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Carlos J. Hilado, Nancy V. Huttlinger, Bridget A. O'Neill, Demetrius A. Kourtides, and John A. Parker

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Ames Research Center
Moffett Field, California 94035

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Carlos J. Hilado, Nancy V. Huttlinger, and Bridget A. O'Neill
Fire Safety Center, Institute of Chemical Biology
University of San Francisco
San Francisco, California 94117

and

Demetrius A. Kourtides and John A. Parker
Chemical Research Projects Office
Ames Research Center
Moffett Field, California 94035

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ABSTRACT

The toxicity of the pyrolysis gases from nine wood samples was investigated, using the screening test method developed at the University of San Francisco. The samples of hardwoods were aspen poplar, beech, yellow birch, and red oak. The samples of softwoods were western red cedar, Douglas fir, western hemlock, eastern white pine, and southern yellow pine.

Changing from a rising temperature program (40°C/min) to a fixed temperature program (immediate exposure to 800°C) resulted in shorter times to animal responses. This effect is attributed in part to more rapid generation of toxicants.

There was no significant difference between the wood samples under rising temperature conditions, which are intended to simulate a developing fire, or under fixed temperature conditions, which are intended to simulate a fully developed fire.

This test method can be used to determine whether a material is significantly more toxic than wood under the pre-flashover conditions of a developing fire by determining whether time to death is less than 13.5 min and time to first sign of incapacitation is less than 8.8 min using Procedure B; and to determine whether a material is significantly more toxic than wood under fully developed fire conditions by determining whether time to death is less than 5.2 min and time to first sign of incapacitation is less than 2.2 min using Procedure F.

INTRODUCTION

Wood is a natural material which is widely used in construction and furnishings. The nation's forests represent an abundant and renewable resource, and wood will always be a major factor in the materials market.

Because of its universal use and general acceptance, wood is often used as the reference material against which synthetic materials are compared. For example, the 1973 edition of the Uniform Building Code, in defining "approved plastics", required that the products of combustion shall be no more toxic than those of untreated wood when burned under similar conditions" (1).

The toxicity screening test method developed at the University of San Francisco is used to compare the toxicity of pyrolysis gases from materials under different test conditions intended to simulate developing fires and fully developed fires (2). Almost three hundred materials have been evaluated using this test method (3). One possible use of this method is in determining whether a material is significantly more toxic than wood. A logical first step is to determine whether different species of wood give different results under various test conditions.

MATERIALS

Nine samples of wood were provided by the Eastern Forest Products Laboratory of the Canadian Forestry Service at Ottawa.

Four samples were hardwoods:

aspen poplar	populus tremuloides
beech	fagus grandifolia
yellow birch	betula alleghaniensis
red oak	quercus rubra

Five samples were softwoods:

western red cedar	thuja plicata
Douglas fir	pseudotsuga menziesii
western hemlock	tsuga heterophylla
eastern white pine	pinus strobus
southern yellow pine	

Southern yellow pine is a mixture of four species: pinus palustris, pinus echinata, pinus taeda, and pinus elliotti. It was impossible to positively identify this specific sample of southern yellow pine.

APPARATUS

A Lindberg horizontal tube furnace is used for pyrolysis. The sample material is pyrolyzed in a quartz boat centered in a quartz tube, closed at one end with a cap and connected at the open end to the animal exposure chamber.

The animal exposure chamber is of a design developed and patented by NASA and is made of clear polymethyl methacrylate so that continuous observation of the animals is facilitated. The activity of the free moving mice in the chamber allows observation of natural, unrestrained behavior which can be recorded by the average lay person. This spontaneous activity appears to result in fairly uniform distribution of the gases throughout the chamber volume.

The polymethyl methacrylate is superior to glass in ease of fabrication, light weight, resistance to shock, and inertness to hydrogen fluoride, which is a pyrolysis effluent from some synthetic polymers. The chamber has a total free volume of 4.2 liters, and is made of an upper dome section and a lower base section, both with a diameter of 203 mm (8 in).

