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B. F. Goodrich Chemical Company

A DIVISION OF THE B. F. GOODRICH COMPANY

DEVELOPMENT CENTER

COMBUSTION TOXICOLOGICAL TESTING
PART 5:
EVALUATION OF A SERIES OF SYNTHETIC AND NATURAL PRODUCTS BASED ON INCAPACITATION RESPONSE AND ANALYTICAL COMBUSTION GAS DATA

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ABSTRACT

The NBS is playing a key role in the development of a first generation bioassay combustion-inhalation testing protocol for the acceptance of materials. A protocol will be ready in September, 1977. In January, 1977 we reviewed the results of our bioassay testing program with M. Birky of the NBS. As a result of the meeting, M. Birky asked us to quantitatively evaluate a series of materials. Therefore, we have tested Geon 8750 (rigid PVC), polychloroprene, Geon 8750 with zinc ferrocyanide, Estane 58360 and red oak wood by incapacitation bioassay testing. I will summarize the results of this work in this report. Based on the mass of material which induces 50% incapacitation, the materials are ranked as follows (best performing material listed first): Geon 8750 > Estane 58360 > polychloroprene > wood > Geon 8750 + ZFC > polychloroprene + ZFC. In the case of Geon 8750, polychloroprene and red oak wood, carbon monoxide has been found to play the dominant role in inducing the incapacitation response. In the case of Geon 8750 + ZFC and polychloroprene + ZFC, hydrogen cyanide appears to play the most important role in inducing incapacitation. In the case of Estane 58360, the combination of carbon monoxide and hydrogen cyanide may be the two most important components in inducing incapacitation.

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I. Objectives

The objectives of the current round of bioassay testing are:

1.) To evaluate a series of polymeric and natural materials on the basis of the incapacitation and mortality bioresponse.

2.) To couple analytical gas measurements to combustion bioassay testing.

3.) Assess the role of specific toxicants in observed bioresponses.

II. Conclusions

1.) The ranking of the performance of a series of materials depends on the type of bioresponse used in the evaluation.

2.) Based on the mass of material which induces 50% incapacitation, the materials are ranked as follows (best performing material listed first): Geon 8750 > Estane 58360 > polychloroprene > red oak > Geon 8750 with ZPC > polychloroprene with ZPC.

3.) Based on the mass of material which induces 50% mortality at the end of two weeks, the materials are ranked as follows (best performing material listed first): red oak > Estane 58360 > polychloroprene > Geon 8750 > polychloroprene with ZPC > Geon 8750 with ZPC.

4.) Incapacitation for Geon 8750 appears to be due to CO. Long term mortality for Geon 8750 appears to be due to HCl.

5.) Even though polychloroprene also generates HCl upon combustion, both mortality and incapacitation for polychloroprene appear to be mainly due to CO. Since on a gram for gram basis PVC generates only 2-3 times more HCl than does polychloroprene, a moderate reduction of HCl generation from PVC might dramatically improve the combustion toxicological performance.

6.) Both mortality and incapacitation for red oak appear to be due to CO.

7.) Both mortality and incapacitation for Geon 8750 with ZPC and polychloroprene with ZPC appear to be due to HCN.

8.) Estane 58360 is fire retarded with polychloroprene. This appears to cause relatively high levels of HCN evolution upon combustion. Both mortality and incapacitation appear to be due to the combination of CO and HCN.

II. Conclusions - Continued

3. For all of the materials investigated so far, we have seen no evidence that HCl plays even a minor role in inducing incapacitation.

III. Introduction

We have recently completed a fifth round of bioassay testing of the combustion products of a series of natural and synthetic materials. This report describes the objectives of this work, the experiments, their results and the conclusions.

A few years ago several model building codes began to include rules for the regulation of materials based on combustion product toxicity. In most cases these restrictions did not go into effect because no test procedure was available for the evaluation of materials. Since the needed bioassay testing protocol did not exist, the National Bureau of Standards offered to develop a first generation test procedure before September, 1977. Merit Birky was given the responsibility of developing the protocol.

Part of the research for the development of the NBS bioassay testing protocol has been done by Professor Yves Alarie at the University of Pittsburgh. Using a sensory irritation model, Alarie has investigated the combustion products from a wide range of materials. In order to interpret the results of the experiments with combustion products, Alarie has also studied the sensory irritation response to a number of pure gases. Alarie has found, using the sensory irritation model, that HCl is one of the most irritating gases. Because of this, the combustion products of PVC are very irritating in Alarie's sensory irritation model. On the basis of Alarie's sensory irritation procedure, the performance of PVC would be judged very inferior to the performance of most other materials in common useage. Until very recently, Alarie's work has been the only research available to Birky in support of the development of the needed bioassay testing protocol. Because of this, Birky has been strongly influenced by Alarie's work and this has been reflected in preliminary versions of the protocol which Birky will release in September.

Although Birky has been strongly influenced by Alarie, this [illegible] Birky has placed any restriction on which groups [illegible] to him. Therefore, last January we visited [illegible] with him some aspects of our bioassay testing [illegible] believed that by revealing some of the results [illegible] bioassay testing work that the results of Alarie's [illegible] would be brought into better perspective in Birky's view. Specifically, we wanted to familiarize Birky with our findings on the sensitivity of the ranking of a series of materials as a function of the details of the test procedure. In

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III. Introduction - Continued

addition, our own work has shown that carbon monoxide is the most important component of the combustion products of PVC in inducing incapacitation in the rotating cage experiment. Finally, we included results from our work on PVC with Zinc Ferro Cyanide to demonstrate that the protocol which we have used will detect a "super toxic" material. We believed that the results of our experiences with this material would be of great interest and value to Birky because he has emphasized that an acceptable bioassay testing protocol must be sensitive to "super toxic" materials.

Birky was very interested in the correlation which we have found of incapacitation in the rotating cage with carbon monoxide, because he did not accept the implications of the result. Basically Birky believes that HCl is very important in inducing incapacitation or loss of useful function in a fire victim. Since our work has shown that carbon monoxide and not HCl is important in inducing test animal incapacitation in the rotating cage experiment, Birky views this bioresponse as inadequate. This reflects the influence which Alarie has had on Birky.

After hearing our presentation, Birky asked us to do some new experiments and to supply him with samples of PVC/ZPC, which would be tested by Alarie. Birky wanted us to test wood, PVC and urethane so that the relative performance could be determined. Since Alarie would be testing PVC/ZPC by sensory irritation, we believed it was essential to test this material by incapacitation in the rotating cage experiment for comparison. To demonstrate that the effect of ZPC is not exclusive to PVC but that it would operate in any acid gas generating polymer, polychloroprene and polychloroprene/ZPC were also tested. Birky's request to us to do these experiments indicated a genuine receptiveness to further input. Since an input to Birky's work is vital at this point, the experiments have been done. This report gives the results of the series of experiments done in response to Birky's request.

IV. Discussion

1.) [illegible] - Procedure

[illegible] equipment, experimental conditions and procedure have [illegible] since the third round of testing[3]. Three [illegible] have been made: 1.) static animals have been [illegible]; 2.) the heating unit has been rebuilt based on nichrome [illegible] heating elements; and 3.) the squirrel cage air recirculation [illegible] has been replaced with a parastaltic pump of the same air flow rate capacity.

