisfied with a single test (or burn) and can be conducted in 2 options: UL 1581-1160 or CSA FT4.

There are regulatory requirements in the National Electrical Code (NEC) using the vertical cable tray tests discussed above: the UL 1581-1160 test is required for use in areas where tray cables are needed. As an alternative, the CSA FT4 test may be conducted instead. Finally, the UL 1685 test can be used in either case to develop the optional marking of "/LS" or "limited smoke". See Figures 1 and 2 for the NEC requirements for flame spread and smoke. It is important to note that the only mandatory smoke requirements are those for plenum cables (NFPA 262, see below).

A different type of vertical cable tray test also exists addressing the fire performance of grouped cables: the riser test. Riser cables have the second most severe requirement, they must pass ANSI/UL 1666 (see Figure 1). In UL 1666 cables are mounted in a vertical tray arrangement, within a 19 ft high concrete shaft divided into two compartments at the 12 ft level, with a 1 ft x 2 ft opening between the compartments. The ignition source is a gas flame of 527,500 BTU/h (155 kW), on for 30 min. Cables pass the test if there is no "flame" at the top of the bottom compartment during the test; char length and smoke obscuration, mass loss or heat release are not measured. Results are based on flame height, although some temperatures are also measured. This test is considerably less severe than the plenum cable test, although the incident heat is much higher. Both the riser and the plenum cable test are most commonly applied only to communications or data cables.

Horizontal Tray Tunnel Cable Fire Test for Grouped Cables: Steiner Tunnel

Category c test: Plenum cables must pass the severest cable fire test: NFPA 262 (also known as UL 910). It involves loading a horizontal 25 ft long, 1 ft wide tunnel (Steiner Tunnel) with cables and exposing them to a 300,000 BTU/h (87.9 kW) gas flame for 20 min, under an 240 ft/min air flow rate. In order to "pass", cables need to spread flame a distance of less than 5 ft, beyond the gas flame itself, have a peak smoke optical density not exceeding 0.5 and an average optical density not exceeding 0.15, both measured in the exhaust duct. Such cables are then described as "having adequate fire-resistant and low-smoke-producing characteristics" for use in "ducts, plenums and other environmental air-handling spaces", or in any "compartment or chamber to which one or more air ducts are connected and which forms part of the air distribution systems". A plenum is an area located above false ceilings and where the heating, ventilating or air conditioning ducts are located, as well as communications cables and other utilities. Details of the history and controversies surrounding this test have been discussed elsewhere [16-22]. However, the use of this test has resulted in a large increase in the penetration of plenum cables into areas of commercial and public buildings, where communications, data and fire alarm cables are needed.

Small Scale Heat Release Tests

Category d tests: It is now clear that heat release is the single most important fire property, since its peak value is a measure of peak intensity of a fire [23-27]. The recent exponential growth in the interest in the use of heat release rate happened when it became possible to measure this magnitude directly and accurately. The main small scale calorimeter tests measuring heat release [28] are the cone (ASTM E 1354) [29], the OSU (ASTM E 906) [30] and the Factory Mutual apparatus [ASTM E 2058, 31-34]. The cone calorimeter is the most recent of these tests, and the one based on the oxygen consumption principle; thus, most cone work on cables has been relatively recent. On the other hand, work on cables using both older instruments started in the mid 1970's.

E.E. Smith and co-workers published several papers [35-39] showing how the OSU apparatus can be used to predict fire performance of cables. The first work published involved showing how to test materials (plaques), wires and cables with the OSU, at a 30 kW/m^2 incident flux. The work showed the similarities and the differences between the results of both types of testing: wire or cable construction can have a very significant effect on heat and smoke release. When the work was extended to communications cables for use in plenum applications [37], the data from the OSU apparatus was used, in conjunction with the OSU fire model [40], to attempt to predict NFPA 262 results. The prediction was not fully successful, particularly in terms of smoke release, the most critical aspect of tunnel cable tests. In this work the cables were placed in the sample holder by bending them to fill the area without cutting them, while the earlier work used 6" (0.15 m) lengths and laid them side by side. However, even with the various flaws found, this work showed that heat release rate data could be used to predict full scale fire performance. Improvements have been made since, especially on smoke release. In fact, later work [41] showed that the OSU apparatus could also be used, at incident heat fluxes of # 30 kW/m^2, to predict length of char and flame spread in a vertical cable tray test [CSA FT4].

Some other work, independently done for the US Navy, also found it possible to predict vertical cable tray data (in this case the IEEE 383 test) from OSU data, the preferred incident flux being 20 kW/m^2 [42-43]. This work represents a fundamental effort, unfortunately finally truncated, intending to develop a correlation between the data on heat release of electrical cables (using two types of cables: one with high flame spread and one with low flame spread) in the OSU apparatus and the IEEE 383 cable tray flame spread test. The same work also studied several effects on the burning characteristics of selected cables:

#	cable diameter
#	ratio of copper conductor cross-sectional area to overall cable cross-sectional area
#	cable spacing
#	incident energy level.