The upper dome section is removable, and is connected to the base section by means of a conventional toggle snap ring; the joint is sealed by an O-ring. Access to the chamber is provided by two horizontal cylinders of different diameter mounted on the dome section. The larger horizontal cylinder, having a diameter of 59 mm (2.38 in), is fitted with an adapter to accomodate the open end of the pyrolysis tube. The smaller horizontal cylinder, having a diameter of 39 mm (1.56 in), is fitted with an adapter to accomodate the probe of a Beckman process oxygen analyzer, and serves also as the entry port for the test animals. A perforated polymethyl methacrylate plate across the larger horizontal cylinder prevents movement of the mice into the pyrolysis tube.

The upper end of the dome section is provided with apertures and a clear polymethyl methacrylate cylinder having a cover plate; the cover plate is connected to a bubbler to permit venting of pressure exceeding 25 mm (1 in) of water and prevent entry of fresh air, and is provided with fittings for a thermometer and for gas sampling.

PROCEDURE

The pyrolysis tube, pyrolysis boat, animal exposure chamber, and all fittings and adapters are thoroughly cleaned and dried before each test. The pyrolysis boat is weighed without and with the sample under test. A sample weight of 1.00 g is normally used for screening studies, and was used in this study.

The test animals are received in plastic cages, with each test group in its own cage. Each animal is removed, inspected for freedom from abnormalities, weighed, and marked on some part of the body with different colors of ink for identification. Four Swiss-Webster male mice, 25 to 35 g body weight, are used for each test. Four appears to be the optimum number of mice which can be used for each test without excessive oxygen consumption during the test period, as well as the largest number which can be satisfactorily observed by a single operator.

Each experiment is repeated two or more times. This replication provides measures of variation between test animals and between experiments.

The mice are placed in the animal exposure chamber and given a minimum of 5 min to accustom themselves to their surroundings. The entire system is sealed (except for the safety vent) and all joints are checked for proper seating. The pyrolysis tube containing the sample is introduced into the furnace, which is preheated to 200°C in the case of the rising temperature program, or 800°C in the case of the fixed temperature program. In the case of the rising temperature program, the furnace is turned on at the start of the test at the predetermined heating rate of 40°C/min; when the furnace approaches or reaches 800°C, this temperature is maintained by either automatic or manual control until the end of the test. The test period is 30 min, unless 100% mortality occurs earlier; the test is terminated upon the death of the last surviving animal, and any samples for gas analysis are taken at that time before the system is opened.

Time to first sign of incapacitation is defined as the time to the first observation of loss of equilibrium (staggering), prostration, collapse, or convulsions in any of the test animals.

Time to staggering is defined as the time to the first observation of loss of equilibrium or uncoordinated movement in a specific test animal.

Time to convulsions is defined as the time to the first observation of uncontrolled muscular movements in a specific test animal.

Time to collapse is defined as the time to the first observation of loss of muscular support in a specific test animal.

Time to death is defined as the time to the observed cessation of movement and respiration in a specific test animal.

Temperatures and oxygen concentrations in the animal exposure chamber are recorded at 1-min intervals throughout the entire test period.

After the test is terminated and the animals are removed from the chamber, the pyrolysis boat containing the sample is removed, allowed to cool, and weighed to permit calculation, by difference, of the weight of sample pyrolyzed. Surviving animals are observed daily for a 14-day period after the test, and any significant changes from normal appearance, behavior, or weight are noted.

RESULTS AND DISCUSSION

Animal Responses

The results of toxicity tests on nine wood samples are presented in Tables 1 and 2. Test results using the fixed temperature program are presented in Table 1, and test results using the rising temperature program are presented in Table 2. The values given for individual tests, as indicated by a test reference, are mean ± standard deviation within experiment (between animals); the mean values given for individual wood samples are mean ± standard deviation between experiments.

The mean values for the different wood samples, listed in order of increasing time to death for each temperature program, are presented in Table 3. The values given are mean ± standard deviation between experiments, with n being the number of experiments.