1.) Apparatus - Procedure - (Continued)

The physical system consists of a 40 liter inhalation chamber and a 20 liter combustion chamber interconnected by an air circulation system. The experimental conditions are the same as previously used*. The partial recirculation of the atmosphere which is used in this procedure permits the fulfillment of three critical criteria: 1.) the animals are exposed to air no hotter than 32°C; 2.) test animal anoxia is prevented since the % O_2 does not go below 18%; and 3.) a pseudo-stable atmosphere of combustion products is generated. The duration of the exposure is fifteen minutes for each experiment. Since all exposures are of the same duration, meaningful comparisons of post exposure mortality data can be made. The fifteen minute time period of the experiment is important for another reason. During combustion, PVC releases HCl early, further heating results in the evolution of CO. It is important that the test animals be exposed to the products of all phases of the decomposition process. The fifteen minute exposure allows nearly complete combustion to occur.

The inhalation chamber holds six rotating cages on a common drive shaft. One animal is placed in each cage and the cages are rotated at six RPM by an electric motor. The bioresponses which were determined with their definitions are:

1.) Incapacitation - At the end of the 15 minute exposure, the number of animals incapacitated out of six was determined. The result is reported as a percent.

2.) Time to Incapacitation - The time at which incapacitation occurred was determined for each animal which became incapacitated. The time interval during which incapacitation occurred is reported.

3.) Mortality at End of Exposure - At the end of the exposure, the number of animals dead out of the original six was determined. The result is reported as a percent.

4.) Long Term Mortality - If at the end of the exposure at least two animals were not dead, enough were sacrificed so that two were available for % CO·Hb determination. The surviving animals were returned to holding cages for observation. Food and water were available. At the end of two weeks, the cumulative number of animals dead out of the original six was determined. Animals sacrificed for % CO·Hb were not included in the statistics. The result is expressed as a percent.

* 2.5 watts/cm², smoldering combustion, 8 liters per minute of 50% relative humidity fresh air enters the combustion chamber, 16 liters per minute transfers from the combustion to the inhalation chamber, 8 liters per minute returns from the inhalation to the combustion chamber, 8 liters per minute is exhausted.

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1.) Apparatus - Procedure - Continued

Two expressions of the mass of material used in each experiment are given: 1.) the actual weight of the sample used, and 2.) a concentration parameter -- the weight of sample consumed divided by the volume of atmosphere in the experiment. This parameter facilitates intercomparison of results from various types of apparatus by accounting for differences of volume. The volume of our experiment is defined as 180 liters [40 + 20 + 15 minutes X (8 liters per minute flow rate)].

The results are shown in Table I.

2.) Developing Dose-Response Curves

The evaluation of the performance of a material is based on the mass of material which will induce 50% response. For a given material, as the mass increases, the percent of the exposed animals which will respond increases. A plot of the percent response versus the mass of material exposed is defined as a dose response curve. The mass of material which will induce 50% response can be obtained directly from such a curve. The numerical value of the mass of material which induces 50% response depends on : 1.) the specific bioresponse in question. . .incapacitation, mortality, or other, and 2.) the properties of the material. . . low or high toxic gas release. In a comparison of [illegible] materials, the material with the largest value of [illegible] which induces 50% response is judged to be better or safer.

The incapacitation bioresponse has been seen in our previous [illegible] to be a very sensitive response[3]. That is, a small increment of [illegible] of material exposed will result in a change from 0% animals responding to 100% animals responding. Ideally, dose-response curves are defined by non-zero non-100 percent responses. Experimentally this is a problem because several experiments may be required to hone in on a range of sample weights which will give the desired type of result. In order to have the best data possible for [illegible] the National Bureau of Standards, for this round of testing we have taken special efforts to define the [illegible] curves with non-zero, non-100 percent response data [illegible] is illustrated in Figure I which shows the [illegible] defined by the data from Table I for Geon 8750.

[illegible] the results for the mass of material which [illegible].

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TABLE I

Biological Response to the Products of Combustion

Part 1: Geon 8750 Rigid PVC, 50 mil Thick

Sample Mass		%	Time incapacitation occurs	% Mortality	
g exposed	mg consumed per liter air	of animals incapacitated	min:sec	at end of exposure	at end of two weeks
8.3	33.3	0	- -	0	100
9.9	42.2	17	15:00	0	75
11.2	47.4	50	9:30 - 12:30	50	100
12.7	56.1	83	11:30 - 14:30	33	75
15.8	62.2	100	11:00 - 13:45	66	100

Part 2: Geon 8750/70C Rigid PVC, 25 mil Thick

[illegible]	3.9	0	- -	0	0
[illegible]	5.6	0	- -	0	0
[illegible]	6.1	50	7:45 - 13:00	0	0
[illegible]	6.1	50	7:00 - 8:40	0	0
[illegible]	7.2	66	4:15 - 10:30	0	0
[illegible]	11.1	100	2:40 - 4:50	50	50
[illegible]	13.3	100	2:30 - 5:45	50	75

[illegible] mil Thick

3.1	19.5	0	- -	0	0
[illegible]	19.4	17	12:15	0	0
[illegible]	25.0	83	11:45 - 14:45	0	0
7.2	[illegible]	100	9:30 - 12:15	33	33
8.2	[illegible]	100	9:25 - 12:40	50	100
11.1	[illegible]	100	5:00 - 6:15	100	100

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Table I - (Continued)

Part 4: Polychloroprene/XPC, 20 mil Thick

Sample Mass		% of animals incapacitated	Time incapacitation occurs min:sec	% Mortality	
gm exposed	mg condensed per liter air			at end of exposure	at end of two weeks
1.01	3.9	0	- -	0	0
1.05	3.3	0	- -	0	0
1.10	4.4	17	12:45	0	0
1.25	4.7	66	3:50 - 7:00	0	0
1.50	6.7	100	3:45 - 7:20	0	0
2.25	8.2	100	1:50 - 10:00	0	25
2.50	11.1	100	2:10 - 3:15	0	0
2.75	12.5	100	1:15 - 2:45	83	83
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	15:00	0	0
[illegible]	[illegible]	[illegible]	12:45 - 14:50	0	0
[illegible]	[illegible]	[illegible]	11:45 - 15:00	0	75
[illegible]	[illegible]	[illegible]	10:45 - 14:20	0	25
[illegible]	[illegible]	[illegible]	8:30 - 9:55	83	83
[illegible]	[illegible]	[illegible]	8:00 - 10:35	100	100
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	33	13:40 - 14:05	0	25
[illegible]	[illegible]	[illegible]	13:00 - 14:55	0	0
7.5	[illegible]	[illegible]	12:00 - 15:00	17	0
[illegible]	[illegible]	[illegible]	9:45 - 13:30	83	83

