

from exposure to this substance at relevant levels. While the CPSC staff review did not examine exposure or risk, it did find that antimony trioxide was a chronic toxicant under the FHSA. This was based on systemic toxicity after oral exposure in experimental animals, and non-cancer effects observed in humans and animals after inhalation of the dust. In addition, CPSC staff considered antimony trioxide to be a probable human carcinogen. The UK Report did not consider the carcinogenic effects in animals to be relevant to humans. Animal data can be considered relevant for human extrapolation under the FHSA. The CPSC staff considered it a probable skin and eye irritant. The CPSC staff maintains its assessment that antimony trioxide is a chronic toxicant under the FHSA.

c) With regard to the toxicity assessments for *decabromodiphenyl oxide (DBDPO)*, there are some differences between the UK Report and the CPSC toxicity review in the data that were reviewed and interpretation of these data. The UK Report included data on workers exposed to dioxins and furans (IPCS 1994; OECD 1994). Data on these compounds were not included in the CPSC review because, while dioxins and furans may be combustion by-products of DBDPO, they are of questionable relevance to the toxicity of DBDPO. *In vitro* data on immunoglobulin synthesis in human lymphocytes exposed to lower brominated diphenyl ethers (Fernlof, 1997) and other data on these substances were not included in the CPSC report because the FRCA has advised the CPSC that lower brominated diphenyl ethers are not likely candidates for use in upholstered furniture.

The UK Report concludes that there is no evidence of toxic risk from the levels of exposure to DBDPO that are anticipated for use in consumer products, which is in agreement with the findings in the CPSC risk assessment (Babich and Thomas, 2001).

d) For the compound called *tris(chloropropyl)phosphate (TCPP)*, there was some difference in the compounds that were reviewed. Due to inconsistencies and errors in nomenclature in various studies and by some manufacturers, the CPSC staff reviewed data on several compounds while the UK Report reviewed data on only one. This might account for some of the differences in conclusions.

The CPSC staff reviewed data on TCPP as represented by several CAS numbers, which were not necessarily included in the UK review. The UK Report concluded that TCPP has low acute toxicity, while the CPSC reported that TCPP is acutely toxic by the inhalation, oral, and dermal routes of exposure under the FHSA (Bittner, 1999c). Several studies were included in one or the other review, but not both. Neither the UK nor the CPSC reported any carcinogenicity data. The CPSC staff concluded that there are inadequate data available to characterize the toxicity of the isomers identified as the chemical TCPP in the UK Report, as well as the other isomers reviewed, and concluded that they merit further study. The UK Report concluded that available data do not indicate that TCPP is likely to pose any toxic risk at exposure levels envisaged in consumer products. The CPSC staff found that there are inadequate toxicity data available to determine whether TCPP causes chronic organ toxicity or other toxic effects. Since TCPP cannot be considered toxic under the FHSA, an ADI was not calculated. The lack of toxicity data does not mean TCPP is "safe", only that there are insufficient data available to satisfy the regulatory definition of toxic. Therefore, a risk assessment was not performed on this chemical by the CPSC staff.

Thus, the conclusions drawn in the CPSC staff toxicity reviews and the UK report with regard to the toxicity of the chemicals generally agree and are not sufficient to cause a change in the conclusions of the CPSC staff toxicity reviews. Differences in evaluation of the chlorinated "tris" compound may be due to differences in the compounds identified as TCPP. Specific differences are discussed in the CPSC Comparison of the UK DTI Assessments on FR Chemicals (Bittner and Ferrante, 1999; Bittner et al., 1999c).

EU Draft Risk Assessments

The EU is currently performing risk assessments on several FR chemicals that are either proposed or currently in use by certain member states.

a) Decabromodiphenyl Oxide

The latest available draft Human Health Assessment, dated February, 2000, did not contain any information that would alter the findings of the CPSC toxicity review on decabromodiphenyl oxide (Bittner, 1999a). The EU draft report, however, concludes that a "sound" risk assessment for consumers cannot be performed due to a lack of exposure data. It further states that based upon the scattered information available and in agreement with the IPCS (1994) risk assessment, consumer exposure is likely to be negligible, with no resulting risk for consumers. The CPSC staff obtained exposure data through migration studies in fabrics treated with DBDPO, and completed a risk assessment based on these data. The staff concluded that DBDPO is not likely to present a hazard to consumers (Babich and Thomas, 2001).

NRC Risk Assessment

In general, the conclusions reached by the NRC (NRC, 2000) regarding toxicity of specific chemicals are congruous with the CPSC findings. The approach used in the NRC report was intended to yield a highly conservative estimate of risk extremely protective of human health. This was accomplished in several ways. Because exposure data were generally limited or not available for the 16 chemicals, the NRC subcommittee used very conservative assumptions about how consumers might be exposed to FR chemicals on upholstered furniture. As the NRC acknowledges, this approach tended to overestimate the potential exposure, and therefore the risk, to consumers using FR-treated upholstered furniture. The NRC stated that actual risk to human health is likely to be lower than that estimated by the subcommittee.

In addition, the subcommittee based its assessment of certain FR chemicals on surrogate compounds that represent chemical classes of FR chemicals. Those selected chemicals were not necessarily the most likely candidates for use on upholstered furniture, but were either the most toxic chemical in the class or the member of the chemical class with the most available data. Therefore, conclusions about the chemical class were derived based upon the properties of the surrogate. The risk to consumers could be lower if the chemical used for the FR treatment were less toxic than the surrogate chemical used for the risk assessment.

IV. CONCLUSION

CPSC staff prepared toxicity reviews of 16 chemicals or chemical classes that may be used in upholstered furniture fabrics to meet a small-open-flame performance standard. Staff received and reviewed additional data from several sources, including industry studies, NAS, and the EU. The staff amended its findings as necessary in light of the additional data. The CPSC staff's general conclusions regarding the overall toxicity of the 16 chemicals/chemical classes are unchanged.

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APPENDIX A

In the developmental study performed by Stump et al. (1999b), it was reported that one mid-dose female (identified as animal #3620 in the study "Results Summary" on pp. 22 and 31) delivered on GD 20 and was examined at the scheduled laparohysterectomy on that day. The study authors concluded that the early delivery was not treatment-related based on the pup/fetal weights, which they believed indicated an error in the detection of mating.

However, it was not possible to match this conclusion to the individual data. No dam #3620 was listed either in Table 25 of the study (p. 138), which shows individual fetal weights for each dam in the mid-dose group, or in tables for any other dose group. Table 25, did, however, show the fetal body weight data for dam #3658, (mean 5.04 g), which was greater than the mid-dose group and control means (3.4 and 3.6 g, respectively). The footnote for fetus #3658 states that it was "obviously advanced beyond gestation day 20--not included in the calculation of mean." Thus, it appears that either the data from animal #3658 was inadvertently attributed to #3620 by the authors, or there were 2 dams in this litter with increased fetal weight. Since all 23 dams with viable fetuses in this group (listed in the Summary on p. 31) are accounted for in the individual data (p. 138) it appears probable that what the study authors refer to as fetus #3620 is really #3658.

APPENDIX B

CD(SD)IGS BR pregnant rats were used in the developmental study by Stump et al. (1999b). The incidence of retroesophageal subclavian artery reported in the fetuses follows in Table 1.

Table B-1. Incidence of fetal retroesophageal subclavian artery (Stump et al. 1999b)

Dose Group (mg/kg)	Incidence (number affected/total)	
	Fetus	Litter
0	0/322 (0%)	0/22 (0%)
250	0/331 (0%)	0/23 (0%)
500	1/338 (0.3%)	1/23 (4.4%)
1,000	1/290 (0.34%)	1/20 (5%)

In the WIL historical control data, which was included in Stump et al. (1999b), the incidence of major blood vessel variations was 18 of 39,442 CD (SD) BR fetuses (0.045% of fetuses) in 18 of 3,574 litters (0.5% of litters). The range was reported to be 0.0-1.5% of fetuses per litter. The experimental data show a litter effect that is outside of historical control limits.

The WIL historical control data does not break out the variations by category. Since these data are inclusive of many alterations, they may represent an inflated value for any one specific blood vessel alteration. Furthermore, the mid- and high-dose groups show an increased incidence compared to the concurrent experimental controls.



United States
CONSUMER PRODUCT SAFETY COMMISSION
Washington, D.C. 20207

MEMORANDUM

DATE: June 2, 2000

TO : Dale R. Ray, Project Manager for Upholstered Furniture

Through : Andrew G. Stadnik, Associate Executive Director for Laboratory Sciences
Warren, K. Porter, Jr., Director, Division of Chemistry *sent call for WKP*

FROM : Bharat Bhooshan, Chemist, Division of Chemistry *sent call for BB*
David Cobb, Chemist, Division of Chemistry *sent call*

SUBJECT : Migration of Flame Retardant Chemicals from Upholstery Fabrics

BACKGROUND

The U.S. Consumer Product Safety Commission (CPSC) initiated a regulatory proceeding in 1994 to address the hazard associated with small open flame ignitions of upholstered furniture.¹ Small open flame sources include cigarette lighters, matches, and candles. An estimated 90 deaths, 420 injuries, and \$40 million in property damage are associated with small open flame ignitions of upholstered furniture every year in the U.S. The CPSC staff has developed a draft performance standard to address this hazard.² Furniture manufacturers would be free to choose their methods for complying with the standard. However, the manufacturers have informed us that they would treat upholstery fabrics with flame retardant (FR) chemicals to meet the draft standard. In addressing the hazard associated with the small open flame ignition of upholstered furniture, the CPSC staff is working to develop a performance standard to reduce furniture ignitions without creating additional hazards to consumers. Therefore, the CPSC staff is assessing the potential risks from consumer exposure to FR chemicals.

FR chemicals may be applied to textiles by a variety of methods, and the method of application may affect the potential for exposure.^{3,4,5,6} FR chemicals may be mixed

with an emulsion polymer such as an acrylic latex that is applied to the back of the fabric. Such back coatings, as they are called, typically contain antimony trioxide in combination with a brominated FR, such as decabromodiphenyl oxide (DBDPO) or hexabromocyclododecane (HBCD). Back-coatings are most often used with synthetic fabrics such as polyester and polyolefins, although they may also be used with cellulosic fabrics. Back coating is expected to reduce the potential for exposure, because the FR chemicals are essentially encapsulated in the polymer, which is applied to the back of the fabric.

Cellulosic fabrics, such as, cotton and rayon, may be treated with reactive FR chemicals. Phosphonic acid, (3-[[hydroxymethyl]amino]-3-oxopropyl)-, dimethyl ester (PE) (e.g., Pyrovatex®) forms covalent bonds with hydroxyl groups in cellulose fibers and with melamine resin. Tetrakis (hydroxymethyl) phosphonium salts (Tetrakis) (e.g., Proban®) reacts to form an insoluble polymer which is physically trapped within the fabric fibers.^{7, 8} The formation of covalent bonds or polymerization of these reactive compounds is expected to reduce the potential for exposure to these reactive FR chemicals.

Although these application methods are expected to reduce the potential for consumer exposure to FR chemicals during upholstered furniture use, some exposure may occur as a result of migration from the back coating, the presence of residual unreacted compounds, or degradation of covalent bonds or polymers over time. Additionally, upholstered furniture may be subjected to spilled liquids, cleaning agents, and mechanical wear. Under these conditions, the FR chemical could dissolve into these agents, migrate to the upper surface of the fabric, and result in consumer exposure. The present study was undertaken to determine the migration (leaching) or release of FR chemicals from upholstered fabrics under various conditions. These data will be used to assess consumer exposure to FR chemicals and the potential toxicological risks under various conditions of upholstered furniture use.

METHODS

A. Upholstery Fabrics

The staff divided the fabrics into four groups based on the FR chemicals used in manufacturing them as follows:

1. Fabrics back-coated with antimony trioxide and decabromodiphenyl oxide (DBDPO),
2. Fabrics back-coated with antimony trioxide and 1,2,5,6,9,10-hexabromocyclododecane (HBCD),
3. Fabrics immersion-treated with PE, which cross-links with the fabric fiber, and
4. Fabrics immersion-treated with Tetrakis, which polymerizes within the fabric fiber.

Two samples were selected from each group for this study. The fabrics are described in Table 1.

B. FR Chemical Loading

Each fabric sample was analyzed for its FR chemical content. Back-coated fabrics were analyzed for antimony as well as DBDPO or HBCD, while immersion treated fabrics were analyzed for phosphorus. Since immersion treatment causes polymerization of PE or Tetrakis, these fabric samples were analyzed for phosphorus, rather than the corresponding reacted FR chemical. Details on analytical methods are discussed below.

1. Determination of Antimony in Fabrics

About 50 milligram of the fabric sample is weighed accurately and placed in a 20-ml test tube. The fabric is suspended in 10 ml of 4.0 N hydrochloric acid and the test tubes are vortexed several times. After two hours, the test tubes are centrifuged for 5 minutes at 4000 rpm in order to settle any suspended particles/fibers. The clear solution is analyzed for antimony (at 206.833 nm) by Inductively Coupled Plasma Spectrometer (ICP) from Thermo Jarrell Ash (model # Atom Scan -16). The ICP is calibrated using a five point calibration curve (0.0, 1.0, 5.0, 10.0, and 25.0 ppm of antimony) for the quantitation of antimony. Limit of detection (LOD) for antimony is determined by preparing standard antimony solutions (0.05, 0.10, 0.50, and 0.75 ppm) and measuring the ICP responses. The LOD for antimony is calculated to be 0.07 ppm.

2. Determination of phosphorus in Fabrics

About 40 milligram of the fabric sample is weighed accurately and placed in a 20-ml test tube. The fabric is digested in 4 milliliters of concentrated nitric acid at gentle reflux (140°C) for six hours. The digest is diluted to 10 ml by adding de-ionized water and the test tubes are vortexed. The test tubes are centrifuged for 5 minutes at 4000 rpm in order to settle any insoluble material. The clear solution is analyzed for phosphorus by ICP. The ICP is calibrated using a five point calibration curve (0.0, 1.0, 5.0, 10.0, and 25.0 ppm of phosphorus) for the quantitation of phosphorus. The LOD for phosphorus is determined by preparing standard phosphorus solutions (0.05, 0.10, 0.50, and 0.75 ppm) and measuring the ICP responses. The LOD for phosphorus is calculated to be 0.11 ppm.

3. Determination of DBDPO in Fabrics

About 40 milligram of the fabric sample is weighed accurately and placed in 20-ml test tubes. Five ml of tetrahydrofuran is added to each tube and the whole rack (containing all the tubes) is placed on a shaker for 48 hours. Tetrahydrofuran from each test tube is transferred to a vial and all the vials are analyzed for DBDPO by High Pressure Liquid Chromatograph (HPLC) from

Waters Associates (model # Alliance; Data System – Millennium). The HPLC conditions used are as follows:

Column:	Symmetry C18, 2.1 X 100 mm
Eluant:	100% acetonitrile
Flow:	0.5 ml/min
Separation Module:	Water 2690
Detector:	Photodiode Array (UV-Visible), Waters 990
Wavelength:	228 nm
Volume injected:	5 µl

The HPLC is calibrated using a five point calibration curve (0.0, 1.0, 5.0, 10.0, and 25.0 ppm of DBDPO) for the quantitation of DBDPO. The LOD for DBDPO is calculated to be 0.06 ppm.

4. Determination of HBCD in Fabrics

About 40 milligram of the fabric sample is weighed accurately and placed in a 20-ml test tube. Four milliliters of acetonitrile is added to each tube and the whole rack (containing all the tubes) is placed on a shaker for 48 hours. Acetonitrile from each test tube is transferred to a vial and all the vials are analyzed for HBCD by HPLC. The ICP is calibrated using a five point calibration curve (0.0, 1.0, 5.0, 10.0, and 25.0 ppm of HBCD) for the quantitation of HBCD. The LOD for HBCD is calculated to be 1.0 ppm.