Changing from a rising temperature program to a fixed temperature program resulted in shorter times to animal responses. This effect is attributed in part to more rapid generation of toxicants.

There was no significant difference between the different samples of wood under rising temperature conditions, which are intended to simulate a developing fire, or under fixed temperature conditions, which are intended to simulate a fully developed fire.

The differences in rank order between the two sets of test conditions, while not statistically significant, may indicate differences in the decomposition of the wood species arising from differences in the relative content of cellulose, hemicellulose, lignin, tars, resins, and moisture.

For practical purposes, wood may be considered a generic material which gives a time to death of 14.72 ± 0.59 min by Procedure B and 6.16 ± 0.52 min by Procedure F. Using confidence limits of twice the standard deviation gives the following ranges:

Procedure B:	time to first sign of incapacitation	10.3 ± 1.5 min
	time to death	14.7 ± 1.2 min
Procedure F:	time to first sign of incapacitation	3.2 ± 1.0 min
	time to death	6.2 ± 1.0 min

Chamber Gas Analyses

The recorded oxygen concentrations in the animal exposure chamber during the test consistently decreased with time; the oxygen concentrations obtained by gas analysis at the time of death of the last surviving animal are therefore the lowest concentrations encountered by the test animals.

Although the oxygen concentrations obtained during the test by the polarographic membrane technique provided reliable information on trends, the oxygen analyzer used frequently malfunctioned and the readings were sometimes at considerable variance from the data obtained using a gas chromatograph with thermal conductivity detector. Interference from other compounds and smoke deposits were possible causes of the discrepancies observed. The values obtained by gas chromatography are considered more reliable.

The concentrations of methane, carbon monoxide, and oxygen in the animal exposure chamber at the time of death of the last surviving animal are presented in Table 4. Because these analyses are essentially isolated spot values which provide no information about concentration trends, only limited conclusions can be based on these data (4). However, because a closed system is used to prevent entry of fresh oxygen and escape of toxicants, it seems reasonable to assume that the oxygen concentrations are the lowest encountered and that the methane and carbon monoxide concentrations are the highest encountered.

The gas analyses were limited in extent, with samples taken from only 12 tests with the rising temperature program and 6 tests with the fixed temperature program. The oxygen concentrations averaged 18.2 $\pm$ 0.6 per cent with the rising temperature program and 19.2 $\pm$ 0.3 per cent with the fixed temperature program; the values given are mean $\pm$ standard deviation. The higher oxygen concentrations observed with the fixed temperature program are believed to be due to the shorter times to death and hence reduced oxygen consumption by the test animals.

The methane concentrations ranged from 1,000 to 5,700 ppm with the rising temperature program and from 1,500 to 6,100 ppm with the fixed temperature program. Because 10,000-ppm (1 per cent) of methane displaces only sufficient air to reduce oxygen concentration by 0.2 per cent, the contribution of methane as a simple asphyxiant in this study was not considered significant. The contribution of these concentrations of methane to hazard with regard to flammable mixtures (5) is outside the scope of this study.

Carbon monoxide concentrations averaged 11,025 $\pm$ 3,138 ppm with the rising temperature program and 19,167 $\pm$ 6,938 ppm with the fixed temperature program. Because CO concentrations of above 15,000 ppm could result in death in less than 3 min (6), these CO levels account for the 5.3 to 7.0 min times to death observed with the fixed temperature program.

The wide range of concentrations of carbon monoxide and methane encountered in these gas analyses is believed to be due to differences in the relative proportions of cellulose, hemicellulose, and lignin in specific 1.0 g samples of wood, and to differences in pyrolysis arising from variations in sizes and size distributions of the wood chips comprising the samples.

The gradual pyrolysis of the rising temperature program seems to produce less carbon monoxide than the essentially flash pyrolysis of the fixed temperature program.

Chamber Atmosphere Temperatures

The recorded temperatures in the animal exposure chamber during the test did not exceed 30°C in any of the experiments. These temperatures are not considered to have a significant effect on animal responses.