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FIGURE 1

Dose Response Curve for Geon 8750

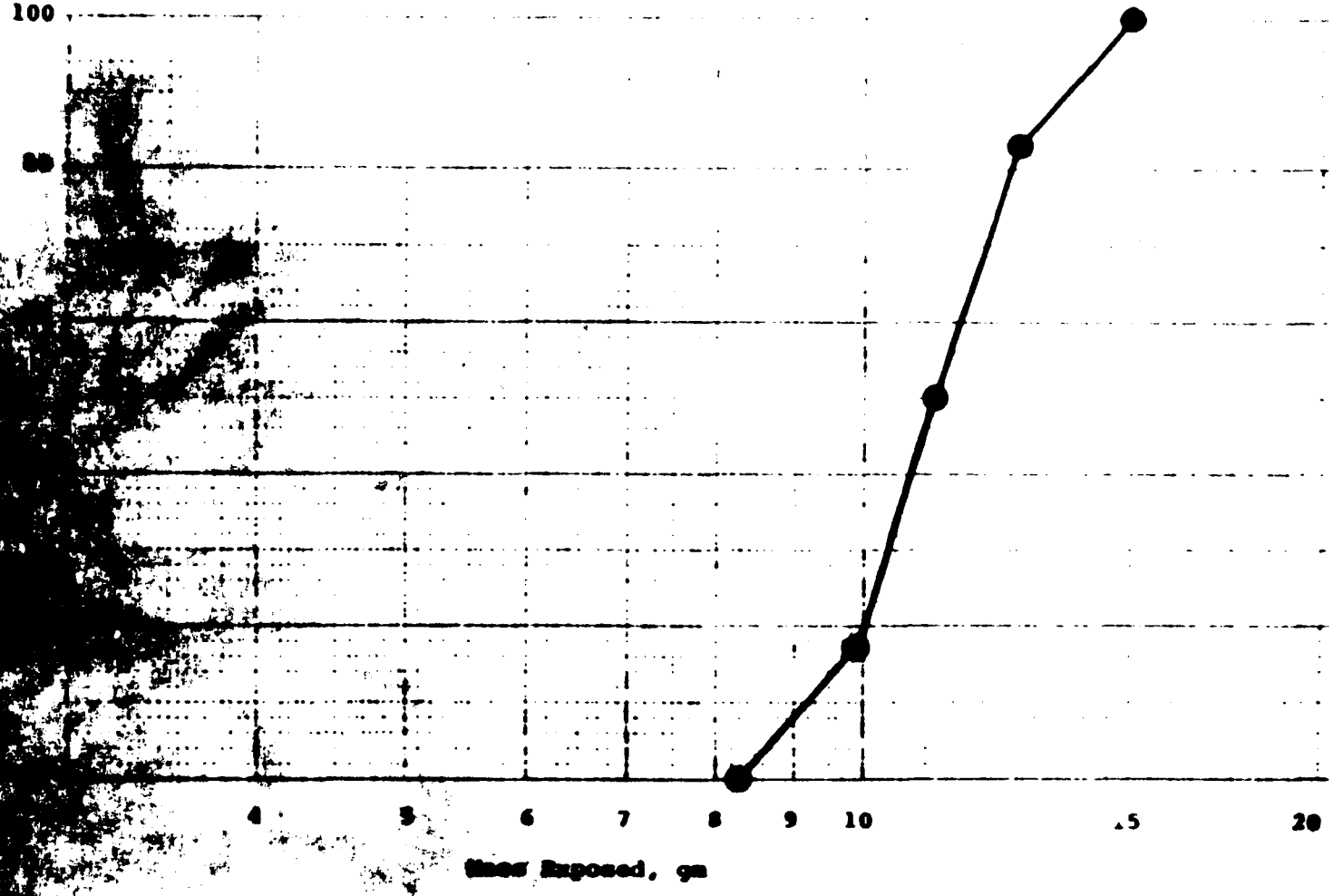

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TABLE II

Mass of Material Which Induces a 50% Response for Various Bioresponses

Material	Bioresponses: Incapacitation	Mortality: At End of Exposure	Mortality: At End of Two Weeks
Geon 8750			
gm exposed	11.2	12.5	< 8.3
mg consumed per liter air	47.3	52.8	< 35.0
Geon 8750/EPC			
gm exposed	1.45	2.7	2.5
mg consumed per liter air	6.3	11.6	10.8
Polychloroprene			
gm exposed	4.5	8.1	7.5
mg consumed per liter air	22.4	40.2	37.2
Polychloroprene/EPC			
gm exposed	1.2	2.7	2.7
mg consumed per liter air	4.8	10.8	10.8
Red Oak			
gm	3.9	9.4	9.1
mg	20.8	50.0	48.4
Butyl 9310			
gm exposed	5.0	8.1	7.7
mg consumed per liter air	22.3	36.2	34.4

3.) Comparison of Materials

Based on the data from Table II for the mass of material which will induce 50% incapacitation, the materials are ranked as follows (best performing material listed first : Geon 8750 > Estane 58360 > polychloroprene > Red Oak > Geon 8750/ZFC > polychloroprene/ZFC. The performance of Geon 8750 is measurably superior to that of any of the other materials. The next best material is Estane 58360, more than twice as much Geon 8750 as Estane 58360 is required to induce 50% incapacitation. The three materials, Estane 58360, polychloroprene and red oak, for practical purposes are equivalent. The effect of ZFC in imparting excessive toxicity to chlorine containing polymers is demonstrated in the performance of Geon 8750/ZFC and polychloroprene/ZFC. Nearly ten times as much Geon 8750 as Geon 8750/ZFC or polychloroprene/ZFC is required to induce 50% incapacitation.

We have seen as shown in Table II that for different materials there are substantial differences in the mass of material which induces a 50% response. Likewise for different materials there may be substantial differences in the time at which response occurs. This phenomenon has served many workers in this field as a basis from which to evaluate and rank materials. For example, Smith and Crane[4] of the FAA evaluate materials on the basis of time to incapacitation (t_i), all materials compared at equal mass. Smith and Crane believe that this parameter may have some relationship to the amount of time which would be available to escape a burning environment. Thus, the greater t_i is, the better the material. This approach is valid and indeed both parameters (t_i and mass which induces incapacitation) are important in any complete account of the toxicological properties of a material. This philosophy is being implimented into the latest results from the University of Michigan program[5]. In our previous rounds of incapacitation bioassay testing, no substantial differences of the time to incapacitation were noted for the materials which were tested. For any given material, samples of relatively low weight would induce no response. In the case of samples which induced incapacitation of some of the animals, incapacitation occurred at about 12-15 minutes. Relatively heavy samples induced incapacitation at about 9-12 minutes. However, dramatically different behavior was observed for the two ZFC containing materials evaluated in this round of testing. This is illustrated in Table III which shows the time to incapacitation corresponding to the mass of material which induces 50% incapacitation. The data in Table III is calculated from the results of Table I. Incapacitation occurs much earlier in the case of the ZFC containing materials. This represents an added dimension to the hazard of these materials. In order to demonstrate the combined effect of the mass of material which induces incapacitation and the time to incapacitation, the following hazard index equation is offered:

$$\text{Hazard Index} \quad \frac{1}{IC_{50} \times t_i} \qquad (1)$$

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TABLE III

Time to Incapacitation Associated with the Mass of Material Which Induces 50% Incapacitation (Estimated From Data in Table I)

Material	t_i, min.
Geon 8750	13
Polychloroprene	13
Red Oak	14
Estane 58360	14
Geon 8750/ZFC	8
Polychloroprene/ZFC	5.5

It must be emphasized that the purpose of Equation (1) is purely illustrative. IC_{50} is the mass which induces 50% incapacitation. The larger the value of the hazard index for a particular material, the greater the toxicological hazard. The hazard index values for the six materials are shown in Table IV. Based on the results in Table IV, the least hazardous material out of the six is separated from the most hazardous by a factor of about twenty. The worst performing -- and therefore the least acceptable -- materials are the two ZFC containing compounds.

