

IV. ENVIRONMENTAL DATA

Sampling and Analytical Methods

No one analytical technique will detect all the decomposition products of fluorocarbon polymers, but gas chromatography has been used to measure some of the pyrolysis products. Tetrafluoroethylene (TFE), hexafluoropropylene (HFP), octafluorocyclobutane (OFCB), and perfluoroisobutylene (PFIB) have been monitored by a gas chromatograph using a flame ionization detector [7]. A 1/8-inch x 60-foot stainless steel column containing 10% dibutyl maleate on 60/80 mesh Chromasorb W was operated at room temperature. The carrier gas was prepurified commercial nitrogen. The identities of all materials detected with this column were confirmed using a 1/8-inch x 4-foot stainless-steel column packed with Porapak Q, 80/100 mesh, on which TFE, HFP, OFCB, and PFIB had different retention times. The lower limit of reliable analysis was 0.1 ppm of either TFE, HFP, OFCB, or PFIB. Amounts as low as 30 ppb were semiquantitatively estimated. No sampling methods were reported.

Hydrolyzable fluoride is a decomposition product of fluorocarbon polymers. Hydrolyzable fluoride could include hydrogen fluoride, inorganic fluoride, carbonyl fluoride, or other organic forms of fluoride which are hydrolyzed in an alkaline solution. Sampling and analysis procedures which could be used for hydrolyzable fluoride are discussed in the NIOSH criteria documents for recommended standards for inorganic fluorides [75] and hydrogen fluoride [76]. In these methods, fluoride is ultimately determined by a fluoride-ion-selective electrode.

Environmental Data

Environmental concentrations of fluorocarbon polymer dust and decomposition products have been measured in several industrial situations, but no correlation of environmental measurements with adverse effects in workers was possible [22,46,47,77]. Polakoff et al [46] supplied information on breathing-zone and general area sampling of PTFE dust concentrations in a fabricating plant. Sampling times ranged from 40 to 117 minutes. Dust concentrations in breathing-zone samples ranged from 0 to 2.4 mg/cu m for workers in the blow-mold area, 0.4 to 5.5 mg/cu m for workers in the machine shop, and 2.5 to 2.9 mg/cu m for a worker who operated the ring-grinding machine. Concentrations in general area samples in the blow-mold area ranged from 0 to 3.2 mg/cu m.

Sherwood [47] sampled for fluoride in a PTFE-fabricating plant before and after improvements in exhaust ventilation systems. Solids were separated from gases by drawing air through filter papers and then through a dilute alkali solution. The analytical results were expressed as PTFE/unit volume. Before ventilation improvements, air samples contained up to 3.5 mg/cu m of PTFE, and after the improvements were made air samples held only 0.2-0.4 mg/cu m of PTFE. After factory improvements, airborne dust counts were of the order of 1,000 particles/cc with diameters smaller than 5 μm , 15 particles/cc with diameters between 0.5 and 1.0 μm , and 1 particle/cc with a diameter greater than 1 μm .

Adams [22] sampled air in a finishing room where PTFE was dried, sifted, and packed. At collection sites close to ovens which were heated occasionally to above 300 C, he found concentrations of hydrogen fluoride up to 6 ppm.

Marchenko [77] carried out sampling studies during the heating of PTFE at temperatures between 375 and 514 C. Analytical methods and sampling techniques were not reported. Measurements were taken before and after installation of engineering controls, which included isolation of ovens from other sections, construction of block exhaust ventilation, hermetic sealing of oven doors, and construction of exhaust vents adhering tightly to the upper walls of the ovens. Before improvements, 14 samples contained organic fluorine compounds at concentrations ranging from 20 to 884 mg/cu m (calculated on the basis of tetrafluoroethylene), with an average concentration of 90 mg/cu m. After improvements, 16 of 17 samples contained only trace amounts of organic fluorine compounds and the remaining sample contained 3.5 mg/cu m.

