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Evaluation of Toxic Potency Values for Smoke from Products and Materials

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Abstract. Many devices have been used to generate data on the toxic potency of smoke from burning products and materials. This paper critically reviews those apparatus and sorts them by the combustion conditions (related to a type of fire) producing the smoke, the specimens tested, and the animal effect measured. All the usable data were derived using rats, and the toxicological effects encountered were lethality, represented by an LC_{50} value, and incapacitation, expressed as an IC_{50} value. The data showed a wide range of toxic potency values for the products and materials tested. For those engineering applications where the mix of combustibles is unknown, generic values of smoke toxic potency were derived. Statistical analysis of the wealth of published data yielded a generic LC_{50} value of 30 g/m^3 ± 20 g/m^3 (one standard deviation) for 30 minute exposure of rats for smoke from well-ventilated combustion. There are limited data for underventilated combustion, and a value of 15 g/m^3 ± 5 g/m^3 is suggested. The mean value of the ratios of IC_{50} values to LC_{50} values is 0.50 ± 0.21, consistent with a prior review. Thus, for well-ventilated fires, a generic 30 minute IC_{50} value (for rats) would be 15 g/m^3 ± 10 g/m^3; for underventilated fires, the corresponding number would be 7 g/m^3 ± 2 g/m^3. There are some materials with appreciably lower potency values, indicating higher smoke toxicity. If materials like these are expected to comprise a large fraction of the fuel load, a lower generic value should be used.

Key words: fire, smoke, smoke toxicity, incapacitation, lethality

1. Introduction

To be able to perform the toxicity component of a fire hazard or risk analysis, the practitioner needs to know how much smoke it takes to produce undesirable effects on people. Over the past 30 years, scientists have developed numerous methods and extensive data for a variety of single component materials and commercial products. Nearly all of the studies involved combusting a small sample in a laboratory apparatus intended to simulate some type of fire; exposing laboratory animals, generally rodents, to the smoke; and characterizing the result. The typical measurement is an EC_{50}, the **c**oncentration of smoke (e.g., in g/m^3) needed to produce an **e**ffect in half (**50**%) of the animals in a given exposure time. Nearly all of the material and product data are for lethality (LC_{50}) or incapacitation (IC_{50}).

This paper examines that wealth of data, sorts it by the combustion conditions (related to a type of fire) producing the smoke, the specimens tested, and the animal effect measured. We then update the generic values to use in fire hazard analysis when the composition of the mix of combustibles is unknown. This is valuable in both building design and fire

reconstruction. A key component of this evaluation is the assignment of a confidence limits to the derived toxic potency values.

2. Compilation of Toxicological Data

The search for lethal and sublethal toxic potency data for materials and products involved on-line library searches for pertinent books, journal articles, proceedings, and technical reports. The primary on-line database used for this literature search was the Fire Research Information Services (FRIS) maintained by the Building and Fire Research Laboratory at NIST. Other on-line library searches were performed using TOXLINE and MEDLINE (maintained by the National Institutes of Health) and the Office of Pollution Prevention and Toxic Substance Library (maintained by the Environmental Protection Agency). In addition, technical experts involved in the project were asked for unpublished data and other published data that were not readily available otherwise. Table 1 presents a summary of the literature search, including the number of citations found. A complete list of references obtained is presented as a separate list in the Appendix to this paper.

TABLE 1
Sources of Toxic Potency Data

Source	Number of Citations
Annual Review of Pharmacology and Toxicology	1
ASTM/ISO Publications	4
Environmental Health Perspectives	2
Journal of American Industrial Hygiene Association	2
Journal of Archives of Environmental Health	3
Journal of Combustion Science and Technology	1
Journal of Combustion Toxicology	39
Journal of Consumer Product Flammability	1
Journal of Fire and Flammability	1
Journal of Fire and Materials	18
Journal of Fire Safety	2
Journal of Fire Sciences	23
Journal of Fire Technology	4
Journal of Forensic Materials and Pathology	1
Journal of Fundamental and Applied Toxicology	3
Journal of Industrial Hygiene and Occupational Medicine	1
Journal of Macromolecular Science-Chemistry	1
Journal of Medical Science and Law	1
Journal of Science	2
Journal of Testing and Evaluation	1
Journal of the American College of Toxicology	2
Journal of Toxicology	1
Journal of Toxicology and Applied Pharmacology	3
Journal Zeitschrift Fur Rechtsmedizin	1
NIST Publication, Technical Notes, and Reports	23
Proceedings	38
Other Reports	25
Toxicology Letters	1

3. Data Organization

The literature review identified different types of toxicity test methods ranging from laboratory small-scale tests to full-scale tests. To enable analysis of the full set of toxic potency data, the results from the various test methods were categorized by:

- Combustion/pyrolysis condition
- Material/product examined
- Type of test animal
- Toxicological endpoint

3.1. Combustion/pyrolysis Conditions

There is a small number of types of thermal decomposition in fires:

- oxidative pyrolysis (non-flaming), typical of products being heated without bursting into flames themselves;
- well-ventilated flaming combustion, typical of pre-flashover fires;
- ventilation-limited combustion, typical of post-flashover fires or fires in nominally airtight spaces; and
- smoldering, or self-sustaining, non-flaming combustion.

The purpose of a small-scale toxic potency measurement is to obtain data from a small material or product sample that is germane to some particular set of realistic fires. In this section, we assess the combustion conditions in the 12 small-scale apparatus for which data are available. Each apparatus will then be aligned with one or more of these realistic fire conditions.

As shown in Table 2, the combustors in the small-scale apparatus fall into three types: cup furnace, radiant heater, and tube furnace. While measurements of combustion gases have been made in a number of other small-scale devices, these 12 are the only ones for which animal exposure data have been reported.