CONCLUSIONS

For practical purposes, wood can be considered to be a generic material with no significant difference in performance between the species tested under either developing fire and fully developed fire conditions. The principal effect of immediate exposure to high temperature appears to be more rapid generation of toxicants and more rapid animal response.

This test method can be used to determine whether a material is significantly more toxic than wood under developing fire conditions by determining whether time to death is less than 13.5 min and time to first sign of incapacitation is less than 8.8 min under Procedure B; and to determine whether a material is significantly more toxic than wood under fully developed fire conditions by determining whether time to death is less than 5.2 min and time to first sign of incapacitation is less than 2.2 min using Procedure F.

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Table 1. Toxicity Test Data on Wood Samples: USF Method F: 800°C fixed temperature, no forced air flow

test reference	time to first sign of incapacitation min	average time to staggering min	average time to convulsions min	average time to collapse min	average time to death min	weight of animals g
aspen poplar						
PAR-9	3.98	4.51 ± 0.41		4.92 ± 0.63	6.30 ± 0.27	34.25 ± 0.97
BAO-12	2.32		3.24 ± 1.01	4.79 ± 0.16	5.67 ± 0.19	35.13 ± 2.69
AML-3	2.20		3.79 ± 1.26	3.90 ± 0.11	5.95 ± 0.62	35.30 ± 1.01
AML-15	2.48	3.33	4.16 ± 1.20	3.58 ± 0.35	6.44 ± 0.45	36.12 ± 1.55
mean	2.74 ± 0.83	3.92 ± 0.83	3.73 ± 0.46	4.30 ± 0.66	6.09 ± 0.35	
beech						
PAR-8	2.95	4.44 ± 0.99		5.83 ± 0.74	6.80 ± 0.92	36.83 ± 2.07
BAO-13	3.25		4.04 ± 1.00	5.06 ± 1.12	6.17 ± 0.49	29.85 ± 2.97
AML-5	3.83	3.83	5.55 ± 0.50	5.33	6.71 ± 1.81	34.30 ± 2.24
BAO-27	2.98	3.40 ± 0.60	4.04 ± 0.66	3.98 ± 0.18	4.98 ± 0.47	33.85 ± 3.32
AML-14	3.50	5.11 ± 1.38	6.31 ± 0.60	5.48	8.41 ± 0.43	36.52 ± 3.29
mean	3.30 ± 0.37	4.20 ± 0.74	4.98 ± 1.13	5.13 ± 0.71	6.61 ± 1.24	
yellow birch						
BAO-6	2.50	2.50	3.65 ± 0.36	3.90 ± 0.53	4.66 ± 0.39	32.88 ± 2.91
ANS-1295	3.72	4.14 ± 0.32	4.34 ± 0.16	4.50 ± 0.24	5.22 ± 0.20	32.10 ± 2.42
NVH-23	2.87		3.31 ± 0.62	3.91 ± 0.54	4.62 ± 0.00	32.28 ± 2.14
AML-8	2.87		3.58 ± 0.54	4.61 ± 0.32	6.73 ± 0.83	38.62 ± 2.59
mean	2.99 ± 0.52	3.32 ± 1.16	3.72 ± 0.44	4.23 ± 0.38	5.31 ± 0.99	

values given are mean ± standard deviation

Table 1. Toxicity Test Data on Wood Samples: USF Method F: 800°C fixed temperature, no forced air flow (continued)