Marchenko [77] also provided data on an unspecified work area during processing of PTFE. The methods of sampling and analysis were not described. He found, on the average, 0.13 mg/cu m of perfluoroisobutylene (PFIB), 7 mg/cu m of organic fluorine compounds (calculated as tetrafluoroethylene), 0.72 mg/cu m of hydrogen fluoride, and 0.013 mg/cu m of polymer aerosols.

Engineering Controls

Recommended ventilation rates for certain fluorocarbon polymers were specified by EI du Pont de Nemours and Company based on the known decomposition rates at specific temperatures, as shown in Table IV-1 [4]. Armitage (written communication, November 1976) has supplied the information on which the recommended ventilation rates were based. Du Pont has assumed that a ventilation rate which would reduce the total

concentration of decomposition products of fluorocarbon polymer to a level of 1 ppm would offer an adequate safeguard. This assumption was used because the toxic effects of decomposition products of PTFE are associated with a particulate substance which is a small fraction of the total decomposition products. Waritz and Kwon [7] observed that test animals died after being exposed to the particles at a concentration of 1.4 mg/cu m (equivalent to 1.2 ppm by weight at ambient conditions).

TABLE IV-1

VENTILATION RATES
FOR FLUOROCARBON POLYMERS RECOMMENDED BY DU PONT

Temperature (C)	Ventilation Rate (cu ft/min/lb resin)		
	PFA	PTFE	FEP
230	-	0.50	0.86
260	-	1.3	2.1
290	-	3.5	21
320	-	10	42
340	63	33	180
370	270	73	650
400	1,000	180	-
425	3,200	325	-

Adapted from reference 4

The ventilation rate necessary to reduce the total concentration of the decomposition products of fluorocarbon polymers to 1 ppm can be calculated from the known rates of decomposition measured by weight loss of the polymer [4]. For example, FEP resin processed at 370 C has a weight loss of 0.3%/hour. Since air at ambient temperature and pressure has a density of 0.077 lb/cu ft, the recommended ventilation rate is 650 cu ft/minute/lb of polymer:

$$\frac{(0.3\%/hour)(1,000,000)}{(60\text{ minutes}/hour)(0.077\text{ lb}/\text{cu ft})} = 650$$

This equation has been used as the basis for all the recommended ventilation rates published by Du Pont [4]. However, toxicity data for the decomposition products of FEP and other fluorocarbon polymers are not available. It is not known whether extrapolation from data on PTFE provides adequate safety for workers exposed to the decomposition products of other fluorocarbon polymers.

NIOSH maintains that the most important feature of an exhaust ventilation system is its design. Guidance for designing a local exhaust ventilation system can be found in Industrial Ventilation--A Manual of Recommended Practice [78] and in Fundamentals Governing the Design and Operation of Local Exhaust Systems [79]. Ventilation systems of this type require regular inspection and maintenance to ensure effective operation. Regularly scheduled inspections should include face-velocity measurements of the collecting hood and inspection of the air mover and collector.

In addition to providing adequate ventilation, it may be appropriate, under certain circumstances, to isolate a process or system in an especially designed enclosure to minimize exposure. Other control measures

may be intentionally redundant temperature monitoring systems and alarms to signal harmful thermal excursions.

Biologic Evaluation

Urinary fluoride levels have been measured in humans and animals exposed to pyrolyzed fluorocarbon polymers or to their individual decomposition products. Abnormally high concentrations of fluoride in the urine of an employee who works with fluorinated polymers may be taken as signs of exposure to these compounds but cannot be used as reliable indices of the extent of exposure at present.

Okawa and Polakoff [80] analyzed urine samples for fluoride from 99 workers in a PTFE-fabricating plant. Urinary fluoride levels ranged from 0.098 to 2.19 mg/liter. Only eight samples contained fluoride concentrations in excess of 1 mg/liter; in one sample the concentration exceeded 2 mg/liter. The authors reported that the drinking water from this area contained fluoride at 0.19 mg/liter. Since a mean daily urinary output of 4 mg of fluoride reflects the maximum permissible fluoride exposure [81], the authors [80] concluded that the workers from whom urine specimens were collected had not been exposed to toxic levels of soluble fluorides.