TABLE 2
Small-Scale Toxicity Test Methods

Method Group	Individual Test
Cup Furnace Methods	NBS Cup Furnace
	Dow Chemical Company Method
	University of Utah Method
Radiant Heat Methods	Weyerhaeuser Method
	NIST/SwRI Method
Tube Furnace Methods	UPITT Method
	DIN 53 436 Method
	Federal Aviation Administration Method
	University of San Francisco Method
	University of Michigan Method
	University of Tennessee Method
	NASA/JSC Method

In the cup furnace methods, the sample is placed in an open-top quartz beaker that is set in a furnace. The bottom and lower portions of the beaker are heated to a pre-set *temperature*, which is generally picked to be above or below the autoignition temperature (AIT) of the pyrolysis vapors. The oxidative pyrolysis or combustion vapors rise and flow out the top of the beaker into the box in which the animals are exposed. The box is closed, so the test animals experience the accumulated combustion products, some of which diminish in concentration due to adsorption on the chamber walls. Combustion tests have shown that the lethal toxic potency of pyrolysis smoke is at a maximum at furnace temperatures near the AIT. Thus, in most non-flaming cup furnace tests, the furnace temperatures are kept at approximately 25°C below the predetermined AIT to ensure conservative toxic potency values. For flaming tests, the oxygen concentration remains high enough that the vitiation does not obscure the toxicity of the smoke. Natural buoyancy tends to draw sufficient "fresh" air to the sample so that the combustion product profile for flaming samples is indicative of fuel-limited combustion. Thus, cup furnace data are typically used to represent well-ventilated flaming combustion and oxidative pyrolysis.

In the radiant heat devices, the sample is exposed to a defined *heat flux*. The irradiance is generally sufficiently high (e.g., 50 kW/m^2) and abetted by an ignition device to ensure flaming for all but the most resistive products or low enough (e.g., 25 kW/m^2) to preclude flaming of all but the most readily ignitable smoke. The combustion products remain in a closed compartment, and the animals are exposed to the time-integrated accumulation of smoke. The smoke is indicative of well-ventilated burning. [It has also been shown that the data can be used to calculate the toxic potency of smoke from post-flashover burning by enhancing the carbon monoxide yield to that level observed in post-flashover fires [1]. No corrections were made for changes in the yields of other toxicants.]

Like the cup furnaces, the combustion environment in tube furnaces is defined by *temperature*. This can be uniform, a fixed value, or a time-variant (ramped) range. The sample lies within a long horizontal tube, much of which lies inside the furnace. In some devices the sample is stationary, in others it is moved through the heated zone of the tube, replenishing the supply of fresh fuel. In the tube furnace experiments reviewed there is no mention of the ignition of smoke in the combustion device. Tube furnaces are open systems (except for the University of San Francisco Method), with the air flowing to the sample and through the combustion zone. The animals are thus exposed to a time-varying smoke composition. The exception was the DIN test, in which both the sample and air were introduced at constant rates.

None of these devices can accurately replicate a true smoldering combustion. Achievement of the low heat losses needed for this self-sustained process requires a physically larger sample than that which can be accommodated by bench-scale devices.

With the exception of the radiant heat methods, these furnaces are limited in their ability to evaluate test specimens representative of configured products (e.g., mattresses or chairs). Depending on the end product design, this may have a significant effect on the combustion of the specimen in the apparatus and on the measured toxic potency.

In most of the cited literature, the combustion conditions represented in a test were either vague or completely undefined. Thus, in order to make use of as large a fraction of the accumulated data as possible, we attempted our own assignments. This was achieved as

follows:

- For those tests in which the sample flamed, the ratio of the concentrations or yields of carbon dioxide (CO_2) and carbon monoxide (CO) was reported, and the [CO_2]/[CO] ratio was eight or greater, the combustion mode was considered well-ventilated. For tests in which the [CO_2]/[CO] ratio was less than 8, the combustion mode was considered ventilation-limited. In cases of flaming combustion where the concentrations or yields were not reported, the toxicity data were most often set aside. [It was recognized that a flame-resistant material could yield a low [CO_2]/[CO] ratio even under well-ventilated conditions.]
- In some flaming experiments, the nature of the sample being burned had a strong influence on the ventilation. For example, in cup furnace experiments with low-density samples (with a corresponding large size relative to the beaker), oxygen access to the burning site is expected to be impeded, and the combustion would tend toward ventilation-limited. In experiments with high-density samples (with a corresponding small size relative to the beaker), oxygen levels are expected to be higher.
- In many of the tube furnace tests, it was not reported whether the sample flamed and, if so, for what portion of the test. To determine retroactively whether flaming was likely, we compared the reported furnace temperature with an AIT for the material being tested. [The source of these temperatures was the cup furnace literature, in which the AIT of the test material was measured in order to assure flaming or non-flaming combustion. Knowing that, e.g., all polystyrenes do not have the same AIT, we nonetheless used the cup furnace AIT value as indicative, for lack of better information.] If the furnace temperature was at least 25°C above the AIT, we considered the combustion to be flaming. Where the furnace temperature was at least 25°C below the AIT, the combustion was labeled non-flaming (oxidative pyrolysis). When the furnace temperature was within 10°C or so of the AIT, the data were set aside. In some cases, CO and CO_2 concentration or yield data were reported. This information was also used to make the determination of combustion conditions.

Reports on many of the tube furnace articles (specifically, the descriptions for the combustion oven experiments at the University of Pittsburgh, University of Michigan, University of Tennessee, and NASA/Johnson Space Center) did not provide sufficient information to establish the fire conditions being represented. Furthermore, in some of the tests, spontaneous flaming occurred in otherwise non-flaming experiments. In either of these cases, the data generated from these experiments were set aside since they could not be directly related to one of the three combustion conditions. Table 3 summarizes the relationships we found between toxicity methods and fire conditions.

TABLE 3
Fire Conditions Replicated by Principal Toxicity Test Methods

	Fire Conditions			
Method Type	**Well-Ventilated Flaming**	**Ventilation-Limited Flaming**	**Oxidative Pyrolysis**	**Mixed or Unknown**
Cup Furnace	X	X	X	
Radiant Furnace	X	X		
Tube Furnace		X		X

TABLE 4
Material and Product Groupings

Acrylic Fibers	Polyesters
Acrylonitrile butadiene styrenes	Polyester fabric/polyurethane foam
Bismaleimide	Polyethylenes
Carpet (modacrylic/acrylic)	Polyphenylene oxides
Carpet foam (with nylon)	Polyphenylene sulfides
Carpet jute backing (with nylon)	Polyphenylsulfones
Chlorofluoropolymers	Polystyrene foams
Epoxy	Polyurethanes, Flexible
Fabric, vinyl	Polyurethanes, Rigid
Fluoropolymers (data set A)	Polyvinyl chlorides, Plasticized
Fluoropolymers (data set B)	Polyvinyl chlorides
Modacrylics	Urea formaldehydes
Phenolic resins	Wire insulation, NFR cross-linked EVA
Polyacrylonitriles	Wire, PTFE coaxial
Polyamides	Wire, THHN with nylon-PVC jacket
Polycarbonates	Woods

3.2. Materials and Products Examined

The citations included toxic potency data for a wide range of single component materials and for a limited number of products. Very few references provided the detailed composition of the test specimens. Typically, the sources provided the generic polymer and whether or not the material or product was fire retarded. The type or formulation of the retardant(s) was often lacking. Given the vagueness of such details, we grouped the tested items into generic classes of materials and products, which are presented in Table 4.