Our primary objective in this round of testing was to obtain animal incapacitation data for the six selected materials. Merit Birky of the NBS believes that loss of survival response or incapacitation is the best bioresponse to use in the assessment of combustion product hazard[6]. This philosophy will almost certainly be reflected in the bioassay testing protocol which the NBS is developing for the use of code groups and regulatory agencies to [illegible] acceptability. Also the incapacitation response [illegible] important in relation to the hazard of the real fire [illegible] because incapacitation of a fire victim represents the [illegible] which he cannot rescue himself. If the victim cannot [illegible] himself, death is virtually certain. However as a secondary [illegible] this round of testing, we have attempted to also obtain [illegible] data (at end of exposure and at end of two weeks post exposure) for the six selected materials. This was considered to be important for the following reason. Several important workers in the field base their evaluations of the performance of materials on the mortality response[7,8]. Secondly, Alarie evaluates

TABLE IV

Hazard Index Values
Calculated from Data in Table II and Table III

Material	Hazard Index
Geon 8750	0.007
Polychloroprene	0.017
Red Oak	0.018
Estane 58360	0.014
Geon 8750/ZFC	0.086
Polychloroprene/ZFC	0.151

materials not only on the basis of sensory irritation but also on the mortality response. These workers consider the mortality hazard an important parameter in the total toxicological equation. Therefore, despite the fact that Birky considers incapacitation to be the most useful bioresponse for the evaluation of the combustion products of materials, the mortality response to combustion products may show up as, at least, a part of the final proposal. For this reason, it is important to have some basic understanding of the performance of our materials with respect to the mortality response.

[redacted] materials are evaluated and compared on the basis of the mass which produces 50% mortality. The results are listed in [redacted] results for the mass of material which induces 50% [redacted] in Table II must be considered as estimates. This is because the mortality response is relatively less sensitive to the mass of material combusted than is the incapacitation response. That is, it is necessary to make large changes in mass [redacted] combusted in order to effect the percent mortality. [redacted] determination of the mass of material which induces [redacted] relatively less precise than the determination [redacted] material which induces 50% incapacitation. Also, [redacted] to anticipate the correct range of mass of material [redacted] properly span the range of mortality response in [redacted] of the two week post exposure mortality results. Reduced animal resistance to disease as a result of the combustion exposure can also confuse the two week post exposure mortality data. With these reservations in mind, a comparison can be made.

3.) Comparison of Materials - Continued

Based on the data in Table II for the mass of material which will induce 50% mortality at the end of two weeks, the materials are ranked as follows (best performing material listed first): Red Oak > Estane 58360 > polychloroprene > Geon 8750 > polychloroprene/ZFC > Geon 8750/ZFC. The rank of Geon 8750 was based on results obtained in the third round of testing where the mass of Geon 8750, which induced 50% mortality at the end of two weeks, was 6.1 grams. In the current round, samples low enough in mass to define this result were not used. Essentially equivalent performance is observed for red oak, Estane 58360, polychloroprene and Geon 8750. The performance of Geon 8750/ZFC and polychloroprene/ZFC is significantly inferior to that of the other four materials. Again the effect of ZFC in imparting excessive toxicity to chlorine containing polymers is demonstrated in the performance of Geon 8750/ZFC and polychloroprene/ZFC.

These results for the ranking of the materials based on the three bioresponses are summarized in Table V. Table V shows that Geon 8750 outperforms red oak on the basis of the incapacitation response but red oak outperforms Geon 8750 on the basis of the mortality at the end of two weeks response. This reversal of performance is due to the role different components of the combustion products play in inducing different bioresponses. We have previously seen that CO plays the dominant role in inducing incapacitation[3]. Since wood generates more CO than PVC does, PVC outperforms wood on the basis of the incapacitation response. On the other hand, our earlier work has also shown that HCl plays a very important role in inducing mortality[9]. Since PVC generates HCl and wood does not, wood outperforms PVC on the basis of the mortality response. The role of specific components of combustion products in inducing response will be discussed in greater detail in a later section of this report.

One of the major conclusions from our earlier work[9,10] is that while using only one bioresponse (death), the details of the conditions of combustion of the samples have a pronounced effect on the ranking of a series of materials. The results of this round of testing demonstrate that the ranking of a series of materials also depends strongly on which specific incapacitation bioresponse is used for the evaluation. Earlier this year, Birky related to us some results from Alarie and Jounay for the ranking of wood, PVC and polyurethane based on the sensory irritation type of bioresponse[2]. These results are summarized in the first two columns of Table VI and show that on the basis of this response, the performance of wood is superior to the performance of PVC by a factor of about one hundred. For comparison, our results for the performance of wood, PVC and polyurethane based on incapacitation in the rotating cage are given in the third column of Table VI. These results show that the performance of PVC is more than a factor of two superior to the performance of wood. This reversal of the order of ranking of wood and PVC was surprising,

TABLE V

Ranking* of Materials Based on Mass
which Induces 50% Response for Various Bioresponses

Material	Bioresponses		
	Incapacitation	Mortality	
		At End of Exposure	At End of Two Weeks
Geon 8750	1	1	4
Polychloroprene	3	3	3
Estane 58360	2	3	2
Red Oak	4	2	1
Geon 8750/ZPC	5	4	6
Polychloroprene/ZPC	6	4	5

* Best performing material = 1
Materials ranked identically when they have the same value of mass which induces 50% response.

TABLE VI

Mass of Material Which Induces a 50% Response

[redacted]	Bioresponses		
	Alarie Sensory Irritation	Jouney Sensory Irritation	Incapacitation in Rotating Cage
[redacted]	0.5	0.5	47
[redacted]	50	66	21
[redacted]	50	30	22

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3.) Comparison of Materials - Continued

but is not due to differences in the details of the sample combustion. Rather it is the outcome of the fact that each incapacitation bioresponse is sensitive to different individual chemical components of the combustion gases. Alarie has shown that HCl is much more important than CO in inducing sensory irritation. Our own work has shown that CO is much more important than HCl in inducing incapacitation in the rotating cage. Since PVC generates HCl and wood does not, and wood generates more CO than PVC, evaluation by incapacitation in the rotating cage shows wood worse than PVC. Our results suggest that the importance of HCl in a real fire situation may have been greatly overemphasized. This issue must be further investigated. However, as shown in Table VI, our work has established that the ranking of a series of materials depends on which type of bioresponse is used for the evaluation. Since all incapacitation bioresponses do not rank all materials in roughly the same order, for a bioassay testing protocol to be used to control the acceptability of materials, it is critical to establish which bioresponse most realistically models the real fire hasard. Merit Birky must decide which type of bioresponse most closely models the hazard of a real fire situation. Our input to him on the basis of the work reported here should be useful in that it demonstrates that not all incapacitation bioresponses are equivalent.

One feature of a bioresponse which adequately models the real fire hazard is that it will detect materials which are excessively toxic. Based on incapacitation in the rotating cage, addition of FPC to Geon 8750 increases the toxicity by more than a factor of ten. Thus, it appears that the incapacitation bioresponse, as determined in the rotating cage, is sensitive to "super toxicants".

4.) Analytical Data

Our bioassay testing program has been coupled with a program of analytical gas measurements. Through correlation of bioresponses with the dose of specific components of combustion products, it is possible to identify the components most important in inducing response. A basic understanding of the factors contributing to the observed bioresponses enhances the reliability of our work. In addition to this, such information serves as a basis for analytical programs for the guidance of programs for the development of improved materials.

