

FIRE AND POLYVINYL CHLORIDE



TECHNICAL INFORMATION

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FIRE & POLYVINYL CHLORIDE

Polyvinyl chloride (PVC, or vinyl) materials or products tend to have excellent fire performance properties. In particular, pure PVC will not burn once the source of heat or flame is removed. This is because 56.8% of the base polymer weight of PVC is chlorine. It is well known that chlorine is one of the few elements that confers good fire properties to a polymer.^{1,2}

Unplasticized (rigid) vinyl materials, such as those used for making pipe, siding or vertical blinds, cause less fire hazard than similar samples of wood. When PVC is plasticized to make flexible products such as wire coatings, upholstery, or wall coverings, its fire properties become less favorable, depending on the amount and kind of plasticizer and other additives used. However, most plasticized PVC products in use will still tend to have good fire performance, particularly if additionally treated with fire retardants.

In order to assess fire hazard in a specific scenario, it is usually necessary to measure the fire properties of the relevant materials or products in small-scale and full-scale tests, and interpret them in terms of overall fire hazard.

ASSESSING FIRE HAZARD

Fire hazard, or the potential for a fire to cause harm to people or property, results from a combination of factors including the ignitability and flammability of the products being considered, amount of heat released on burning, rate of heat release, flame spread, smoke obscuration and smoke toxicity, as well as the specific conditions of the fire scenario.

Whenever possible, the data presented here are based on a series of 35 commercial materials in use in the 1980s and 1990s, (all but one of which are plastics, and a dozen of which are vinyl, including eight flexible, or semi-rigid, vinyls). Table 1 lists the materi-

Table 1

**Description of materials used in cone calorimeter (and some other) tests:
(All samples are at 6 mm thickness, except as indicated.)**

A: NON VINYLs

ABS:	Cyclocac' CTB acrylonitrile butadiene styrene terpolymer (Borg Warner) (# 29)
ABS FR:	Cyclocac' KJT acrylonitrile butadiene styrene terpolymer fire retarded with bromine compounds (Borg Warner) (# 20)
ABS FV:	Polymeric system containing acrylonitrile butadiene styrene and some poly(vinyl chloride) as additive (# 19)
ACET:	Polyacetal: polyformaldehyde (Delrin™, Commercial Plastics) (# 24)
DFIR:	Douglas fir wood board (# 22)
EPDM:	Copolymer of ethylene propylene diene rubber (EPDM) and styrene acrylonitrile (SAN) (Rovei™ 701) (# 31)
KYDEX:	Kydex™: fire retarded acrylic panelling, blue, (samples were 4 sheets at 1.5 mm thickness each, Kleerdex) (# 15)
PCARB:	Polycarbonate sheeting (Lexan™ 141-111, General Electric) (# 5)
PCARB B:	Commercial polycarbonate sheeting (Commercial Plastics) (# 16)
NYLON:	Nylon 6,6 compound (Zytel™ 103 HSL, Du Pont) (# 28)
PBT:	Polybutylene terephthalate sheet (Celanex™ 2000-2 polyester, Hoechst Celanese) (# 32)
PE:	Polyethylene (Marlex™ HXM 50100) (# 34)
PET:	Polyethylene terephthalate soft drink bottle compound (# 33)
PMMA:	Poly(methyl methacrylate) (25 mm thick, lined with cardboard, standard RHR sample) (# 26)
PP:	Polypropylene (Dypro™ 8938) (# 35)
PPO/PS:	Blend of polyphenylene oxide and polystyrene (Noryl™ N190, General Electric) (# 18)
PPO GLAS:	Blend of polyphenylene oxide and polystyrene containing 30% fiberglass (Noryl™ GFN-3-70, General Electric) (# 17)
PS:	Polystyrene, Huntsman™ 333 (Huntsman) (# 30)
PS FR:	Fire retarded polystyrene, Huntsman™ 351 (Huntsman) (# 23)
PTFE:	Polytetrafluoroethylene sheet (samples were two sheets at 3 mm thickness each, Du Pont) (# 1)
PU:	Polyurethane flexible foam, non fire retarded (25 mm thick, Jo-Ann Fabrics) (# 25)
THM PU:	Thermoplastic polyurethane containing fire retardants (Estane™, BFGoodrich) (# 27)
XLPE:	Black non-halogen flame retardant, irradiation crosslinkable, polyethylene copolymer cable jacket compound (Unigard™ DEQD-1388, Union Carbide) (# 11)

B: VINYLs:

Rigid

PVC EXT:	Poly(vinyl chloride) rigid weatherable extrusion compound with minimal additives (BFGoodrich) (# 13)
PVC LS:	Poly(vinyl chloride) rigid experimental sheet extrusion compound with smoke suppressant additives (BFGoodrich) (# 10)
PVC CIM:	Poly(vinyl chloride) general purpose rigid custom injection moulding compound with impact modifier additives (BFGoodrich) (# 8)
CPVC:	Chlorinated poly(vinyl chloride) sheet compound (BFGoodrich) (# 7)

Flexibles

FL PVC:	Standard flexible poly(vinyl chloride) compound (non-commercial; similar to a wire and cable compound) used for various sets of testing (including Cone Calorimeter RHR ASTM round robin; it contains PVC resin 100 phr; diisodecyl phthalate 65 phr; tribasic lead sulphate 5 phr; calcium carbonate 40 phr; stearic acid 0.25 phr (# 21)
PVC WC:	Flexible wire and cable poly(vinyl chloride) compound (non fire retarded) (BFGoodrich) (# 14)
PVC WC SM:	Flexible wire and cable poly(vinyl chloride) compound (containing minimal amounts of fire retardants) (BFGoodrich) (# 12)
PVC WC FR:	Flexible wire and cable poly(vinyl chloride) compound (containing fire retardants) (BFGoodrich) (# 9)
VTE 1:	Flexible vinyl thermoplastic elastomer alloy wire and cable jacket experimental compound, example of the first of several families of VTE alloys (# 6)
VTE 2:	Flexible vinyl thermoplastic elastomer alloy wire and cable jacket experimental compound, example of the second of several families of VTE alloys (# 3)
VTE 3:	Flexible vinyl thermoplastic elastomer alloy wire and cable jacket experimental compound, example of the third of several families of VTE alloys (# 2)
VTE 4:	Semi flexible vinyl thermoplastic elastomer alloy wire and cable jacket experimental compound, example of a family of VTE alloys containing CPVC (# 4)

als, a sequence number (by which they are identified in Figures and Tables) and a short description. Figures are presented in such a way that the better fire responses tend to be at the top.

Ignitability

If a material does not ignite, there is no fire. Therefore, low ignitability is the first line of defense in a fire. In fact, however, all organic materials do ignite, but the higher the temperature a material has to reach before it ignites, the safer it is. Thus, it is possible to determine ignition temperatures using a traditional test: ASTM D1929 (Setchkin test). Figure 1 presents the self-ignition and flash-ignition temperatures of many common materials.³⁻⁵ The PVC material tested has a flash ignition temperature of 391°C. A better way of measuring ignitability is to determine a time to ignition (TTI) or a minimum heat input needed to ignite the material. This can be done using a modern standard test, ASTM E1354 (cone calorimeter). Fire performance improves as either one of these properties becomes larger. Figure 2 (page 4) shows some results of this test, the minimum ignition fluxes required to cause ignition within 100 seconds or 10 minutes, for the 35 materials in Table 1.⁶ It is very clear that most vinyls tend to be difficult to ignite.