C. Migration Studies

1. Head over Heels

These studies were conducted to simulate oral exposure from chewing upholstery fabric such as armrests and head rests. Normal saline was used as a surrogate for saliva. A small piece of fabric (1.5"x1.5") was weighed and then placed in a screw-cap bottle (2.5"x5.5") containing 25 ml of normal saline and rotated (12" diameter) at 60 rpm for 30 minutes. The fabric piece was removed and placed in another bottle containing 25 ml of normal saline. The bottle was rotated as above for 30 minutes. This 'head over heels' rotation was repeated one more time. The solutions obtained from these treatments were analyzed for antimony or phosphorus by inductively coupled plasma spectroscopy (ICP) as discussed above. To determine the release of HBCD, the solution was extracted with acetonitrile (3 times, 15 ml each). The three extracts for each fabric piece were combined and evaporated to dryness. The residue was dissolved in acetonitrile (4 ml) and analyzed for HBCD by HPLC as discussed above. To determine migration of DBDPO, the saline solution was extracted with tetrahydrofuran (3 times, 15 ml each). All extracts for each saline solution were combined and evaporated to dryness. The residue was dissolved in tetrahydrofuran (5

ml) and analyzed for DBDPO by HPLC as discussed above. Thus, each fabric piece followed three sequential extractions (or migration) by this method and each fabric sample was studied in duplicate.

2. Migration to Filter Paper

These studies were conducted to assess consumer exposure to FR chemicals by skin contact. Five types of reagents were used during these studies. Normal saline was used as simulated perspiration, five percent citric acid was used as simulated acid food or beverage, such as orange juice, and methylchloroform as a drycleaning agent. Two additional types of cleaning agents were used: a non-phosphate detergent (a standard detergent used by LS for other studies) and a detergent for upholstery/carpet cleaning machines available to consumers.

In a typical experiment, a 1.5"x1.5" piece of a fabric was weighed and then placed face up in a 400-ml beaker and covered with a circular filter paper having a diameter of 5.5 centimeters. About 1.5 ml (2.0 ml for thick fabrics) of the reagent is added onto the filter paper (both the fabric and the filter paper are saturated). The beaker is left in a hood until the filter paper and fabric are dry (4 to 6 hours). The dry filter paper is removed and placed in a test tube to be analyzed for antimony, phosphorous, DBDPO, or HBCD. The fabric in the beaker is covered with another filter paper and the process is repeated to give a total of five consecutive extractions of the same fabric sample by each reagent; each time, the dry filter paper is removed and placed in a test tube for analysis. Each fabric sample is studied in duplicate.

ICP was used to analyze each filter paper for either antimony or phosphorous using procedures as discussed above. HPLC was used to analyze for HBCD or DBDPO as discussed earlier.

D. Artificially Aged Fabrics

Some fabric samples were subjected to accelerated aging in a Q-Panel Accelerated Weathering Tester (model # QUV). It was fitted with an UVA-351 lamp to simulate 'sunlight through glass' indoor exposure. A 12" x 15" piece of each fabric sample was exposed to this UV light for 500 hours (about 42 days). The operating manual from the company suggests that these exposures should be used in relative terms to compare degradation among various samples. However, their technical staff suggested five to ten times accelerated degradation. Thus, 500 hours of exposure could equal up to 5000 hours of actual sunlight through glass indoor exposure.

The UV light was on for six hours followed by off for six hours – a total of 12 hours of UV light per day. Neither the temperature nor the humidity of the exposure chamber was controlled. The temperature ranged from 20°C (lamp off) to 55°C (lamp

on). Selected samples from this pool were subjected to Head Over Heels Studies and Filter Paper Migration Studies, as described above.

E. Artificially Worn Fabrics

One back-coated fabric sample (IL-5) was subjected to an accelerated wear procedure for various time points and studied by Head Over Heels for the migration of antimony and DBDPO. The process is described elsewhere.⁹ Briefly, the fabric sample was placed under a test impactor (as described in ASTM3574) and pounded for 200,000 cycles at a frequency of 70 cycles per minute. The test load was 750 \pm 20 N (169 \pm 4.5 lb.). The flat impactor was used to produce large shear effects on the material at the edges of the impactor.

F. Acid Extraction

These studies were performed to assess exposure to antimony after ingestion of an upholstery fabric. A solution of hydrochloric acid (0.07 N, pH 1.5) served as a simulant for gastric fluid. A 1.5"x1.5" piece of fabric was weighed and placed in a 125-ml Erlenmeyer flask. The acid was added at a rate of 50 ml per gram of fabric. The flask was placed on a shaker bath (60 rpm) maintained at 37°C. At one hour, all the acid was removed from the flask for analysis and the same volume of fresh acid was added. The same process was repeated two hours later (total time of three hours). The same extraction process was repeated for a third time after an additional three hours (total time of six hours) to provide the final extraction sample. Thus, three samples for analysis were collected for each fabric piece studied for acid extraction. All extracts were analyzed for antimony by ICP using methods as discussed above.

G. Calculations

The concentrations of FR chemicals are reported as milligrams of FR chemical per gram of fabric. In head over heels studies, three consecutive extractions were combined so as to determine maximum levels of FR chemical migration/extraction. The results for head over heels experiments were expressed as the migration rate (milligrams of FR chemical per gram of fabric per hour). In filter paper migration studies, all five sequential migrations were combined to give the total amount of FR chemical released from each fabric sample. The results for each experiment were reported in three ways: (a) milligrams of FR chemical released per gram of fabric weight, (b) percent of available FR chemical released, and (c) micrograms of FR chemical released per square centimeter of fabric.

RESULTS & DISCUSSION

A. FR Chemical Loading

The results of the loading studies are shown in Table 1. The antimony concentration in back-coated fabrics ranged from 1.6 to 2.8 percent with an average level of 2.3 percent by weight. The average DBDPO concentration was 6.5 percent, while HBCD levels averaged 9.2 percent. For immersion-treated fabrics, the concentration of phosphorus ranged from 1.3 to 2.5 percent.

B. Head Over Heels

Results of the head over heels (HOH) study are shown in Tables 2 through 5. Table 2 depicts antimony released from back-coated fabrics. Under the conditions of the experiment, fabric samples UF-6 and UF-8 released the greatest amount of antimony (0.038 mg per gram of fabric per hour). Percent of available antimony released (0.168 percent) is maximum for sample UF-6. However, on surface area basis, the release rates are comparable (2.07 vs. 1.94). Table 3 shows DBDPO release from samples IL-5 and UF-6. These values are comparable to those found for antimony. Table 4 shows HBCD release from fabric samples UF-8 and UK-12. Fabric sample UF-8 released 1.5 mg of HBCD per gram of fabric per hour, leading to 1.7 percent of available HBCD released per hour. Among the four fabric samples studied by HOH, the HBCD release rate from sample UF-8 is 77.5 $\mu\text{g}/\text{cm}^2/\text{hr}$ while the release rates of other FR chemicals (antimony and DBDPO) range from 0.43 to 2.1 $\mu\text{g}/\text{cm}^2/\text{hr}$.

Table 5 gives phosphorus released from immersion treated fabric samples. Tetrakis treated fabric samples released about 0.44 mg of phosphorus per gram of fabric per hour while PE treated fabric samples released phosphorus at much higher rate of 1.1 mg phosphorus per gram of fabric per hour. Percent of available phosphorus released for PE treated sample was over three times (7.46 vs. 2.22) that of Tetrakis treated samples.

C. Migration to Filter Paper

Back-coated fabric samples were treated with various reagents and the migration of antimony, DBDPO, and HBCD to filter paper was determined. These results are shown in Tables 6 through 11. Reported values in the tables are for the total of five consecutive extractions with the same fabric sample. Table 6 describes antimony release to filter paper after normal saline treatment. The average was 0.023 mg per gram of fabric, with sample UF-8 releasing the maximum level at 0.042 mg/g. The percent of available antimony released from UF-8 and UK-12 (HBCD containing samples) is over three times that of IL-5 and UF-8 (DBDPO containing samples). Tables 7 and 8 show antimony released from back-coated fabrics after cleaner 1 & cleaner 2 treatments. The amount of antimony released is comparable in both experiments with sample UF-8 releasing the most antimony on a fabric weight basis. However, sample UK-12 released the most antimony (0.18 percent) on a percent available basis. Table 9 shows antimony released from back-coated fabric samples after treatment with 5 percent citric acid, which was used as a surrogate for acidic beverages such as orange juice. The amount of antimony released was 100 to 1000 times greater than all other treatments. Again, sample UF-8 showed the maximum migration, releasing 9.9 mg of antimony per gram of fabric and 37 percent of the available antimony. Sample IL-5 released the lowest amount. The antimony released from back-coated fabrics after treatment with methylchloroform was low, below the LOD as may be expected.

Tables 10 & 11 show the release of DBDPO and HBCD, respectively, from the back-coated fabrics after treatment with five reagents discussed above. All treatments caused the release of low levels of DBDPO and HBCD, often below the LOD, except methylchloroform, the hydrophobic reagent in the group. Sample IL-5 released 2.0 percent of available DBDPO while sample UF-6 released 0.90 percent of available DBDPO. However, the release of HBCD was about 10 times that of DBDPO (406 vs. 38 $\mu\text{g}/\text{cm}^2$). Under the conditions of this experiment, sample UF-8 released 8.6 percent of available HBCD while sample UK-12 released 17.7 percent of HBCD. The values for the two samples were comparable when calculated as $\mu\text{g}/\text{cm}^2$ of fabric (396 vs. 417).

Tables 12 through 15 show phosphorus released from immersion treated fabrics after treatment with four reagents (normal saline, cleaner 1, cleaner 2, and 5 percent citric acid). For Tetrakis treated fabric samples IL-3 and UF-11, the release of phosphorus ranged from 2.5 to 3.3 percent of available phosphorus for all reagents. On fabric weight basis, the release of phosphorus ranged from 0.42 to 0.83 mg/g. For PE treated fabric samples UF-13 and UF-16, the release of phosphorus ranged from 6.3 to 9.4 percent of available phosphorus for all reagents, except citric acid which affected the release of about 27 percent of available phosphorus from these samples.

The phosphorus released from immersion treated fabrics after methylchloroform treatment was very low, usually near the LOD for phosphorus as may be expected.

D. Artificially Aged Fabric Samples

1. Head over Heels

The effects of the accelerated aging process on migration were evaluated by the head over heels methods and compared with the corresponding new fabric samples. Antimony migration was studied in two back-coated fabric samples--IL-5 and UK-12. The results (Table 16) suggest that aging had little effect on sample IL-5. However, the release of antimony from sample UK-12 was doubled, although the increase was not statistically significant (t-test).

Migration of DBDPO was studied in aged fabric sample IL-5 and that of HBCD in aged fabric sample UK-12. These results are shown in Tables 17 and 18, respectively. The accelerated aging process resulted in a decrease in the release of DBDPO from sample IL-5 and increased the release of HBCD from sample UK-12. However, these effects are not statistically significant.

Four immersion-treated fabric samples (IL-3, UF-11, UF-13, and UF-16) were tested after the accelerated aging by the head over heels experiments. The results for aged fabric samples are shown in Table 19 and can be compared with control fabric samples (Table 5). Tetrakis treated fabric samples IL-3 and UF-11 showed 100 to 150 percent increases in the percent of available phosphorus released. On a fabric weight basis, the amount of phosphorus released is also increased. On the other hand, for PE treated fabric samples UF-13 and UF-16, the increase is only 20 to 50 percent

2. Migration to Filter Paper

Aged fabric samples IL-5 and UK-12 were subjected to filter paper migration studies, as discussed above, using the same five reagents --normal saline, cleaner 1, cleaner 2, 5 percent citric acid, and methylchloroform. Table 20 shows results of antimony release from IL-5 after these treatments. The values have changed only slightly for all treatments except for 5 percent Citric acid treatment, which increased the antimony migration to 14.7 percent of available antimony from 5.1 percent of available antimony (Table 21). Table 22 shows results of antimony release from aged sample UK-12 after various treatments. Most of the numbers have decreased slightly for the aged fabric sample when compared with the results for new fabric (Table 23).

Aged fabric sample IL-5 was also studied for the migration of DBDPO from the fabric to the filter paper. The results are shown in Table 24. Methylchloroform treatment seems to increase the release of DBDPO by 20 percent (2.436 % vs. 1.988 % of available DBDPO released) when compared with the data for the control fabric (Table 10). On fabric weight basis, the increase is 65 %. Aged fabric sample UK-12 was also studied for the migration of HBCD from the fabric to the filter paper. The

results are shown in Table 25. In this case, methylchloroform increased the release of HBCD in aged fabric by 100 percent (36.65 % vs. 17.68 % (Table 11) of available HBCD).

Phosphorus release from aged fabric samples UF-11 and UF-13 to filter paper was determined after treatment with various reagents. The results are shown in Tables 26 and 27. The release of phosphorus from these fabrics increased significantly after aging for all treatments except methylchloroform which showed no impact.

3. Acid Extraction

Under the conditions of the experiment, sample IL-5 released about 45 µg of antimony, or 0.073 mg per gram of fabric weight. This corresponds to 0.26 percent of available antimony released into simulated gastric juice in six hours. However, fabric sample UK-12 released 19 times more antimony at 4.9 percent of available antimony.

E. Artificially Worn Fabrics

In order to determine durability of back-coating, sample IL-5 was subjected to accelerated wear testing, followed by professional cleaning and ending with an additional wear test. These samples were studied for the migration of antimony and DBDPO by head over heels. The results are shown in Tables 29 and 30. The accelerated wear test and cleaning did not significantly affect the migration rate.

CONCLUSION

Eight upholstery fabric samples were studied for the migration (leaching) of FR chemicals from their surfaces during various consumer use situations. Four of these samples were back-coated and four were immersion treated. Three methods were used to assess migration: (1) head over heels extraction with normal saline to simulate mouthing of fabric (e.g., cushions, arm rests, and headrests) by children; (2) migration to filter paper to simulate skin contact; and (3) acid extraction to simulate ingestion. Five different solvents were used for migration to filter paper: Normal saline to simulate saliva and sweat, 5 percent citric acid for acidic beverages (e.g., juice or soft drinks), methylchloroform as dry-cleaning agent, a laundry detergent, and an upholstery cleaning solution (sold to consumers for carpet cleaning machines). The effects of accelerated aging and accelerated wear on of FR chemical migration were also studied.

Five FR chemicals were analyzed during this study. Decabromodiphenyloxyde (DBDPO) and 1,2,5,6,9,10-hexabromododecane (HBCD), which are used in back-coated fabrics, were analyzed by high performance liquid chromatography (HPLC). Antimony, which is generally in the form of antimony trioxide, is used in back-coated fabrics in combination with either of the brominated flame retardants. The immersion treated fabrics used either of two phosphorus-based FR's: phosphonic acid, (3-

{[hydroxymethyl]amino}-3-oxopropyl)-, dimethyl ester (PE) or tetrakis (hydroxymethyl) phosphonium salts (Tetrakis). Phosphorus was used as a surrogate to study the migration of PE and Tetrakis. Antimony and phosphorus were analyzed by inductively coupled plasma (ICP) spectrometry.

In general, the migration of FR chemicals from upholstery fabrics was low. Some reagents increased the migration of certain FR chemicals, as one might expect. For example, citric acid increased the migration of antimony while methylchloroform increased the migration of decabromodiphenyl oxide (DBDPO) and 1,2,5,6,9,10-hexabromododecane (HBCD). Accelerated wear did not have a significant affect on migration by the head over heels method, although only a limited number of tests were performed.

In some cases, accelerated wear (combination of UV and heat) led to significant increases in migration. For example, the migration of antimony as well as HBCD from sample UK-12 was increased in the head over heels experiment, although the data was not significantly different from the control. Similarly, tetrakis treated fabric samples IL-3 and UF-11 showed 100 to 150 percent increases in the percent of available phosphorus released.

The two immersion treatments studied, PE and Tetrakis, are reactive chemicals. PE covalently bonds to cellulose fibers, while Tetrakis polymerizes within the fibers becoming physically trapped. Phosphorus was used as a surrogate for migration of these chemicals. The chemical form of the phosphorus that migrates from these fabrics is unknown. In the case of PE, some of the migrating phosphorus may be inorganic phosphate, because the chemical formulation contains phosphate buffer.

The data obtained in this study will be used by CPSC staff to assess consumer exposure to FR chemicals during varied conditions of upholstery fabric use.