Sherwood [47] found a fluoride concentration of 5 mg/liter in the urine of a man suffering from an acute attack of polymer fume fever.

In 1974, Dilley et al [82] studied urinary fluoride excretion in adult male Sprague-Dawley rats which had inhaled various fluorocarbon gases. Fluoride concentrations in drinking water and food were determined to establish baseline measurements. Fifteen rats were exposed for 30

minutes at each of the following chamber concentrations of gases: 2,600 ppm of hexafluoropropene, 3,500 ppm of tetrafluoroethylene, 2,200 ppm of vinylidene fluoride, 3,000 ppm of vinyl fluoride, and 3,000 ppm of hexafluoroethane. Urinary fluoride excretion was measured daily for 14 days postexposure in 10 of the rats exposed to each fluorocarbon and in an untreated control group of 10 rats.

The results showed a significant increase over control rats in urinary output of fluoride by all experimental groups 4-6 days postexposure [82]. Rats exposed to hexafluoropropene and vinylidene fluoride had immediate and significant increases in urinary fluoride excretion 1 day after exposure. Those exposed to tetrafluoroethylene had a second peak period for urinary fluoride excretion at 13-14 days postexposure. Rats exposed to both hexafluoropropene and tetrafluoroethylene excreted large quantities of glucose for 3 days after exposure.

The authors [82] concluded that the fluorocarbon gases studied are metabolized, since there was an observed increase in fluoride excretion. They also noted the apparently cyclic nature of the urinary fluoride excretion and suggested that the turnover time of either the fluoride or the fluorocarbons is approximately 5 days.

In 1968, Scheel et al [83] studied the metabolic effects of inhalation of PTFE pyrolysis products in rats to determine whether toxicity could be linked to fluoride. The authors directed specific attention to the relationship between urinary fluoride excretion and succinic dehydrogenase activity, hypothesizing that, if the toxicity of PTFE is caused by fluoride, increased urinary fluoride and decreased succinic dehydrogenase activity would be found. Controlled-flora rats, 20 males and

20 females, were exposed 1 hour a day for 5 days to PTFE pyrolysis products containing hydrolyzable fluoride equal to 50 ppm of carbonyl fluoride. The authors stated that the cumulative concentration of 158 ppm-hours of inhaled gases and 18 mg of particles, which killed 9 of 40 rats, was less than half the LC50 for acute single exposures.

After the first exposure [83], 10 experimental and 10 colony control rats were placed in metabolism cages. Urinary fluoride determinations were made after the first and fifth exposures and at 4, 7, and 18 days postexposure. The principal result was an increase in urinary fluoride excretion that peaked at approximately 42 $\mu\text{g}/\text{ml}$ after the fifth exposure. Controls showed no changes in urinary fluoride levels. The urinary fluoride level of experimental rats was 10 $\mu\text{g}/\text{ml}$ at 18 days postexposure, which was approximately four times that of controls. The urine samples were normal except for increased levels of fluoride still present 18 days after exposure.

The authors [83] noted that urinary fluoride increased from 3 to 42 $\mu\text{g}/\text{ml}$ in 5 days. They concluded that the carbonyl fluoride generated during PTFE pyrolysis was hydrolyzed in body fluids to produce a substance, presumably hydrogen fluoride, capable of inducing a toxic syndrome identical with fluoride poisoning.

More information is required to determine whether urinary fluoride excretion can be correlated with exposure to the pyrolyzed decomposition products of fluorocarbon polymers. At present, NIOSH does not recommend that biological monitoring be used to determine the extent of exposure to the decomposition products of fluorocarbon polymers.

V. WORK PRACTICES

Work practices and safety precautions for handling fluorocarbon polymers and their decomposition products are the subject of two reports [4,5]. To reduce workers' exposure to the decomposition products of fluorocarbon polymers, employers must actively seek and implement engineering controls and should maintain all engineering, dust-capture, ventilation, sanitation, and physical control systems in efficient working order at all times by a program of regular inspection and maintenance.