Figure 1

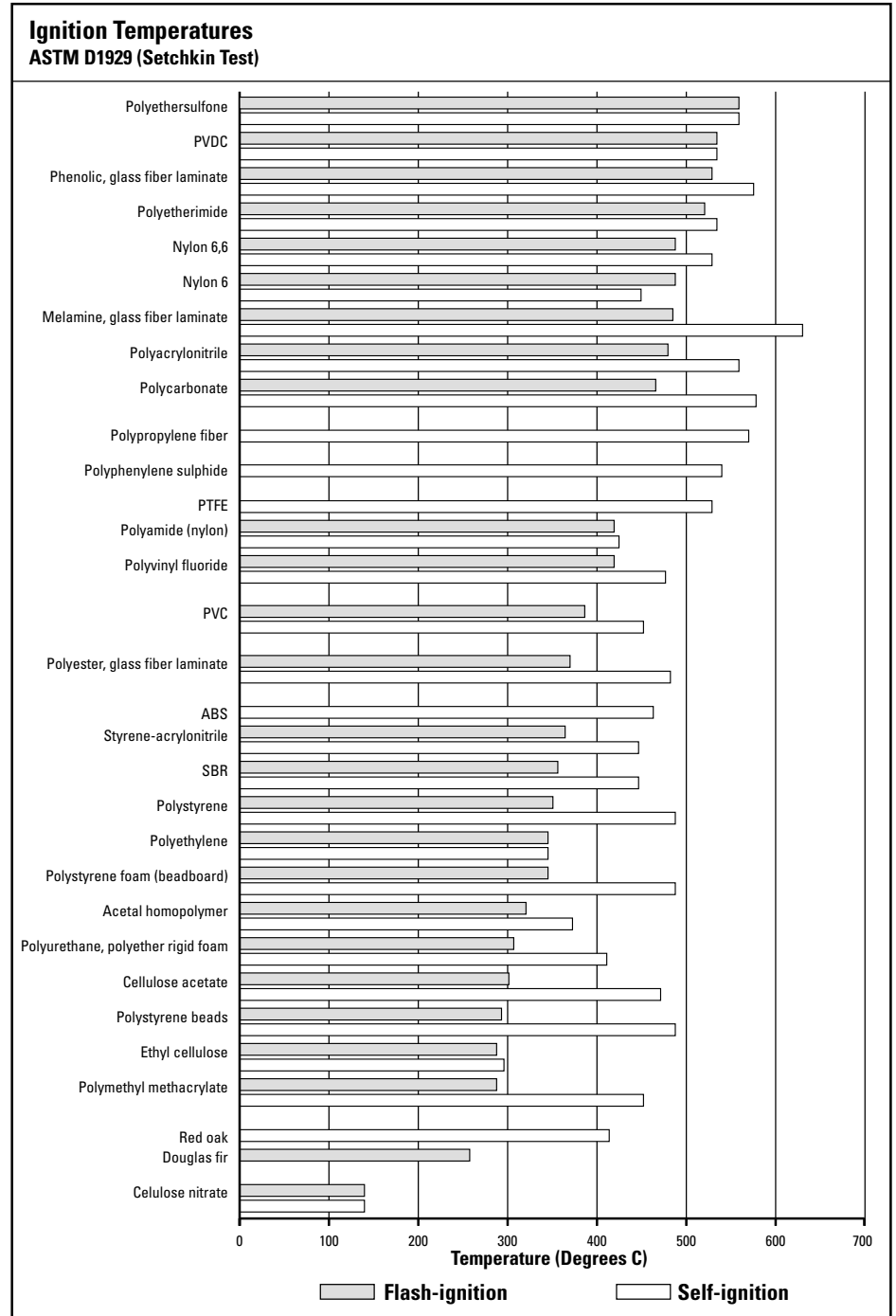
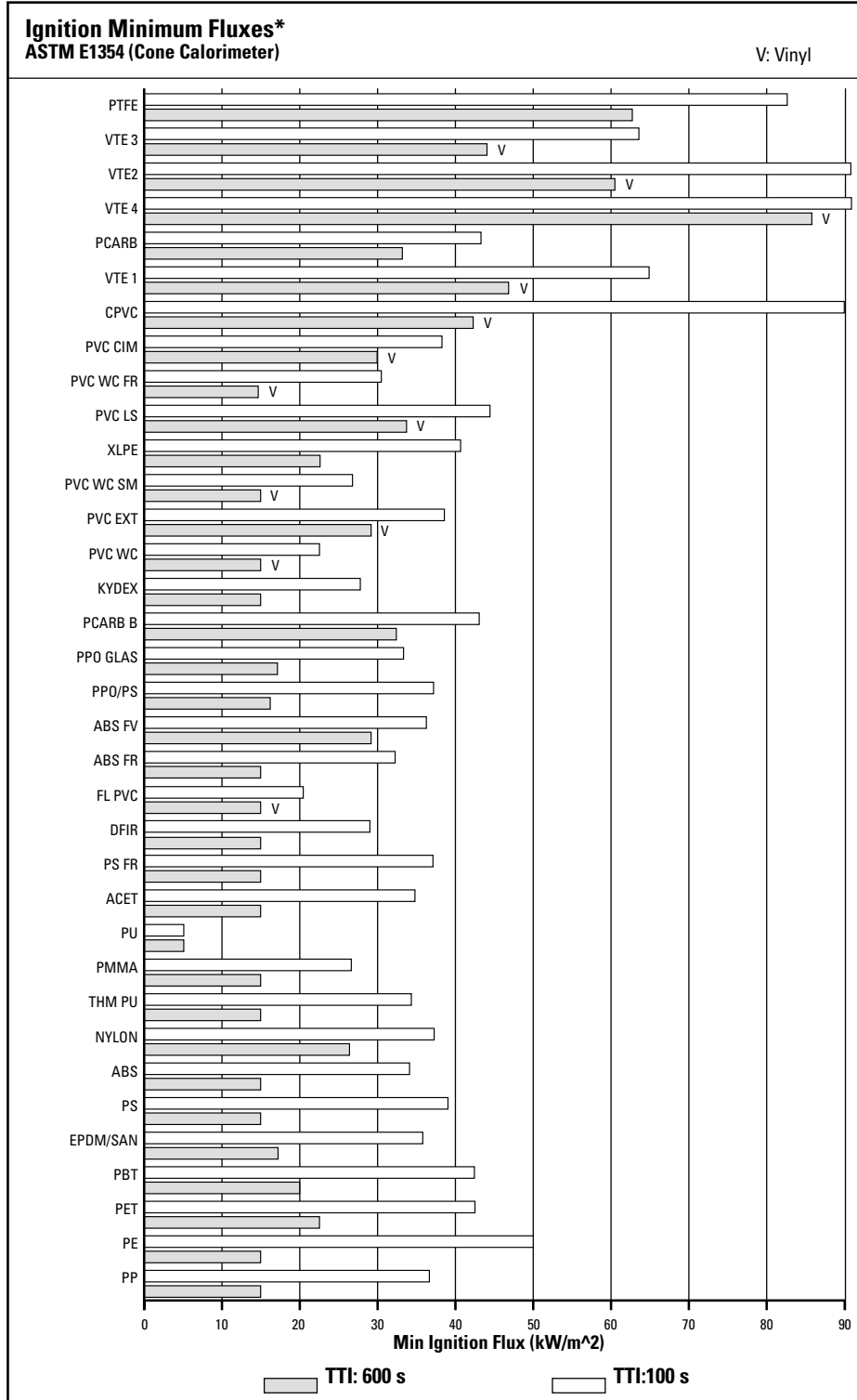


Figure 2



*materials listed are identified in Table 1

Ease of Extinction

Once ignited, the easier a material is to extinguish, the lower the fire hazard associated with it. One of the most widely used small-scale tests is the limited oxygen index test (LOI; ASTM D2863), an ease of extinction test. It gives the limiting concentration of oxygen in the atmosphere necessary for sustained combustion (higher numbers reflect greater ease of extinction). This test is widely used for specifications, although its applicability to real-scale fires has been severely criticized.⁷ Figure 3 shows that very few common materials have an LOI higher than rigid PVC.