The gases we have monitored included CO, HCl and HCN. Samples for CO were collected in vaccutainers, carried back to ALTC and analyzed by GC. The HCl content of the atmosphere was determined on-site using a chloride ion selective electrode method. The details of the procedures for CO and HCl have been reported[3,9,10]. The procedure for the determination of the HCN content of the

4.) Analytical Data - (Continued)

atmosphere was the same as the HCl procedure except that the absorbing solution was dilute NaOH and the electrode was a cyanide ion selective electrode. Simultaneous measurements of HCl and HCN were not possible in the case of materials which generate both because cyanide interferes with the chloride ion selective electrode. In these cases, measurements were made only for HCN content. During the course of each exposure experiment, sufficient samples were taken in order to adequately define the nature of the concentration-time profiles of the gases. At the end of each 15 minute exposure, blood samples were taken from the two weakest animals for CO·Hb determination. The concentration-time data is used to calculate the total dose to which the test animals are exposed during the course of the experiment. The dose is directly related to the integral of the concentration-time profile and this parametsr has been determined for each gas in each experiment. The results are given in Table VII.

From the data in Table II and Table VII, we are able to deduce the dose of CO·Hb, CO, HCl, and HCN associated with 50% response for each material. The results are given in Table VIII. The best way to determine the significance of CO, HCl, and HCN in inducing bioresponse would be to compare the results from Table VIII with the results of experiments where response is induced with pure gases. However, we do not have the required pure gas-bioresponse information. But by investigating a series of materials which have differing composition of the combustion products, it is possible to identify the important components in inducing bioresponse. When the same high dose of a specific toxicant from at least two different source materials induces the same bioresponse, it is justified to conclude that that toxicant is important in inducing the bioresponse. When low doses for all analyzed gases are associated with the bioresponse to a particular material, either of two conclusions is possible: 1.) the combination of toxicants is important, or 2.) some other component unaccounted for is responsible.

5.) Relationship of Dose of Specific Components of Combustion Products to Mortality Hazard

For 50% mortality at the end of the exposure with Geon 8750, the [illegible] is 64% and the dose of HCl is 105,000 ppm-minute. In the third round of bioassay testing, Geon 8750 and Geon 87235 were both evaluated on the basis of the mortality response at the end of the exposure. The levels of CO·Hb were 65% and 58% and the levels of HCl were 56,000 ppm-minute and 44,000 ppm-minute, respectively. These results suggest that in the presence of HCl mortality is induced at the end of the exposure with 60-65% CO·Hb. The response is apparently somewhat insensitive to the level of HCl since we have found 44,000-105,000 ppm-minute at the end-point.

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TABLE VII

Analytical and Biological Dose Data

Part 1: Gmm 8750

8.3 Grams Butanol, 49-53% CO·Hb

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
1.00	6,600	3,300				
2.25	16,500	17,700				
3.00			760	1,140		
3.50	13,000	36,200				
4.75	6,300	48,300				
5.00	3,200	54,200	1,780	4,950		
	1,300	58,700				
			1,920	10,500		
	500	61,400				
			3,000	17,870		
.00	300	63,200	2,890	26,710		

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17.

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
9.9 Grams Exposed, 49-58% CO-Hb						
1.00	7,100	3,600				
2.25	16,500	18,300				
3.0			930	1,390		
3.50	10,600	35,300				
4.75	5,200	45,200				
6.00	2,700	50,100	2,680	6,800		
8.00	1,300	54,200				
9.00			3,540	16,120		
11.00	900	57,600				
12.00			2,520	25,210		
15.00	400	60,300	2,520	32,780		
[illegible] Grams Exposed, 45-45% CO-Hb						
[illegible]	15,500	7,800				
[illegible]	25,800	33,600				
[illegible]			1,390	2,090		
[illegible]	19,600	62,000				
4.75	11,800	81,700				
6.00	6,600	93,200	3,420	9,320		
8.00	2,700	102,400				
9.00			3,640	19,910		
11.00	1,100	108,200				
12.00			3,530	30,670		
15.00	800	112,200	2,870	40,280		

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
12.7 Grams Exposed, 68-68% CO·Hb						
1.00	1,400	700				
2.25	6,200	5,500				
3.00			620	930		
3.50	8,200	14,500				
4.75	3,900	22,000				
6.00	2,100	25,700	3,360	6,910		
8.00	1,100	28,900				
9.00			4,800	19,200		
11.00	600	31,500				
12.00			4,300	32,800		
13.00	500	33,700	3,840	45,010		
[illegible] Grams Exposed, 71% CO·Hb						
[illegible]	16,800	10,500				
[illegible]	29,800	39,700				
[illegible]			1,120	1,680		
[illegible]	23,300	72,900				
[illegible]	13,700	96,000				
[illegible]			3,440	8,530		
[illegible]	6,300	111,100				
[illegible]	2,700	120,100				
[illegible]			4,150	19,920		
[illegible]	1,200	125,000				
[illegible]			4,060	32,240		
[illegible]	700	128,900	3,460	43,520		

Table VII - (Continued)

Part 2: Geon 8750/ZFC

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
1.00 Grams Exposed, 17-14% CO·Hb						
1.00					1,110	560
2.25					970	1,860
3.00			30	50		
3.75					470	2,940
5.00					280	3,400
6.00			390	700		
6.50					140	3,730
9.00			460	1,980	60	3,980
12.00			290	3,120	30	4,120
15.00			180	3,840	20	4,190
1.30 Grams Exposed, 14-15% CO·Hb						
1.00					490	240
2.25					450	830
3.00			-	-		
5.00					350	1,340
6.75					250	1,720
8.00			280	420	190	1,990
9.00					130	2,310
9.00			460	1,540		
11.00					70	2,620
12.00			300	2,680		
15.00			180	3,400	30	2,810

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
1.36 Grams Exposed, 20-9% CO·Hb						
1.00					450	230
2.25					590	880
3.00			-	-		
3.50					490	1,560
4.75					370	2,100
6.00			-	-		
6.30					240	2,640
[illegible]			210	320	140	3,110
[illegible]			390	1,220	70	3,420
[illegible]			320	2,290	30	3,580
[illegible] Grams Exposed, 22-26% CO·Hb						
1.00					580	290
[illegible]					560	1,010
[illegible]			-	-		
[illegible]					430	1,630
[illegible]					300	2,090
[illegible]			150	230	240	2,430
[illegible]					160	2,840
[illegible]			350	980		
[illegible]					70	3,190
[illegible]			270	1,900		
[illegible]			240	2,670	30	3,400

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
1.60 Grams Exposed, 33-16% CO·Hb						
1.00					760	380
2.25					650	1,260
3.00			50	80		
3.50					500	1,980
4.75					330	2,500
6.00			300	600	250	2,860
8.00					150	3,270
9.00			290	1,480		
11.00					70	3,610
12.00			210	2,230		
15.00			200	2,870	30	3,830
[illegible] Grams Exposed, 25-15% CO·Hb						
1.00					1,410	700
2.25					1,210	2,340
[illegible]			310	470		
[illegible]					800	3,600
[illegible]					590	4,470
[illegible]			850	2,210	440	5,110
8.00					270	5,810
9.00			1,110	5,140		
11.00					140	6,430
12.00			820	8,030		
15.00			600	10,160	60	6,830

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
2.98 Grams Exposed, 11-15% CO-Hb						
1.00					780	390
2.25					1,080	1,560
3.00			-	-		
3.50					870	2,780
4.75					700	3,760
6.00			450	670	540	4,540
8.00					350	5,430
9.00			770	2,500		
11.00					230	6,290
12.00			810	4,880		
15.00			690	7,130	140	7,010
Part 3: Polychloroprene						
2.1 Grams Exposed, 51.5% CO-Hb						
1.00	680	340				
2.25	830	1,290				
3.00			740	1,120		
3.50	510	2,130				
4.75	330	2,660				
6.00	220	3,000	1,830	4,980		
8.00	190	3,420				
9.00			3,070	12,320		
11.00	130	3,900				
12.00			2,760	21,050		
15.00	90	4,350	2,010	28,200		