test reference	time to first sign of incapacitation min	average time to staggering min	average time to convulsions min	average time to collapse min	average time to death min	weight of animals g
red oak						
PAR-6	1.95	3.12 ± 1.00		4.92 ± 0.22	5.84 ± 0.37	34.20 ± 1.58
ANS-1293	1.75	2.47 ± 1.21	4.60 ± 0.45	4.70 ± 0.42	6.02 ± 0.55	29.65 ± 3.24
BAO-15	4.00	4.62 ± 0.87	4.73 ± 0.50	5.72 ± 0.20	6.15 ± 0.24	35.43 ± 2.87
NVH-22	3.60	3.60	4.11 ± 0.19	4.38 ± 0.05	5.61 ± 0.68	32.72 ± 2.04
AML-9	2.97	3.49 ± 0.46	4.50 ± 0.18		6.68 ± 0.40	37.82 ± 1.39
mean	2.85 ± 0.99	3.46 ± 0.78	4.48 ± 0.27	4.93 ± 0.57	6.06 ± 0.40	
western red cedar						
BAO-5	1.95	2.82 ± 1.22	4.41 ± 0.25	4.28	4.61 ± 0.43	34.43 ± 0.42
ANS-1294	4.53	4.78 ± 0.19	5.00 ± 0.38	5.16 ± 0.38	6.54 ± 1.14	30.90 ± 1.96
NVH-24	5.13		5.22 ± 0.13	5.48 ± 0.10	7.33 ± 1.13	31.20 ± 3.04
BAO-26	3.98	4.36 ± 0.40	4.68 ± 0.32	5.13 ± 0.10	5.73 ± 0.12	35.75 ± 1.77
AML-12	2.08	2.50 ± 0.59	4.48 ± 0.46	4.12 ± 0.53	6.50 ± 0.25	35.65 ± 2.26
mean	3.53 ± 1.45	3.62 ± 1.12	4.76 ± 0.34	4.83 ± 0.60	6.14 ± 1.03	
Douglas fir						
PAR-7	3.67	4.80		4.31 ± 0.51	5.78 ± 0.34	33.78 ± 1.56
BAO-14	3.50		4.04 ± 0.42	4.37 ± 0.26	5.46 ± 0.67	32.78 ± 3.72
AML-4 *	11.60	11.60	4.83 ± 1.00	13.14 ± 0.46	21.51 ± 3.02	37.55 ± 1.69
AML-6	5.82		7.49 ± 0.59	6.07 ± 0.35	9.89 ± 2.00	38.35 ± 1.64
mean	4.33 ± 1.29	4.80	5.76 ± 2.44	4.92 ± 1.00	7.04 ± 2.47	

values given are mean ± standard deviation
* not included in calculation of mean values

Table 1. Toxicity Test Data on Wood Samples: USF Method F: 800°C fixed temperature, no forced air flow (continued)

test reference	time to first sign of incapacitation min	average time to staggering min	average time to convulsions min	average time to collapse min	average time to death min	weight of animals g
western hemlock						
BAO-8	3.45	3.95 ± 0.46	4.88 ± 0.18	5.02 ± 0.04	5.95 ± 0.58	33.35 ± 1.58
PAR-12	2.90	4.05 ± 0.95		3.90	5.04 ± 0.70	33.85 ± 1.58
AML-7	4.67	4.67	5.40 ± 1.03	4.90 ± 0.11	7.38 ± 0.49	34.72 ± 2.71
AML-13	2.47	3.70 ± 0.93	4.96 ± 0.29		7.26 ± 1.14	36.10 ± 4.32
mean	3.37 ± 0.95	4.09 ± 0.41	5.08 ± 0.28	4.61 ± 0.62	6.41 ± 1.12	
eastern white pine						
BAO-7	2.67	3.28 ± 0.60	4.10 ± 0.48	4.13 ± 0.64	5.12 ± 0.25	31.80 ± 3.29
PAR-11	2.13	2.84 ± 0.97		3.73 ± 0.09	5.27 ± 0.85	32.78 ± 1.03
BAO-28	4.00	4.50 ± 0.36	5.36 ± 0.89	6.34 ± 0.12	6.54 ± 0.15	33.75 ± 2.47
AML-11	3.70		5.74 ± 0.67	4.25 ± 0.42	8.05 ± 1.67	36.20 ± 5.84
mean	3.12 ± 0.87	3.54 ± 0.86	5.07 ± 0.86	4.61 ± 1.17	6.24 ± 1.36	
southern yellow pine						
PAR-10	2.38	2.94 ± 0.39		3.74 ± 0.06	4.19 ± 0.55	32.55 ± 1.66
PAR-13	3.32	3.38 ± 0.09		4.16 ± 0.68	5.30 ± 0.70	30.38 ± 2.03
AML-10	2.27		4.84 ± 0.51	3.12 ± 0.76	6.98 ± 0.46	36.82 ± 2.96
KLK-16	3.35	3.76 ± 0.31	4.17 ± 0.51	4.48 ± 0.24	5.69 ± 0.63	34.90 ± 3.19
mean	2.83 ± 0.58	3.36 ± 0.41	4.50 ± 0.47	3.88 ± 0.59	5.54 ± 1.15	