Flame Spread

The tendency of a material to spread flame can be measured with a variety of tests. The sample sizes range from very small (5 in. by 0.5 in., UL 94) to quite large (24 ft. by 22 in., ASTM E84, Steiner tunnel). These two tests are very widely used for various specifications and building code requirements. PVC materials tend to perform very well in both tests: UL 94 V-0 and Steiner tunnel Class I (flame spread less than 25). In comparison, red oak has a flame spread index of 100 (meaning that it spreads flame much more quickly than vinyl in the tunnel). However, both of these fire tests have been criticized because they are not indicative of real fire performance.⁷⁻⁸ There are, unfortunately, no good flame spread tests for full-scale testing, but a good indicator of performance in this area is given by the radiant panel test, ASTM E162. Results from this test (Figure 4, on a logarithmic scale)³⁻⁴ show PVC as one of the materials with the lowest flame spread rating; it will not spread flame on its own.

Figure 3

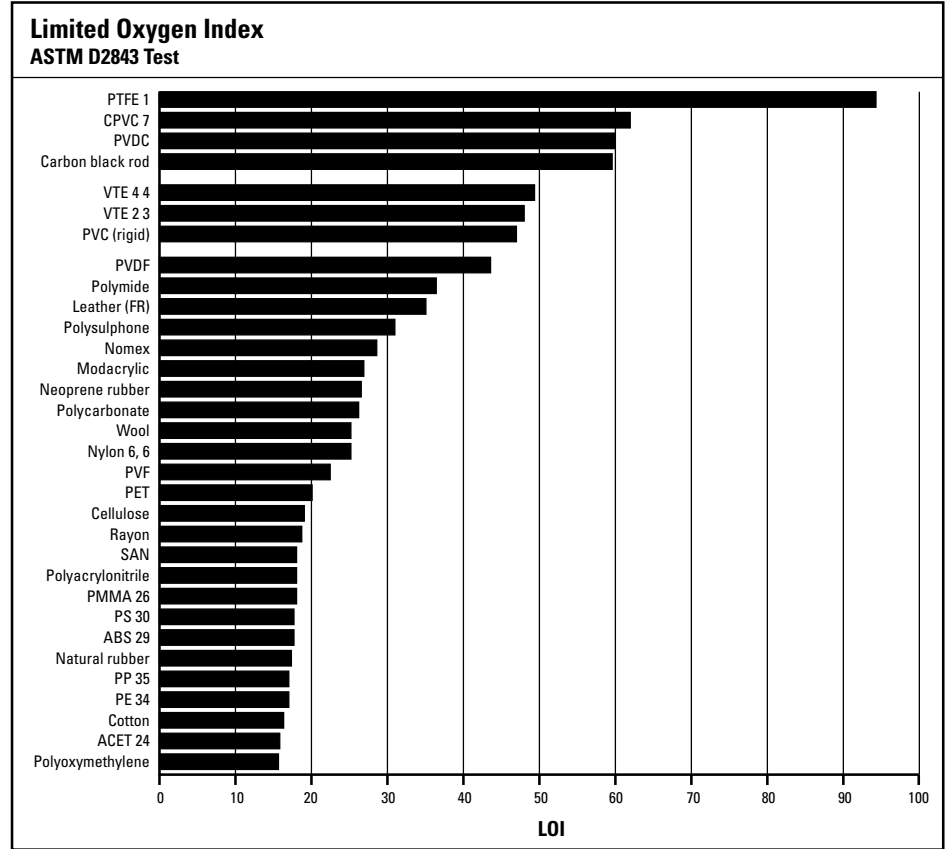
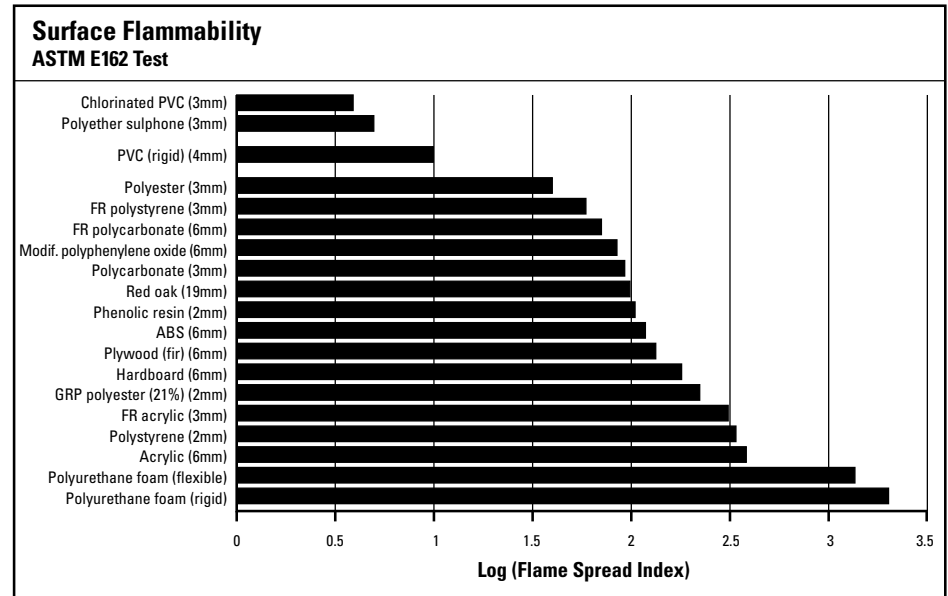


Figure 4



Heat Release

The key question in a fire is: “How big is the fire?” The one fire property that answers that question is the rate of heat release. A burning object will spread a fire to nearby products only if it gives off enough heat to ignite them. Moreover, the heat has to be released fast enough not to be dissipated or lost while traveling through the cold air surrounding anything not on fire. Therefore, fire hazard is dominated by the rate of heat release.^{9,10}

In fact, rate of heat release has been shown to be much more important than either ease of ignition, smoke toxicity or flame spread in controlling the time available for potential victims of a fire to escape.¹¹ Fire victims often die of smoke poisoning in a fire. However, unless the fire becomes very big, there is unlikely to be enough toxic smoke to kill. Therefore, fire fatalities occur when the rate of heat release of the fire is sufficiently large to cause many (or even most) products in the room of fire origin to burn.

In the late 1960s, Professor Edwin Smith, at The Ohio State University, developed the first test instrument to measure rates of heat release, the OSU-RHR calorimeter (ASTM E906).¹² Figure 5 presents results of maximum rate of heat released for a variety of materials, at an incident heat flux of 20 kW/m², as measured in an Ohio State University rate of heat release calorimeter.^{3,13} This graph shows the good fire performance of vinyl materials. In order to put the heat flux used into perspective, a heat flux of 20 kW/m² applied from 8 feet away (the normal distance from ceiling to floor) is sufficient to ignite a sheet of newspaper lying on the floor.

Since the early 1980s, a new, more sophisticated test has been developed by the National Institute of Standards and Technology (NIST, formerly National Bureau of Standards) which measures rate of heat release: the cone calorimeter (ASTM E1354, NFPA 264, ISO 5660).¹⁴ This instrument also can be used to assess other fire properties,