Table 1. Concentration of FR chemicals in Upholstery Fabric Samples

Fabric ID	Fabric type	Fabric weight Oz/yd ²	Treatment	% Concentration of FR Chemical (w/			
				Sb	DBDPO	HBCD	P
IL-5	Cotton	12.0	Back coated	2.8	6.2		
UF-6	Rayon/poly-ester/ cotton	16.2	Back coated	2.2	6.8		
UF-8	Polyester/ rayon	14.0	Back coated	2.7		9.0	
UK-12	Cotton	7.7	Back coated	1.6		9.4	
IL-3	Cotton/nylon	10.3	Tetrakis				2.5
UF-11	Cotton	10.0	Tetrakis				1.7
UF-13	Cotton	8.0	PE				1.4
UF-16	Cotton	7.3	PE				1.3

Table 2. Antimony released from Back-coated Fabrics after Head over Heels Experiments

Fabric ID	Antimony released (mg/g of fabric/hr)		Percent of available Antimony released		Antimony released (µg/cm ² of fabric/hr)	
		Average		Average		Average
IL-5	0.007	0.016	<LOD	0.085	0.328	0.698
IL-5	0.024		0.085		1.068	
UF-6	0.037	0.038	0.164	0.168	2.019	2.074
UF-6	0.039		0.172		2.128	
UF-8	0.041	0.038	0.154	0.142	2.119	1.941
UF-8	0.034		0.129		1.763	
UK-12	0.009	0.015	0.059	0.097	0.267	0.430
UK-12	0.022		0.134		0.592	
LOD	0.007		0.033		0.301	

Table 3. DBDPO released from Back-coated Fabrics after Head over Heels Experiments

Sample #	DBDPO released (mg/g of fabric/hr)		Percent of available DBDPO released		DBDPO released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
IL-5	0.013	0.016	0.021	0.026	0.566	0.690
IL-5	0.018		0.030		0.813	
UF-6	0.046	0.036	0.073	0.057	2.492	1.952
UF-6	0.026		0.041		1.411	
LOD	0.001		0.002		0.052	

Table 4. HBCD released from Back-coated Fabrics after Head over Heels Experiments

Sample #	HBCD released (mg/g of fabric/hr)		Percent of available HBCD released		HBCD released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
UF-8	1.536	1.500	1.707	1.668	80.474	77.496
UF-8	1.464		1.628		74.518	
UK-12	0.102	0.073	0.109	0.078	2.870	2.063
UK-12	0.044		0.047		1.255	
LOD	0.024		0.024		0.549	

Table 5. Phosphorus released from Immersion treated Fabrics after Head over Heels Experiments

Sample #	Phosphorus released (mg/g of fabric/hr)		Percent of available Phosphorus released		Phosphorus released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
IL-3	0.57	0.55	2.29	2.19	19.35	18.20
IL-3	0.52		2.09		17.85	
UF-11	0.38	0.38	2.26	2.24	13.17	13.11
UF-11	0.38		2.22		13.04	
UF-13	1.10	1.05	7.88	7.50	30.78	28.82
UF-13	1.00		7.12		26.93	
UF-16	1.10	1.00	8.21	7.42	29.17	26.12
UF-16	0.89		6.63		23.06	
LOD	0.01		0.07		0.39	

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Table 6. Antimony released from Back-coated Fabrics after Normal saline Treatment*

Sample #	Antimony released (mg/g of fabric)		Percent of available Antimony released		Antimony released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
IL-5	0.011	0.013	0.040	0.045	0.494	0.566
IL-5	0.014		0.049		0.617	
UF-6	0.011	0.011	0.049	0.048	0.633	0.621
UF-6	0.011		0.047		0.608	
UF-8	0.041	0.042	0.154	0.157	2.080	2.134
UF-8	0.043		0.160		2.188	
UK-12	0.025	0.026	0.157	0.159	0.587	0.595
UK-12	0.026		0.160		0.603	
LOD	0.006		0.031		0.246	

* The values are sum of five consecutive treatments.

Table 7. Antimony released from Back-coated Fabrics after Cleaner 1 Treatment*

Sample #	Antimony released (mg/g of fabric)		Percent of available Antimony released		Antimony released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
IL-5	0.019	0.017	0.068	0.061	0.851	0.777
IL-5	0.016		0.056		0.702	
UF-6	0.007	0.007	0.031	0.029	0.374	0.363
UF-6	0.006		0.027		0.351	
UF-8	0.038	0.036	0.143	0.134	2.034	1.903
UF-8	0.033		0.124		1.772	
UK-12	0.031	0.021	0.193	0.131	0.741	0.529
UK-12	0.011		0.069		0.317	
LOD	0.006		0.029		0.238	

* The values are sum of five consecutive treatments.

Table 8. Antimony released from Back-coated Fabrics after Cleaner 2 Treatment*

Sample #	Antimony released (mg/g of fabric)		Percent of available Antimony released		Antimony released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
IL-5	0.011	0.011	0.039	0.040	0.487	0.492
IL-5	0.011		0.040		0.497	
UF-6	0.005	0.005	0.023	0.023	0.290	0.286
UF-6	0.005		0.022		0.281	
UF-8	0.033	0.033	0.125	0.125	1.758	1.751
UF-8	0.033		0.124		1.743	
UK-12	0.030	0.028	0.188	0.179	0.764	0.721
UK-12	0.027		0.170		0.678	
LOD	0.006		0.030		0.251	

* The values are sum of five consecutive treatments.

Table 9. Antimony released from Back-coated Fabrics after 5% citric acid Treatment*

Sample #	Antimony released (mg/g of fabric)		Percent of available Antimony released		Antimony released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
IL-5	1.402	1.442	4.935	5.078	62.415	64.529
IL-5	1.482		5.220		66.642	
UF-6	2.987	3.216	13.277	14.294	170.026	184.319
UF-6	3.445		15.311		198.611	
UF-8	9.880	9.858	37.143	37.060	516.183	514.079
UF-8	9.836		36.976		511.975	
UK-12	3.962	3.448	24.609	21.412	97.003	83.886
UK-12	2.933		18.215		70.769	
LOD	0.058		0.275		2.312	

* The values are sum of five consecutive treatments.

Table 10. DBDPO released from Back-coated Fabrics after Various Treatments*

Treatment	Sample #	DBDPO released (mg/g of fabric)		Percent of available DBDPO released		DBDPO released (mg/sq. inch of fabric)	
			Average		Average		Average
Saline	IL-5	0.001	0.001	0.002	0.002	< LOD	< LOD
		0.001		0.001		< LOD	
	UF-6	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
		< LOD		< LOD		< LOD	
Cleaner 1	IL-5	0.051	0.049	0.082	0.079	2.242	2.173
		0.047		0.076		2.104	
	UF-6	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
		< LOD		< LOD		< LOD	
Cleaner 2	IL-5	0.007	0.008	0.011	0.013	0.315	0.356
		0.009		0.015		0.397	
	UF-6	< LOD	< LOD	< LOD	0.000	< LOD	< LOD
		< LOD		< LOD		< LOD	
Citric acid	IL-5	< LOD	0.001	< LOD	0.002	< LOD	0.046
		0.002		0.003		0.092	
	UF-6	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
		< LOD		< LOD		< LOD	
Methylchloroform	IL-5	0.535	0.923	0.863	1.988	23.800	41.138
		1.310		2.113		58.475	
	UF-6	0.706	0.613	1.038	0.901	40.575	35.278
		0.519		0.763		29.981	
LOD		0.001		0.001		0.021	

* The values are sum of five consecutive treatments.

Table 11. HBCD released from Back-coated Fabrics after Various Treatments*

Treatment	Sample #	HBCD released (mg/g of fabric)		Percent of available HBCD released		HBCD released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
			Average		Average		Average
Saline	UF-8	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
		< LOD		< LOD		< LOD	
	UK-12	0.103	0.093	0.110	0.099	2.747	0.017
		0.083		0.088		2.271	
Cleaner 1	UF-8	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
		< LOD		< LOD		< LOD	
	UK-12	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
		< LOD		< LOD		< LOD	
Cleaner 2	UF-8	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
		< LOD		< LOD		< LOD	
	UK-12	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
		< LOD		< LOD		< LOD	
Citric acid	UF-8	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
		< LOD		< LOD		< LOD	
	UK-12	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
		< LOD		< LOD		< LOD	
Methylchloroform	UF-8	3.358	7.762	3.731	8.624	171.084	395.951
		12.165		13.517		620.819	
	UK-12	15.331	16.618	16.310	17.679	382.748	417.083
		17.904		19.047		451.418	
LOD		0.035		0.035		1.550	

* The values are sum of five consecutive treatments.

Table 12. Phosphorus released from immersion treated Fabrics after Normal saline*
Treatment

Sample #	Phosphorus released (mg/g of fabric)		Percent of available Phosphorus released		Phosphorus released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
IL-3	0.799	0.783	3.207	3.143	26.692	25.824
IL-3	0.766		3.078		24.956	
UF-11	0.505	0.489	2.986	2.891	17.527	17.145
UF-11	0.472		2.796		16.762	
UF-13	1.335	1.319	9.536	9.448	36.199	35.869
UF-13	1.302		9.303		35.539	
UF-16	1.035	1.050	7.721	7.834	27.155	27.528
UF-16	1.065		7.946		27.901	
LOD	0.013		0.075		0.363	

* The values are sum of five consecutive treatments.

Table 13. Phosphorus released from immersion treated Fabrics after Cleaner 1
Treatment*

Sample #	Phosphorus released (mg/g of fabric)		Percent of available Phosphorus released		Phosphorus released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
IL-3	0.603	0.649	2.422	2.604	20.865	22.450
IL-3	0.694		2.786		24.035	
UF-11	0.432	0.423	2.554	2.493	15.110	14.898
UF-11	0.411		2.431		14.686	
UF-13	0.993	1.017	7.090	7.260	28.793	28.951
UF-13	1.040		7.430		29.108	
UF-16	0.830	0.845	6.198	6.304	22.095	22.803
UF-16	0.859		6.410		22.710	
LOD	0.012		0.072		0.364	

* The values are sum of five consecutive treatments.

Table 14. Phosphorus released from immersion treated Fabrics after Cleaner 2 Treatment*

Sample #	Phosphorus released (mg/g of fabric)		Percent of available Phosphorus released		Phosphorus released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
IL-3	0.745	0.743	2.993	2.985	25.974	25.792
IL-3	0.741		2.977		25.610	
UF-11	0.398	0.415	2.357	2.455	14.406	15.041
UF-11	0.431		2.552		15.676	
UF-13	1.240	1.263	8.857	9.021	33.732	34.605
UF-13	1.286		9.185		35.477	
UF-16	1.097	1.135	8.184	8.470	29.871	30.712
UF-16	1.173		8.755		31.552	
LOD	0.012		0.079		0.387	

* The values are sum of five consecutive treatments.

Table 15. Phosphorus released from immersion treated Fabrics after Citric acid Treatment*

Sample #	Phosphorus released (mg/g of fabric)		Percent of available Phosphorus released		Phosphorus released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
IL-3	0.802	0.819	3.220	3.286	27.969	28.821
IL-3	0.835		3.352		29.673	
UF-11	0.433	0.461	2.564	2.726	15.908	16.993
UF-11	0.488		2.888		18.077	
UF-13	3.631	3.703	25.939	26.447	96.315	103.569
UF-13	3.774		26.955		110.822	
UF-16	3.631	3.765	27.098	28.087	94.829	99.432
UF-16	3.896		29.076		104.034	
LOD	0.012		0.076		0.365	

* The values are sum of five consecutive treatments.

Table 16. Comparison of Antimony released from Back-coated Fabrics after Head over Heels Experiments from New and Aged Fabric

Fabric Type	Sample #	Antimony released (mg/g of fabric/hr)		Percent of available Antimony released		Antimony released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
			Average		Average		Average
New	IL-5	< LOD	0.008	< LOD	0.056	0.328	0.698
	IL-5	0.024		0.085		1.068	
Aged	IL-5	0.019	0.019	0.065	0.065	0.857	0.857
	IL-5	0.018		0.065		0.857	
New	UK-12	0.009	0.016	0.059	0.096	0.267	0.430
	UK-12	0.022		0.134		0.592	
Aged	UK-12	0.036	0.031	0.222	0.193	0.871	0.746
	UK-12	0.026		0.164		0.620	
LOD		0.008		0.041		0.241	

Table 17. Comparison of DBDPO released from Back-coated Fabrics after Head over Heels Experiments from New and Aged Fabric

Sample #	Fabric Type	DBDPO released (mg/g of fabric/hr)		Percent of available DBDPO released		DBDPO released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
			Average		Average		Average
IL-5	New	0.013	0.016	0.021	0.026	0.566	0.690
IL-5		0.018		0.030		0.813	
IL-5	Aged	0.010	0.008	0.016	0.013	0.316	0.240
IL-5		0.005		0.009		0.163	
LOD		0.001		0.001		0.038	

Table 18. Comparison of HBCD released from Back-coated Fabrics after Head over Heels Experiments from New and Aged Fabric

Sample #	Fabric Type	HBCD released (mg/g of fabric/hr)		Percent of available HBCD released		HBCD released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
			Average		Average		Average
UK-12	New	0.102	0.073	0.109	0.078	2.870	2.063
UK-12		0.044		0.047		1.255	
UK-12	Aged	0.247	0.184	0.262	0.293	5.720	4.314
UK-12		0.120		0.128		2.907	
LOD		0.024		0.024		0.549	

Table 19. Phosphorus released from Immersion treated Aged Fabrics after Head over Heels Experiments

Sample #	Phosphorus released (mg/g of fabric/hr)		Percent of available Phosphorus released		Phosphorus released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
IL-3	1.040	1.030 **	4.178	4.185	36.062	35.751
IL-3	1.019		4.091		35.439	
UF-11	0.957	0.973	5.660	5.757	33.179	33.848
UF-11	0.989		5.853		34.516	
UF-13	1.377	1.414	9.834	10.101	35.395	36.765
UF-13	1.451		10.367		38.134	
UF-16	1.158	1.164	8.641	8.688	29.879	30.206
UF-16	1.170		8.734		30.533	
LOD	0.013		0.079		0.374	

Table 20. Antimony released from Aged Fabric Sample IL-5 after various Treatments*

Treatments	Antimony released (mg/g of fabric)		Percent of available Antimony released		Antimony released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
Saline	0.008	0.009	0.029	0.031	0.358	0.382
	0.009		0.033		0.405	
Cleaner 1	0.029	0.029	0.102	0.101	1.274	1.252
	0.028		0.099		1.230	
Cleaner 2	0.018	0.021	0.063	0.073	0.784	0.912
	0.024		0.083		1.040	
5 % Citric acid	4.600	4.180	16.196	14.717	201.433	183.922
	3.759		13.237		166.411	
Methylchloroform	< LOD	0.004	< LOD	0.017	< LOD	0.173
	0.006		0.021		0.269	
LOD	0.005		0.019		0.232	

* The values are sum of five consecutive treatments.

Table 21. Antimony released from Fabric Sample IL-5 after various Treatments*

Treatments	Antimony released (mg/g of fabric)		Percent of available Antimony released		Antimony released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
Saline	0.011	0.013	0.040	0.045	0.494	0.566
	0.014		0.049		0.617	
Cleaner 1	0.019	0.017	0.068	0.061	0.851	0.777
	0.016		0.056		0.702	
Cleaner 2	0.011	0.011	0.039	0.040	0.487	0.492
	0.011		0.040		0.497	
5 % Citric acid	1.402	1.442	4.935	5.078	62.415	64.529
	1.482		5.220		66.642	
Methylchloroform	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
	0.006		< LOD		< LOD	
LOD	0.005		0.019		0.232	

* The values are sum of five consecutive treatments.

Table 22. Antimony released from Aged Fabric Sample UK-12 after various Treatments*

Treatments	Antimony released (mg/g of fabric)		Percent of available Antimony released		Antimony released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
Saline	0.018	0.020	0.114	0.121	0.411	0.444
	0.021		0.128		0.476	
Cleaner 1	0.034	0.030	0.214	0.185	0.823	0.697
	0.025		0.156		0.571	
Cleaner 2	0.043	0.038	0.267	0.232	1.036	0.877
	0.032		0.196		0.717	
5 % Citric acid	4.160	4.043	25.836	25.111	99.719	96.812
	3.926		24.385		93.904	
Methylchloroform	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
	< LOD		< LOD		< LOD	
LOD	0.011		0.065		0.243	

* The values are sum of five consecutive treatments.