The main hazard of fluorocarbon polymers is from the products of pyrolysis, to which workers may be exposed when the polymers are heated in industrial processing or when tobacco contaminated with polymer dust is smoked [23]. For this reason, it is essential that a no-smoking rule be enforced in all areas where fluorocarbon polymers are handled and processed. No-smoking signs should be posted in all such areas, and smoking materials should not be carried into these areas. Employers should also require that employees wash their hands before smoking and should ensure that suitable protective equipment be worn so that fluorocarbon polymers are not transferred to tobacco from hands or clothing. Employees should be informed of the potential hazards from fluorocarbon polymers.

Airborne dust levels should be minimized by taking appropriate precautions during the initial mixing and formulating of fluorocarbon polymers. Canopy hoods should be provided for all mixing and shaking operations. Spills of fluorocarbon polymers should be cleaned up immediately to prevent slippery surfaces. Some form of nonslip flooring or

finish should also be provided in areas where these materials are regularly handled.

Any dust or waste resulting from processing must be removed by appropriate engineering controls. Airborne dust should be removed by exhaust ventilation systems equipped with filters for dust collection. Fluorocarbon polymer dust should be removed from work-area surfaces by vacuuming collection systems, and not by blasts of compressed air. Any equipment which operates at temperatures sufficient to cause decomposition of the fluorocarbon polymer must always be kept as dust-free as possible and must be equipped with a dust and fume removal system.

During preforming operations (including automatic and isostatic operations), all the handling precautions described above must be observed in handling preforms, in filling molds, and in loading hoppers. Machines used to compress the fluorocarbon polymer into the preform should be equipped with local exhaust ventilation.

In sintering processes, temperatures in excess of the normal sintering range must be avoided. Ovens should be located in a separate section outside the general work areas. Ovens must be fitted with an automatic temperature cutout, set at the manufacturer's recommended temperature for the particular fluorocarbon polymer, to prevent overheating. The temperature-regulating system should be checked at regular intervals.

Ovens should be operated at negative pressure relative to the room, with a 100-foot/minute design velocity for exhaust (DYBVA, written communication, June 1977). An appropriate alarm system, such as flapper valves or pressure-differential devices, should be incorporated into the

exhaust system to ensure that it can be shut off automatically. Large ovens should be enclosed in walk-in cabinets equipped with separate exhaust systems and makeup air systems. Oven liners must be regularly inspected and repaired to prevent air leaks into the work area.

In all extrusion processes, the handling precautions described above must be observed. As in sintering operations, the temperature to which the fluorocarbon polymer is subjected must not be allowed to exceed the manufacturer's recommended processing temperature, and an appropriate temperature cutout system must be used. Local exhaust ventilation must be installed at the orifice from which the melt is extruded to keep decomposition products from entering the work area. An appropriate alarm system must be incorporated into the exhaust ventilation system.

In thermoforming, compression molding, and coining, and in all processes in which the temperature of the fluorocarbon polymer approaches its melting point, ovens must be fitted with exhaust ventilation and temperature-regulating systems. These systems must be equipped with appropriate alarms and must be serviced at regular intervals.

Coagulated dispersion polymers are usually processed by "paste extrusion." This involves mixing the fluorocarbon polymer with a lubricant, generally a volatile petroleum fraction. This use of flammable liquids adds a potential hazard. The lubricant may be removed in a drying oven or in a continuous oven constructed in series with the extruder and a sintering oven. Precautions must be taken to minimize the risk of forming explosive mixtures of vapor and air and to prevent their ignition if they should form. These precautions might include controlling the rate of solvent removal, increasing the exhaust ventilation in the solvent-removal

area, and locating the solvent-removal zone apart from the sintering area. If flammable vapor enters the sintering oven, it probably will ignite. Removal of all traces of the lubricant before sintering is necessary. As in sintering operations, appropriate temperature-regulating and exhaust-ventilation systems should be used on ovens where solvent removal takes place. Fire-extinguishing equipment should also be readily available.