Figure 5

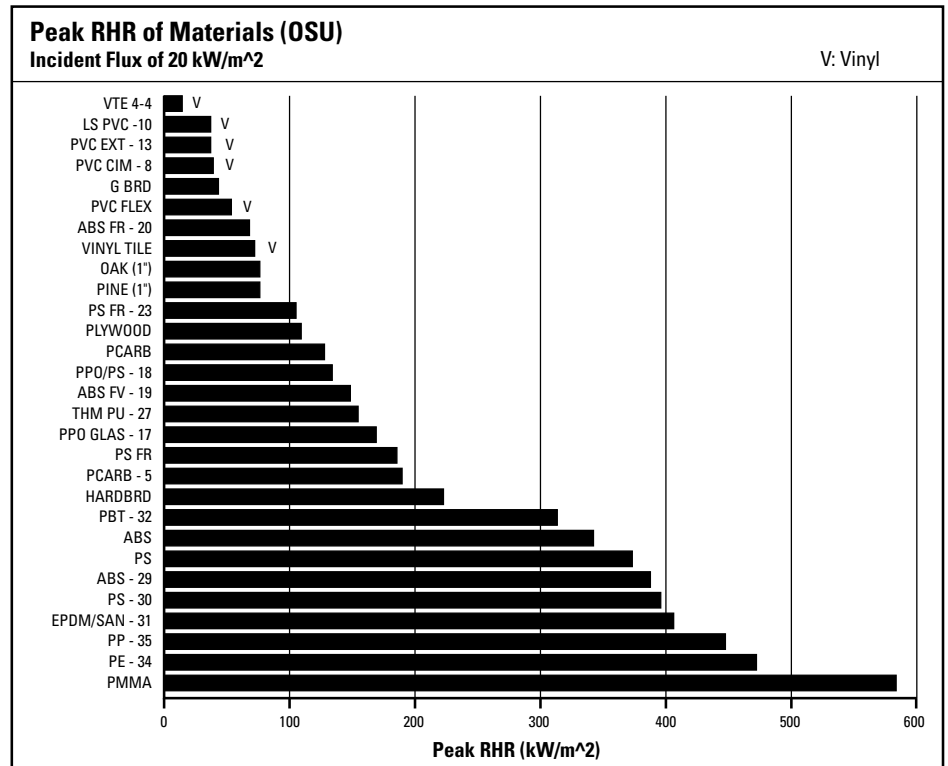
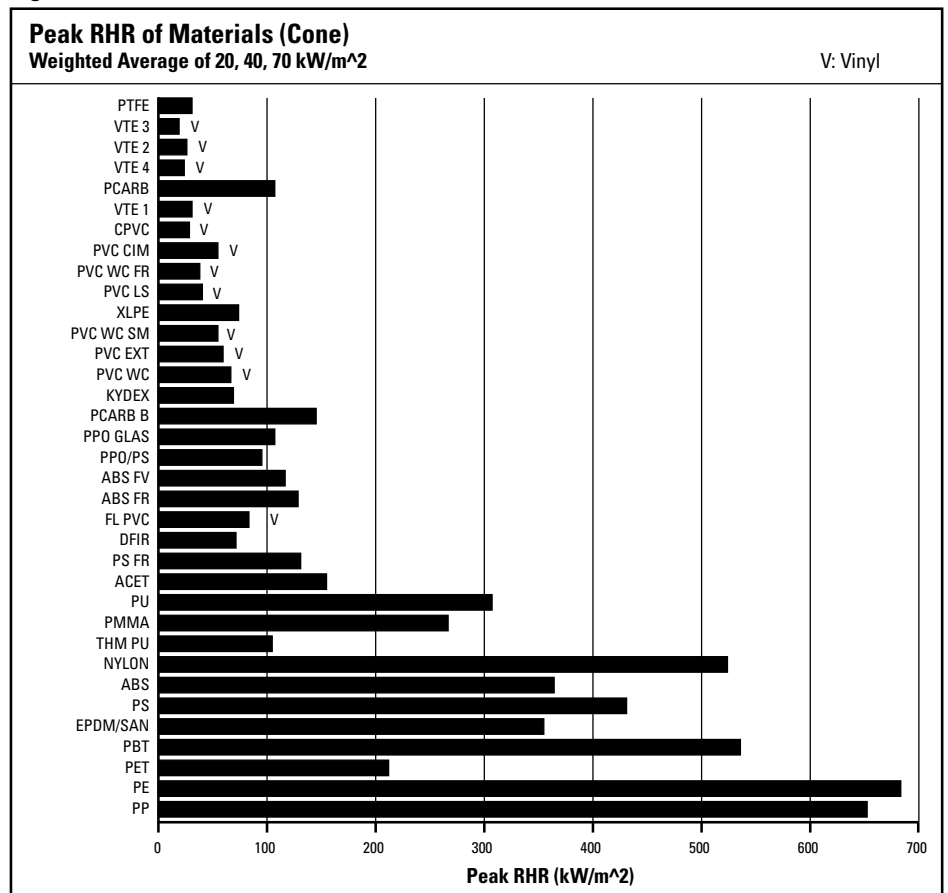


Figure 6



the most important of which are ignitability, a ratio of ignitability and heat release known as the fire performance index (for which performance improvements correspond to higher values), mass loss rate and smoke release. Moreover, results from this instrument correlate with those from full-scale fires.¹⁵⁻¹⁷

In order to get an overall view of the fire performance of materials, it is important to test materials under a variety of conditions. Therefore, test results often are carried out at a variety of incident heat fluxes. Figures 6-9 (pages 6-8) show the four most important fire properties from the cone calorimeter: peak rate of heat release; time to ignition; fire performance index; and smoke factor (a smoke hazard parameter). All of these results are weighted averages of three fluxes: 20, 40 and 70 kW/m² for the set of 35 materials in Table 1 (page 2).⁶ Figure 2 (page 4) shows a different way of presenting ignitability data for the same test, and the same materials. The peak rates of heat release at each incident flux are shown in Table 2 (page 9) (the order of the materials is based on the increasing value of the peak rate of heat release at an incident flux of 20 kW/m²). It is clear from the results shown in the Figures and in Table 2 that very few materials have lower rates of heat release than vinyl.

Modern full-scale fire test methods for products also tend to rely on rate of heat release measurements, such as those involving testing of upholstered furniture (ASTM E1537, CA TB 133), mattresses (ASTM E1590, CA TB 129), electrical cables (UL 1685), packaging systems (UL 2019), plastic display stands (UL 1975), or wall lining products (UBC 42-2, ISO 9705). In every case, whenever applicable, results indicate that products based on properly formulated PVC materials are invariably top-rated performers.

Figure 7

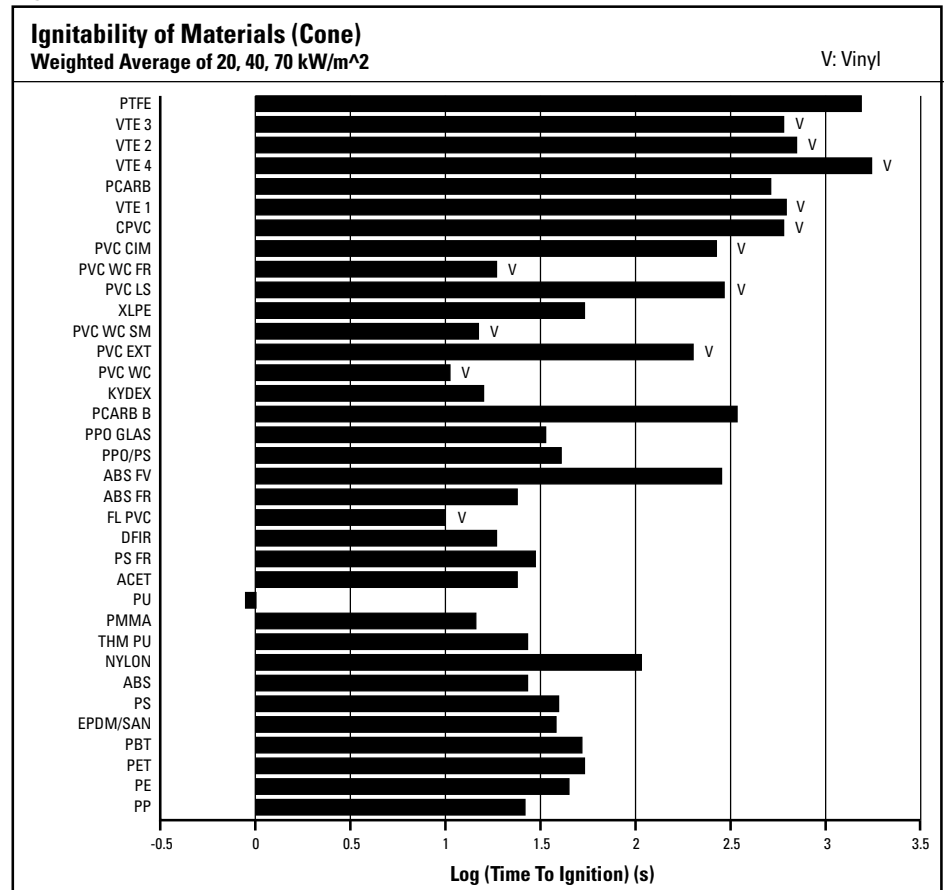
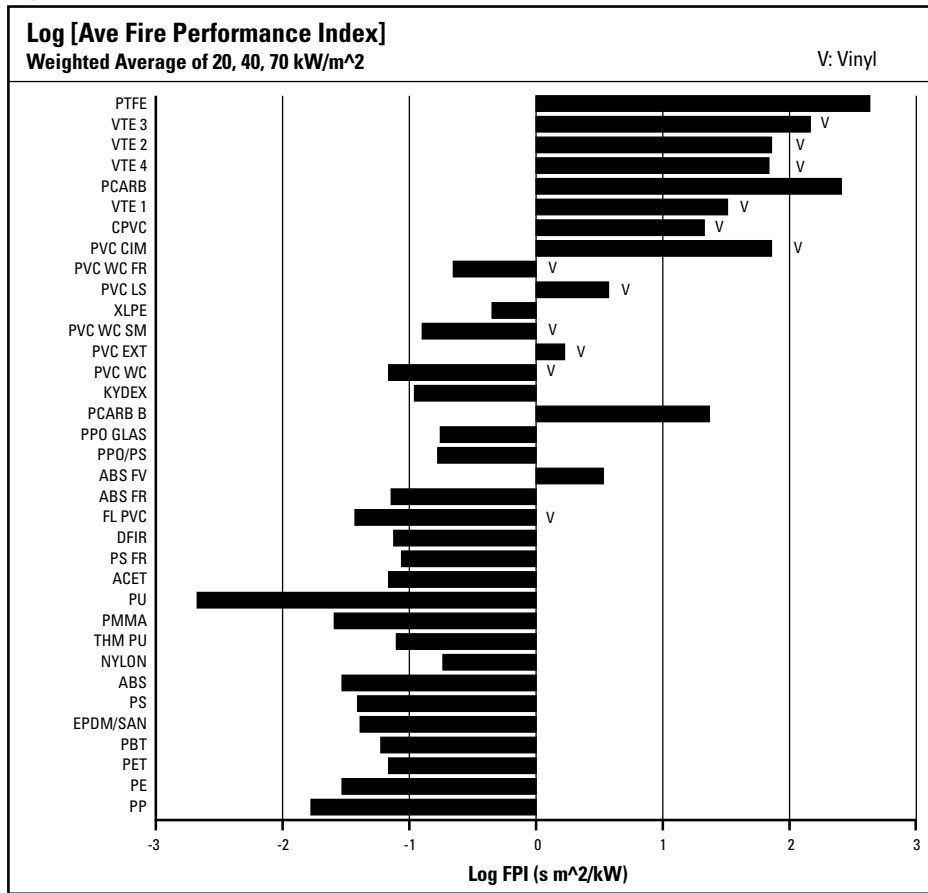