Table 23. Antimony released from Fabric Sample UK-12 after various Treatments*

Treatments	Antimony released (mg/g of fabric)		Percent of available Antimony released		Antimony released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
Saline	0.025	0.026	0.157	0.159	0.587	0.595
	0.026		0.160		0.603	
Cleaner 1	0.031	0.021	0.193	0.131	0.741	0.529
	0.011		0.069		0.317	
Cleaner 2	0.030	0.028	0.188	0.179	0.764	0.721
	0.027		0.170		0.678	
5 % Citric acid	3.962	3.448	24.609	21.412	97.003	83.886
	2.933		18.215		70.769	
Methylchloroform	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
	< LOD		< LOD		< LOD	
LOD	0.011		0.065		0.243	

* The values are sum of five consecutive treatments.

Table 24. DBDPO released from Aged Fabric Sample IL-5 after various Treatments*

Treatments	DBDPO released (mg/g of fabric)		Percent of available DBDPO released		DBDPO released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
Saline	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
	< LOD		< LOD		< LOD	
Cleaner 1	0.030	0.037	0.048	0.055	1.296	1.613
	0.044		0.071		1.929	
Cleaner 2	0.009	0.015	0.014	0.025	0.388	0.666
	0.021		0.035		0.945	
5 % Citric acid	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
	< LOD		< LOD		< LOD	
Methylchloroform	1.355	1.505	2.186	2.436	60.203	67.335
	1.665		2.685		74.467	
LOD	0.002		0.003		0.095	

* The values are sum of five consecutive treatments.

Table 25. HBCD released from Aged Fabric Sample UK-12 after various Treatments*

Treatments	HBCD released (mg/g of fabric)		Percent of available HBCD released		HBCD released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
Saline	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
	< LOD		< LOD		< LOD	
Cleaner 1	0.127	0.080	0.136	0.101	2.941	1.814
	< LOD		< LOD		< LOD	
Cleaner 2	< LOD	< LOD	< LOD	0.253	< LOD	< LOD
	< LOD		< LOD		< LOD	
5 % Citric acid	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
	< LOD		< LOD		< LOD	
Methylchloroform	34.720	34.448	36.937	36.647	818.015	818.650
	34.175		36.356		819.285	
LOD	0.065		0.065		1.372	

* The values are sum of five consecutive treatments.

Table 26. Phosphorus released from Immersion treated Aged Fabric Sample UF-11 after Various Treatments*

Treatments	Phosphorus released (mg/g of fabric)		Percent of available Phosphorus released		Phosphorus released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
Saline	1.323	1.311	7.831	7.757	46.038	45.668
	1.298		7.682		45.297	
Cleaner 1	1.351	1.365	7.994	8.077	47.185	47.560
	1.379		8.160		47.935	
Cleaner 2	1.507	1.498	8.915	8.862	52.600	52.207
	1.489		8.809		51.814	
5 % Citric acid	1.677	1.702	9.922	10.068	58.590	59.548
	1.726		10.214		60.505	
Methylchloroform	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
	< LOD		< LOD		< LOD	
LOD	0.011		0.067		0.392	

* The values are sum of five consecutive treatments.

Table 27. Phosphorus released from Immersion treated Aged Fabric Sample UF-13 after Various Treatments*

Treatments	Phosphorus released (mg/g of fabric)		Percent of available Phosphorus released		Phosphorus released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
		Average		Average		Average
Saline	1.856	1.934	13.254	13.812	55.349	0.371
	2.012		14.369		59.521	
Cleaner 1	2.064	1.989	14.742	14.204	60.027	0.365
	1.913		13.666		52.933	
Cleaner 2	2.074	2.048	14.817	14.660	58.860	0.38
	2.022		14.442		59.963	
5 % Citric acid	4.960	4.958	35.431	35.417	145.876	925
	4.956		35.403		140.912	
Methylchloroform	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
	< LOD		< LOD		< LOD	
LOD	0.014		0.096		0.389	

* The values are sum of five consecutive treatments.

Table 28. Antimony released from Back-coated Fabrics by Simulated Gastric juice

Sample #	Antimony release rate ($\mu\text{g}/\text{hr}$)	Antimony released (mg/g of fabric)		Percent of available Antimony released		Antimony released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
			Average		Average		Average
IL-5	9.13	0.015	0.013	0.052	0.043	0.629	0.523
	6.15	0.010		0.034		0.417	
UK-12	49.20	0.137	0.133	0.849	0.823	3.389	3.306
	46.79	0.128		0.796		3.223	
LOD		0.002		0.009		0.062	

Table 29. Antimony released from Fabric Sample IL-5 after various Durability Treatments

Treatments*	Sample #	Antimony released (mg/g of fabric/hr)		Percent of available Antimony released		Antimony released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
			Average		Average		Average
C	IL-5	0.030	0.025	0.105	0.086	1.294	1.055
	IL-5	0.019		0.066		0.816	
PD	IL-5	0.016	0.016	0.056	0.055	0.677	0.660
	IL-5	0.015		0.054		0.642	
PD/CD	IL-5	0.013	0.013	0.046	0.046	0.569	0.564
	IL-5	0.013		0.046		0.559	
PD/CD/PD	IL-5	< LOD	< LOD	< LOD	< LOD	< LOD	< LOD
	IL-5	< LOD		< LOD		< LOD	
LOD		0.012		0.042		0.510	

*C = Control; PD = Pounded; CD = Cleaned.

Table 30. DBDPO released from Fabric Sample IL-5 after various Durability Treatments

Treatments*	Sample #	DBDPO released (mg/g of fabric/hr)		Percent of available DBDPO released		DBDPO released ($\mu\text{g}/\text{cm}^2$ of fabric/hr)	
			Average		Average		Average
C	IL-5	0.078	0.046	0.126	0.075	3.390	1.999
	IL-5	0.014		0.023		0.608	
PD	IL-5	0.014	0.014	0.022	0.022	0.583	0.568
	IL-5	0.013		0.021		0.553	
PD/CD	IL-5	0.020	0.017	0.033	0.027	0.890	0.723
	IL-5	0.013		0.021		0.556	
PD/CD/PD	IL-5	0.010	0.006	0.016	0.010	0.417	0.261
	IL-5	0.002		0.004		0.105	
LOD		0.001		0.002		0.052	

*C = Control; PD = Pounded; CD = Cleaned.

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- ¹ U.S. Consumer Product Safety Commission (CPSC) (1994) Upholstered furniture; advance notice of proposed rulemaking; request for comments and information. Federal Register, 59: 30735-30738. June 15, 1994.
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- ³ Sanders, H.J. (1978) Flame retardants. Chemical and Engineering News. Pages 22-36, April 24, 1978.
- ⁴ Ulsamer, A.G., R.E. Osterburg, and J. McLaughlin, Jr. (1980) Flame-retardant chemicals in textiles. Clinical Toxicology, 17: 101-131.
- ⁵ Powell, C., and R. Rose (1998) Testimony presented before the U.S. Consumer Product Safety Commission. May 5, 1998.
- ⁶ Fire Retardant Chemicals Association (1998) Letter from Russell C. Kidder, Fire Retardant Chemicals Association, Lancaster, PA to the Office of the Secretary, U.S. Consumer Product Safety Commission, with attachments. August 3, 1998.
- ⁷ Sanders, H.J. (1978)
- ⁸ Albright & Wilson (1998), Letter from Celia Powell, Albright & Wilson, Glen Allen, VA to Dale Ray, U.S. Consumer Product Safety Commission, with attachments. July 17, 1998.
- ⁹ Tao, W., Sushinsky, G., Bhooshan, B., and Cobb, D. (2000). Briefing Package on Upholstered Furniture: Cleaning and Wear Effects on Upholstery Fabric Flammability.

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- ¹ U.S. Consumer Product Safety Commission (CPSC) (1994) Upholstered furniture; advance notice of proposed rulemaking; request for comments and information. Federal Register, 59: 30735-30738. June 15, 1994.
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- ⁴ Ulsamer, A.G., R.E. Osterburg, and J. McLaughlin, Jr. (1980) Flame-retardant chemicals in textiles. *Clinical Toxicology*, 17: 101-131.
- ⁵ Powell, C., and R. Rose (1998) Testimony presented before the U.S. Consumer Product Safety Commission. May 5, 1998.
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- ⁷ Sanders, H.J. (1978)
- ⁸ Albright & Wilson (1998), Letter from Celia Powell, Albright & Wilson, Glen Allen, VA to Dale Ray, U.S. Consumer Product Safety Commission, with attachments. July 17, 1998.
- ⁹ **Sushinsky, G.F. (1999) Mechanical**



United States
CONSUMER PRODUCT SAFETY COMMISSION
Washington, D.C. 20207

MEMORANDUM

DATE: Dec 2000

TO : Michael Babich, Ph.D, Toxicologist, Directorate for Health Sciences

Through : Andrew G. Stadnik, Associate Executive Director
Directorate of Laboratory Sciences, LS
Warren Porter, Division Director, Division of Chemistry (LSC), *usph*
Directorate of Laboratory Sciences

FROM : David Cobb, Division of Chemistry, LSC *real Cobb*

SUBJECT : Identification of P Compounds in Migration Study of Flame Retardant Chemicals from Upholstered Furniture Fabric

BACKGROUND

Some types of upholstery fabrics are treated with organic flame retardant chemicals (FRC) that contain phosphorus (P). LSC conducted a migration study¹ to determine the quantity of FRC migrating under various conditions from fabrics with different phosphorus FRC treatments. During this study P content in extracts was measured, and the amount of FRC was estimated using stoichiometry and assuming all the phosphorus detected was in the form of the FRC treatment chemical. This assumption can lead to overestimating the amount of FRC migrating. Additional work has been done to identify the migrating P compounds. This memorandum describes that work.

METHODS

Fabrics:

Four upholstery fabric samples were used in this study. These fabrics were also used in the original study¹, and are identified as follows:

IL3 = Cotton/nylon fabric treated with tetrakis(hydroxymethyl) phosphonium chloride (THPC)

UF11 = Cotton fabric treated with THPC

UF13 = Cotton fabric treated with phosphonic acid, (3- {[hydroxymethyl] amino}-3-oxopropyl)-, dimethyl ester (PE)
UF16 = Cotton fabric treated with PE

Migration Procedure:

Fabric specimens weighing 1-2 grams were placed in 250 milliliter (ml) beakers containing 25 ml of solvent. The solvents used were deionized water and 5% citric acid solution. The beakers were placed on a shaker bath set at 60 rpm and room temperature for 24 hours. The solvent extract was removed for analysis, and fresh solvent was added to the fabric specimens. This process was repeated until three sequential extractions were done for each specimen using both solvents. Three specimens from each of the four fabric samples were exposed to each of the two solvents.

Analysis:

The extracts were analyzed for total P using inductively coupled plasma spectrometry (ICP). Phosphate (PO_4^{3-}) ion in the extracts was determined by high pressure liquid chromatography (HPLC). Instrument conditions used were as follows:

Column: IC-Pak, Anion HR 4.6 X 75 mm
Eluant: Borate/Gluconate in 12 % acetonitrile
Flow: 1 ml/min
Detector: Conductivity

THPC was determined by HPLC. Instrument conditions were as follows:

Column: YMC-Pack NH_2 , 4.6 x 250 mm
Eluant: 97% acetonitrile/ 3% water
Flow: 1 ml/min
Detector: Photodiode Array (UV-Vis)
Wavelength: 200 nm

Analysis of PE was attempted using HPLC. Instrument conditions were similar to that which were used for analyzing THPC.

RESULTS AND DISCUSSION

The mean results for total P, PO_4^{3-} , THPC, and PE are contained in table 1. The spreadsheets showing all the P and PO_4^{3-} results are contained in attachment A. The following results were noted:

1. THPC was not detected in any of the deionized water extracts. It was determined that the detection limit for THPC using the HPLC method was 10 ppm. Based on this detection limit, less than 2% of the P extracted in deionized water could be in the form of THPC.

2. PE could not be determined. A pure standard of PE was not available. The commercial product pyrovatex was analyzed, but the chromatogram indicated that this product consisted of at least 2 major chemicals with different retention times. Analysis of the sample extracts produced multiple peaks that could not be separated and were within the retention times of the 2 major peaks found for pyrovatex.
3. Approximately 25% of the P found in the extracts of the PE treated garments was determined to be PO_4^{-3} . About 10% of the P found in the extracts of the THPC treated garments was determined to be PO_4^{-3} .
4. Most of the P and PO_4^{-3} extracted from each of the fabric specimens occurred during the first extraction with deionized water.
5. Higher levels of P were extracted using citric acid than with deionized water. THPC and PO_4^{-3} could not be determined in the citric acid extracts. By itself, citric acid does not interfere in the analysis of THPC or PO_4^{-3} , but the citric acid extracted other ions from the fabric that could not be separated from phosphate ion, and THPC could not be determined in the background of the large amounts of other chemicals extracted from the fabric by citric acid.

REFERENCES

1. Memorandum to Dale Ray from Bharat Bhooshan, *LSC Migration of Flame Retardant Chemicals from Upholstery Fabrics*, June 2000, CPSC

Table 1. Identification of Phosphorus Compounds in Migration Study of Immersion Treated Fabrics

Fabric ID	Treatment	Extract	Total P released (mg/gram of fabric)	Phosphate P released		THPC P released		PE P released	
				mg/gram of fabric	% of total P	mg/gram of fabric	% of total P	mg/gram of fabric	% of total P
IL3	Proban	Deionized Water	1.28	0.06	4.8	<0.037	<1.7	NA	NA
IL3	Proban	5% Citric Acid	2.10	*	*	**	**	NA	NA
UF11	Proban	Deionized Water	0.85	0.14	16.8	<0.037	<1.8	NA	NA
UF11	Proban	5% Citric Acid	1.38	*	*	**	**	NA	NA
UF13	Pyrovatex	Deionized Water	2.21	0.44	20.1	NA	NA	***	***
UF13	Pyrovatex	5% Citric Acid	14.06	*	*	NA	NA	***	***
UF16	Pyrovatex	Deionized Water	2.07	0.58	27.8	NA	NA	***	***
UF16	Pyrovatex	5% Citric Acid	12.71	*	*	NA	NA	***	***

Note: THPC = Tetrakis(hydroxymethyl)amino phosphonium chloride

PE = Phosphonic acid (3-{{[hydroxymethyl]amino}-3-oxopropyl)-, dimethyl ester

NA = Not applicable

* Phosphate ion could not be determined in the citric acid extracts. Citric acid does not interfere, but the citric acid extracted other ions from the fabric that could not be separated from phosphate ion.

** THPC could not be determined in the citric acid extracts. THPC could not be determined in the background of the large amounts of other chemicals extracted from the fabric by citric acid.

*** PE could not be determined. A pure standard of PE was not available. The commercial product pyrovatex was analyzed, but the chromatogram indicated that this product consisted of at least 2 major chemicals with different retention times. Analysis of the sample extracts produced multiple peaks that could not be separated and were within the retention times of the 2 major peaks found for pyrovatex..



UNITED STATES
CONSUMER PRODUCT SAFETY COMMISSION
WASHINGTON, DC 20207

Memorandum

Date: November 1, 2000

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SUBJECT : Statistical Analysis of the Migration of Flame-Retardant Chemicals

BACKGROUND

To assess the potential health risks associated with the use of flame-retardant chemicals (FRCs) in upholstery fabrics, the U.S. Consumer Product Safety Commission conducted a series of experiments. The experiments were designed to measure the migration of FRCs from fabrics due to common household use. The details of the experiments and the results are summarized in the memorandum "Migration of Flame Retardant Chemicals from Upholstered Fabrics¹."