The fluoropolymers were separated into two distinct sets (A and B) because, as will be seen below, the lethality values fell into two groups that were two orders of magnitude apart. Fluoropolymer data set B is shown only for completeness. Real-scale experiments have shown that these very high toxic potencies are not realized when hydrogen-containing combustibles are also involved in the fire [2]. Thus, this set of values has not been used in the analyses that follow. The fluoropolymers were the only product group for which the data warranted this separation.

3.3. Test Animals

The test subjects used in all the listed toxicity test reports were rats and mice. As noted above, the data from the two methods that used mice (University of Pittsburgh and University of San Francisco devices) were not used in this analysis because of the indeterminate flame conditions in those apparatus. Thus, the data evaluated below are based solely on rats as the test subject. We do not differentiate among strains of rats used in the experiments.

The number of test subjects and their exposure to the smoke also varied among the tests. In the cup furnace and radiant heat methods, individual rats were positioned such that only their heads were exposed to the smoke. In the tube furnace methods, the animals were exposed as either individuals in a head-only position or as groups in whole-body positions. In this study, the toxicity data are evaluated only in terms of the species used, not the number or position of the subject.

TABLE 5
Toxicological Effects Measured Using Types of Test Methods

	Toxicological Effect			
Method Type	**LC_{50}**	**LL_{50}**	**IC_{50}**	**Other**
Cup Furnace	X		X	
Radiant Heat	X			
Tube Furnace	X	X		

3.4. Toxicological Endpoint

The toxicological effects encountered during the literature review were lethality and incapacitation. There were no data found on other sublethal effects. Table 5 presents a matrix of the reported lethality endpoints, grouped by the toxicity methods.

Smoke lethality was expressed as either a lethal concentration or lethal loading. The lethal concentration, which is expressed as an LC_{50}value, is the mass loading or mass combusted of a specimen per unit chamber volume (smoke concentration, in g/m^3 or mg/l) that kills 50% of the test animals during a fixed exposure time and perhaps a post-exposure observation period. The lethal loading, which is expressed as an LL_{50}value, is defined as the mass loading (g) in the furnace that kills 50% of the test animals as a result of a fixed exposure time. Unless the latter could be converted to a concentration, the data from the tests could not be used in hazard analyses and were not included in analyses here.

Sublethal endpoints are typically expressed as either an effect concentration or a time-to-effect. Time-to-effect measurements provide information on the rapidity of toxic action rather than on toxic potency. Since the purpose of this study is to generate dose-response information, the time-to-effect endpoints are not included in this evaluation. Thus, the sublethal effect data compiled here are incapacitating concentrations (expressed as an IC_{50} value), which are defined as the mass loading or mass combusted per unit chamber volume (smoke concentration, in g/m^3 or mg/l) that causes incapacitation of 50% of the test animals during a fixed exposure time and perhaps a post-exposure observation period. While a variety of pure gas exposure studies have used various techniques for measuring incapacitation, all the articles collected for this project used the hind-leg flexion conditioned avoidance response test [3].

Among the large number of methods and laboratories, there was variation in the length of time the animals were exposed to the smoke. Table 6 presents a summary of the different exposure times reported for the toxicity test methods reviewed. Most of the data are for an exposure time of 30 min with a post-exposure observation period ranging from 10 min to 14 days. In some experiments, there were no post-exposure observation periods. For the tube furnace methods (specifically the combustion oven devices including the University of Pittsburgh, University of Michigan, University of Tennessee, and NASA/JSC methods), the exposure times were (10, 30, 60, 140, or 240) min, with post-exposure observation periods of 5 min or 10 min, or 7 days or 14 days. However, since as noted above, the data from these devices did not meet other criteria, all the LC_{50} and IC_{50} values in the following discussions and analyses are for 30 min exposures.

TABLE 6
Exposure Times for Principle Test Methods Reviewed

	Exposure Time (min)				
Method Type	**10**	**30**	**60**	**140**	**240**
Cup Furnace		X			
Radiant Heat		X			
Tube Furnace	X	X	X	X	X

For the evaluation in this paper, we used only toxic potency data developed from tests that included a post-exposure period. In the reported tests, incapacitation (from a combination of narcotic and irritant effects) typically occurred during an animal's exposure to the smoke. Lethality, on the other hand, occurred either during the exposure to smoke or during the post-exposure period. The relationship between these post-exposure effects in rats and the effects on people during a fire remains to be assessed. However, we felt it more appropriate to use the more conservative toxic potency values (i.e., those that include a post-exposure period) for the current purpose. Alternative analyses can be performed as desired using the information assembled in the Appendix.

4. Evaluation of Toxicological Data

The usable sets of LC_{50} and IC_{50} data are shown in Tables 7 and 8, respectively. As noted above, all data are for rats exposed to the smoke for 30 min and then observed for some post-exposure period. Each cell contains a median value for the experimental determinations and 95% confidence limits; the number of determinations is also shown.

4.1. Estimation of Confidence Intervals

The original toxic potency data, compiled in the Appendix, is of varying quality. Some LC_{50} and IC_{50} values have corresponding 95% confidence intervals and some do not. In addition, the numbers of individual experiments (sample sizes) used to calculate these confidence intervals are not always available. This varying quality of the individual data presents some challenge to appraising the aggregated set of toxicological values.