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
4.0 Grams Exposed, 40-50% CO·Hb						
1.00	1,000	500				
2.25	1,000	1,800				
3.00			840	1,260		
3.50	590	2,850				
4.75	310	3,410				
6.00	230	3,740	2,290	5,960		
8.00	230	4,210				
9.00			3,800	15,090		
11.00	180	4,820				
12.00			3,410	25,890		
15.00	130	5,440	2,650	34,980		
4.5 Grams Exposed, 46.5-46.5% CO·Hb						
1.00	940	470				
2.25	1,870	2,230				
3.00			1,480	2,210		
3.50	1,470	4,320				
4.75	770	5,720				
6.00	510	6,520	3,220	9,260		
8.00	400	7,440				
9.00			4,840	21,350		
11.00	320	8,520				
12.00			4,420	35,230		
15.00	190	9,540	3,290	46,790		

Table VII (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
7.2 Grams Exposed, 87-76% CO-H						
1.00	900	450				
2.25	2,650	,670				
3.00			2,490	3,730		
3.50	1,100	,020				
4.75	900	,270				
6.00	560	,180	4,850	14,740		
8.00	420	,160				
9.00			7,010	32,530		
11.00	250	,160				
12.00			6,420	52,680		
15.00	220	1 ,110	4,440	68,980		
8.2 Grams Exposed, 76-63% CO-H						
1.00	2,000	,000				
2.25	7,990	,240				
3.00			2,400	3,610		
3.50	4,160	1 ,830				
4.75	1,840	1 ,580				
6.00			4,200	13,520		
6.50	670	2 ,780				
8.00	540	2 ,680				
9.00			6,570	29,670		
11.00	310	2 ,960				
12.00			7,620	50,970		
15.00	260	2 ,090	6,650	72,380		

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
11.1 Grams Exposed, 88-83% CO-Hb						
1.00	5,350	2,670				
2.25	16,210	16,150				
3.00			8,880	13,320		
3.50	8,750	31,750				
4.75	4,540	40,060				
6.00	2,260	44,300	12,560	45,480		
8.00	1,080	47,640				
9.00			12,240	82,680		
11.25	880	50,810				
12.00			8,600	113,950		
15.00	510	53,420	6,390	136,440		
Mat 4: Polychloroprene/ZPC						
1.01 Grams Exposed, 16-6% CO-Hb						
1.00					440	220
2.25					490	800
3.00			-	-		
3.50					390	1,350
5.00					271	1,850
6.00			-	-		
6.50					190	2,200
9.00			120	180	100	2,570
12.00			110	520	50	2,800
15.00			-	690	30	2,920

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
1.05 Grams Exposed, 12-11% CO·Hb						
1.00					590	300
2.25					550	1,010
3.00			-	-		
3.50					390	1,600
4.75					290	2,030
6.00			-	-		
8.00					140	2,680
9.00			100	160		
11.00					70	2,990
12.00			150	540		
15.00			140	990	30	3,200
1.10 Grams Exposed, 9-20% CO·Hb						
1.00					550	270
2.25					550	960
3.00			-	-		
3.50					420	1,570
4.75					290	2,020
6.00			60	90	230	2,350
8.00					140	2,720
9.00			120	360		
11.00					80	3,040
12.00			130	720		
15.00			110	1,080	40	3,270

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
1.25 Grams Exposed, 7-9% CO·Hb						
1.00					710	360
2.25					640	1,200
3.00			-	-		
3.50					460	1,880
4.75					370	2,400
6.00			40	60	270	2,790
8.00					160	3,230
9.00			160	360		
11.00					90	3,610
12.00			150	830		
15.00			180	1,330	40	3,870
1.50 Grams Exposed, 9-4% CO·Hb						
1.00					730	360
2.25					730	1,270
3.00			60	90		
3.50					560	2,080
4.75					400	2,680
6.00			240	390	270	3,100
8.00					160	3,530
9.00			270	1,000		
11.00					90	3,900
12.00			280	1,820		
15.00			270	2,640	30	4,150

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
2.24 Grams Exposed, 21-29% CO-Hb						
1.25					1,180	[illegible]
2.50					1,050	2,[illegible]
3.00			170	250		
3.75					800	3,290
5.00					620	4,170
6.00			410	1,110		
6.25					460	4,840
8.50					250	5,640
9.00			390	2,300		
11.00					140	6,120
12.00			450	3,560		
15.00			430	4,880	50	6,510
[illegible] Grams Exposed, 18-18% CO-Hb						
[illegible]					1,320	660
[illegible]					1,180	2,220
[illegible]			620	930		
[illegible]					840	3,480
[illegible]					620	4,380
[illegible]			880	3,180	440	5,040
[illegible]					270	5,750
[illegible]			880	5,830		
[illegible]					120	6,330
[illegible]			780	8,330		
[illegible]			660	10,500	50	6,560

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
2.97 Grams Exposed, 9-7% CO·Hb						
1.00					1,930	960
2.25					1,590	3,160
3.00			520	770		
3.50					1,220	4,920
4.75					900	6,250
6.00			710	2,610	670	7,230
8.00					390	8,290
9.00			720	4,750		
11.00					180	9,150
12.00			680	6,850		
18.00			600	8,770	70	9,660
Part 5: Red Oak						
[illegible] Grams Exposed, 54-55% CO·Hb						
3.00			1,100	1,660		
6.00			3,240	8,170		
9.00			3,420	18,160		
12.00			2,880	27,600		
[illegible].00			2,160	35,160		

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
4.3 Grams Exposed, 62-71.5% CO-Hb						
3.00			1,010	1,520		
6.00			4,010	9,050		
9.00			4,250	21,440		
12.00			3,920	33,700		
15.00			3,480	44,800		
6.6 Grams Exposed, 69.5-73.5% CO-Hb						
3.00			1,250	1,880		
6.00			5,010	11,270		
9.00			5,520	27,070		
12.00			5,300	43,300		
15.00			4,500	57,990		
8.5 Grams Exposed, 58-61% CO-Hb						
3.00			870	1,310		
6.00			5,560	10,960		
9.00			7,380	30,360		
12.00			6,570	51,270		
15.00			6,010	70,140		
[illegible] Grams Exposed, 81-83% CO-Hb						
3.00			1,850	2,780		
6.00			8,480	18,270		
9.00			9,030	44,520		
12.00			8,440	70,720		
15.00			7,340	94,380		

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
12.5 Grams Exposed, 82.5-85% CO·Hb						
3.00			1,930	2,890		
6.00			10,720	21,860		
9.00			12,800	57,140		
12.00			11,380	93,400		
15.00			10,070	125,580		
Part 6: Butane 68360						
Grams Exposed, 36-37% CO·Hb						
2.00					10	10
3.00			30	40		
[illegible]					10	30
[illegible]					20	60
[illegible]					70	110
[illegible].00			890	1,420		
[illegible]					130	240
[illegible]			1,710	5,330	210	570
[illegible]			2,180	11,170	310	1,340
[illegible]			2,130	17,630	310	2,260

Table VII - (Continued)