In brief, eight fabrics with various properties were examined. Two fabrics had FR treatments of antimony (Sb) and decabromodiphenyl (DB), two had treatments of Sb and hexabromocyclododecane (HBCD), two had treatments of Proban (Pro), and two had treatments of Pyrovatex (Pyr). The application of the Sb and DB treatment and the Sb and HBCD treatment used a process known as backcoating. The Pro and Pyr treatments used an immersion process. In the case of Pro and Pyr, the chemicals were not measured directly. For these chemicals, phosphorus (P), a constituent of both chemicals, was measured. For this reason, it is possible that other nontoxic sources of P may explain some of the observed migration.

Migration was measured using the "Head Over Heels" (HOH) method and a filter paper method. The HOH method involves mixing samples of a fabric specimen in a saline solution. The process is meant to simulate the chewing of the fabric. The resulting solution is chemically analyzed for an FRC. The filter paper method consists of placing a piece of filter paper over a fabric specimen and applying one of five solvents. After drying, the filter paper is chemically analyzed for an FRC. The five solvents used are saline, two cleaners, citric acid, and methylchloroform. To

¹ Bhooshan B. and Cobb D., Migration of Flame Retardant Chemicals from Upholstery Fabrics, June 2, 2000.

examine the effect of aging, the migration test methods were applied to new fabric specimens and UV-aged fabric specimens.

Table 1 displays the various experiments that were performed. Each experiment consisted of two repetitions. The HOH method and the filter paper method with the five solvents were applied to new specimens of all eight fabrics and analyzed for all associated FRCs. Representative fabrics of the eight fabrics were UV aged and analyzed.

Fabric			Migration Studies												
			New Fabric					Aged Fabric							
			HOH	Filter paper				HOH	Filter paper						
Fabric ID	FR type	FR Chemical	Saline	Saline	Cleaner 1	Cleaner 2	Methylchloroform	Citric acid	Saline	Saline	Cleaner 1	Cleaner 2	Methylchloroform	Citric acid	
UF-6	B	Sb													
UF-6	B	DB													
IL-5	B	Sb													
IL-5	B	DB													
UF-8	B	Sb													
UF-8	B	HBCD													
UK-12b	B	Sb													
UK-12b	B	HBCD													
UF-11	I	Pro													
IL-3	I	Pro													
UF-13	I	Pyr													
UF-16	I	Pyr													

Table 1: Migration Experiments. The shaded boxes indicate the experiments that were performed. B and I represent backcoated and immersion applications, respectively.

The present statistical analysis addresses the following questions:

1. Does migration vary for different fabrics?
2. Does migration vary by the test method or solvent?
3. For each FRC, which solvent produces the largest migration?
4. What is the effect of the UV aging on the migration?
5. Does the aging effect differ for fabrics with backcoated and immersion applications?

STATISTICAL ISSUES

The statistical analysis is based on modeling and graphical analysis. For example, to examine the effect of a solvent, the following three models might be fit.

Model 0:

$$\text{Migration} = \text{FRC Effect}$$

Model 1:

$$\text{Migration} = \text{FRC Effect} + \text{Solvent Effect}$$

Model 2:

$$\text{Migration} = \text{FRC Effect} * \text{Solvent Effect}$$

All three models allow for different FRCs to produce different migrations. Model 0 does not allow for any solvent effect, which implies that migration does not vary by solvent. Model 1 allows for an additive solvent effect. This effect is “added” to the FRC effect and is the same for all FRCs. Model 2 has an interaction (indicated by the symbol “*”) between the solvent effect and the FRC effect. An interaction implies that the solvent effect may differ for different FRCs. The three models can be compared using analysis of variance (ANOVA) to determine which effects are statistically significant. The advantages of the modeling approach are (1) it pools the greatest amount of data to address a hypothesis and (2) it reduces the number of statistical tests. Both of these advantages increase the power to test hypotheses.

There are some cautions associated with statistical significance. In general, statistical significance identifies unusual outcomes. However, it does not address whether the magnitude of the outcome is of scientific interest. With enough data, arbitrarily small differences will be statistically significant. Another problem with significance testing in the present study is that it assumes that the two repetitions of an experiment are statistically independent. However, in the present study multiple samples share common sources of variations. For example, multiple samples were analyzed with common instrument calibrations. Instrument drift and environmental conditions may impose additional common sources of variation. With such common sources of variation, the differences between results from distinct experimental conditions may appear overly large relative to the differences between repetitions of the same experiments. The end result is that differences in the distinct experiments appear more statistically significant than they should.

The use of reference materials, check standards, and quality control procedures could have been used to alleviate some of these problems. Because of these cautions, conclusions will be based on both statistical significance testing and graphical analysis.

There are several choices of units on which the data may be analyzed. They are (1) amount of extraction, (2) amount of extraction per unit area of fabric, (3) amount of extraction per unit weight of fabric, and (4) amount of extraction as a percentage of the total amount of FRC in the

fabric. The statistical analysis will use the last measure, referred to as “Percent of Available.” The measure normalizes results across fabrics and FRCs, making comparisons more direct.

The results for the new and UV aged fabrics are shown in Figure 1. The figure is composed of plots arranged in two rows of six columns. Each plot gives the results for all of the FRC and fabric combinations. The two rows of plots separate the new and UV-aged results. Within each row, the results for the HOH method and the filter paper method with the five solvents are separated. Each line contains two dots representing the two repetitions. Many of the repetitions overlap at this scale. Entries without circles imply that the associated experiments were not performed, as indicated in Table 1.

For two experiments, the results were declared to be outliers and were not used in the statistical analysis. These values are noted as triangles in the plots. The first set of outliers was for the analysis of HBCD using the HOH method on the new specimen of fabric UF8. The result was considered unusual, because for all other saline-based results (filter paper and HOH) on HBCD, the values were several orders of magnitude smaller. The second set of outliers was for the analysis of HBCD with the MC solvent on the new specimen of fabric UF8. The two repetitions for this experiment differed by 10 units. The next largest difference between repetitions occurs for the analysis of Sb with the citric acid solvent on the new specimen of fabric UK12b. The difference there is 6 units.

Certain conditions need to be met for the statistical significance testing to be valid. The independence of the repetitions has already been discussed. Another condition is that the data must have a distribution that is not too far from a normal distribution. Outliers, which have already been addressed, are one way a distribution can deviate from normality. A graphical technique, known as a normal probability plot, is useful in addressing normality. Results that have a normal distribution will appear as a straight line in a normal probability plot. S-shapes indicate deviations from normality.

Figure 2 displays some diagnostic plots to address the normality. The plots are of the differences between the two repetitions and the differences of the logarithms of the two repetitions. By examining the differences, the fixed effects such as fabric, solvent and FRC effects are removed, leaving only the random effect of the measurement. The normal probability plot of the differences of the repetitions (upper left plot) displays some of the S-shape behavior indicating non-normality. The logarithm transform improves the normality somewhat (see upper right plot).

The logarithm transformation can be appropriate if the random variations in the measurements are proportional to the magnitudes of the measurements. This behavior can be seen in the migration data. However, the use of standard models with the logarithm transform implies that a given percentage change in a small magnitude result is equally important as one in a large magnitude result, e.g., 2 % of .01 and 2 % of 10 are of equal importance. I have chosen to analyze the results without the logarithm transform, because I believe the relative accuracy of the small magnitude results may be low compared to that of the other results.

RESULTS

Fabric Effect

Figure 3 displays the results for the new specimens grouped by FRC and solvent. The distinct plot characters are used to indicate different fabrics. The two repetitions have been averaged in this figure and in all subsequent figures. Pyr, Pro, HBCD, and DB are each present in two fabrics. Sb is present in four fabrics; in two fabrics it is co-present with HBCD and in two fabrics it is co-present with DB.

Except for the citric acid solvent on Sb, there appears to be little difference across the fabrics for particular solvent and FRC combinations. Several models were fit to examine this hypothesis. All the models included an interaction between the solvent and FRC effects. Such an interaction allows results to vary for each FRC and solvent combination. The models indicated that the fabric did have a significant effect on migration. The models were then re-fit excluding the Sb results. Without the Sb results, the fabrics did not have a significant effect. It is notable that the two fabrics with Sb and DB have lower migration rates than the two fabrics with Sb and HBCD.

In the subsequent analyses, no fabric effect is considered, except in the case of Sb.

Conclusion: F
fabric, except in the case of Sb.

vary significantly by

Solvent Effect

Figure 4 again displays the results for the new specimens grouped by FRC and solvent. However, as noted above, the four fabrics with Sb are treated separately. The plot characters indicate whether the FRC is water-soluble (s) or not water-soluble (i). The only notable migration for HBCD and DB is with the MC solvent. MC is the only organic solvent among the solvents. For Sb, the only notable migrations are with the citric acid solvent. In the cases of Pyr and Pro, there is notable migration in all cases except the organic solvent.

A series of models was fit to test the effect of the type of solvent. The models implied that there exist significant differences among the solvents, and that the effects of the solvents vary significantly for the different FRCs.

In Figure 5, the aqueous neutral solvent results, HOH, saline, cleaner 1, and cleaner 2, are combined and are labeled as neutral. Citric acid is labeled as acid and MC is labeled as organic. From this figure it is clear that the neutral solvents behave very similarly to each other. Also, the three types of solvents behave very differently from each other. Models fit to test the hypothesis that within each solvent type the solvents behaved similarly rejected this hypothesis. However, although the neutral solvents are significantly different from one another, Figure 5 implies that the differences may not be large in a scientific sense.

Based on a fitted model for migration, estimates for each FRC for each solvent type are given in Table 2. The +/- indicates the limits of a 95 % confidence interval. For each FRC, the confidence

interval has been adjusted to allow for the multiple comparison of the three estimates. This was done using the Bonferroni technique. With this adjustment, one can compare, for a given FRC, the estimates for the three solvent types at once and determine if any is significantly larger than the other two. Note that if all six solvents were considered, the multiple comparison problem would reduce the statistical power to compare the results.

FRC	Solvent Type			Significantly Largest
	Neutral	Acid	Organic	
DB	0.03 +/-0.5	0.00 +/-1.01	1.19 +/-1.01	None
HBCD	0.05 +/-0.54	0.02 +/-1.01	17.68 +/-1.42	Organic
Pro	2.90 +/-0.5	3.01 +/-1.01	0.03 +/-1.01	None
Pyr	8.84 +/-0.5	27.27 +/-1.01	0.06 +/-1.01	Acid
Sb (IL5)	0.05 +/-0.71	5.08 +/-1.42	0.01 +/-1.42	Acid
Sb (UF6)	0.07 +/-0.71	14.29 +/-1.42	0.01 +/-1.42	Acid
Sb (UF8)	0.14 +/-0.71	37.06 +/-1.42	0.01 +/-1.42	Acid
Sb (UK12b)	0.14 +/-0.71	21.41 +/-1.42	0.03 +/-1.42	Acid

Table 2:FRC Migration Estimation for Three Solvent Types. The limits defined by the +/- indicate 95 % confidence intervals calculated to have simultaneous coverage for a given FRC.

Based on the simultaneous intervals, Table 2 also gives the solvent type that produces the significantly largest migration. The organic solvent produces the largest migrations for DB and HBCD. In the case of DB, the difference between the organic solvent and the acid solvent is not statistically significant. In the case of Pro, the neutral solvents and the acid solvent are not statistically significantly different, but they are significantly different from the organic solvent. In the four Sb cases, the acid solvent produces the significantly largest migrations.

Conclusion: The solvents produce significantly different migrations from one another. The effects of the solvents vary for the different FRCs.

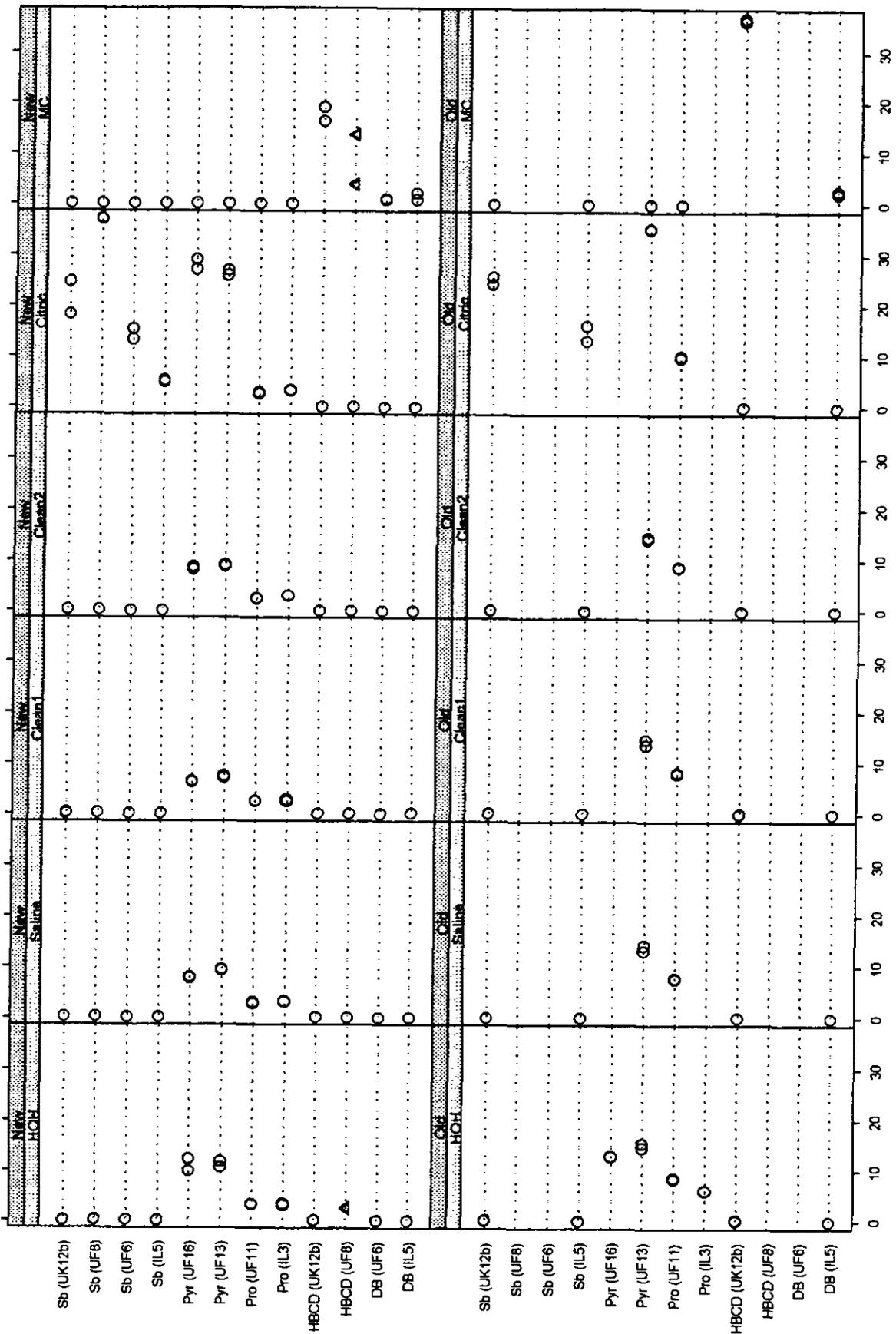
New Versus UV Aged Fabrics

For the comparison of the new and UV-aged fabrics only combinations of FRCs and solvents for which there are results for both fabric conditions are used. Figure 6 displays the comparison between the new (n) and UV aged (o) fabrics. In almost all cases, the UV-aged fabrics produce larger migrations. The effect is seen mainly for FRC and solvent combinations for which there are large migrations. Models fit to examine the effect of UV aging on migration showed that the effect is significant.

The effect of UV aging is further explored to examine if it depends on the method of application, i.e., backcoated versus immersion. Figure 7 displays the differences between new and UV-aged fabrics with the plot character distinguishing between the backcoated (b) and immersion (i) treatments. To test for differences between backcoated and immersion applications, a series of models were fit. For each FRC, only the results from the solvent determined to produce the largest migration were used. The models concluded there was not a significant difference between backcoated and immersion treated fabrics.

Conclusion: Overall, UV aging of fabrics significantly increases migration. The effect is seen mainly for FRC and solvent combinations for which there is large migration. For the fabrics tested, there does not appear to be a difference between backcoated and immersion treated fabrics with respect to UV aging.