To estimate the 95% confidence intervals for each combination of material, combustion condition, and toxicological endpoint, the available information was grouped into three cases:

1. For some combinations, each of the (one or more) reported toxic potency values includes a 95 % confidence interval. The standard uncertainties were derived from the confidence intervals. A hierarchical Bayesian model [4], implemented with the BUGS software [5], was then used to obtain a consensus LC_{50} or IC_{50} value and its 95% confidence interval. These results are indicated in the cells of Tables 7 and 8.
2. For other such combinations, some of the reported toxic potency values include 95% confidence intervals and some do not. To estimate 95% confidence intervals for the latter, we assumed that their precision was similar to that of the former. For a given

TABLE 7
Estimated Mean LC_{50} Values (g/m^3) (confidence limits, g/m^3) (sample size)

Material	Well-Ventilated Combustion	Ventilation-Limited Combustion	Oxidative Pyrolysis
Acrylonitrile butadiene styrenes	**17.7 (14.8,20.7) 4		**32.3 (28.2,35.3) 4
Bismaleimide	14.9 (12.8,17.2) 1		41.9 (38.8,45.1) 1
Carpet foam (with nylon)	*108 (47,138) 1		*68.0 (36.0,81.1) 1
Carpet jute backing (with nylon)	*57.0 (35.5,69.4) 1		*90.0 (53.7,99.2) 1
Chlorofluoropolymers	**17.6 (10.2,33.6) 2		**24.6 (17.7,32.1) 2
Epoxy	*7.3 (1.5,15.8) 1		11.0 (8.9,13.1) 1
Fabric, Vinyl	32.0 (28.0, 37.0) 1	19.0 (17.7, 20.9) 1	
Fluoropolymers (data set A)	**27.4 (19.0,35.8) 4		**25.4 (17.8,33.5) 4
Fluoropolymers (data set B)	**0.12 (0.04, 0.93) 6		**0.37 (0.10, 0.96) 4
Modacrylics	**5.6 (4.0,7.2) 3		6.5 (4.6,8.3) 4
Phenolic resin	8.4 (7.3,9.5) 1		5.9 (4.8,7.0) 1
Polyacrylonitriles	**40.2 (37.0,43.4) 2		
Polyesters	**35.6 (31.4,39.4) 4	**40.5 (18.7,56.2) 1	**37.8 (29.2,46.9) 3
Polyester fabric/polyurethane foam	*42.0 (30.9,55.9) 1		*30.0 (25.2,42.2) 1
Polyethylenes	**36.8 (30.1,43.0) 3		5.8 (3.5,8.9) 2
Polyphenylene oxide	*31.5 (22.3,35.6) 1	*24.0 (17.8,36.5) 1	
Polyphenylsulfones	27.2 (20.6,33.7) 4		18.0 (13.1,23.1) 4
Polystyrene foams	**35.6 (33.4,37.9) 7		*43.5 (41.1,45.6) 6
Polyurethanes, Flexible	**35.4 (31.8,38.9) 18	**20.4 (16.0,24.9) 4	**29.9 (26.5,33.0) 15
Polyurethanes, Rigid	**13.0 (11.6,14.5) 12	14.0 (13.4,14.5) 1	**29.5 (25.2,33.9) 10
Polyvinyl chlorides, Plasticized	**26.2 (20.1,33.2) 3	16.0 (13.7, 17.5) 1	**22.9 (11.8,34.4) 3
Polyvinyl chlorides	**20.0 (16.8,23.2) 8		**16.1 (13.2,19.3) 5
Strandboard			47.0 (37.7,57.3) 1
Tempered hardwood	58.1 (40.8,67.0) 1		86.5 (79.4,93.0) 1
Urea Formaldehyde	11.2 (10.4, 12.0) 1		1.20 (1.10,1.30) 1
Wire, PTFE coaxial wire	*9.6 (5.7,25.7) 1		*125 (8.00,25.2) 1
Wire, THHN wire w/ nylon-PVC	55.0 (44.0,66.0) 1		**8 (88.6, 107.2) 1
Wire insulation, NFR crosslinked EVA	51.0 (40.8,61.2) 1		
Wire insulation, FR crosslinked EVA		*25.0 (18.9,33.5) 1	
Woods	**40.2 (34.8,45.1) 14		**36.1 (30.8,41.0) 14
Estimated mean	30.1	24.4	27.8
95% Confidence Interval	(5.1,58.0)	(15.8,40.3)	(1.6,78.4)

*Confidence Interval constructed as described in Section 4.1, case 3.
**Confidence Interval constructed as described in Section 4.1, case 2.

test material, we compiled the results from studies of the same material and combustion mode for which 95% confidence intervals were available, translated each interval into a percentage of the mean value, and assigned the mean value of those percentages to the datum for which no confidence interval was available. The now-complete set of data was then fed into the same model used in case 1. These cells in Tables 7 and 8 are marked with a double asterisk.

3. For the third group of such combinations, there are no studies with reported confidence intervals, but confidence intervals are available for the same generic material under a different combustion method. We assumed the accuracy of results is similar across

TABLE 8
Estimated Mean IC_{50} Values (g/m^3) (confidence limits, g/m^3) (sample size)

Material	Well-Ventilated Flaming	Oxidative Pyrolysis
Acrylonitrile butadiene styrene	**11.2 (6.1,15.8) 3	**15.4 (7.9,22.0) 3
Bismaleimide	6.8 (5.4,8.3) 1	20.1 (16.3,24.0) 1
Epoxy	6.2 (5.2,7.3) 1	4.1 (3.3,5.0) 1
Fluoropolymers (data set A)	**14.8 (6.9,21.9) 2	**14.9 (7.9,19.9) 2
Fluoropolymers (data set B)	**0.55 (0.10,1.01) 2	**0.68 (0.31,1.49) 1
Modacrylic	**3.0 (0.7,6.0) 2	3.3 (0.2,6.7) 3
Phenolic resin	2.0 (1.6,2.4) 2	*1.5 (1.2,1.8) 1
Polyphenylsulfone	**15.3 (10.0,19.8) 3	**11.6 (6.6,16.8) 3
Polystyrene foam	**20.0 (15.0,24.9) 5	**33.4 (22.4,39.8) 5
Polyurethane, Flexible	**17.4 (10.1,25.2) 8	**15.5 (7.6,22.7) 8
Polyurethane, Rigid	**5.4 (4.0,6.8) 8	**9.5 (5.3,14.00) 8
Polyvinyl chloride, Plasticized	**7.1 (4.9,9.3) 1	**3.4 (2.8,4.0) 1
Polyvinyl chloride	**12.2 (8.6,16.3) 4	**13.5 (6.1,20.4) 4
Urea Formaldehyde	7.4 (6.5,8.3) 1	0.7 (0.6,0.8) 1
Wood	**21.4 (17.5,25.3) 10	**15.3 (12.2,18.5) 12
Estimated mean	11.2	11.5
95% Confidence Interval	(1.4,24.0)	(1.1,25.0)

*Confidence Interval constructed as described in Section 4.1, case 3.
**Confidence Interval constructed as described in Section 4.1, case 2.

combustion methods and used an approach analogous to that described for set 2.These cells in Tables 7 and 8 are marked with a single asterisk.

It appears that, although the data were reported in the source articles to as many as three significant figures, the repeatability of these results is probably not better than ±30%.