values given are mean ± standard deviation

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Table 2. Toxicity Test Data on Wood Samples: USF Method B:
200-800°C rising temperature, 40°C/min, no forced air flow

test reference	time to first sign of incapacitation min	average time to staggering min	average time to convulsions min	average time to collapse min	average time to death min	weight of animals g
aspen poplar						
LAG-11	9.62	9.75 ± 0.18	11.91 ± 1.45		13.18 ± 2.01	25.38 ± 0.22
LAG-27	8.50	9.85 ± 1.22	11.54 ± 2.40		12.84 ± 2.76	32.48 ± 4.50
LAG-37	11.77	12.85 ± 1.21	15.63	12.72 ± 0.25	16.17 ± 1.44	36.35 ± 3.08
mean	9.96 ± 1.66	10.82 ± 1.76	13.03 ± 2.26	12.72	14.06 ± 1.83	
beech						
LAG-12	8.83	10.73	11.62 ± 1.00	8.83	14.48 ± 0.93	25.68 ± 0.94
LAG-26	9.73	10.46 ± 0.66	10.84 ± 0.76		11.90 ± 0.54	27.40 ± 1.86
LAG-35	10.50	10.77 ± 0.28	12.64 ± 1.30		15.07 ± 1.24	34.80 ± 1.99
mean	9.69 ± 0.84	10.65 ± 0.17	11.70 ± 0.90	8.83	13.82 ± 1.68	
yellow birch						
LAG-15	10.68	12.86 ± 2.76	13.78 ± 2.03	10.77	17.16 ± 3.30	26.90 ± 1.48
LAG-28	9.08	10.57 ± 1.64	14.56 ± 2.22		15.90 ± 2.74	28.15 ± 3.42
LAG-32	8.93	9.24 ± 0.46	10.85 ± 1.37		12.22 ± 1.45	30.80 ± 2.32
mean	9.56 ± 0.97	10.89 ± 1.83	13.06 ± 1.96	10.77	15.09 ± 2.57	
red oak						
LAG-16	11.08	11.80 ± 0.59	13.32 ± 1.57		15.92 ± 1.70	29.38 ± 2.01
LAG-24	10.13	11.25 ± 0.52	11.68 ± 1.24		13.70 ± 1.78	27.48 ± 0.69
LAG-29	9.47	10.37 ± 1.36	12.35 ± 2.40		13.88 ± 3.12	27.70 ± 3.13
mean	10.23 ± 0.81	11.14 ± 0.72	12.45 ± 0.82		14.50 ± 1.23	

values given are mean ± standard deviation

Table 2. Toxicity Test Data on Wood Samples: USF Method B: 200-800°C rising temperature, 40°C/min, no forced air flow (continued)