The studies found that incident energy and cable diameter had the greatest effect on heat release rate, while copper ratio and cable spacing (in the OSU test) had very little significant effect on test results. They also found that the OSU results were reasonably reproducible, particularly on heat release, although somewhat less on smoke release. It was felt that the OSU was a more adequate bench scale fire test than some alternatives investigated at the time (ASTM E 2058 [FM calorimeter] and smoke obscuration tests: ASTM E 662, ASTM D 4100, ASTM E 84). Moreover, cables passing the IEEE 383 test had very little heat release per square meter of cable surface during the first 5 min of the test, at an incident flux of 20 kW/m^2. On the other hand, cables that failed the IEEE 383 test released substantial amount of heat over that same initial period. Another possible screening parameter is the peak heat release rate (Pk RHR): most cables passing the IEEE 383 test had values < 100 kW/m^2 while failing cables had values >> 100 kW/m^2. However, a few passing cables had Peak RHR only slightly > 100 kW/m^2. More recent work used the OSU to compare the fire performance of various types of cable materials: traditional vinyls, vinyl thermoplastic elastomers, traditional polyolefins and highly fire retarded polyolefins [6].

The oxygen consumption principle is key to measurements in the cone calorimeter (and in full scale heat release tests). It states that the amount of heat generated per unit mass of oxygen consumed has been shown to be almost independent of the material burning, it is usually very close to 13.1 MJ of energy per kg of oxygen consumed, for normal combustible materials. Thus, the heat release (and cone calorimeter) measurement concept is: it is not necessary to capture all the heat emitted but simply to ensure that all the smoke and gases released are assessed.

Many tests were carried out using the cone calorimeter, most often using plaques of materials to be used for making cable insulations or cable jackets. It is worth highlighting studies by British workers [44-45] and by US workers [6-11, 46-49] and later work [12-13, 50-55]. In the first case a variety of cable materials with different chemistries were being compared, to understand the advantages of each material, with a variety of tests, including the cone calorimeter. The work showed that no material is universally adequate for making cables, and each material has different advantages and disadvantages. The first stage of the US work was designed as a fundamental series of research projects, trying to understand the way to develop new compounds with better fire performance characteristics. Materials were tested in the cone calorimeter and in the OSU apparatus, and very good correlations were found between the results in both apparatuses. Two other studies followed, the first one [27] comparing the fire properties of many materials (a total of 35, of which ca. 12 were designed for wire and cable coating applications) and a series of cable fire tests designed to predict full scale results from RHR fire tests [910, 47, 52]. The work involved cone calorimeter cable burns and some full scale cable burns, carried out in two facilities. Both facilities were instrumented to be able to measure heat release, smoke release, mass loss and gas release for each test. The conclusions were that cables can be burnt adequately in the cone calorimeter and that the results can then be used to predict the outcome of cable tray tests: UL 1581-1160, CSA FT4 (or IEEE 1202) or ICEA T29-520. In the full scale tests it was found that peak flame height correlated well with extent of char length. In both cases, when the cable fails the test, and burns to the top, there is a plateau, since, obviously, a further increase in peak heat release rate can no longer increase char length or flame height. The results indicate a number of reasonable correlations can be found, for example, (a) between extent of char length and peak heat release rate in the full scale test, and (b) between peak heat release rate in the full scale test and in the cone calorimeter. In order for the cone calorimeter to be a good predictor of full scale fire performance, it must be run at an incident flux of 20-30 kW/m^2. The addition of results from burns at 40-50 kW/m^2 improves the correlation even more. The only exception is the ICEA T29-520 test, which is more severe and requires a combination of results at two fluxes, a low of ca. 20 and a high of 40-50 kW/m^2 in the cone calorimeter. An especially interesting set of results from this work were the conclusions on smoke obscuration. Many of the cables that gave off higher heat release also gave off higher releases of smoke (albeit with some exceptions) and of combustion products. It is interesting to note that this is consistent with the real life results from a cable fire in a Japanese underground tunnel. The cables involved in the tunnel fire contained insulation and jacketing materials made with compounds releasing very little smoke in the small scale smoke test (NBS smoke chamber, ASTM E 662) in the specification; however, the cables released large quantities of black smoke in the real fire [56]. It is not unusual to find poor direct correlations between smoke obscuration results in small scale tests and real scale fires. Thus, calculations are often required before predicting smoke results. However, there are also some clear-cut cases, where relatively high smoke can be released from relatively low heat release cables. These are the cases requiring special attention.

During the course of this cable work the researchers went a step further. They tested the compounds insulating the cables, both in the cone calorimeter and in the OSU apparatus [7]. This showed a reasonable correlation between rate of heat release results of jacket compounds and cable tray test rate of heat release results of cables, in either RHR calorimeter [9-10]. Furthermore, smoke factor appeared to be a fairly effective first approximation parameter to measure [57-59], since the cone calorimeter results of tests at 20 and at 40 kW/m^2 correlated well both among themselves and with the OSU apparatus results. Another set of industrial cable burn tests involves a large number of different chemistries in the polymers used, but maintaining a constant cable construction, to eliminate this variable [52]. The set of 21 cables was tested in the cone calorimeter at 20, 40 and 70 kW/m^2 and in ASTM D 5537, additionally measuring smoke release [13, 53-55]. The work confirms most results predicted earlier, but goes further in indicating, as suggested by the previous British work on cable compounds [44-45], that there is more than one reason for picking a particular set of compounds for building cables. The main conclusions drawn from these cable tray tests were:

- Cable tray tests are well suited to measure many essential fire hazard assessment parameters, and not only flame spread.
- Peak and average heat release rate values are excellent indicators of overall cable fire performance in tray tests, and are much better discriminators than char length or peak flame height.
- Cables that pass tray tests will release # 50% of their combustible mass, while those that fail release much more.
- Full scale heat release rate is a reasonable predictor of total smoke release, albeit mostly for passing cables.
- Large improvements in smoke obscuration in full scale fires can be achieved by improving cable fire performance, without necessarily decreasing the specific (per unit mass) amount of smoke emitted by the products.
- Trends found by the cone calorimeter are similar to trends found in full scale tests.
- Cone calorimeter heat release rate is a reasonable predictor of full scale rate of heat release and char length, particularly for passing cables.
- Cone calorimeter smoke factor correlates reasonably well with full scale total smoke release, at least in the first instance.
- The cone calorimeter, with the large number of parameters it measures appears to be a very promising instrument for testing cable fire performance and predicting full scale results.
- For all correlations investigated, it appears that results for passing cables can be analyzed more adequately than those for failing cables.
- In the only case investigated where sheath and insulation materials were the same, the overall fire performance of the cables appeared similar. However, ignitability and propensity to flashover, in the cone calorimeter, still suggest that the sheath may be more important for overall fire performance than the primary insulation.

It needs to be borne in mind, however, that more recent work categorically demonstrates that smoke obscuration must be considered, since approximately 10% of large scale tests on materials with excellent heat release/flame spread characteristics give fairly high smoke release [60-61]. Thus, smoke obscuration is crucial, as lack of visibility is critical in delaying escape and preventing rescue.

Work by UL [62] shows independent confirmation of the industrial work referenced. Unfortunately, the work involved very few cables and has little information on the type of cables involved. The work decided that the optimum range of fluxes for predictions is 20-30 kW/m^2. This work is an affirmation that small scale calorimetry can be used to predict results of full scale cable tray tests, as found previously from the calorimeter work (Factory Mutual, OSU calorimeter and cone) described before.

Similarly, it has now also been shown that IEC 60332-3 and FIPEC cable tray test results can also be predicted with a reasonable degree of confidence from cone calorimeter test data [63-64], once more confirming that the combination of the cone calorimeter in the small scale and a vertical cable tray test in the large scale is a reassonable way of assessing fire hazard.

Fire Tests for Ancillary Properties

Category e tests: These tests assess smoke obscuration, smoke toxicity or smoke corrosivity.

Smoke obscuration is mostly assessed in materials tests, such as those mentioned above, particularly the NBS smoke chamber, with a number of designations, e.g. ASTM E 662, BS 6401, NFPA 258, NES 711, Boeing BSS 7238, Airbus ATS 1000, NF C 20-902-1. Smoke obscuration can be measured, mostly for quality control, in the Arapahoe smoke test (ASTM D 4100) or the Rohm and Haas chamber (ASTM D 2843). A variant of the NBS smoke chamber has been developed, mainly for the maritime industry: ISO 5659-2 (also NFPA 270 and ASTM E 1995), mandatory for naval use. Research and development measurements of smoke obscuration are made with one of the heat release tests mentioned above: cone calorimeter (ASTM D 6113, for cables), OSU (ASTM E 906) or FM (ASTM E 2058) apparatuses. The cone was shown to give reasonable correlations with larger scale smoke tests, but only if derived parameters are used [55]; by extension, it was proposed that the OSU is also adequate for the purpose (e.g. Hirschler 1991 [58]). The lack of correlation of the NBS smoke chamber (ASTM E 662) with full scale dynamic smoke environments has already been mentioned and has also long been documented (e.g. Hirschler 1993 [65]). On the other hand, little information has been published on correlations of results for cables or cable materials between ASTM D 2843 or ISO 5659-2 and full scale fire situations. It is important to stress, however, that little work has been done on predicting data from fire scenarios for which such static tests were developed: closed compartments (or concealed spaces) where there is the potential for oxygen vitiation. In larger scale, vertical cable tray tests offer the opportunity for measuring smoke obscuration (see Table 2), as does the NFPA 262 plenum cable test.

Internationally, low smoke cables are qualified by the 3 meter cube test, (IEC 61034), where the vertical cable tray and the propane burner are replaced by a horizontal tray and an alcohol pan fire (formerly a baker's tray). The cable samples are only 2 m long at a 5 kg combustible/m packing density. The test method chamber is a 3 meter cubical room (volume 27 m^3). A section of cable is mounted horizontally over 1 L alcohol, burning for ca. 25 min. The smoke is mixed by a small fan. Smoke obscuration is measured photometrically, horizontally. Attenuation, A_0, is defined as

$$A_0 = \frac{V}{L} \log\left(\frac{I_0}{I_t}\right) \quad (1)$$

(V is the chamber volume, L the light path length, I_o the initial transmittance, and T_t the measured transmittance). UK recommended values for A_o, based on cable diameter, are:

Cable Diameter (mm)	Number of Cable Sections	A_o (m^{-1})
10-15	4	0.7
15-25	3	0.8
25-40	2	1.0
40+	1	1.5

Unfortunately, correlation between ASTM D 5424 and IEC 61034 was found to be poor [55].