It is important to note, however, that the gas yields and toxic potency data from only one of these 12 bench-scale devices (the radiant furnace now used in NFPA 269 and ASTM E1678) has been validated against room-scale experiments [1]. The accuracy of the other bench-scale data is undetermined.

4.2. Generic Toxic Potency Values

A quick scan of Tables 7 and 8 shows a wide range of toxic potencies. A hazard or risk analysis for a known set of combustibles should use toxic potency values appropriate to those products, the expected combustion conditions, and the proper toxicological effect.

In many cases, however, there is a mix of combustibles whose composition and time of entry into the fire are not well known. In those instances, generic values of toxic potency are desirable, ones that can be held constant throughout the analysis.

The last two rows of Tables 7 and 8 contain estimated mean LC_{50} or IC_{50} values for each of the combustion conditions and the estimated 95% confidence interval for the median value obtained using the following Monte Carlo method. For each combustion condition (column), a random sample of size 1500 was drawn from the materials in that column. At each draw, each material present in the column for that combustion condition had an equal probability of being selected. Then, for that draw a random value was picked from a presumed normal

distribution with mean and standard deviation given by the entry for that material and combustion condition. For example, suppose that for well-ventilated combustion the first draw chose "epoxy." The random value would then be from a normal distribution with mean 7.3 and standard deviation of 4.1. These 1500 points were then averaged to obtain an estimated overall mean LC_{50} or IC_{50} value. The 95% confidence interval was determined assuming that the 1500 points represented a normal distribution.

4.3. Comparison among Combustion Conditions

Since the combustion conditions and the products on fire vary within a fire compartment and evolve as the fire grows and ebbs, it is useful to assess the accuracy of using a single toxic potency value in engineering calculations. The following examines lethality data for two pairs of fire conditions and incapacitation for one pair.

Lethality: well-ventilated flaming and ventilation-limited combustion. These data sets in Table 7 were compared in two ways:

- The first generalized approach was a comparison of the mean LC_{50} values for both conditions, including all materials (except fluoropolymers B) in the data set. There is a wide range of LC_{50} values and modest differences between the mean values for the two columns. The broad 95% confidence limits around the two mean values suggest that any difference between the lethal toxic potencies of the smoke generated under these two sets of conditions is not resolvable.

  Examination of the data in the column labeled "Ventilation-limited Combustion" suggests that some of these numbers may be too high for use in evaluating post-flashover fires. Carbon monoxide yields from underventilated flaming fires are generally distinctly higher, so LC_{50} values should fall relative to the same products burning with ample ventilation. Further, the LC_{50} value for post-flashover smoke is about 25 g/m^3 if the only toxicants it contains are CO_2 and CO [1]. The presence of additional toxicants will reduce this. There are six materials with entries in these two columns. Five of these appear to behave as expected. The underventilated LC_{50} value for the polyester sample is above 25 g/m^3. However, even were this "Ventilation-limited" value reflective of the two (above) guidelines for underventilated fires, the mean value for this column would not likely be sufficiently lower that the two confidence intervals would not overlap.
- The second approach was a comparison of LC_{50} values on a material-by-material basis. For three of the six combustibles the 95% confidence intervals overlap. In one of those cases, the ventilation-limited value is lower; in the other two, the reverse is true. This does not constitute strong evidence for a fundamental difference between the data in the two columns.

Thus, while there is reason to expect that the lethal toxic potency of smoke from underventilated fires would be higher than for well-ventilated fires of the same combustibles, the published data do not present sufficient evidence to resolve such a difference. This comparison is especially compromised by the small data set for ventilation-limited combustion.

Lethality: flaming combustion and oxidative pyrolysis. Comparison of the mean LC_{50} values and 95% confidence intervals for the three combustion conditions reveals no statistical difference between them; the mean values are very close and the confidence intervals for

well-ventilated combustion and ventilation-limited combustion are fully contained within those for oxidative pyrolysis.

Incapacitation: well-ventilated flaming combustion and oxidative pyrolysis. Recall there were no reported IC_{50} values for ventilation-limited flaming conditions. The mean values of the two columns are nearly identical and the 95% confidence intervals are essentially congruent. For about half the materials the individual confidence intervals show considerable overlap. The remaining half are split between the flaming value being higher and the reverse. Thus, any possible difference in incapacitating toxic potency between the smoke from these combustion modes is not discernible.

4.4. Comparison between Toxicological Effects

Kaplan and Hartzell [6] had reviewed the literature and found that for exposures to narcotic gases (CO or HCN), the concentrations that caused incapacitation (measured by a variety of devices) were one third to one half of those that resulted in the death of various animal species.

For the smoke data collected here, the mean value of the ratios of IC_{50} values to LC_{50} values and the standard deviation are 0.50 and 0.21, respectively. There is no significant difference between well-ventilated flaming combustion and oxidative pyrolysis.

These results are consistent with the Kaplan and Hartzell ratio, given the uncertainty in the measurements. In addition, since there is a broad set of expected toxic gases (e.g., CO, halogen acid gases, HCN, partially-oxidized organics) in the smoke from this group of materials, it is not unreasonable to generalize that an incapacitating exposure is about half that of a lethal exposure.

4.5. Comparison among Materials and Products

As noted above, it would benefit engineering calculations if there were a single LC_{50} (and thus IC_{50}) value to be used when the mixture of combustibles in a fire is unknown. In HAZARD I [8], the suggested values are 30 g/m^3 and 10 g/m^3, respectively (for 30 min exposures of rats to smoke).

The wide range of toxic potency values in Tables 7 and 8 strongly suggests that any such generic value must be used with caution. However, should such a number be needed, a generic value (from column 2 in Table 7) for lethal toxic potency (30 min rat exposure) in well-ventilated fires (even if much of the smoke were generated from pyrolysis rather than flaming) would be 30 g/m^3 $\pm$ 20 g/m^3. For underventilated fires, the situation is less clear. The data compiled here (column 3 of Table 7) and the value calculated for CO and CO_2 only [1] suggest an upper limit of 25 g/m^3. Data derived from the NFPA 269 radiant furnace [1] suggest a value of 15 g/m^3 $\pm$ 5 g/m^3. [The uncertainty in the underventilated value is much lower because the toxic potency is dominated by the large amount of CO produced during underventilated burning. This CO yield is controlled by the shortage of oxygen more than differences in the fuel chemistry [7]]. The above numbers have been rounded to convey the proper number of significant figures.