Figure 8



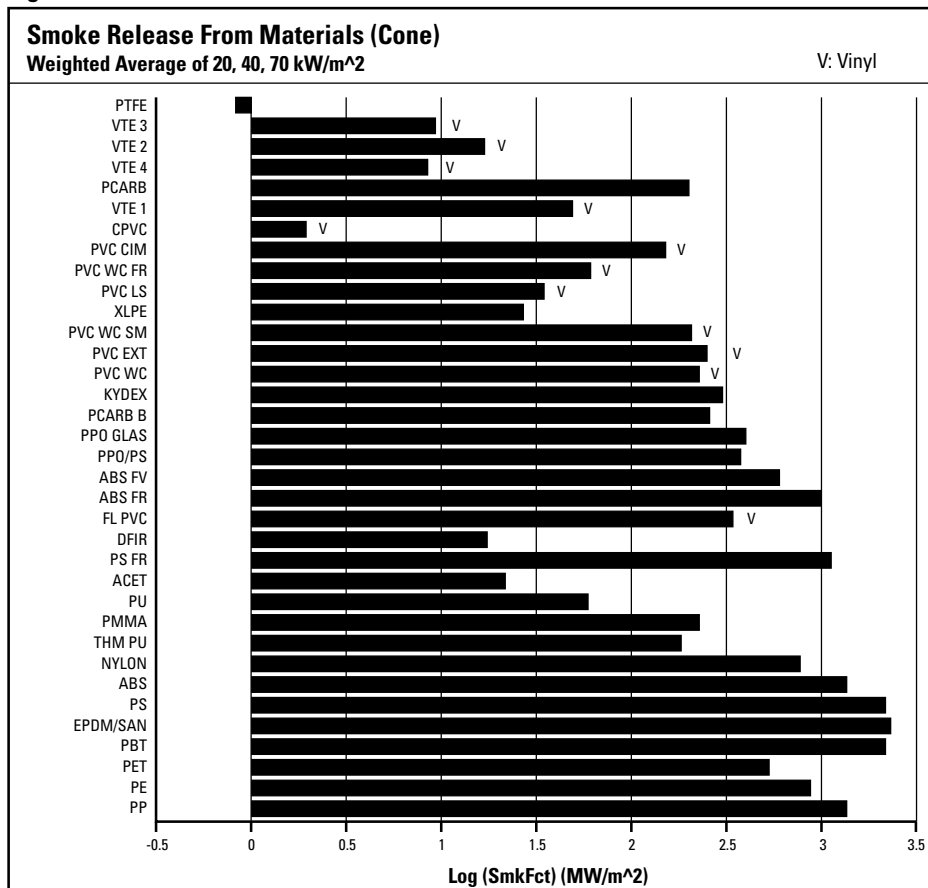
Smoke Obscuration

Decreased visibility is a serious concern in a fire, because both escape from the fire and rescue by fire fighters is more difficult. The main way in which a fire decreases visibility is by the release of smoke.

However, decreased visibility is the result of a combination of two factors: how much material is burned in the fire (which will be less if the material has better fire performance) and how much smoke is released per unit of material burned. Several empirical parameters have been proposed to compensate for incomplete sample consumption under testing conditions. One of them — known as the smoke factor — recently has been used with small-scale rate of heat release calorimeters.¹³ It combines the two aspects mentioned above: light obscuration and rate of heat release. Results are shown in Figure 9.

The most common small-scale test method for measuring smoke from burning products is the traditional smoke chamber in the vertical mode (ASTM E662). This test has now been exhaustively proven to be seriously flawed; the principal deficiencies identified are shown in Table 3.¹⁸⁻²² The most important problem is its misrep-resentation of the smoke obscuration found in real fires. Results from the smoke chamber test are shown in Figure 10 (page 10): vinyl materials can generate results covering a very broad range. A comparison of Figures 9 and 10 shows how low the smoke from PVC materials can be when they are tested in a realistic test, such as the cone calorimeter.

Figure 9



One other problem associated with the smoke chamber is the effect of sample orientation. Some materials melt or drip when exposed to flame. When samples of such materials are exposed vertically in the smoke chamber test, the molten portions escape the effect of the radiant heat source. This means that some of the material does not burn during the test (and does not give off smoke). In a real fire, the molten material will burn and generate smoke. If these dripping products are exposed horizontally, the entire sample will be consumed (see the difference in test results shown in Table 4).¹⁸ The test, therefore, measures an amount of smoke artificially lower than what would be formed in a realistic scenario. PVC, however, does not melt or drip and the test, thus, gives the same smoke production results in vertical or horizontal orientations. This is another reason why the test misrepresents the amount of smoke generated from burning PVC.