Smoke toxicity has been one of the most emotional issues in the fire area for > 20 years. It has been shown that about 2/3 of people US fire fatalities die of smoke inhalation, but a similar fraction of the fatalities die in "flashover" fires, where the fire has progressed beyond the room of fire origin. In such flashover fires, the carbon monoxide yield is sufficient (and virtually independent of the material burning) to cause lethal atmospheres. Thus, it is now clear that in the majority of fires, particularly large fires, the smoke toxicity of individual materials or products has little effect on the overall toxic hazard. Furthermore, very small fires, where the toxic hazard can be heavily dependent on the individual material burning, rarely generate sufficient smoke to cause lethal concentrations. However, rare situations can be envisaged where toxic potency can make a difference. Both ASTM and NFPA have developed a test method (ASTM E 1678, NFPA 269), based on the NIST radiant method: radiant exposure to quartz lamps (50 kW/m^2 heat flux) and a ca. 200 L exposure chamber, for 6 rats (nose exposure only), in a closed system. Animals are exposed to smoke for 30 min, and then followed for a 14 day post-exposure period. Fatalities are counted and toxic potencies calculated (as LC_{50}: lethal concentration killing 50% of the animals: as the LC_{50} decreases the toxic potency increase, because it means that less material is needed for lethality). For post-flashover fires, values of $LC_{50} > 8$ mg/L are considered of "normal toxicity", since that level corresponds to the toxicity of the carbon monoxide inevitably present at flashover. Moreover, a material containing only carbon, hydrogen, nitrogen, chlorine, bromine, aluminum and silicon is expected to be of normal toxicity, and need not be retested, but there is no consensus on this. New York State and New York City use the University of Pittsburgh test [66] which is a flow through system exposing 4 mice. This test method has been the subject of much controversy. The test has been broadly attacked for technical deficiencies, including the fact that multiple toxic potencies can be obtained with the same material, depending on initial mass loaded, and the excessive sensitivity of mice to irritants. However, it has been used to obtain a very large data base, particularly of electrical materials and products (as administered by the National Electrical Manufacturers Association, NEMA), which showed little differences between materials: 96% of all toxic potencies were statistically indistinguishable, including polyolefins, fluoropolymers and PVC compounds. The UK Navy (and some other military and transport specifiers) requires cable materials to meet NES 713: a small burner is used on cable materials, and concentrations of a set of 12 combustion gases are measured with Draeger tubes. Concentrations are then divided by arbitrary NES 713 toxicity indices to obtain an overall index, which is best if it is very low. The method has no pass-fail criteria, but specifications do. The indices produce high values for materials containing halogens, which rarely "pass" this arbitrary test. Similar tests, using the NBS smoke chamber as the test apparatus, are used by both of the major air frame manufacturers. Internationally, animal bioassays are not used, and all testing involves chemical analysis. No international standard toxicity test exists, but work is in progress, at IEC TC89, to develop a test based on the DIN tube furnace.

It should also be mentioned that smoke toxicity information has been used for assessment of fire hazard (and fire risk) in scenarios involving electrical cables, indicating the small degree of importance of this parameter [67-69].

Smoke corrosivity has been a subject of intense debate for a number of years, but the issue seems to have peaked now. The issue is, primarily, of commercial or marketing interest, while most other fire issues, are safety concerns. Three types of corrosive effects of smoke on electrical or electronic circuitry exist: metal loss, bridging of conductor circuits and formation of non-conducting surfaces on contacts. Metal loss results in an increase in resistance of the circuitry, so that electrical conduction is impaired. Bridging (or leakage current) has the opposite effect: decrease in resistance by creating alternative simple paths for current flow. Deposit formation can cause, like metal loss, a loss of electrical conductivity and, thus, make an electrical contact unusable. It can also, mechanically, render parts, such as ball bearings, ineffective as they are not able to turn adequately.

Acid gases combine with water to causes metal corrosion. Originally acid gases were believed to be the **only** entities capable of causing corrosion. Thus, corrosive potential of smoke was determined based only on acid gas emission rankings following material combustion in a hot tube furnace, under an air flow. Water soluble effluents were captured and the solutions titrated for acid gas content (HCl, HBr, HF), acidity (pH) and/or conductivity. In practice, decisions were often taken based purely on chemical composition: i.e. halogen content (or simply whether or not halogens are present). It has since been found that smoke corrosivity can occur with halogen-free smoke, and that it can, under certain conditions, be larger than that due to halogens. Post-exposure treatments, such as cleaning, can retard (or even fully stop) the corrosion process and save the equipment.