From the results in Section 4.4, for well-ventilated fires, a generic 30 min IC_{50} value (for rats) would be 15 g/m^3 $\pm$ 10 g/m^3. For underventilated fires, the corresponding number would be 7 g/m^3 $\pm$ 2 g/m^3.

In all cases, it is important to note that there are some materials with appreciably lower potency values, indicating higher smoke toxicity. If materials like these are expected to comprise a large fraction of the fuel load, a lower generic value should be used. Examples of lower numbers can be found in Tables 7 and 8, but prudence suggests obtaining measured values for the materials under consideration.

Appendix: Toxicological Data

TABLE A.1
LC_{50} and IC_{50} Values for Well-Ventilated Flaming Combustion

Material	Reference	30 min LC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$	30 min IC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$
Acrylonitrile butadiene styrene					
Pellets	1	15.0	12.3, 18.3	10.6	7.4, 15.2
Pellets	1	15.6	13.2, 18.4	6.0	4.1, 8.9
Pellets	1	20.8	15.9, 27.2	17.0	15.0, 20.0
Pellets	1	19.3	16.7, 22.3		
Bismaleimide					
No details provided	2	14.9	12.8, 17.2	6.8	5.4, 8.3
Carpet foam (with nylon)	3	108.0	NA		
Carpet jute backing (with nylon)	3	57.0	NA		
Chlorofluoropolymers					
Ethylene-chlorotrifluoroethylene (39.4% fluorine; 24.6% chlorine)	4	15.1	NA		
Blown ethylene-chlorotrifluoroethylene (39.4% fluorine; 24.6% chlorine)	4	20.0	NA		
Epoxy					
No details provided	2	7.3	NA	6.2	5.2, 7.3
Fabric					
Vinyl	5	32.0	28.0, 37.0		
Fluoroopolymers (data set A)					
Ethylene-tetrafluoroethylene (59.4% fluorine)	4	30.2	22.8, 40.0		
Polyvinylidene fluoride (59.4% fluorine)	4	27.3	17.9, 41.7		
Tedlar—thin opaque	2	40.0	NA	21.0	14.2, 27.8
Fluorenone-polyester—thin clear film	2	13.2	11.8, 14.6	10.7	9.9, 11.5

(*Continued on next page.*)

TABLE A.1 (Continued).

Material	Reference	30 min LC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$	30 min IC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$
Fluoropolymers (data set B)					
Fluorinated ethylene/ fluorinated propylene—76% fluorine	4	0.075	0.03, 0.27		
Polytetrafluoroethylene-Teflon	6	0.045	0.04, 0.05		
Polytetrafluoroethylene-Teflon	7	0.017	NA		
Polytetrafluoroethylene-powder	1	0.164	0.07, 0.37	0.8	0.06, 1.51
Polytetrafluoroethylene-powder	1	0.400	0.02, 6.81		
Polytetrafluoroethylene-powder	1	0.045	0.04, 0.05	0.25	NA
Modacrylic					
Knit fabric	1	7.1	6.4, 7.9		
Knit fabric	1	4.7	3.2, 6.9	2.8	2.0, 3.0
Knit fabric	1	4.4	3.9, 5.0	3.1	2.2, 4.3
Phenolic resin					
Rigid foam	8	8.4	7.3, 9.5	2.0	NA
Polyacrylonitrile					
No details provided	7	38.7	36.2, 42.4		
No details provided	7	41.8	NA		
Polyester					
NFR Fiberfill	9	30.8	28.2, 33.6		
NFR polyester upholstery fabric	10	37.5	35.3, 39.8		
NFR polyester upholstery fabric with NFR FPU	10	39.0	36.0, 42.2		
NFR laminated circuit boards; polyester resin with $CaCO_3$ filler	11	53.0	NA		
Polyester fabric/PU foam composite	10	42.0	NA		
Polyethylene					
NFR semi-flexible foam	12	35.0	34.0, 41.0		
FR semi-flexible plastic foam	12	31.3	29.3, 33.3		
Wire	1	46.0	NA		
Polyphenylene oxide					
NFR business machine housing	11	31.5	NA		

(*Continued on next page.*)

TABLE A.1 (Continued).

Material	Reference	30 min LC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$	30 min IC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$
Polyphenylsulfone					
Pellets	1	25.3	22.0, 29.2	15.0	NA
Pellets	1	36.0	24.9,39.6	21.8	12.9, 36.7
Pellets	1	11.7	9.1, 15.0	10.0	NA
Pellets	1	19.8	14.8, 26.5		
Polystyrene					
NFR rigid foam; GM-51	1	53.5	NA	30.0	NA
FR foam; GM-49; expanded	13	35.8	23.6, 48.0	17.9	NA
NFR rigid foam; GM-51	1	32.6	30.5, 34.8		
NFR rigid foam; GM-51	1	38.9	37.9, 39.9	28.7	27.5, 30.4
NFR rigid foam; GM-51; extruded	13	33.8	30.7, 36.9	12.7	NA
NFR foam; GM-47; expanded	13	27.8	NA	15.4	12.0, 18.8
NFR TV cabinet housing; high impact polystyrene base formulation	11	40.0	NA		
Polyurethane, Flexible					
NFR FPU #12	9	40.0	NA		
FR FPU #11	9	40.0	NA		
No details provided	5	52.0	46.0, 59.0		
Melamime type foam	5	12.5	9.7–16.1		
Melamime type foam with vinyl fabric	5	26.0	24.0–28.0		
FR FPU #14	9	27.8	23.3, 33.1		
FR foam; 22.3 kg/m^3	14	26.0	NA		
FR GM-23	13	34.5	31.2, 37.8	15.1	NA
FR GM-27	13	33.1	26.5, 39.7	9.6	6.0, 13.2
NFR FPU #13	10	40.0	NA		
NFR foam; 22.3 kg/m^3	14	40.0	NA		
NFR GM-21	1	38.0	NA	9.6	4.1, 22.1
NFR GM-21	1	49.5	NA	49.5	NA
NFR GM-21	1	40.0	NA	37.5	35.8, 39.3
NFR GM-21	13	43.2	39.8, 46.6	8.3	NA
NFR GM-25	13	37.5	NA	14.5	11.3, 17.7
NFR foam	8	43.2	39.8, 46.6	8.1	6.7, 9.5
NFR upholstered chairs with flexible polyurethane padding foam, a cover fabric, and steel frame; density of foam is 25 kg/m^3	11	35.0	NA		

(*Continued on next page.*)

TABLE A.1 (Continued).