Time, min	HCl, ppm	HCl ppm-min	CO, ppm	CO ppm-min	HCN, ppm	HCN ppm-min
5.5 Grams Exposed, 54-45% CO·Hb						
1.00					30	10
2.25					20	40
3.00			350	520		
3.50					20	60
4.75					60	110
6.00			1,510	3,310	120	230
9.00			2,640	9,530	270	830
12.00			2,880	17,800	330	1,730
18.00			2,650	26,100	310	2,690
[illegible] Grams Exposed, 70.5-35.5% CO·Hb						
[illegible]			220	330	20	30
[illegible]			1,380	2,740	90	210
[illegible]			2,400	8,420	280	780
[illegible]			3,360	17,060	490	1,940
[illegible]			3,480	27,310	550	3,500
[illegible] Grams Exposed, 70.5-74% CO·Hb						
[illegible]			730	1,090	40	60
[illegible]			2,960	6,630	180	410
[illegible]			4,480	17,780	530	1,480
[illegible]			5,440	32,670	700	3,310
[illegible]			5,350	48,850	700	5,400

TABLE VIII

Dose for 50% Bioresponse

Material	CO·Hb %	15 min CO ppm-min	15 min HCl ppm-min	15 min HCN ppm-min
Incapacitation				
Geon 8750	58	37,000	92,000	-
Geon 8750/ZFC	21	4,500	-	3,600
Polychloroprene	53	41,000	7,500	-
Polychloroprene/ZFC	12	1,400	-	3,500
Red Oak	59	38,000	-	-
Estane 58360	45	24,000	-	2,400
Mortality at End of Exposure				
Geon 8750	64	42,000	105,000	-
Geon 8750/ZFC	20	8,500	-	6,800
Polychloroprene	80	75,000	24,000	-
Polychloroprene/ZFC	20	8,800	-	7,800
Red Oak	80	92,000	-	-
Estane 58360	70	39,000	-	4,400
Mortality at End of Two Weeks				
Geon 8750	< 47	< 27,000	< 63,000	-
[redacted]	20	7,800	-	6,200
[redacted]	75	69,000	22,000	-
[redacted]	20	8,800	-	7,800
[redacted]	79	90,000	-	-
[redacted]	67	37,000	-	3,800

5. Relationship of Dose [illegible] Products to Mortality Hazard

Low levels of HCl require higher levels of [illegible] to cause mortality at the end of the exposure. Apparently, with HCl at or below 24,000 ppm-minute, it does not strongly contribute to mortality at the end of the exposure. This is seen for polychloroprene and red oak where % CO·Hb is 80% for both. Carbon monoxide is probably the most important component of the combustion products of polychloroprene and red oak in inducing mortality at the end of the exposure. Low % CO·Hb is seen for Geon 8750/ZFC and polychloroprene/ZFC. We were not able to make measurements; however, it is likely that the level of HCl is significantly higher for Geon 8750/ZFC than for polychloroprene/ZFC at 50% mortality at the end of the exposure. The HCN levels are 6,800 ppm-minute and 7,800 ppm-minute respectively. These results suggest that HCN is probably the most important component in the decomposition products of Geon 8750/ZFC and polychloroprene/ZFC in inducing mortality at the end of the exposure. Moderate levels of % CO·Hb and of HCN are seen for Estane 58360. This suggests that in the case of Estane 58360, both carbon monoxide and HCN contribute to inducing mortality at the end of the exposure.

Comparison of the results for all materials, except Geon 8750, for mortality at the end of the exposure and at the end of two weeks shows insignigicant differences. This is because for, these materials after the end of the exposure, no further fatalities occur. Thus the same factors responsible for mortality at the end of the exposure are responsible for mortality at the end of two weeks. The case of Geon 8750, however, is dramatically different. During the two week post exposure holding period, fatalities continue to occur. This delayed mortality feature appears to be characteristic of PVC. The component of the combustion products of Geon 8750 responsible for the mortality response during the two week post exposure holding period appears to be the HCl. This is seen in comparison of the results from Geon 8750 and from polychloroprene for mortality at the end of two weeks. For Geon 8750, the level of HCl is higher while the level of % CO·Hb is lower than the corresponding levels from polychloroprene.

It is further very interesting to note that the performance of polychloroprene is different from the characteristic performance of PVC in that significant numbers of post exposure mortalities do not occur. Since post exposure mortalities in the case of PVC are due to HCl, this suggests that if the evolution of HCl from PVC could be reduced to the level of evolution of HCl from polychloroprene, the performance of PVC on the basis of mortality at the end of two weeks could be dramatically improved. Data in Table VII shows that Geon 8750 evolves only 2-3 times more HCl per gram than does polychloroprene.

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5.) Relationship of Dose of Specific Components of Combustion Products to Mortality Hazard - (Continued

For the current round of bioassay testing the purpose of the preceeding analysis is to substantiate the ranking and evaluation of the series of materials in part (3) of the Discussion section. It is not adequate to simply evaluate a material on the basis of animal response to the combustion products. It is necessary to have some understanding of how the response is induced by the combustion products. This gives a more complete account of the potential toxicological properties of a material beyond a simple rank ordering of a series from "worst" to "best". Two materials which are ranked equivalently may be evaluated differently if their mode of action is different. Fairly or not, carbon monoxide is considered an acceptable hazard of a fire situation. A material which induces response via carbon monoxide is considered more acceptable than a material which has a different mode of action. Coupling analytical testing to bioassay testing also has the effect of enhancing the reliability of the bioresponse results.

6.) Relationship of Dose of Specific Components of Combustion Products to Incapacitation Hazard