There are two major alternative types of tests to acid gas or conductivity tests: those based on mass loss, with an example being the cone corrosimeter (ASTM D 5485) and those based on current leakage [5]. In the first type, the smoke corrosivity is usually measured with copper circuit board targets, based on the principle of a Wheatstone bridge circuit, or with other metal targets for which some electrical measure serves as a surrogate for mass loss. The latest performance test to be developed for smoke corrosivity is one based on leakage current (or bridging), and the targets are copper "interdigitated combs", developed for atmospheric "dust" testing. The targets cannot conduct electricity when clean (as there is no connection between the terminals), but "leakage current" caused by the smoke produces conductor bridging and increases in current. The test, thus, assesses the decrease in resistance of the targets by different types of smoke. This is dependent not only on the fire conditions (heat flux, in the cone calorimeter; temperature, residence time and air flow rate, in the tube furnace) but also on the voltage applied to the targets and the corresponding relative humidity. Early reported results indicate that materials with excellent fire performance give the best results, irrespective of halogen content. Similar results have been found with cables containing such materials: plenum-rated cables perform well and others do not. The main reason seems to be that leakage current appears to be caused by additives and particles, such as soot or smoke, and not halogen atoms.

Activity in Public Transportation

Fire testing of cables in transportation environments has been reviewed recently [70] and is of growing importance, particularly in view of the increasing number and selection of entertainment and other communications devices present in transportation environments. The number of seats per unit area (or volume) is not increasing (even perhaps decreasing, with the enlargement of size of people in the developed world), as the need is still for one seat per passenger. On the other hand, the amount of cabling is increasing very rapidly, with one key new ingredient being the communications and control cables for personal entertainment systems provided.

<u>Early Requirements for Rail Transportation</u>: Fire testing requirements for wire and cable are found in specifications by rail operators and in NFPA 130 (for which early editions addressed only fixed guideway transit systems). High performance wire and cable insulated conductors must meet the VW-1 flame test and ASTM E 662 smoke obscuration limits. In NFPA 130 vehicles, also, power cables must meet the requirements of IEEE 383, with the additional requirement that circuit integrity continue for 5 minutes after the start of the test (*even though circuit integrity is not defined in the IEEE 383 test).* All cables must meet National Electrical Code construction requirements, but not necessarily the fire test requirements.

<u>Rail Transportation Now</u>: Now NFPA 130 has expanded its scope to address all passenger rail systems, without recent changes to the requirements for electrical cables or electrical installations. However, the new edition of NFPA 130 also discusses the need to consider heat release rate as a critical component of fire hazard assessment, and that the mandatory rules are simply one way of solving the fire safety problem. In 1999 two other major developments occurred: the Federal Railroad Administration published a new mandatory Rule [71], to be applied to all new rail passenger systems, and the ASTM committee on Fire Standards issued a new guide for the fire hazard assessment of rail transportation vehicles: ASTM E 2061. Both contain significant new concepts for fire testing of electrical cables.

The new Federal Railroad Administration (FRA) Rule is a set of Mandatory Requirements, as opposed to the Guidelines and Voluntary Requirements of earlier vintages. The new Table of mandatory requirements contains only a few subtle changes for most materials (such as upholstery or interior finish), when compared to earlier guidelines, but it includes a section on electrical cables, absent before. The new tests for wire and cable flame spread are almost identical to those included in NFPA 130, but were then not applied system wide, and smoke tests were added. Another major change presented by the new FRA rule is the explicit assertion that alternative test methods can be used to replace existing test methods. Finally, the most important change is the fact that the FRA Rulemaking publication explicitly states the desirability to use overall systems approaches to fire hazard, including mentioning specifically the ASTM E2061 guide, which was, at the time of publication of the FRA rule, under development at ASTM.

The recommendations by FRA constitute a significant step forward in the way to develop fire safety assessments for an overall system. In view of this, and submissions made both to FRA and to NFPA 130, the following concepts are being considered:

* The concept of using a vertical cable tray test such as IEEE Standard 383 is correct, in principle, as IEEE 383 is a medium-to-large scale test, assessing flame spread. However, there are 3 disadvantages of IEEE 383: (a) it is an old version (issued in 1974 and not amended) of the same test now addressed better in ASTM D5424 [53] (for flame spread and smoke release) and ASTM D5537 [54] (for flame spread and heat release), or by UL 1685 [49], and IEEE 383 can be conducted by using an "oily rag" as the ignition source (instead of a well-characterized gas burner); (b) it measures only flame spread (and neither release of heat nor smoke) and (c) it cannot fully differentiate between cables with good and mediocre fire performance. On the other hand, the ASTM pair of tests (which can both be conducted together in a single burn) can do a much better job of differentiating products and identifying the truly excellent performers, by assessing heat and smoke release. UL 1685 contains two protocols for flame spread, heat release and smoke release, with pass/fail criteria for flame spread and smoke, and the ASTM D5424/D5537 standards have the same tests, more fully described, albeit without pass-fail criteria. In the proposed FRA requirements, smoke is measured in a small-scale test (ASTM E662) instead of in the medium-large scale vertical cable tray test. Thus, the IEEE 383/ASTM E662 combination should be replaced by ASTM D5424/ASTM D5537, with the addition of pass-fail criteria (char length of 2.4 m, total smoke released of 95 m^2 and peak rate of smoke release 0.25 m^2/s [UL protocol] and char length of 1.5 m, total smoke released of 150 m^2 and peak rate of smoke release 0.40 m^2/s [CSA protocol]) or by UL 1685, which already contains the pass-fail criteria but is less well defined and has not been developed through the consensus process.