(continued, next page)

Table 2

Peak Rate of Heat Release in the Cone Calorimeter

#	Material	Pk RHR 20 kW/m ²	Pk RHR 40 kW/m ²	Pk RHR 70 kW/m ²
1	PTFE	3	13	161
2	VTE 3	4	43	70
3	VTE 2	9	64	100
4	VTE 4	14	87	66
5	PCARB	16	429	342
6	VTE 1	19	77	120
7	CPVC	25	84	93
8	PVC CIM	40	175	191
9	PVC WC FR	72	92	134
10	PVC LS	75	111	126
11	XLPE	88	192	268
12	PVC WC SM	90	142	186
13	PVC EXT	102	183	190
14	PVC WC	116	167	232
15	KYDEX	117	176	242
16	PCARB B	144	420	535
17	PPO GLAS	154	276	386
18	PPO/PS	219	265	301
19	ABS FV	224	291	409
20	ABS FR	224	402	419
21	FL PVC	233	237	252
22	DFIR	237	221	196
23	PS FR	277	334	445
24	ACET	290	360	566
25	PU	290	710	1221
26	PMMA	409	665	988
27	THM PU	424	221	319
28	NYLON	517	1313	2019
29	ABS	614	944	1311
30	PS	723	1101	1555
31	EPDM/SAN	737	956	1215
32	PBT	850	1313	1984
33	PET	881	534	616
34	PE	913	1408	2735
35	PP	1170	1509	2421

Table 3

Deficiencies in the NBS smoke chamber

- Results do not correlate with full-scale fires
- Vertical orientation leads to melt and drip
- Time dependency of results cannot be established
- No means of weighing sample during test
- Maximum incident radiant flux is 25 kW/m²
- Fire self-extinguishes if oxygen level becomes <14%
- Therefore, composites often give misleading results
- Wall losses are significant
- Soot gets deposited on optics
- Light source is polychromatic
- Rational units of m²/kg are not available

Table 4

Effect of Orientation on Smoke Density (NBS Chamber)

(maximum smoke density; flaming mode)

	Horizontal	Vertical
Paraffin Wax	228	83
Nylon	264	48
Polyethylene	286	35
Polypropylene	398	57

Figure 10

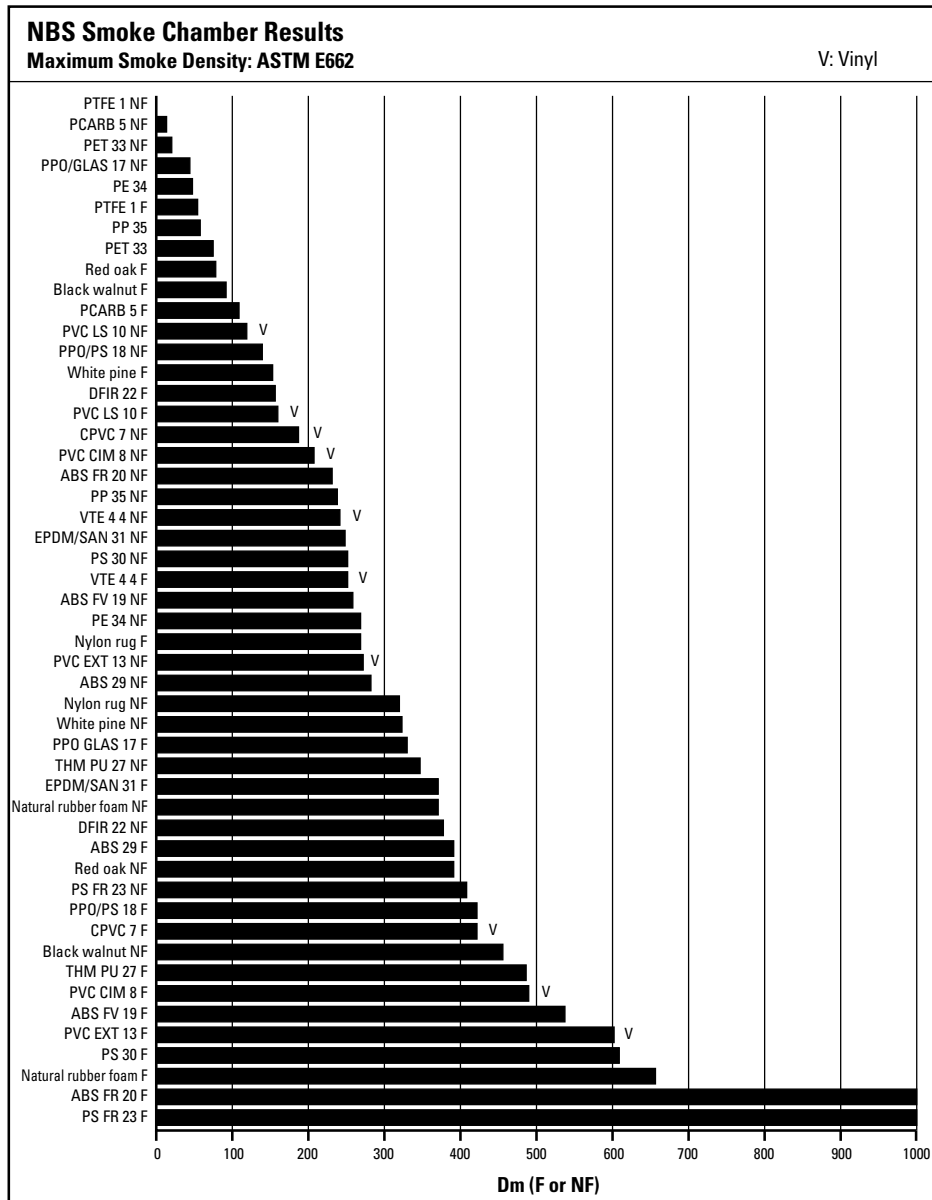


Table 5 (where products are listed in the order of increasing average rate of heat release) shows how smoke obscuration produced by the smoke chamber totally misrepresents the real smoke obscuration obtained in a full-scale room test.²³ Interestingly, the average rate of heat release in the full-scale test was a significantly better predictor of real smoke obscuration than the smoke chamber test.

Toxicity

Finally, fire hazard also is associated, at least to some extent, with the toxicity of the smoke itself. Figure 11 presents some results for the toxic potency of the smoke produced by a variety of common materials,³ as measured by the NBS cup furnace toxicity test,²⁴ and compares them with the intrinsic toxic potency of other poisons and toxic gases, as well as with textbook toxicity categories²⁵ (as the LC_{50} or the LD_{50} increase, the toxicity potency gets lower). The figure clearly puts into perspective the very small range of smoke toxicities of all organic materials (with very few exceptions). The main reason for this is that the most important toxic product in any fire is carbon monoxide (CO), which is produced by all organic materials when they burn. The Society of the Plastics Industry funded a comprehensive study of fire (and non-fire) fatalities associated with CO, which was published in 1992.²⁶ This study, examining almost 5,000 fatalities, found that the toxicity of fire atmospheres is determined almost exclusively by CO. Moreover, there is no minimum lethal CO threshold level (which was previously thought to be 50% carboxy-hemoglobin, COHb), since any blood COHb value greater than 20% can pro-

Table 5

Results of Corner Burn Room Fire Test

Material	Temp at door (°C)	Avg RHR (13 min) (kW)	Peak smoke at door (OD/m)	E 662 smoke flaming D_m
Crib only (6.3 kg)	171	39	1.7	—
Low smoke rigid PVC	178	33	6.2	94
Rigid PVC	180	38	8.5	780
Chlorinated PVC	169	39	1.4	53
FR Acrylic	322	47	22.1	435
FR ABS	748	90	44.9	900
Wood (oak panel)	558	109	35.0	106
Polycarbonate	418	172	33.0	247

duce lethality, depending on the victim. NIST has since developed a new, and definitive, smoke toxicity test, leading to the following main conclusions: ²⁷⁻³⁰

- Most fatalities occur in fires that become very big; that is, go to flashover.
- The concentrations of CO in the fire atmospheres of those flashover fires are virtually unaffected by the materials burning. The corresponding yields of CO are approximately 0.2 grams per gram mass of fuel burned, which translates to a toxic potency of 25 mg/L, for a 30 minute exposure.
- Conventional small-scale fire tests always predict concentrations of CO that are much lower than the full-scale ones. Therefore, when assessing real fires using small-scale test data, real-scale CO concentrations must be factored in by a calculated correction to obtain relevance to real flashover fires.

■ The new NIST radiant small-scale toxicity test has been well validated against toxicity in full-scale fires. However, such a validation cannot be done to a better approximation than a factor of 3.

■ This means that the toxicity of the CO inevitably present in flashover fires corresponds to a toxic potency of 8 mg/L. This thus represents the toxicity of flashover smoke.