test reference	time to first sign of incapacitation min	average time to staggering min	average time to convulsions min	average time to collapse min	average time to death min	weight of animals g
western red cedar						
LAG-18	11.02	11.96 ± 3.03	15.16 ± 0.23	12.70	18.50 ± 1.97	30.00 ± 3.36
LAG-25	9.88	10.90 ± 1.85	11.54 ± 2.28	11.00	13.78 ± 2.15	28.30 ± 1.96
LAG-30	9.10	9.85 ± 0.84	10.46 ± 0.35		12.44 ± 1.35	26.02 ± 0.82
mean	10.00 ± 0.96	10.90 ± 1.06	12.39 ± 2.46	11.85 ± 1.20	14.91 ± 3.18	
Douglas fir						
LAG-13	11.60	11.98 ± 0.53	11.86 ± 0.10		13.73 ± 0.46	26.42 ± 0.94
LAG-20	11.00	12.40 ± 1.38	13.46 ± 1.02		15.19 ± 1.44	30.42 ± 1.36
LAG-36	12.77	13.61 ± 1.19	13.83 ± 0.80		15.36 ± 0.81	35.02 ± 4.08
mean	11.97 ± 0.90	12.66 ± 0.85	13.05 ± 1.05		14.76 ± 0.90	
western hemlock						
LAG-17	10.45	11.37 ± 0.85	14.24 ± 1.18	**13.15 ± 0.48**	15.83 ± 1.24	26.72 ± 2.26
LAG-22	9.72	9.72	11.24 ± 0.28		12.80 ± 0.77	28:78 ± 1.51
LAG-31	9.80	10.50 ± 0.95	12.64 ± 1.28		14.47 ± 1.52	28.22 ± 3.41
mean	9.99 ± 0.40	10.53 ± 0.82	12.71 ± 1.50	13.15	14.37 ± 1.52	
eastern white pine						
LAG-14	9.95	11.82 ± 1.27	13.03 ± 1.05		14.45 ± 1.04	28.02 ± 2.35
LAG-21	11.63	12.57 ± 1.48	15.28 ± 1.63		16.24 ± 0.95	29.62 ± 2.89
LAG-33	10.58	10.97 ± 0.60	13.81 ± 2.49		15.56 ± 2.84	29.10 ± 1.36
mean	10.72 ± 0.85	11.79 ± 0.80	14.04 ± 1.14		15.42 ± 0.90	
southern yellow pine						
LAG-19	10.37	11.93 ± 0.62	12.68 ± 1.44	**11.82 ± 2.05**	15.43 ± 1.76	28.78 ± 1.82
LAG-23	10.47	11.88 ± 1.43	13.70 ± 2.36		15.59 ± 2.20	26.50 ± 0.93
LAG-34	11.90	12.67 ± 0.88	13.26 ± 1.46		15.67 ± 1.75	28.20 ± 1.64
mean	10.91 ± 0.86	12.16 ± 0.44	13.21 ± 0.51	11.82	15.56 ± 0.12	

values given are mean ± standard deviation

Table 3. Toxicity Test Data on Wood Samples, Listed in Order of Increasing Time to Death

wood	time to first sign of incapacitation min	time to staggering min	time to convulsions min	time to collapse min	time to death min	number of tests
USF Method B: 200-800°C rising temperature, 40°C/min, no forced air flow						
beech	9.69 ± 0.84	10.65 ± 0.17	11.70 ± 0.90	8.83	13.82 ± 1.68	3
aspen poplar	9.96 ± 1.65	10.82 ± 1.76	13.03 ± 2.26	12.72	14.06 ± 1.83	3
western hemlock	9.99 ± 0.40	10.53 ± 0.82	12.71 ± 1.50	13.15	14.37 ± 1.52	3
red oak	10.23 ± 0.81	11.14 ± 0.72	12.45 ± 0.82		14.50 ± 1.23	3
Douglas fir	11.97 ± 0.90	12.66 ± 0.85	13.05 ± 1.05		14.76 ± 0.90	3
western red cedar	10.00 ± 0.96	10.90 ± 1.06	12.39 ± 2.46	11.85 ± 1.20	14.91 ± 3.18	3
yellow birch	9.56 ± 0.97	10.89 ± 1.83	13.06 ± 1.96	10.77	15.09 ± 2.57	3
eastern white pine	10.72 ± 0.85	11.79 ± 0.80	14.04 ± 1.14		15.42 ± 0.90	3
southern yellow pine	10.91 ± 0.86	12.16 ± 0.44	13.21 ± 0.51	11.82	15.56 ± 0.12	3
mean	10.34 ± 0.75	11.28 ± 0.74	12.85 ± 0.65	11.52 ± 1.56	14.72 ± 0.59	
USF Method F: 800°C fixed temperature, no forced air flow						
yellow birch	2.99 ± 0.52	3.32 ± 1.16	3.72 ± 0.44	4.23 ± 0.38	5.31 ± 0.99	4
southern yellow pine	2.83 ± 0.58	3.36 ± 0.41	4.50 ± 0.47	3.88 ± 0.59	5.54 ± 1.15	4
red oak	2.85 ± 0.99	3.46 ± 0.78	4.48 ± 0.27	4.93 ± 0.57	6.06 ± 0.40	5
aspen poplar	2.74 ± 0.83	3.92 ± 0.83	3.73 ± 0.46	4.30 ± 0.66	6.09 ± 0.35	4
western red cedar	3.53 ± 1.45	3.62 ± 1.12	4.76 ± 0.34	4.83 ± 0.60	6.14 ± 1.03	5
eastern white pine	3.12 ± 0.87	3.54 ± 0.86	5.07 ± 0.86	4.61 ± 1.17	6.24 ± 1.36	4
western hemlock	3.37 ± 0.95	4.09 ± 0.41	5.08 ± 0.28	4.61 ± 0.62	6.41 ± 1.12	4
beech	3.30 ± 0.37	4.20 ± 0.74	4.98 ± 1.13	5.13 ± 0.71	6.61 ± 1.24	5
Douglas fir	4.33 ± 1.29	4.80 ±	5.76 ± 2.44	4.92 ± 1.00	7.04 ± 2.47	3
mean	3.23 ± 0.49	3.81 ± 0.49	4.67 ± 0.65	4.60 ± 0.40	6.16 ± 0.52	