* Low voltage wire and cable: The VW1 test required is much less severe than the IEEE 383 (or the ASTM D5424/ASTM D5537, or the UL 1685) test for cables, except that it is sometimes unsuitable for very thin wires (which are very desirable, as they have lower weight and occupy less space). In recognition of this, the National Electrical Code accepts the idea of substitutions for cables meeting more severe fire tests. This issue did not present a problem in NFPA 130, because the scope permitted substitutions. However, as the new FRA rule is intended to be mandatory, the following leeway should be allowed, accepting the substitutions, so that a cable required to meet a small-scale vertical test, such as the UL VW-1 test, can be replaced by a cable meeting the requirements from any of the more severe tests: (a) IEEE 383 or UL 1685 or ASTM D5424/ASTM D5537; (b) UL 1666 (riser cable test) or (c) NFPA 262 (plenum cable test). This would ensure that fire safety is not dependent on simply cable thickness but on actual fire performance. The National Electrical Code details the fire test requirements for cables. It

contains 4 types of test requirements (see Figure 1): UL 1581 VW1, UL 1581-1160 or UL 1581-1164 (CSA FT4), UL 1666 and NFPA 262, in degree of increasing severity. Of these tests, the UL VW1 test can usually be met by any cable that has a thick enough insulation, irrespective of the fire performance of the insulating material used. The NEC understands, too, that, as a cable meets more severe fire test requirements, it can replace one that meets less severe requirements. Thus, the NEC permits cables meeting the UL 1581 cable tray test, the UL 1666 riser test or the NFPA 262 plenum cable test to be used in any application where the VW1 test is required. This is particular important in environments where space and weight are at a premium, such as a transportation environment (train, ship or aircraft), where the "modern" trend is to develop cables with thinner walls.

* IEEE 383 does not contain a circuit integrity test, leaving room for misinterpretation and misapplication of the rule. Thus, this vague reference to a circuit integrity test, should be replaced by a test, for fire alarm cables only, requiring that one cable conductor not cease transmitting electricity during the first 5 min of test, as verified, for example, by a flashlight bulb remaining lit for the entire period or some other method. Alternatively, cables listed to a circuit integrity test, such as IEC 60331, should be acceptable.

Thus, all cables in trains will probably eventually have to meet the vertical cable tray test and a smoke obscuration test, *once all the dust has settled*.

Ships: All ships engaging in international trade and flying the flag of a country that is a signer to the International Convention for Safety of Life at Sea (SOLAS), which includes the USA, must comply with International Maritime Organization (IMO) regulations, as detailed in the SOLAS book (periodically amended by "Resolutions" of IMO committees, and ratified by the signatory states). Details of the fire issues are given in the IMO Fire Test Procedures Code, also reissued regularly. Some special vessels are regulated separately: high speed craft that is never too far from shore is regulated by the IMO High Speed Craft Code. All ships that sail in US waters must comply with the requirements specified by the US Coast Guard, laid out in US Federal Government - Coast Guard: Title 46, Shipping, Code of Federal Regulations, Parts 1–199, and in NVIC (US Coast Guard Guide to Structural Fire Protection). The Coast Guard is also the authority having jurisdiction over ships engaging in international trade and sailing into US waters or US ports; such ships must comply with IMO regulations and need not also comply with separate Coast Guard requirements. With the instructions from the US federal government that standards should, whenever possible, be delegated to private organizations, the Coast Guard and NFPA agreed to develop NFPA 301. NFPA 301 applies to passenger vessels carrying more than 12 passengers, cargo and tank vessels and towing vessels 12 m or more in length and greater than 500 hp; it does not apply to military ships (although military ships must comply with Coast Guard requirements). In order for NFPA 301 to be a requirement, someone must choose to meet them, and that would typically be a shipbuilder in conjunction with ABS (American Bureau of Shipping, who certify ships in the USA). The market of ships that are not built to comply with IMO requirements is actually extremely large, because it encompasses all the ships sailing through rivers (e.g. Mississippi River), lakes (e.g. Great Lakes) and (most importantly) the ships sailing in amusement parks (e.g. Disney parks, as the Disney fleet is one of the largest fleets in the world). Typically, wire and cable for ships in the USA was regulated by military specifications included in CFR 46 (Subchapter J) and by the recommendations of IEEE 45.

The present edition of NFPA 301 contains fire test requirements for cables by reference to 46 CFR Subchapter J (Electrical Engineering, Parts 110-113), to IEEE 45 (1983 edition) and to the National Electrical Code. It requires all shipboard cables to meet the IEEE 1202 vertical cable tray fire test (equivalent to CSA FT4). It also has a specific chapter devoted to fire testing of cables, both communications (or data) and power cables, which contains the hierarchical substitution permitted in the National Electrical Code. Thus, cables in ships would normally be required to pass a vertical cable tray test (IEEE 1202), and cables listed as meeting UL 1666 (riser) or NFPA 262 (plenum), can be substituted for them. This has become very critical since modern ships are: (a) multi-storied constructions, with many shafts communicating the various storeys and concealed spaces and (b) have a multitude of communications cables critical for ship performance.