Material	Reference	30 min LC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$	30 min IC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$
Polyurethane, Rigid					
NFR foam, 25 mm thick, 96 kg/m^3	15	11.0	10.0–13.0		
FR GM-31	13	14.2	NA	6.7	5.5, 7.9
No details provided	5	22.0	21.6, 22.2		
NFR GM-30	1	38.4	NA		
NFR GM-30	1	13.3	12.2, 14.5		
NFR GM-30	1	11.3	7.6, 16.8	8.9	5.1, 15.6
NFR isocyanurate; GM-41	13	11.4	9.3, 13.5	4.1	3.3, 4.9
NFR isocyanurate; GM-43	13	5.8	5.0, 6.6	2.8	2.3, 3.3
NFR GM-29	13	11.2	9.3, 13.1	5.2	3.4, 7.0
NFR GM-35	13	12.1	8.0, 16.2	5.8	4.5, 7.1
NFR GM-37	13	10.9	9.4, 12.4	3.9	2.9, 4.9
NFR GM-39; sprayed	13	16.6	NA	4.8	2.7, 6.9
Polyvinyl chloride, Plasticized					
Plasticized PVC	16	26.0	NA	7.1	4.9, 9.3
CPVC water pipe	3	16.0	NA		
Commercial rigid 1/2″ PVC conduit	3	29.5	NA		
Polyvinyl chloride, Resin					
Sheets, 12.7 mm thick, 1,490 kg/m^3 density	15	20.0	NA		
No details provided	5	26.0	21.0, 31.0		
Sheets	15	25.0	NA		
Pellets	1	15.0	10.0, 19.0	6.0	4.0, 8.9
Pellets	1	17.3	14.8, 20.2	18.5	17.5, 19.8
Pellets (w/zinc ferrocyanide)	1	9.4	7.2, 12.3	11.8	10.1, 15.1
Pellets (w/zinc ferrocyanide)	1	14.3	12.5, 16.3	13.2	11.3, 15.4
Pellets (w/zinc ferrocyanide)	1	15.0	15.0, 15.5		
Tempered Hardwood					
No details provided	17	58.1	40.8–67		
Urea formaldehyde					
Foam	8	11.2	10.4, 12.0	7.4	6.5, 8.3
Wires and Cable Products					
Commercial PTFE coaxial wire (product)	3	9.6	NA		
Commercial THHN wire with nylon-PVC jacket (product)	3	55.0	NA		
NFR wire insulation made of cross-linked EVA copolymer (product)	11	51.0	NA		

(*Continued on next page.*)

TABLE A.1
(Continued).

Material	Reference	30 min LC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$	30 min IC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$
Wood					
Douglas fir	15	150	NA		
Douglas fir	1	35.8	28.6, 44.9	20.0	16.4, 24.3
Douglas fir	1	45.3	39.0, 52.7	18.4	14.0, 24.1
Douglas fir	1	24.0	19.0, 29.0	14.5	10.0, 19.1
Douglas fir	1	29.6	22.7, 38.6		
Douglas fir	1	38.4	35.2, 41.9	14.0	10.5, 18.6
Douglas fir	1	41.0	33.0, 50.9	21.8	15.5, 30.7
Douglas fir	1	39.8	38.2, 41.4	23.5	23.0, 24.0
Douglas fir	1	29.8	23.9, 37.1	20.9	NA
Douglas fir	18	106.5	NA		
Douglas fir	18	69.4	NA		
Douglas fir	13			13.3	10.1, 16.5
Red oak	1	45.0	39.9, 50.8	40.6	NA
Red oak	1	56.8	51.6, 62.5	34.8	31.1, 39.0
Red oak	1	60.0	56.6, 63.6		

NA: Values not available in literature.

TABLE A.2
LC_{50} Values for Ventilation-limited Flaming Combustion

Material	Reference	30 min LC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$
Fabric, vinyl	5	19.0	17.7, 20.9
Polyester, Resin	11	40.5	NA
Polyphenylene oxide	11	24.0	NA
Polyvinyl chloride, Plasticized	5	16.0	13.7, 17.5
Polyurethane, Flexible			
No details provided	5	18.0	16.9, 18.4
FR upholstered chairs with flexible polyurethane padding foam, a cover fabric, and steel frame	11	23.0	NA
Melamime type foam	5	8.0	7.2, 10.4
Melamime type foam with vinyl fabric	5	15.0	14.7, 16.2
Polyurethane, Rigid			
No details provided	5	14.0	14.3, 14.5
Wires and Cable Products			
FR wire insulation made of cross-linked EVA copolymer (product)	15	25.0	NA

NA: Values not available in literature.

TABLE A.3
LC_{50} and IC_{50} Values for Oxidative Pyrolysis

Material	Reference	30 min LC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$	30 min IC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$
Acrylonitrile butadiene styrene					
Pellets	1	19.3	13.9, 26.9	21.0	15.1, 25.2
Pellets	1	38.4	NA	5.8	2.8, 8.4
Pellets	1	33.3	23.1, 47.9	23.0	18.5, 27.5
Pellets	1	30.9	21.2, 45.0		
Bismaleimide					
No details provided	2	41.9	38.8, 45.1	20.1	16.3, 24.0
Carpet foam (with nylon)	3	68.0	NA		
Carpet jute backing (with nylon)	3	90.0	NA		
Chlorofluoropolymers					
Ethylene-chlorotrifluoroethylene (39.4% fluorine; 24.6% chlorine)	4	20.1	18.4, 22.0		
Blown ethylene-chlorotrifluoroethylene (39.4% fluorine; 24.6% chlorine)	4	28.9	20.3, 41.1		
Epoxy					
No details provided	2	11.0	8.9, 13.1	4.1	3.3, 5.0
Fluoropolymers (data set A)					
Ethylene-tetrafluoroethylene-59.4% fluorine	4	3.3	NA		
Polyvinylidene fluoride-59.4% fluorine	4	24.3	19.1, 31.2		
Tedlar–thin opaque	2	34.0	NA	18.8	12.0, 25.6
Fluorenone-polyester-thin clear film	2	17.2	NA	10.9	NA
Fluoropolymers (data set B)					
Fluorinated ethylene/fluorinated propylene – 76% fluorine	4	0.05	NA		
Polytetrafluoroethylene-powder	6	0.045	0.02, 0.12		
Polytetrafluoroethylene-powder	1	0.125	0.08, 0.19	0.68	0.31, 1.49
Polytetrafluoroethylene-powder	1	0.235	0.05, 1.20		
Modacrylic					
Knit fabric	1	5.2	4.9, 5.5	2.7	2.1, 3.4
Knit fabric	1	7.8	6.3, 9.7		
Knit fabric	1	7.0	5.0, 9.7	3.0	2.0, 4.0
Knit fabric	1	5.3	4.0, 7.1	3.2	2.8, 3.7

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TABLE A.3 (Continued).