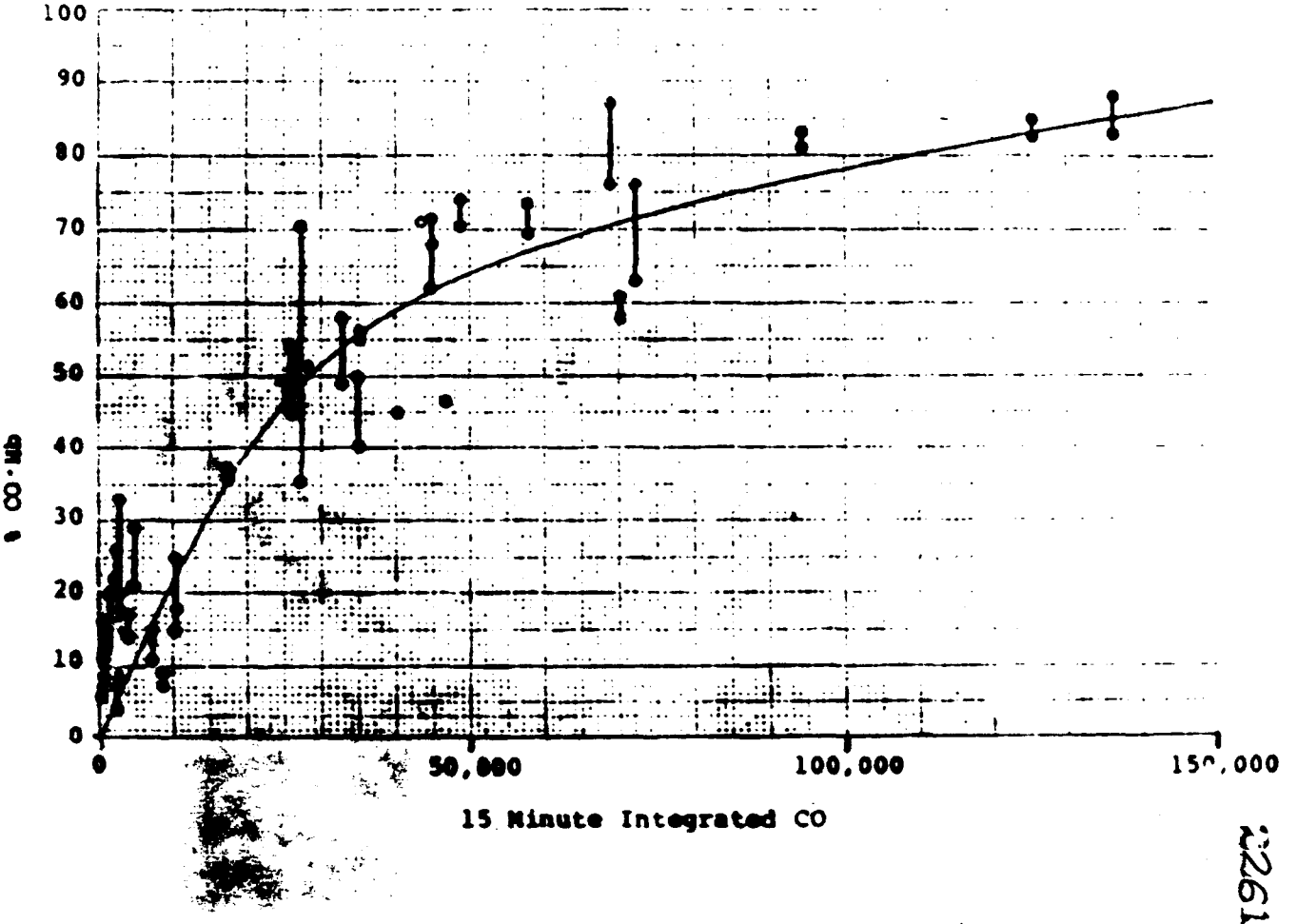
In the current round of testing, we have evaluated a series of chlorine containing and other materials which spans a wide range of chlorine content. . . .red oak 0% to PVC 56%. Thus, a better evaluation of the role of HCl in inducing incapacitation can be made compared to the third round of testing[3] where only PVC compounds were used. The range of HCl at incapacitation is 0-92,000 ppm-minutes for red oak, polychloroprene, and Geon 8750. This lack of correlation of level of HCl with the incapacitation response demonstrates that HCl is not important in inducing the incapacitation response. However, the range of % CO·Hb associated with 50% incapacitation for these three materials is in the range 53-59% CO·Hb. The carbon monoxide levels are in the range 37,000-41,000 ppm-minute. This demonstrates that incapacitation is primarily due to carbon monoxide for red oak, polychloroprene, and Geon 8750. This result (that HCl is not important in inducing incapacitation in the preceding [illegible] experiment) suggests that the importance of HCl in the real fire situation may be overestimated. However, this [illegible] further investigation.

The relationship between atmospheric carbon monoxide and % CO·Hb is demonstrated in Figure II. Figure II includes the results from each experiment conducted in this round of testing. The relationship defined by the data in Figure II demonstrates that the combustion components, other than CO, have a negligible effect on the uptake of CO.

Low values of % CO·Hb are associated with incapacitation in the case of Geon 8750/ZFC and polychloroprene/ZFC. These materials generate hydrogen cyanide upon heating, however; and the level of HCN is 3,600 ppm-minute and 3,500 ppm-minute from Geon 8750/ZFC

FIGURE 2

Relationship of % CO·Hb to Atmospheric CO



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6.1 Relationship of Dose of Specific Components of Combustion Products to Incapacitation Hazard - (continued)

and polychloroprene/ZFC respectively at incapacitation. The data in parts 2 and 4 of Table VII shows that hydrogen cyanide is generated early from Geon 8750/ZFC and polychloroprene ZFC followed by rapid clearing from the chamber. The data in parts 2 and 4 of Table I shows that incapacitation occurs very early in the case of Geon 8750/ZFC and polychloroprene/ZFC. These observations suggest that HCN is the most important component of the combustion products from Geon 8750/ZFC and polychloroprene/ZFC in inducing incapacitation.

Moderate levels of % CO·Hb and HCN at incapacitation are seen for Estane 58360. This suggests that both CO and HCN are important in inducing incapacitation. Estane 58360 contains polychloroprene as a flame/drip retardant. Upon thermal degradation, this releases HCl which may have the effect of increasing HCN release. This effect has been shown in our analytical testing program at ALTC(11).

Our primary bioassay testing objective has been to evaluate and rank materials on the basis of dose-response testing. As a secondary goal, we have coupled analytical testing with the bioresponse testing to determine the role of specific components of combustion products in inducing bioresponse. Unfortunately, the optimum experimental procedure for the achievement of the primary goal does not allow a highly accurate correlation of analytical and bioresponse data. This discrepancy comes about in the following way. We have asserted that carbon monoxide is important in inducing incapacitation because 50% incapacitation is associated with a level of carboxyhemoglobin of 53-58% CO·Hb in our experiments. The data which this is based on contains minor inaccuracies. All measurements of % CO·Hb are made on blood samples taken from animals after the end of the 15 minute exposure. However, comparison of the data in Table II with the data in Table I shows that for any material, for the mass of material which induces 50% incapacitation, the incapacitation response takes place significantly sooner than 15 minutes. The problem arises from the fact that during the time period between when the animal becomes incapacitated and the time when the blood is taken, the animal continues to load carbon monoxide. The result is that artificially high values of % CO·Hb are associated with 50% incapacitation in Table VIII. The magnitude of the discrepancy is not serious and does not alter any of our conclusions. This is demonstrated as follows. For each of the three materials, Geon 8750, polychloroprene, and red oak. . . . where it has been asserted the CO is the combustion component important in inducing incapacitation by chance, incapacitation occurred at or very near 15 minutes for one of the samples. The carboxyhemoglobin values from these experiments should very closely approximate the correct value of % CO·Hb to be associated with 50% incapacitation. The pertinent data taken from Tables I and VII is given in Table IX. For comparison, data is included from Table VIII. This data shows that the results in

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TABLE IX

% CO·Hb at 50% Incapacitation

Material	Results from Sample with Incapacitation at 15 Minutes		Results from Table VIII
	Mass of Sample, gm	CO·Hb %	CO·Hb %
Geon 8750	9.9	54	58
Polychloroprene	4.9	47	53
Red Oak	3.3	55	59

Table VIII may be artificially high by 4-6%. The results in the second column of Table IX are in good agreement with the work of Buckham[12]. Using pure carbon monoxide, incapacitation in the rotating cage experiment was induced at 49% CO·Hb.

We have investigated the animal incapacitation responses to the products of combustion of a series of materials spanning a wide range of chloride content. We have found that at 50% incapacitation -- whether induced by the combustion products of Geon 8750, polychloroprene, or red oak wood, or pure CO gas -- the % CO·Hb level of the exposed animals is about 47-55%. This suggests that carbon monoxide is the most important component of the combustion products of these materials in inducing incapacitation in the rotating cage experiment.

V. [redacted]

[redacted] must be an integral part of any program aimed [redacted] of improved materials. Evaluation of materials [redacted] on the ranking but also on the nature of the [redacted] which is induced. In particular, it is important to [redacted] whether carbon monoxide is most important in inducing response. This judgement is based on % CO·Hb results. In order to most accurately establish this result, additional experiments are needed besides those required to define the dose-response relationship. In these additional experiments, the exposure would be continued until incapacitation occurs, at that moment the experiment would be stopped and blood collected for % CO·Hb.

VI. References

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