Listing and certification of naval cables can happen via a joint UL/CSA standard (UL 1309 and CSA 245) and, internationally, via IEC 92-350 or IEC 92-353, required by SOLAS. UL 1309 requires cables to meet a vertical cable tray test, either the one contained in UL 1581-1160 or IEEE 1202/CSA FT4. The international standards bodies have a set of three fire tests for electrical cables: IEC 60332-1, IEC 60332-2 and IEC 60332-3, where the first 2 apply to a single insulated wire or cable and IEC 60332-3 is a vertical cable tray test, somewhat less severe than both UL 1581-1160 and CSA FT4. The US Coast Guard is recommending that electric installations listed to UL 1309, IEC 92-350 or IEC 92-353 be accepted as equivalent to those presently permitted, but what will happen is that all cables will have to meet the IEEE 1202 vertical cable tray fire test.

Aircraft: In aircraft, the regulatory authority is the Federal Aviation Administration (FAA), via Title 14 in the Code of Federal Regulations. All of their fire test requirements are published in a Fire Test Handbook (latest edition 2000); new versions are made available to all aircraft parts suppliers. Wire and cable needs to meet a relatively mild exposure to a Bunsen burner, at a 60 degree angle, for 30 seconds (similar to the discontinued test in ASTM F 777, from which it originated), although the majority of the wire and cable actually used exhibits a fire performance that significantly exceeds the test requirements. The FAA has announced that it intends to search for a new test for materials concealed outside of the passenger cabin, and wire and cable is prominent in that location. They have a test under development for that purpose, probably based on the flooring radiant panel (ASTM E 648). This is unlikely to happen before 2002. There is also a test for wire and cable in a "designated fire zone" (based on MIL SPEC W 25038E or on ISO 2685) and one for smoke emission from wire and cable, using the NBS smoke chamber (ASTM E662). The FAA prefers to develop test methods that are of specific use to the industry, and to work with the interested parties in the industry to complete the final test modifications and improvements. However, as the FAA is traditionally responsible for developing tests with very high (albeit achievable) degree of fire safety, it is likely that the test that will eventually be developed will be a severe fire test, based on the concept of preventing a fire involving wire and cable in a concealed space to spread flame more than a very short distance.

CONCLUSIONS

Fires in public transportation are relatively rare, but can affect multiple people if they occur. Furthermore, statistics strongly indicate that electrical wire and cable is a critical area in such environments. In recent years, this has led to more emphasis being placed on fire safety requirements for electric cables in various public transportation sectors: ships, trains and aircraft. In particular, in trains and ships, the emphasis is moving towards the use of cables with lower heat release and flame spread. In aircraft, the concept initially put forward is one of preventing flame spread from occurring in a concealed space. In all transportation environments, fire hazard assessment is critical, so that tests can be chosen to obtain valid fire safety engineering test results, which can then be used as input into fire models. A fire hazard assessment developed as a result of these procedures should be able to assess a new product being considered for use in a vehicle, and conclude whether the new product considered is, or not, safer, in terms of predicted fire performance, than the one in established use. The result of such assessments will be the ability to design, with a high degree of confidence, public transportation vehicles which offer excellent fire protection to passengers, while incorporating as much comfort as is consistent with the fire safety required.

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Table 1. Comparison of Some Features of Vertical Cable Tray Tests

	IEEE 383 UL 1581-1160	ICEA T-29-520	CSA FT4	IEEE 1202	UL 1685/ UL1581[a]	UL 1685/ CSAFT4[b]	IEC 60332-3	CEI 20.22 Pt 2
Burner power (kW) (ca.)	21	62	20	20	21	21	20	30 [c]
Time of flame (min)	20	20	20	20	20	20	20, 40 [d]	60
Alternate source	Yes, oily rag [e]	no	no	no	no	no	no	no
Burner placement [f]	600 mm [g] 75 mm in back	300 mm 200 mm in back	300 mm 75 mm in front	300 mm 75 mm in front	457 mm 75 mm in back	457 mm 75 mm in front	600 mm 75 mm in front	200 mm 50 mm [h] front/back
Angle of burner	horizontal	horizontal	20° up	20° up	horizontal	20° up	horizontal	horizontal
Tray length (m)	2.4	2.4	3.0	2.4	2.4	2.4	3.5	4.5
Tray width (m)	0.3	0.3	0.3	0.3	0.3	0.3	0.5	0.5
Sample length (m)	2.4	2.4	2.3	2.3	2.4	2.4	3.5 m	4.5
Width of tray used for cables (m)	0.15 front only	0.15	0.25 front only	full front only	0.15 front only	full front only	0.30 front or front + back [i]	0.20 front + back
Thin-size cables to be bundled	no	no	if D < 13 mm	if D < 13 mm	no	if D < 13 mm	mounted flush, with no spaces	mounted flush, with no spaces
Test enclosure specified	no	no	yes	yes	yes	yes	yes	yes
Required air flow rate	N.A.	N.A.	> 0.17 m^3/s	0.65 m^3/s	5 m^3/s	5 m^3/s	0.08 m^3/s	10 m^3/s
Test runs needed	3	2	2	2 x 2 [j]	1	1	1	1
Max. char length (m, from bottom)	2.4	2.4	1.786 [k]	1.786 [k]	2.4	1.786 [k]	3.1	4.1
Peak smoke release rate ($m^2\ s^{-1}$)	N.A.	N.A.	N.A.	N.A.	0.25	0.40	N.A.	N.A.
Tot. smoke released (m^2)	N.A.	N.A.	N.A.	N.A.	95	150	N.A.	N.A.