Material	Reference	30 min LC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$	30 min IC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$
Phenolic resin					
Rigid foam; GM-57	8	5.9	4.8, 7.0	1.5	NA
Polyester					
Fabric	10	5.0	NA		
NFR polyester upholstery fabric	10	39.0	38.4, 39.5		
NFR polyester upholstery fabric with NFR FPU	10	47.5	43.0, 52.5		
Polyester fabric/PU foam composite	10	30.0	NA		
Polyethylene					
NFR semi-flexible polyethylene foam	12	5.3	4.4, 6.6		
FR semi-flexible plastic polyethylene foam	12	6.1	5.3, 6.9		
Polyphenylsulfone					
Pellets	1	18.7	15.2, 23.0	8.8	6.8, 11.2
Pellets	1	32.2	27.7, 37.5	19.0	10.2, 35.3
Pellets	1	10.7	8.4, 13.6	7.0	NA
Pellets	1	9.5	9.1, 10.1		
Polystyrene					
NFR rigid foam; GM-51	1	50.0	NA	50.0	NA
FR foam; GM-49; expanded	13	40.0	NA	30.9	26.2, 35.6
NFR rigid foam; GM-51	1	46.2	NA		
NFR rigid foam; GM-51	1	40.0	NA	40.0	NA
NFR rigid foam; GM-51; extruded	13	40.0	NA	40.0	NA
NFR foam; GM-47; expanded	13	40.0	NA	27.2	23.0, 31.4
Polyurethane, Flexible					
NFR FPU #12	9	37.8	36.6, 39.0		
NFR FPU #13	10	37.0	29.8, 46.0		
NFR foam; 22.3 kg/m^3	14	33.0	NA		
NFR GM-21	1	27.8	16.9, 45.8	7.0	3.6, 13.6
NFR GM-21	1	40.0	31.2, 51.3	20.2	8.6, 47.3
NFR GM-21	1	26.6	15.3, 46.2	53.0	
FR FPU #11	9	17.2	13.2, 22.4		
FR FPU #14	9	40.0	NA		
FR foam; 22.3 kg/m^3	14	23.0	NA		
FR GM-23	13	12.6	10.5, 14.7	7.3	5.5, 9.1
FR GM-27	13	30.5	23.1, 37.9	25.2	4.7, 45.7
NFR GM-21	13	13.4	NA	3.2	1.6, 4.8
NFR GM-25	13	36.9	30.9, 42.9	15.1	12.4, 17.8
NFR foam	8	14.3	11.9, 16.7	4.2	3.3, 5.1
NFR GM-21; 2 PCF	3	34.7	NA		

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TABLE A.3
(Continued).

Material	Reference	30 min LC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$	30 min IC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$
Polyurethane, Rigid					
NFR GM-30	1	34.0	NA		
NFR GM-30	1	39.6	NA		
NFR GM-30	1	35.1	NA	29.3	NA
FR GM-31	13	40.0	NA	9.0	6.8, 11.2
NFR isocyanurate; GM-41	13	8.0	7.1, 8.9	3.0	2.7, 3.3
NFR isocyanurate; GM-43	13	5.0	4.6, 5.4	3.4	2.8, 4.0
NFR GM-29	13	40.0	NA	8.9	5.1, 12.7
NFR GM-35	13	36.7	NA	10.8	NA
NFR GM-37	13	36.7	NA	6.8	3.4, 10.2
NFR GM-39; sprayed	13	10.9	9.3, 12.5	4.0	2.4, 5.6
Polyvinyl chloride, Plasticized					
CPVC water pipe	3	9.1	NA		
Plasticized PVC	16	21.0	18.8, 23.2	3.4	2.8, 4.0
Commercial rigid 1/2″ PVC conduit	3	37.0	NA		
Polyvinyl chloride, Resin					
Pellets	1	16.0	14.0, 19.0	9.4	NA
Pellets	1	20.0	14.7, 27.2	30.0	NA
Pellets (w/zinc ferrocyanide)	1	7.6	5.5, 10.5	5.4	5.1, 10.1
Pellets (w/zinc ferrocyanide)	1	13.3	11.5, 15.4	11.7	10.3, 13.2
Pellets (w/zinc ferrocyanide)	1	11.3	8.5, 14.9		
Strandboard					
Oriented Strandboard	18	47.0	37.7, 57.3		
Tempered Hardwood					
No details provided	17	86.5	79.4, 93		
Urea formaldehyde					
Foam	8	1.2	1.1, 1.3	0.7	0.6, 0.8
Wires and Cable Products					
Commercial PTFE coaxial wire (product)	3	12.5	NA		
Commercial THHN wire with nylon-PVC jacket (product)	3	100.0	NA		
Wood					
Douglas fir	1	16.7	14.5, 19.3	15.0	12.3, 18.2
Douglas fir	1	27.6	22.9, 33.3	10.1	7.2, 14.2
Douglas fir	1	26.8	21.3, 33.7	5.6	3.1, 9.9
Douglas fir	1	24.0	19.9, 29.0	22.0	13.2, 36.7
Douglas fir	1	25.9	20.0, 33.5	10.1	7.2, 14.2
Douglas fir	1	20.4	16.4, 25.3	18.3	14.5, 23.0
Douglas fir	1	22.8	20.2, 25.8	13.5	12.0, 14.2

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TABLE A.3 (Continued).

Material	Reference	30 min LC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$	30 min IC_{50} Value (With 14 day Post-Exposure Observation) $g \cdot m^{-3}$	95% Confidence Limits $g \cdot m^{-3}$
Douglas fir	1	18.5	17.3, 19.8	14.7	13.3, 16.2
Douglas fir	18	100.8	NA		
Douglas fir	18	64.6	60.6, 77.1		
Douglas fir	13	14.6	8.1, 21.1	4.8	3.8, 5.8
Red oak	1	25.0	18.7, 35.5	25.0	NA
Red oak	1	30.3	26.0, 35.4	23.0	NA
Red oak	1	35.0	24.5, 50.1	24.1	NA

NA: Values not available in literature.

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