■ Therefore, if the corrected LC_{50} (toxic potency) of the smoke of any material or product is higher than 8 mg/L (i.e. its toxicity is less than that of the CO), the material or product is of normal toxicity. Thus, its toxic potency is of no particular importance because it adds nothing to the toxicity of the atmosphere itself.

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Figure 11

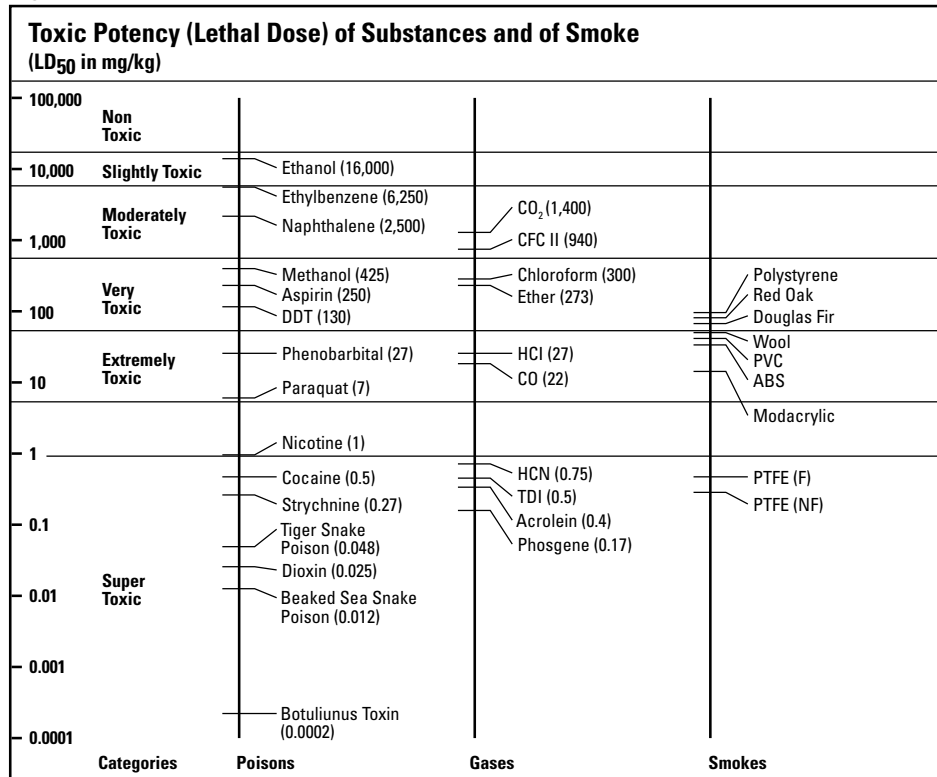


Table 6

NIST Radiant Toxicity Test Results

SPECIMEN	LC50 mg/L	Corr LC50 mg/L
ABS	17.8	11.8
Acrylic F + MELFM	9.6	6.9-8.2
Ceiling tile	30.5	21.9
Composite	20.0	not provided
Cork	ca. 40	not provided
Dg FIR	100-200	21-23
Dg FIR	56.0	21.0
FLX PU FM	52.0	18.0
MELFM	12.5	8.0
Nylon	36.7	17.0
Nylon Rug (Tr)	28.5	14.2 FED 1.2
Nylon Rug (Tr)	42.9	18.1 FED 2.0
Nylon Rug (Un)	> 41	> 16
PVC CB	36.0	not provided
PVC INS	33.4	22.7
PVC INS	29.2	14.9
PVC JK	53.1	25.9
PVC Lw HCl	146.9	28.8
PVC Md HCl	86.2	26.7
PVC PRF	26.0	16.0
PVC PRF	20-30	13-17
Particle board	120-138	not provided
Rg PU FM	22.0	14.0
Rg PU FM	20-30	14-19
Vinyl F	32.0	19.0
Vinyl F + MELFM	26.0	15.0
Vinyl FLR	82.0	not provided
VTE 1 - 6	18.2	10.9
VTE 2 - 3	45.9	16.9
VTE 3 - 2	35.8	15.4
PR FULL		8.0

Legends:

Acrylic F: Acrylic fabric; Composite: Naval composite board; Dg FIR: Fire retarded Douglas fir board; FLX PU FM: Flexible polyurethane foam; MELFM: Melamine polyurethane foam; Nylon: Nylon wire coating compound; Nylon Rug (Tr): Treated with PTFE coating; Nylon Rug (Un): Untreated; PR FULL: Predicted Carbon Monoxide Post Flashover Toxicity; PVC CB: PVC cable insulation; PVC INS: traditional PVC wire insulation compound; PVC JK: traditional PVC wire jacketing compound; PVC Lw HCl: PVC jacket compound + abundant acid retention filler; PVC Md HCl: PVC jacket compound + moderate acid retention filler; PVC PRF: Rigid PVC profile; Rg PU FM: Rigid polyurethane foam; Vinyl F: Vinyl fabric; Vinyl FLR: Vinyl flooring over plywood

Table 6 shows the results of testing a number of products (including several vinyls) with this test.³¹ Corrected toxic potency values (Corr LC₅₀) are determined taking into account the full-scale concentrations of carbon monoxide. It is very clear that all vinyl materials are *well within the normal range of toxicity*, with LC₅₀ values of over 8 mg/L. Materials are listed alphabetically in the table, to highlight the fact that their toxic potencies are not statistically significantly different.

HEALTH EFFECTS OF HYDROGEN CHLORIDE

The major combustion products given off by PVC are the same as those produced by wood or most other common materials, both natural and synthetic.^{1,3} The one product given off by PVC that is not given off by natural materials is hydrogen chloride (HCl).

Extensive studies have been done on the susceptibility of different animals to various toxic gases. These studies have found that rats are reasonable models for primates as far as exposure dose for lethality due to irritants (like HCl)³²⁻³³ or asphyxiants such as CO.³³⁻³⁴ On the other hand, the mouse has been shown to be much more sensitive to irritants (particularly HCl) than rats³⁵⁻³⁷ or baboons.³⁷⁻³⁹

Table 7 shows the lethal dose of some of the most important toxic gases present in fires, as measured in those animal species with responses most similar to those of humans — namely, rats and baboons.^{29, 32-33, 40-41} The data are listed in the order used in the N-gas model.²⁹ These data show that although the mechanisms of action of CO and HCl are totally different, their lethal doses are very similar. Moreover, HCl has an important feature related to fire hazard: a very pungent odor, detectable at a level of less than 1 ppm,⁴² while CO is odorless and narcotic. Therefore, HCl will signal people in a fire atmosphere to escape, while CO will narcotize them.

Table 7

Lethal Exposure Doses for Common Gases				
Gas	LED ppm min	Animals	ODL (a) ppm	Peak in Fire ppm
CO	192,000 (b)	rats	—	7450
CO	203,300 (c)	rats	—	7450
HCN	4,800 (d)	rats	0.58	9
HCN	6,000 (e)	rats	0.58	9
HCl	112,000-169,000 (f)	rats	0.77	280
HCl	ca. 150,000 (g)	baboons	0.77	280
HCl	111,000 (h)	rats	0.77	280
HBr	90,000 (e)	rats	NA	NA
Acrolein	2,500-5,000 (i)	baboons	0.16	98

(a) Odor detection level; Reference 42.

(b) 30 min exposure; within exposure deaths; Reference 41.

(c) 30 min exposure; within exposure deaths; Reference 29; N-gas model.

(d) 30 min exposure; within + post-exposure deaths; Reference 40.

(e) 30 min exposure; within + post-exposure deaths; References 29; N-gas model.

(f) 30-60 min exposure; post-exposure deaths; Reference 32.

(g) 5-15 min exposures; with no deaths; Reference 32.

(h) 30 min exposure; post-exposure deaths; References 29, 40; N-gas model.

(i) 5 min exposure; post-exposure deaths; Reference 33.