Figure 1: Extract by FRC, Fabric, Solvent, and New Vs. UV-Aged



Percent of Available

Figure 2: Diagnostic Plots

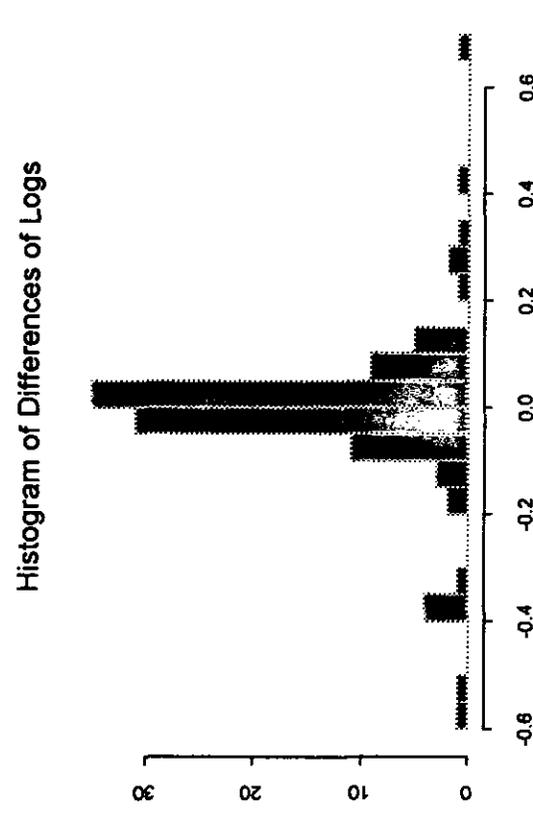
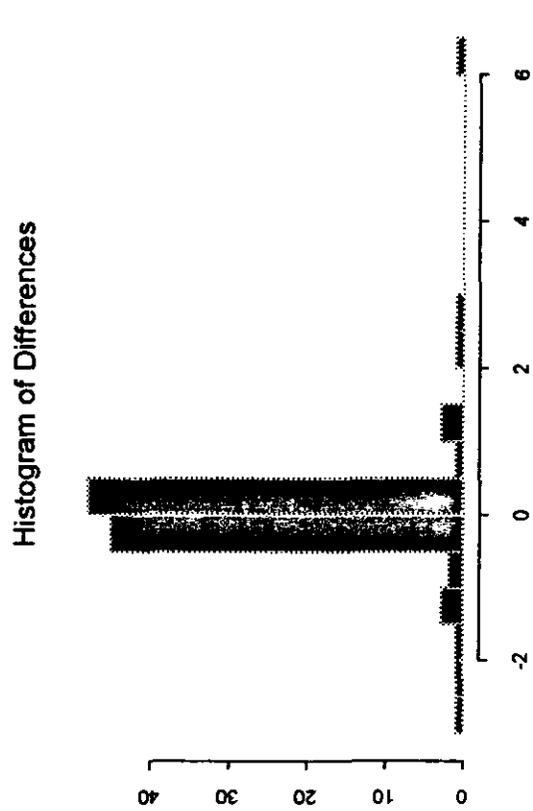
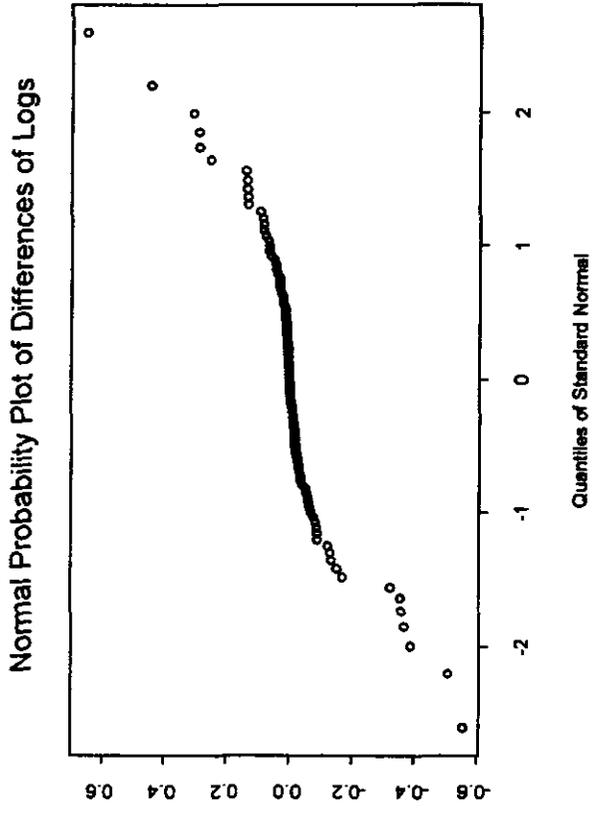
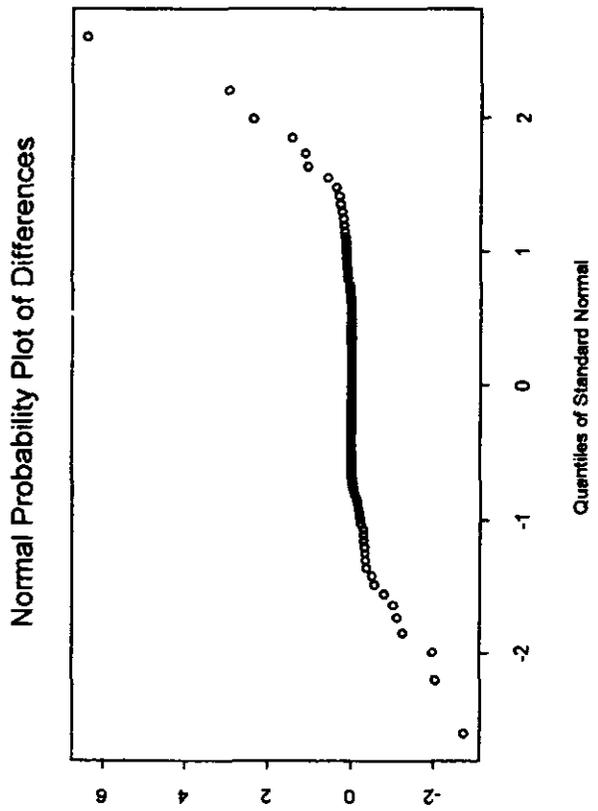
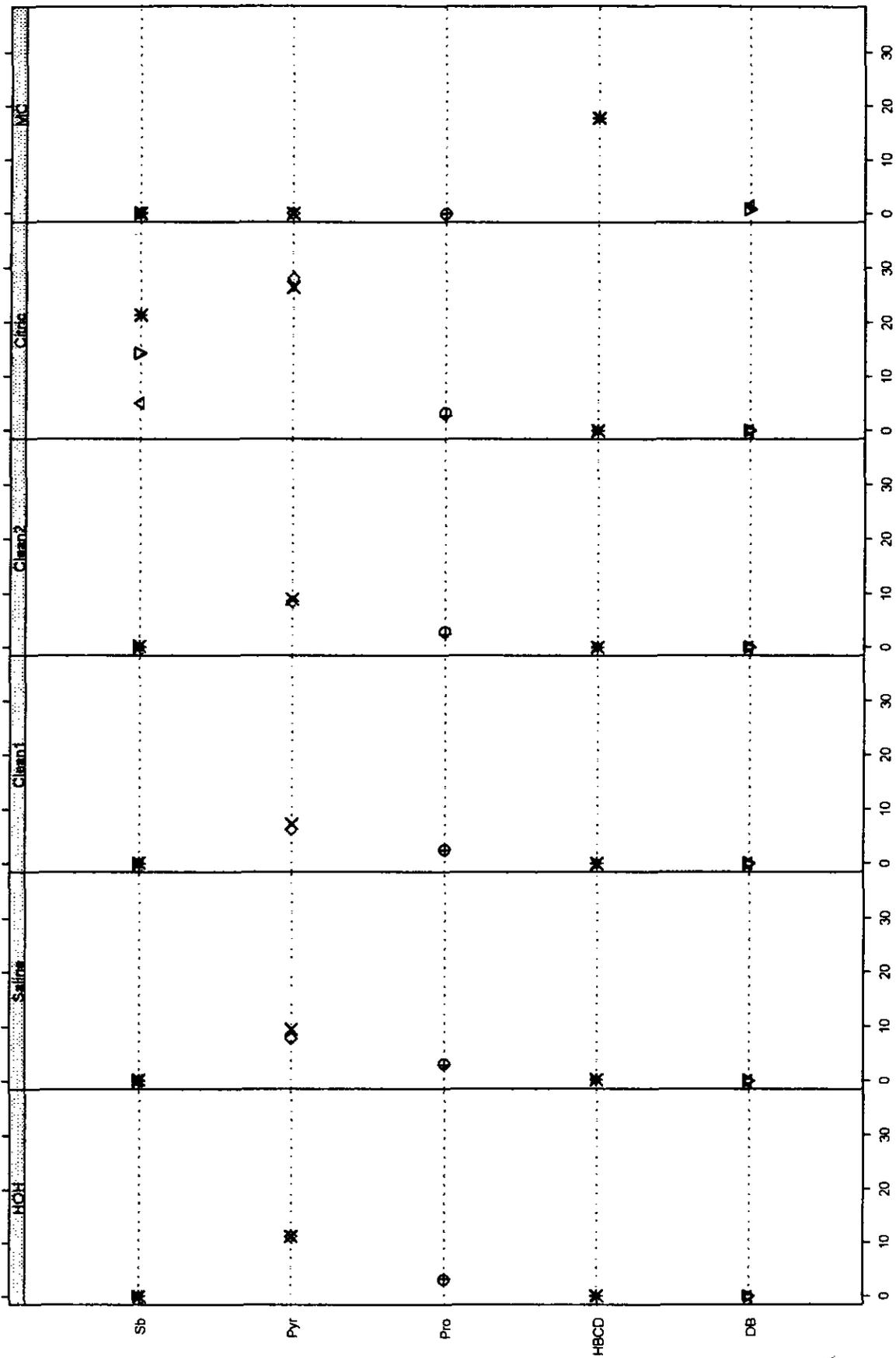
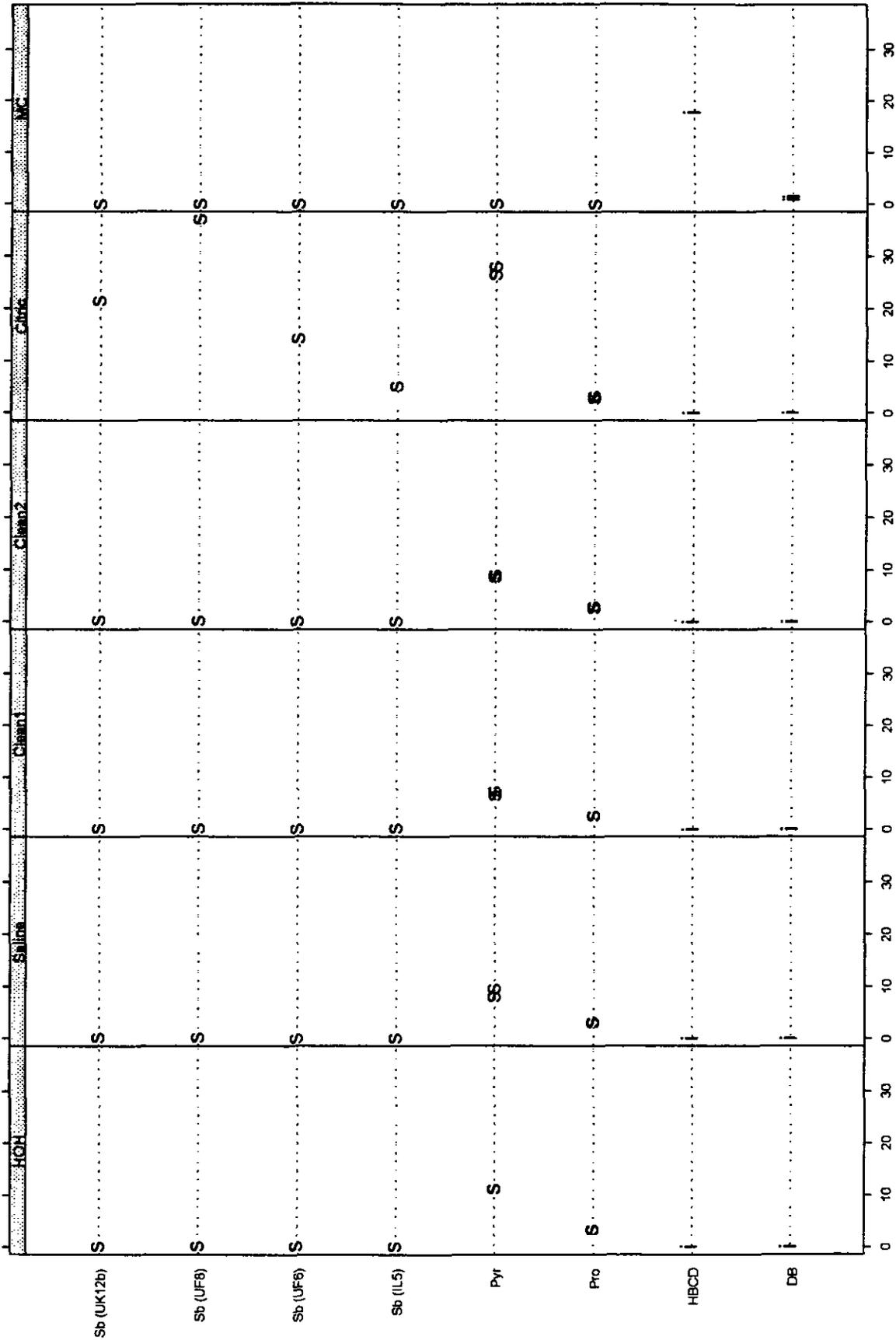


Figure 3: Extract by FR Chemical and Solvent (Plot Characters Indicate Fabrics)



Percent of Available

Figure 4: Extract by FRC (water-soluble = s, water-insoluble = i) and Solvent



Percent of Available

Figure 5: Extract by FRC and Solvent Type (Plot Characters Indicate Solvents)