In soldering, welding, flame-cutting, and wire-stuffing operations, confined spaces where workers may be exposed for prolonged periods must have adequate ventilation. A small exhaust duct should be used in such operations to remove fumes from the breathing zone. When necessary, an air-supplied respirator should be worn.

In grinding, cutting, and machining of fluorocarbon polymers, where temperatures occasionally may exceed the manufacturers' recommended temperatures, coolants should be used to control overheating. Fluorocarbon polymer wastes produced by such operations should be removed by exhaust ventilation or by a waste-reclaiming system. All the handling precautions described above must also be followed.

VI. DEVELOPMENT OF STANDARD

Basis for Previous Standards

In 1960, the American Conference of Governmental Industrial Hygienists (ACGIH) [84] recommended a tentative threshold limit value (TLV) of 0.005 ppm for PTFE decomposition products in air, but they did not specify the products to which the standard was to apply.

The ACGIH [85], in 1961, recommended a tentative TLV of 0.05 mg/cu m, "as F," for PTFE pyrolysis products. In 1962, the ACGIH [86] did not recommend any TLV for PTFE decomposition products, and no reason was given for this omission. In 1963, the ACGIH [87] suggested that a limit for PTFE dust of 15 mg/cu m (on a nuisance basis) should be adequate.

In the 1971 Documentation of Threshold Limit Values, the ACGIH [88] stated that no TLV for decomposition products was recommended, pending determination of the toxicity of the products; but suggested that air concentrations should be minimal.

The ACGIH [89] noted in 1972 that the thermal decomposition of PTFE in air led to the formation of oxidized products containing carbon, fluorine, and oxygen. Because these products decompose partially by hydrolysis in alkaline solution, the ACGIH [89] pointed out that the products could be quantitatively determined in air as fluorine to provide an index of exposure. Again, no TLV was recommended, but the ACGIH stated that the concentrations in the workplace should be kept as low as possible.

In 1974, the ACGIH [90] noted that air concentrations of decomposition products should be kept below the limit of sensitivity of the analytical method, but no analytical method was specified. In 1976, the

ACGIH [91] again suggested that concentrations of airborne PTFE decomposition products should be minimal.

The USSR, in 1970, listed a maximum allowable concentration of 0.1 ppm for perfluoroisobutylene [92], which was identified as a pyrolysis product of PTFE [7], but no basis for this standard was found.

At present, there are no US federal standards for the decomposition products of fluorocarbon polymers. The current US federal standard for hydrogen fluoride and inorganic fluorides in workplace air is 2.5 mg/cu m, as F (combined ionic fluoride, atomic weight 19), determined as a TWA exposure for up to an 8-hour workday, 40-hour workweek (29 CFR 1910.1000).

Basis for the Recommended Standard

The most frequently reported effect of exposure in the workplace to the pyrolysis products of fluorocarbon polymers has been an influenza-like syndrome, polymer fume fever, which was described first by Harris [10] in 1951 and subsequently by several other investigators [34,37,39-41]. The major signs and symptoms associated with polymer fume fever are chest discomfort [10,23,34,36-41], fever [10,23,36,38-40], leukocytosis [10,36], headache [23,34,36,37,40,41], chills [10,23,34,36-38,40,41], achy feeling [10,23,34,36,38], and weakness [10,23,36]. Complete recovery usually occurred within 12-48 hours after the exposure [10,23,34].

Other effects found in humans exposed to the pyrolysis products of fluorocarbon polymers were nausea [40], malaise [10,23,36], congested throat and pharynx [37], rales in the bases of the lungs [39,40], pulmonary edema [39,40], hyperpnea [40], and increased pulse rate [40]. Respiratory irritation and pulmonary edema have been reported in humans [34,37,39,40]

and animals [6,7,14,23,55,69] exposed to the pyrolysis products of fluorocarbon polymers. No reports of serious injury or of long-term effects of polymer fume fever were found in the literature.