values given are mean ± standard deviation

Table 4. Gas Chromatographic Analyses of Chamber Atmospheres at Time of Death of Last Surviving Animal

wood	test reference	oxygen per cent	carbon monoxide ppm	methane ppm
USF Method B				
aspen poplar	LAG-37	18.2	15,000	3,000
beech	LAG-12	18.5	13,000	2,600
	LAG-35	18.5	9,800	1,500
yellow birch	LAG-15	17.6	17,600	3,100
	LAG-32	18.8	6,400	1,000
red oak	LAG-29	18.6	10,200	1,900
western red cedar	LAG-30	18.5	9,100	2,100
Douglas fir	LAG-13	16.7	8,500	5,700
	LAG-36	18.3	9,700	1,600
western hemlock	LAG-31	18.0	13,500	2,100
eastern white pine	LAG-33	18.3	10,300	2,300
southern yellow pine	LAG-34	18.9	9,200	2,200
mean ± std.dev.		18.2 ± 0.6	11,025 ± 3,138	
USF Method F				
aspen poplar	AML-3	19.0	27,100	6,100
beech	BAO-13	19.1	9,000	1,500
	AML-5	18.8	24,900	5,600
red oak	NVH-22	19.0	22,900	6,000
western red cedar	NVH-24	19.6	14,700	4,400
Douglas fir	BAO-14	19.6	16,400	3,100
mean ± std.dev.		19.2 ± 0.3	19,167 ± 6,938	

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15. Supplementary Notes

16. Abstract The toxicity of the pyrolysis gases from nine wood samples was investigated, using the screening test method developed at the University of San Francisco. The samples of hardwood were aspen poplar, beech, yellow birch, and red oak. The samples of softwoods were western red cedar, Douglas fir, western hemlock, eastern white pine, and southern yellow pine.

Changing from a rising temperature program (40° C/min) to a fixed temperature program (immediate exposure to 800° C) resulted in shorter times to animal responses. This effect is attributed in part to more rapid generation of toxicants.

There was no significant differences between the wood samples under rising temperature conditions, which are intended to simulate a developing fire, or under fixed temperature conditions, which are intended to simulate a fully developed fire.

This test method can be used to determine whether a material is significantly more toxic than wood under the pre-flashover conditions of a developing fire by determining whether time to death is less than 13.5 min and time to first sign of incapacitation is less than 8.8 min using Procedure B; and to determine whether a material is significantly more toxic than wood under fully developed fire conditions by determining whether time to death is less than 5.2 min and time to first sign of incapacitation is less than 2.2 min using Procedure F.

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