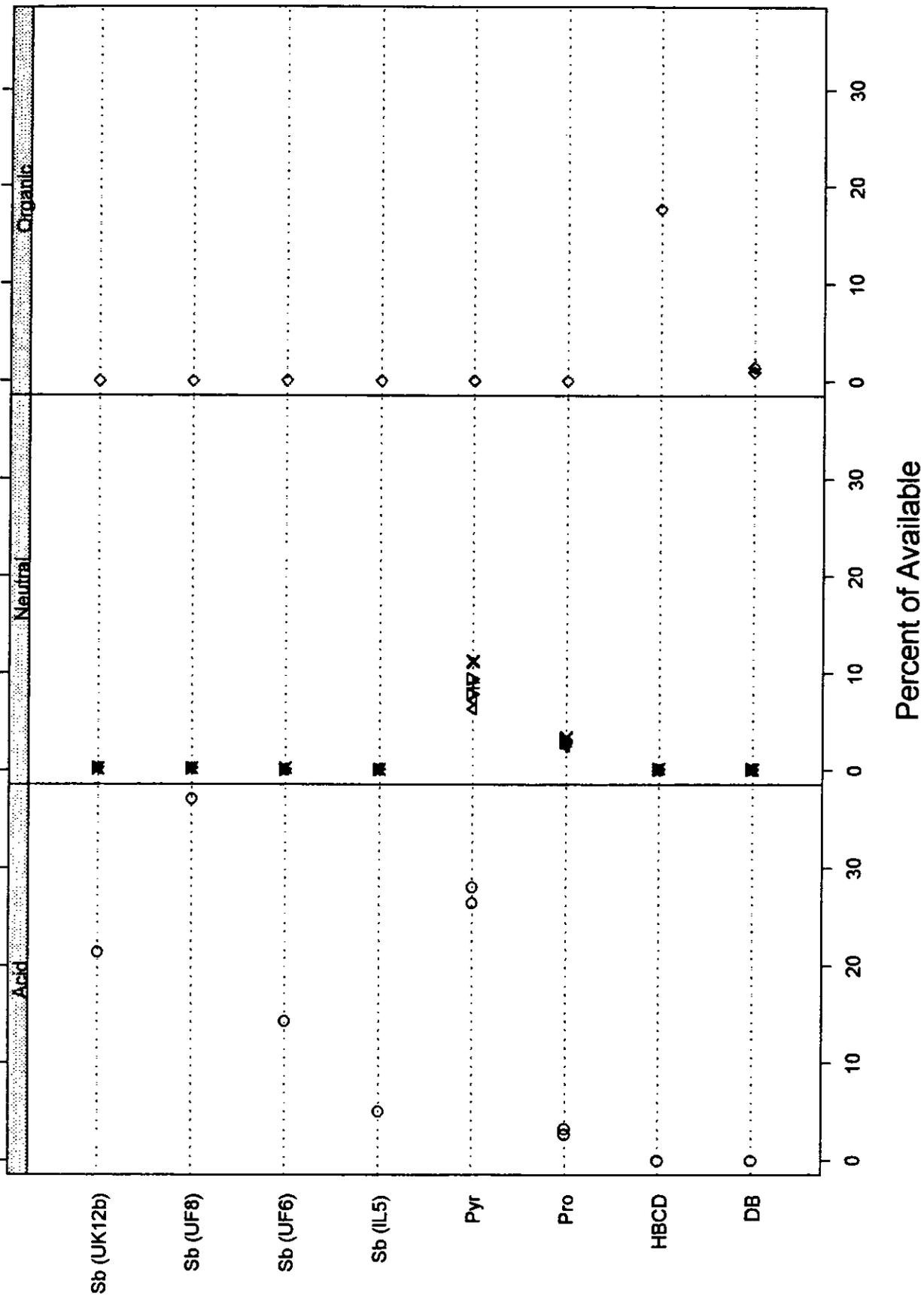
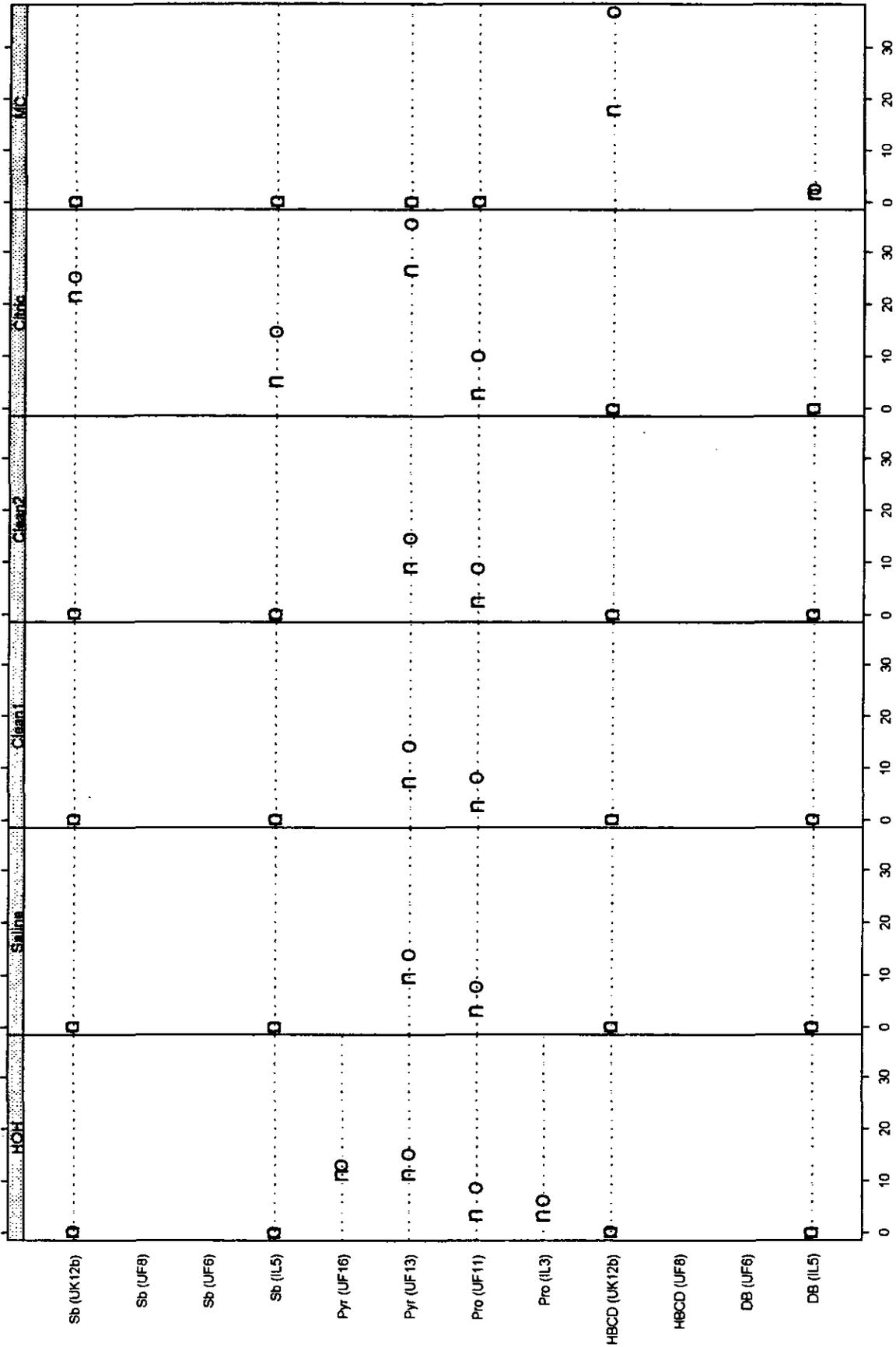
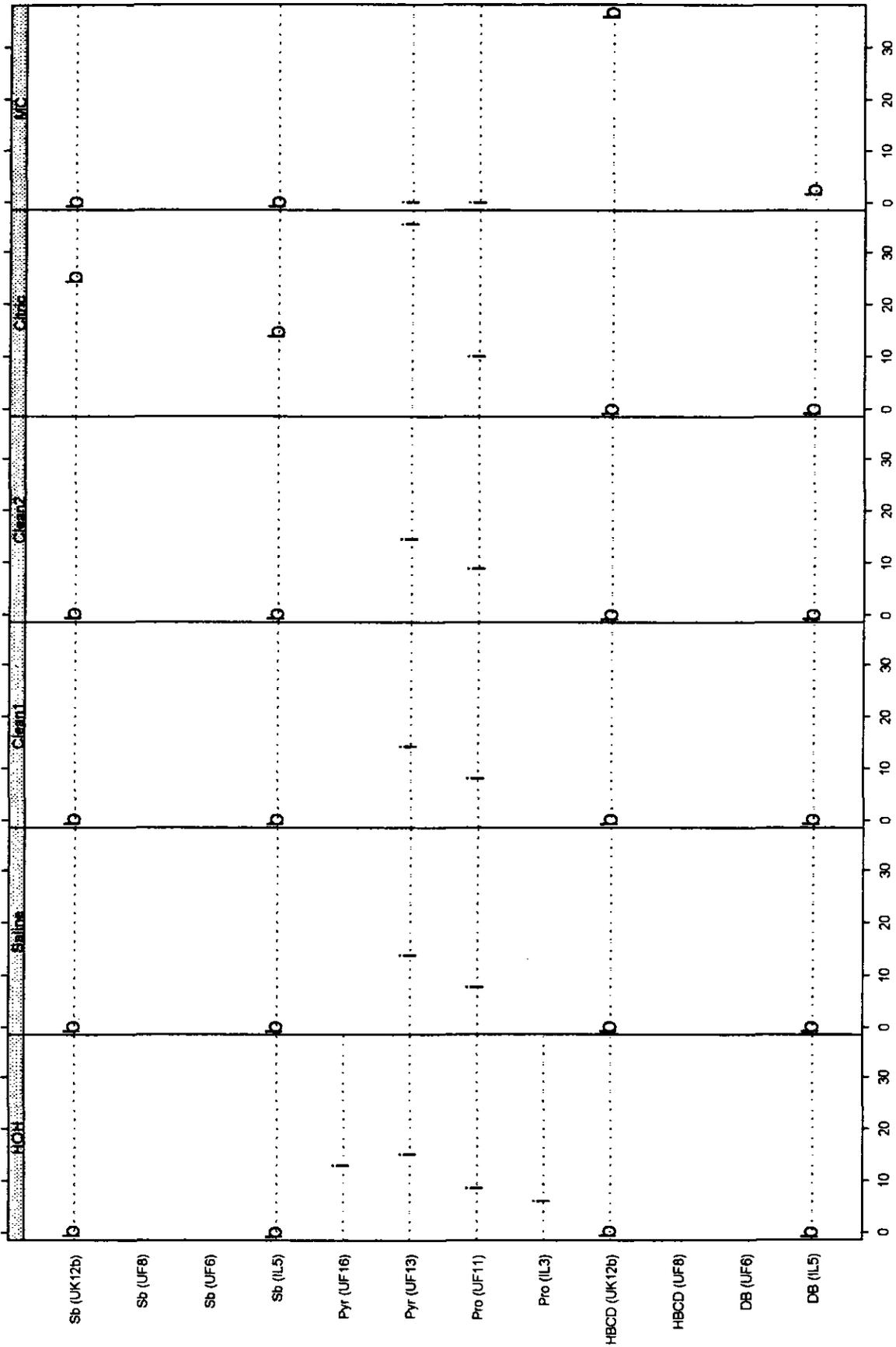


Figure 6: Extract of New (n) and UV-Aged (o) Fabrics by FR Chemical and Solvent



Percent of Available

Figure 7: UV Aging Effect for Backcoated (b) and Immersion (i) Treatments



Percent of Available



United States
CONSUMER PRODUCT SAFETY COMMISSION
Washington, D.C. 20207

MEMORANDUM

DATE: April 4, 2001

TO : Dale Ray, Project Manager for Upholstered Furniture, Directorate for Economic Analysis

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SUBJECT : CPSC Staff Exposure and Risk Assessment of Flame Retardant Chemicals in Residential Upholstered Furniture

This is to transmit the report entitled "CPSC Staff Exposure and Risk Assessment of Flame Retardant Chemicals in Residential Upholstered Furniture," by Michael A. Babich and Trey A. Thomas.



CPSC Staff Exposure and Risk Assessment of Flame Retardant Chemicals in Residential Upholstered Furniture

April 4, 2001

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Summary

The U.S. Consumer Product Safety Commission (CPSC) initiated a regulatory proceeding in 1994 to address the hazard of small open flame ignitions of upholstered furniture (CPSC, 1994). Small open flame sources include cigarette lighters, matches, and candles. Such ignitions of upholstered furniture are associated with an estimated 80 deaths, 350 injuries, and \$32 million in property damage per year in the U.S. (Ault and Levenson, 2000). Adding fires due to cigarette ignitions results in an estimated 540 deaths, 1,330 injuries, and \$168 million in property damage. The CPSC staff has developed a draft performance standard to address the hazards associated with both small open flame and cigarette ignitions (CPSC, 1997). Although furniture manufacturers would be free to choose the means of complying with the draft standard, manufacturers have reported that they would probably treat fabrics with flame retardant (FR) chemicals (Parkes, 1998). In addressing the hazards associated with the small open flame and cigarette ignitions of upholstered furniture, the CPSC staff is working to develop a performance standard to reduce furniture ignitions without creating other hazards to consumers.

The purpose of the present report is to assess the potential health risks from exposure to selected FR chemicals in residential upholstered furniture. These chemicals include: antimony trioxide (AT); cyclic phosphonate esters (CPE) (also known by the tradename Antiblaze N/NT[®]); decabromodiphenyl oxide (DBDPO); 2-ethylhexyl diphenyl phosphate (EHDP); hexabromocyclododecane (HBCD); phosphonic acid, (3-{{hydroxymethyl}amino}-3-oxopropyl)-, dimethyl ester (PA) (sold under the trade name Pyrovatex[®]); tetrakis (hydroxymethyl) phosphonium chloride (THPC) (Proban CC[®]); and tris (1,3-dichloropropyl-2) phosphate (TDCP) (Fyrol FR-2[®]). This risk assessment also describes methods that manufacturers could use to assess the potential risks from other FR chemicals.

The hazard identification and dose response assessment steps of this risk assessment were based primarily on animal studies. The CPSC staff has reviewed all available toxicity data for 16 FR chemicals or chemical classes proposed for this use. However, risk assessments were performed for only 8 FR's. Only chronic hazards are considered here. The exposure assessment was accomplished by evaluating a series of dermal, oral, and inhalation exposure scenarios. Input data for the exposure assessment included migration (leaching) data, *in vivo* or *in vitro* percutaneous absorption data, as well as assumptions regarding consumer behavior. Mathematical models were used to estimate inhalation exposure, as suitable data were not available. However, migration data were available for only 5 FR's—AT, DBDPO, HBCD, PA, and THPC. Percutaneous absorption data were only available for CPE, DBDPO, HBCD, and TDCP. Due to the lack of chemical-specific migration data for some FR chemicals, it was necessary to use data from closely related chemicals to estimate exposure. In some cases, assumptions regarding percutaneous absorption were made. In addition, data on carcinogenicity, teratogenicity, or neurotoxicity were not available for all chemicals. The availability of new data to fill these data gaps may alter some of the conclusions of this report.

The CPSC staff concludes that at least four of the FR treatments would not present a hazard to consumers, as defined by the Federal Hazardous Substances Act (FHSA), including CPE, DBDPO, HBCD, and PA. EHDP would probably also comply with the FHSA. Based on this risk assessment, EHDP might present a hazard only if the treated fabric is exposed to dry

cleaning fluids. However, migration data are needed to confirm the conclusions regarding CPE and EHDP.

The estimated exposure to airborne particles containing AT is near the level of concern for both cancer and non-cancer effects. Given that the airborne particle levels were estimated from mathematical models, empirical data are needed to determine whether exposure by this route may be hazardous. Dermal and oral exposures to AT were estimated to be below the level of concern.

The potential risks from exposure to THPC-treated fabrics could not be assessed. THPC is a reactive FR that polymerizes within fabric fibers. Phosphorus containing compounds were found in extracts from THPC-treated fabrics, although THPC itself was not detected. Additional information on the identity and toxicity of these compounds is needed before the potential risks can be assessed. However, THPC-treated fabrics could be considered hazardous if these compounds were as toxic as THPC.

TDCP appears to be hazardous regarding both cancer and non-cancer health effects. However, data on migration in liquids and emissions into air are needed to confirm this conclusion.