[a] Version run with UL 1581 exposure. Equivalent to ASTM D5424/D5537, except ASTM has no failure criteria.
[b] Version with CSA FT4 exposure. Equivalent to ASTM D5424/D5537, except ASTM has no failure criteria.
[c] Electrical oven, two radiant plates facing cables (500 x 500 mm)
[d] Time is 20 min for Category C, 40 min for Categories A and B.
[e] Valid only for the IEEE 383 and not the UL 1581 version.
[f] Height above bottom, followed by distance from specimen surface.
[g] This dimension is 457 mm in the UL 1581 version.
[h] Minimum distance from cable surface.
[i] Depends on amount of cable loading.
[j] Two each on two different sizes of specimens.
[k] Char length of 1.5 m is measured from horizontal height line of burner.

Table 2. Measurements Required in Cable Tray Tests

	Char Length	RHR	RSR	TSR	Mass Loss
IEEE 383 UL 1581-1160	Mandatory	No	No	No	Optional
CSA FT4	Mandatory	No	No	No	Optional
IEEE 1202	Mandatory	No	No	No	Optional
UL 1685 (UL 1581)	Mandatory	Optional	Mandatory	Mandatory	Optional
UL 1685 (CSA FT4)	Mandatory	Optional	Mandatory	Mandatory	Optional
IEC 60332-3	Mandatory	No	No	No	Optional
ASTM D 5424	Optional	Optional	Mandatory	Mandatory	Optional
ASTM D 5537	Mandatory	Mandatory	Optional	Optional	Mandatory
ICEA T-29-520	Mandatory	No	No	No	Optional
CEI 20-22 Pt 2	Mandatory	No	No	No	Optional

Table 3. Cable Loading & Flame Application in IEC 60332-3

Cable Category	Packing Density	Burner Flame Application
	L of combustion products per m of tray	min
A	7.0	40
B	3.5	40
C	1.5	20

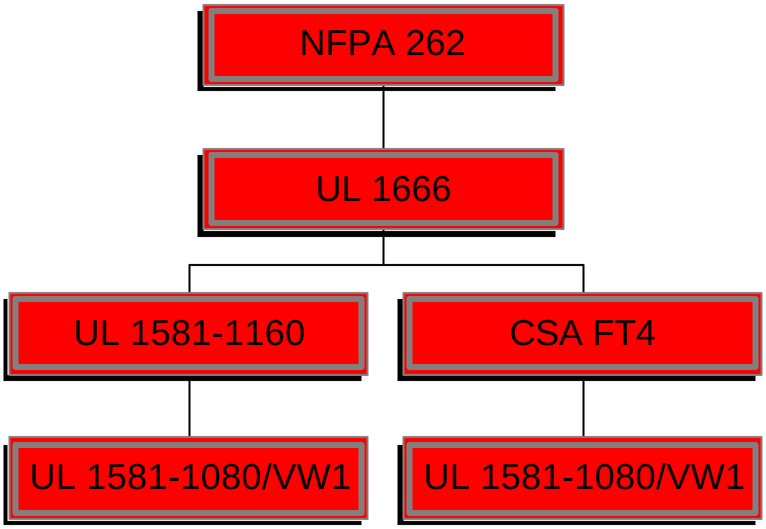

Figure 1: National Electrical Code Cable Fire Test Hierarchy (in decreasing order of severity)

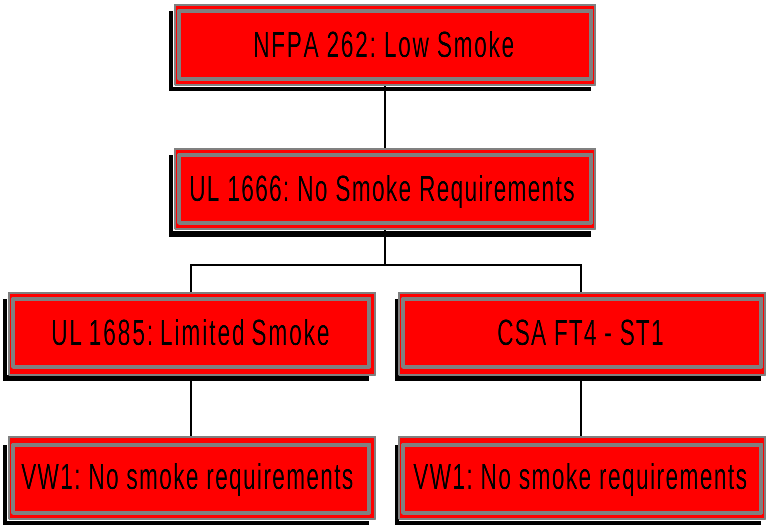

Figure 2: National Electrical Code Cable Smoke Test Hierarchy (in decreasing order of severity). Note that only NFPA 262 has mandatory smoke requirements.