NA — not available

Figure 12

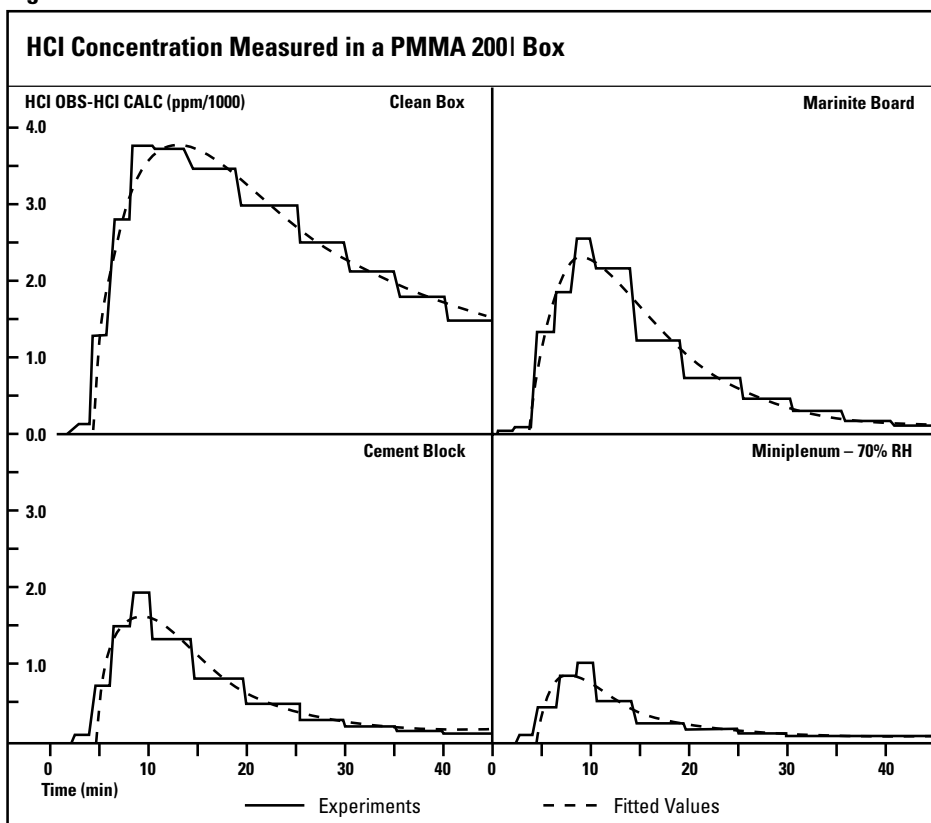


Table 7 also shows the highest concentration of these gases found in two studies involving fire fighters equipped with monitoring devices.⁴³⁻⁴⁴ Interestingly, the peak CO concentration measured when they entered burning buildings was higher than that known to cause lethality at 30 minutes. On the other hand, the peak HCl concentration found was less than one-tenth of the corresponding 30 minute lethal value.

HYDROGEN CHLORIDE DECAY

One of the reasons that HCl causes much less toxic concern than CO in fires is that the HCl “decays.” In other words, the concentration of HCl in the atmosphere decreases by reacting with humidity and with most common construction surfaces (cement block, ceiling tile, gypsum board, etc.). A series of studies was done to investigate the “lifetime” of HCl in a fire atmosphere.⁴⁵⁻⁴⁹ These studies showed that the peak HCl concentration found in a fire is much lower than would be predicted from the chlorine content of the burning material. Moreover, this peak concentration soon decreases and HCl disappears completely from the air. Figure 12 shows the HCl concentration-time pattern for several experiments where PVC wire insulation (containing the chlorine equivalent of 8,700 ppm of HCl) was electrically decomposed in the presence of various sorptive surfaces, in a small chamber. In one experiment, all internal surfaces of the chamber were lined with sorptive materials (gypsum board and ceiling tile), simulating a plenum. The peak HCl concentration found was only 10% of the theoretical concentration.

A computer fire model also was developed to assess HCl transport and decay as seen in these experiments.⁵⁰ The model, which is capable of predicting HCl decay whether it originates from PVC decomposition or from another source,⁵¹ has now been incorporated into the NIST fire hazard assessment model (HAZARD I).⁵²

(continued, next page)

A consequence of these studies is that toxicity tests, usually conducted in glass or plastic exposure chambers, may exaggerate the toxicity of PVC smoke. In the presence of these surfaces, HCl does not decay as fast as it does on the surfaces of typical building materials; therefore, in toxicity tests HCl remains present longer than in real fires. However, as Table 6 shows (page 12), even with this drawback, in adequate toxicity tests, the smoke of PVC materials is of similar toxicity to that of all other common materials.

PVC PERFORMANCE IN LARGE-SCALE TESTS

The most realistic measure of fire safety is the way materials or products behave in actual fires. Many series of large-scale experiments have been run to simulate these conditions, and PVC products have performed well in them. A couple of examples should illustrate this.

A series of tests was conducted in which a corner, floor to ceiling, was paneled with different materials, including wood and rigid PVC.²³ Table 5 (page 10) shows that the PVC (or CPVC) panels added nothing whatsoever to the total heat generated and next to nothing to the temperature measured at the door of the room, as compared to the ignition source itself (a wood crib). The smoke emitted by the burning PVC caused somewhat more smoke obscuration in the room than the crib burning alone; however, there was much less darkness than was generated when the wood panels burned (or when the other panels were burned). The wood also gave off a very considerable amount of additional heat, much hotter temperatures at the door, and a large mass of smoke particulates. The main reason that the vinyl panels generated so little heat or smoke is that most of the vinyl did not burn.

Decay of HCl was also investigated in large-scale experiments.^{45, 53-55} The first series of experiments⁴⁵ showed that, even if massive amounts of PVC are decomposed in a plenum space above a room, no HCl filters down into the room below unless driven by an air conditioning system, while other gases do accumulate in the room. Even with an air conditioning system consisting of a relatively short length of duct work, the concentrations in the room were found to be of virtually no toxicological concern. Experiments also were conducted inside a simulated 400 foot long air conditioning duct.⁵³ Here, 3,000 ppm HCl were pumped in at one end, and virtually no HCl was measured at the outlet. Results of such experiments show that high concentrations of HCl are unlikely to reach rooms other than that of fire origin and, thus, unlikely to severely affect victims in the post-flashover period.

Three fire hazard assessments and one fire risk assessment have addressed burning PVC electrical products in concealed spaces. The fire hazard assessment studies showed the low fire hazard of:

- PVC non-metallic tubing installed behind walls.⁵⁶
- PVC conduit, PVC non-metallic tubing, or PVC wire coating, installed in a plenum, with a fire starting in the room below.⁵⁷
- PVC wire coating installed in a plenum, with a fire starting in the plenum.⁵⁸

In all cases, it was found that the temperatures and concentrations of toxic gases in the room would be lethal long before there would be any effect resulting from the combustion of the PVC products.

The fire risk assessment study, by NFPA and NIST [59], involved PVC cables installed in concealed spaces in hotels. The outcome was that cables with the fire performance of PVC were unlikely to add significantly to the fire risk associated with the other materials present.

SUMMARY

- 1) The most important cause of fire deaths is the rapid release of heat from a burning material.
- 2) PVC is among the materials with the lowest rate of heat release.
- 3) PVC is more difficult to burn than most organic materials and will not continue burning unless there is a powerful external source of heat.
- 4) The smoke released by burning PVC in real fires is within the same range as that of many other materials.
- 5) The toxicity of PVC smoke is within the normal range of all currently used materials.
- 6) PVC is unusual in that, when it burns, it releases HCl, which is irritating. However, HCl odor is easily detectable (at less than 1 ppm) and HCl does not incapacitate or become dangerous until it reaches concentrations much higher than those measured in real fires. Moreover, it is CO, emitted by all organic materials when burning, which is the most serious toxicant in fires.
- 7) HCl is unique among common fire gases in that its concentration in the gas phase decays by reacting very rapidly with most construction surfaces and consequently, is not transported easily to other rooms.
- 8) PVC products are most often associated with low fire hazard and low fire risk in most scenarios.

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