Abbreviations

ADD	average daily dose
ADE	average daily exposure (in this report, generally by inhalation)
ADI	acceptable daily intake
AMEM	A.D. Little migration estimation model
AT	antimony trioxide (CAS no. 1309-64-4)
CPE	cyclic phosphonate ester, that is, a aqueous solution containing 60 to 65% phosphonic acid, methyl-, (5-ethyl-2-methyl-1,3,2-dioxaphosphorinan-5-yl)methyl methyl ester, P-oxide (monomer) (41203-81-0) with 18 to 19% and phosphonic acid, methyl-, bis[(5-ethyl-2-methyl-1,3,2-dioxaphosphorinan-5-yl)methyl] ester, P,P'-oxide (dimer) (42595-45-9)
CPSC	U.S. Consumer Product Safety Commission
DBDPO	decabromodiphenyl oxide (1163-19-5)
EHDP	2-ethylhexyl diphenyl phosphate (1241-94-7)
EPA	U.S. Environmental Protection Agency
FHSA	Federal Hazardous Substances Act
FR	flame retardant
FRCA	Fire Retardant Chemicals Association
HBCD	hexabromocyclododecane, mixed isomers (25637-99-4) and 1,2,5,6,9,10-hexabromocyclododecane (3194-55-6)
HI	hazard index
HS	Directorate for Health Sciences
LADD	lifetime average daily dose
LADE	lifetime average daily exposure (in this report, generally by inhalation)
LD ₅₀	dose at 50 percent lethality
LOAEL	lowest-observed-adverse-effect level
LSC	Directorate for Laboratory Sciences, Division of Chemistry
MOE	margin of exposure
NHEERL	National Health and Environmental Effects Research Laboratory, U.S. Environmental Protection Agency
NIOSH	National Institute for Occupational Safety and Health
NOAEL	no-observed-adverse-effect level
NRC	National Research Council, National Academy of Sciences
PA	phosphonic acid, (3-{[hydroxymethyl]amino}-3-oxopropyl-, dimethyl ester (210-20-33-6)
RfC	reference concentration
RfD	reference dose
SNUR	significant new use rule
TCP	<i>o</i> -tricresyl phosphate
TDCP	tris (1,3-dichloropropyl-2) phosphate (13674-87-8)
THPC	tetrakis (hydroxymethyl) phosphonium chloride (124-64-1) or its reaction products
THPC-urea	compound of THPC with urea (2:1)
THPO	tris (hydroxymethyl) phosphine oxide (1067-12-5)
Tris	tris(2,3-dibromopropyl)phosphate

I. Introduction

The U.S. Consumer Product Safety Commission (CPSC) initiated a regulatory proceeding in 1994 to address the hazard of small open flame ignitions of upholstered furniture (CPSC, 1994). Small open flame sources include cigarette lighters, matches, and candles. Such ignitions of upholstered furniture are associated with an estimated 80 deaths, 350 injuries, and \$32 million in property damage per year in the U.S. (Ault and Levenson, 2000). Including fires due to cigarette ignitions of upholstered furniture results in a total of 540 deaths, 1,330 injuries, and \$168 million in property damage (ibid.). The CPSC staff has developed a draft performance standard to address the hazards associated with both small open flame and cigarette ignitions (CPSC, 1997). Although furniture manufacturers would be free to choose the means of complying with the draft standard, manufacturers have reported that they would probably treat fabrics with flame retardant (FR) chemicals (Parkes, 1998). In addressing the hazard associated with the small open flame ignition of upholstered furniture, the CPSC staff is working to develop a performance standard to reduce furniture ignitions without creating other hazards to consumers.

The purpose of the present report is to assess the potential health risks from exposure to selected FR chemicals in residential upholstered furniture. These chemicals include: antimony trioxide (AT); cyclic phosphonate esters (CPE) (also known by the tradename Antiblaze N/NT[®]); decabromodiphenyl oxide (DBDPO); 2-ethylhexyl diphenyl phosphate (EHDP); hexabromocyclododecane (HBCD); phosphonic acid, (3-{{hydroxymethyl}amino}-3-oxopropyl)-, dimethyl ester (PA) (sold under the trade name Pyrovatex[®]); tetrakis (hydroxymethyl) phosphonium chloride (THPC) (Proban CC[®]); and tris (1,3-dichloropropyl-2) phosphate (TDCP) (Fyrol FR-2[®]) (Figure I-1). At this time, migration data are not available for all of these chemicals, and data on inhalation exposure are lacking. Due to the lack of chemical-specific migration data for some FR chemicals, it was necessary to use data from closely related chemicals to estimate exposure. In some cases, assumptions regarding percutaneous absorption were made. Not all chemicals were tested for carcinogenicity, teratogenicity, or neurotoxicity. The availability of new data to fill these data gaps may alter some of the conclusions of this report.

A. Risk Assessment Activities

As part of the risk assessment process for FR chemicals, the Commission held a public hearing in May 1998. In its testimony, the Fire Retardant Chemicals Association (FRCA) provided a list of 16 chemicals or chemical classes that its members would market for use in upholstered furniture if the draft standard were adopted (Parkes, 1998). The CPSC Directorate for Health Sciences (HS) staff has completed toxicity reviews on these 16 chemicals/chemical classes (Bittner, 2001; Bittner, 1999a-d; Bittner and Ferrante, 1999; Ferrante, 1999a-f; Hatlelid, 1999a-h; see also Babich and Saltzman, 1999). The CPSC Directorate for Laboratory Sciences, Division of Chemistry (LSC) staff conducted migration (leaching) studies with FR-treated fabrics (Bhooshan and Cobb, 2000; Levenson, 2000). Fabrics were exposed to aqueous and non-aqueous solvents to simulate a variety of potential dermal and oral exposure scenarios. Fabrics

treated with AT, DBDPO, HBCD, PA, and THPC were available for testing. Under an interagency agreement with CPSC, staff of the National Health and Environmental Effects Research Laboratory (NHEERL), U.S. Environmental Protection Agency (EPA) conducted *in vitro* percutaneous absorption studies with radiolabeled FR chemicals (Hughes, 2000). NHEERL studied DBDPO, HBCD, TDCP. Data on the percutaneous absorption of CPE were submitted to CPSC (Maibach, 1979).

As part of CPSC's FY99 appropriations, Congress provided funds for an independent study by the National Research Council (NRC), National Academy of Sciences of the "toxic risk" associated with the use of flame retardant chemicals in upholstered furniture. The NRC concluded that eight of the 16 chemicals/chemical classes studied "can be used on residential furniture with minimal risk," including: hexabromocyclododecane; decabromodiphenyl oxide; alumina trihydrate; magnesium hydroxide; zinc borate; ammonium polyphosphates; phosphonic acid, (3-([hydroxymethyl] amino)-3-oxopropyl)-, dimethyl ester; and tetrakis (hydroxymethyl)phosphonium chloride (NRC, 2000, p. 11). The NRC also recommended that exposure studies be conducted before the remaining eight chemicals/classes are used, including: antimony trioxide; antimony pentoxide and antimonates; calcium and zinc molybdates; dimethyl phosphonate (organic phosphonates); tris(chloropropyl) phosphate; tris(1,3-dichloropropyl-2) phosphate; tricresyl phosphate (aromatic phosphate plasticizers); and chlorinated paraffins. The CPSC staff risk assessment addresses some of the same chemicals reviewed by NRC (see below).

In addition, the CPSC staff is cooperating with the EPA to develop a draft significant new use rule (SNUR) for the use of FR chemicals in upholstered furniture. SNUR's address potential risks to consumers, workers, and the environment. If adopted, the EPA SNUR could be used to obtain additional toxicity or exposure data where needed. At the request of CPSC, the National Institute for Occupational Safety and Health (NIOSH) is reviewing the potential occupational exposures and health effects associated with the use of FR chemicals in textile and upholstered furniture manufacturing.

B. Risk Assessment under the Federal Hazardous Substances Act

CPSC addresses chemical hazards under the Federal Hazardous Substances Act (FHSA). The FHSA is risk-based. To be considered a "hazardous substance" under the FHSA, a substance or product must satisfy a two-part definition. 15 USC 1261 (f)(1)(A). First, it must be "toxic" as defined under the FHSA, or present one of the other hazards enumerated in the statute. Second, it must have the potential to cause "substantial illness or injury" during or as a result of "reasonably foreseeable handling or use." Therefore, exposure and risk must be considered in addition to toxicity when assessing potential hazards under the FHSA (CPSC, 1992). The FHSA includes both acute and chronic hazards. It does not require manufacturers to perform any specific battery of toxicological tests to assess the potential for chronic hazards. Thus, risk assessments are based on all the available data.

The first step in the risk assessment process is hazard identification, that is, to review the available toxicity data for each chemical under consideration and determine whether the chemical is "toxic" under the FHSA. Acute toxicity is defined by LD₅₀ (dose at 50 percent

lethality) values in regulations issued under the FHSA. 16 CFR 1500.3 (c) (2) (i). However, reliable human experience data take precedence over animal data. 16 CFR 1500.4. In 1992, the Commission issued guidelines for assessing chronic hazards under the FHSA, including carcinogenicity, neurotoxicity, reproductive and developmental toxicity, exposure, bioavailability, risk assessment, and acceptable risk (CPSC, 1992; summarized at 16 CFR 1500.135). A substance is considered "toxic" under the FHSA due to chronic toxicity, if it is either known to be, or probably, toxic in humans. 16 CFR 1500.3 (c)(2)(ii). Under the FHSA, a substance or mixture is classified as "known to be toxic" in humans only if there is sufficient evidence in humans. It is considered "probably toxic" if there is either limited evidence in humans or sufficient evidence in animals.

Classification of Chronic Hazards under the FHSA.

	Human studies	Animal studies
Sufficient evidence	Known *	Probable *
Limited evidence	Probable *	Possible
Inadequate evidence	Possible	---

*Considered "toxic" under the FHSA.

Determinations of toxicity were made for the 16 chemicals/chemical classes in toxicity reviews conducted by the CPSC staff (see Table I-1) (Bittner, 1999a-d; Bittner and Ferrante, 1999; Ferrante, 1999a-f; Hatlelid, 1999a-h; see also Babich and Saltzman, 1999). The staff reviewed all the available toxicity data on the chemicals, including: all published studies identified through the National Library of Medicine databases, monographs, unpublished studies submitted to the U.S. EPA (Toxic Substances Control Act Test Submissions, or TSCATS), unpublished data submitted to CPSC, and standard references. The staff evaluated the available data for each chemical and determined whether the chemical may be considered "toxic," as defined by the FHSA (Table I-2). The data evaluated included acute and chronic toxicity, eye and skin irritation, and sensitization. Acceptable daily intake values (ADI's) were calculated when a given chemical was considered "toxic" due to chronic effects and sufficient information was available.

If it is concluded that a substance is toxic under the FHSA due to chronic toxicity, then a quantitative assessment of exposure and risk is performed to determine whether the chemical may be a "hazardous substance" under the FHSA. The quantitative risk assessment includes a consideration of dose response, bioavailability, and exposure. The present report describes the risk assessment process for 8 chemicals selected from the 16 chemicals/classes. The CPSC staff believes that these 8 FR's are the most likely to be used in upholstered furniture.

C. FR Chemicals and Methods of Application to Textiles

FR chemicals may be applied to textiles by a variety of methods, and the method of application may affect the potential for exposure (reviewed in Sanders, 1978; Ulsamer et al., 1980; Powell and Rose, 1998; FRCA, 1998). Some FR chemicals are mixed with an acrylic or vinyl polymer that is applied to the back of the fabric. The back-coating may reduce the potential for exposure, because the FR chemicals are applied to the back of the fabric and the polymer encapsulates the FR chemicals. FR back-coating is the most common method of FR-

treatment in furniture sold in the U.K. (FRCA, 1998; Powell and Rose, 1998). Most FR back-coatings contain either DBDPO or HBCD in combination with AT. Many other FR chemicals may be applied by back-coating, including: antimonates, aromatic phosphate esters, phosphonate esters, and TDCP. FR back-coating is used mainly with synthetic fabrics.

AT and DBDPO may also be mixed with an adhesive binder and applied to both surfaces of the fabric (Mischutin, 1975). The binder is heat cured and then the fabric is washed. This method is used in some upholstered furniture sold in the UK. The binder may reduce the potential for exposure by encapsulating the FR chemicals.

The cyclic phosphonate esters (CPE) are a mixture of a monomer and “dimer” in a ratio of roughly 3:1 (Albright and Wilson, 1998a). CPE may be applied by padding, that is, immersing the fabric in a solution of FR chemicals. With synthetic fabrics, the immersion treatment may be followed by baking in an oven to soften the fibers, allowing 25 to 50 percent of the CPE to become trapped within the fibers (Albright and Wilson, 1998a; Ulsamer et al., 1980). This process of surface application followed by heat curing is sometimes referred to as the Thermosol® process. The portion of FR chemicals remaining on the fiber surface can be washed off before the fabric is used, although this step is sometimes omitted. FR chemicals trapped within the fibers have reduced bioavailability, while surface FR's are expected to be bioavailable. Other FR's, such as TDCP, may also be applied in this manner (FRCA, 1998).

Cotton and rayon fabrics may be treated with reactive FR chemicals. PA is typically applied in a solution that contains a durable press resin such as trimethylol melamine, phosphoric acid, and ethyleneurea (D’Ruiz, 1998; Sanders, 1978). The fabric is then dried, heat-cured, and washed. The N-methylol group of the phosphonate ester forms a covalent bond with the hydroxyl groups in the cellulose fibers and with the melamine resin. This method is used to treat cellulosic fabrics in furniture sold in the U.K. (FRCA, 1998).

THPC reacts to form an insoluble polymer which is physically trapped within the fibers (Albright and Wilson, 1998b; Sanders, 1978). In one process, THPC is first reacted with urea to form a 2:1 compound of THPC with urea (THPC-urea) (also known as ProbanCC®) (Figure I-2). The fabric is treated with a solution containing THPC-urea, THPC, and sodium hydroxide. The THPC-urea and THPC are present in a ratio of 2.6:1 by weight. After the fabric is dried, it is exposed to anhydrous ammonia, which leads to the formation of the polymer. Then, the polymer is oxidized with hydrogen peroxide, which changes the phosphorus to a more stable pentavalent form. Finally, unreacted compounds are removed by washing. THPC is used with cellulosic fabrics (that is, cotton or rayon).

The use of reactive FR's such as THPC and PA is expected to reduce exposure to FR chemicals, because they are chemically or physically bound to the fibers. However, exposure to unreacted starting materials, reaction by-products, or decomposition products may be possible.

D. Scope of the Risk Assessment

1. FR Chemical Treatments

The CPSC staff attempted to prioritize the list of candidate chemicals proposed by FRCA. Thus, risk assessments were performed for eight chemicals selected from the FRCA list of 16 chemicals/chemical classes likely to be used in upholstered furniture (Table I-3). Four of these chemicals—AT, DBDPO, HBCD, and PA—are currently being used in the U.K., which has a similar open flame standard. Therefore, they almost certainly would be used in the U.S. if the draft standard were adopted. The CPSC staff considers that four additional chemicals—THPC, CPE, aromatic phosphate esters such as EHDP, and TDCP—also have a high probability of use in upholstered furniture, because they are currently used in either upholstery foam or in apparel. Other FR chemicals were not included because the staff considers them less likely to be used or due to the lack of information on toxicity and exposure.

LSC staff conducted migration studies on fabrics treated with five different FR chemicals—AT, DBDPO, HBCD, PA, and THPC (Bhooshan and Cobb, 2000; Levenson, 2000). The THPC-treated fabrics were pre-production samples made available to CPSC by the U.S. supplier. The remaining samples were generally as produced for use in the U.K. Samples of furniture fabrics treated with CPE, EHDP, or TDCP were not available for testing by LSC. However, CPE is used in apparel and some migration data with apparel fabrics are available. EHDP is an aromatic phosphate ester. Aromatic phosphates are currently used in upholstery foam. Data from a surrogate compound will be used to predict exposure to EDP (see below). The NRC Subcommittee did not review CPE or EHDP (NRC, 2000), which are members of the phosphonate ester and aromatic phosphate ester classes, respectively. Rather, NRC chose more toxic compounds to represent these classes. However, the CPSC staff considers that less toxic members of the class may also be used in furniture. TDCP is currently used to treat polyurethane foam in upholstered furniture sold in California. TDCP also represents a broad class of compounds—halogenated tris(alkyl) phosphates—which are likely to be marketed for use in upholstered furniture fabrics if the draft standard is adopted (FRCA, 1998). TDCP is considered by CPSC to be a probable human carcinogen (Ferrante, 1999b). Data from a surrogate compound will be used to predict exposure to TDCP (see below). For the purpose of this assessment, it will be assumed that CPE is applied by padding and heat curing, and that EHDP and TDCP are applied in back-coatings.

CPE-treated-fabrics are generally washed (scoured) to remove excess CPE, although this step is sometimes omitted. Omitting the wash step increases the bioavailability of the CPE (Albright and Wilson, 1998a; Maibach, 1979; Ulsamer et al., 1980). Therefore, risk assessments will be performed for both washed and unwashed CPE-treated fabrics.

THPC is generally applied as a mixture of THPC itself and its compound with urea, which react to form a polymer within the fabric fibers (see above). To measure migration, LSC used phosphorus as a surrogate for phosphorus-containing compounds (Bhooshan and Cobb, 2000). LSC did not detect THPC in the samples, that is, THPC represents less than 2 percent of total phosphorus present (Cobb, 2000). Between 5 and 17 percent of the total phosphorus in the extracts was in the form of inorganic phosphate. Thus, the chemical form of most of the total