The syndrome outlined above has been described most frequently as a result of exposure to fumes from heated PTFE. Since there are now a number of other fluorinated polymers whose breakdown products are almost entirely unidentified and untested for toxicity, there seems to be no basis for attempting to set an occupational exposure limit that will apply to breakdown products of fluorinated polymers in general. Accordingly, NIOSH suggests that exposure of employees to breakdown products of polymers of fluorinated monomers be limited to the greatest extent possible by designing production processes to restrict heating of these polymers to the lowest temperature that permits the desired operation, to limit access of air and oxygen to heated polymers to the greatest extent feasible, and to take the greatest possible advantage of local ventilation of sites from which polymer fumes may enter the occupational environment. Such steps, in conjunction with effective general ventilation of the workplace and good work practices, should go far toward protecting employees from deleterious effects from breakdown products of the materials with which they work. Although these deleterious effects are more likely to be incapacitating than dangerous, their avoidance is certainly desirable.

(a) Permissible Environmental Limits

Because the available data and techniques, as previously discussed, are so limited, NIOSH is not recommending an environmental limit for the decomposition products of fluorocarbon polymers. Instead, NIOSH recommends that exposure to the decomposition products of fluorocarbon polymers be

controlled by the use of engineering and administrative controls and by strict adherence to work practices that will minimize worker contact with pyrolysis products of fluorocarbon polymers or with potentially pyrolyzable dust.

(b) Sampling and Analysis

Sampling and analysis procedures that could be used for hydrolyzable fluoride are discussed in the NIOSH criteria for recommended standards for inorganic fluorides [75] and hydrogen fluoride [76]. When these methods are used, fluoride is ultimately measured by a fluoride-ion selective electrode. Monitoring for fluoride is inadequate for protection against fluorocarbon polymers because adherence to the recommended standard for inorganic fluorides and hydrogen fluoride does not necessarily protect the worker from adverse effects caused by other decomposition products of fluorocarbon polymers. Because of the multiplicity of the decomposition products of fluorocarbon polymers, no sampling and analytical method is specifically recommended.

(c) Medical

Several studies on humans [34,37,39,40] and animals [6,7,14,23,55,69] showed that exposure to fluorocarbon polymer decomposition products produced respiratory irritation and pulmonary edema. A medical surveillance program should therefore give special attention to the respiratory tract. Medical attention should be provided for employees accidentally exposed to the decomposition products of fluorocarbon polymers.

(d) Work Clothing and Personal Protective Equipment

During emergencies and nonroutine maintenance procedures, the decomposition products of fluorocarbon polymers at unknown airborne concentrations could produce pulmonary irritation and edema. Moreover, these substances may be contaminated with materials which are hazardous upon skin or eye contact. For these reasons, in emergency situations and certain maintenance procedures, employees should wear appropriate respirators as listed in Table I-1, gloves, and clothing other than street clothes.

(e) Informing Employees of Hazards

Personnel occupationally exposed to the decomposition products of fluorocarbon polymers must be advised of the adverse effects of accidental exposure and informed of the signs and symptoms of the disorders. Employees should be warned that the onset of symptoms may be delayed. A continuing education program is an important part of a preventive hygiene program for employees occupationally exposed to the decomposition products of fluorocarbon polymers. Properly trained persons should periodically inform employees about the dangers of smoking on the job, the need for washing before smoking, the hazards of carrying smoking materials into the workplace, possible sources of exposure, engineering controls and work practices in use or planned to limit exposure, and environmental and medical management practices used to check on control procedures and to determine the health status of employees.

(f) Work Practices

Contamination of smoking materials with fluorocarbon polymers is an important cause of polymer fume fever. Therefore, care must be exercised to ensure that such contamination does not occur. Smoking or carrying smoking materials should be prohibited in all areas where fluorocarbon polymers are handled and used. Work clothing should be worn where exposure to fluorocarbon polymers is likely. Such clothing should not be worn outside the workplace. Hand-washing facilities must be available, and employees who work in fluorocarbon polymer areas should wash their hands thoroughly before smoking.

Because of the importance of adequate ventilation and temperature control in processing fluorocarbon polymers, NIOSH recommends that ovens and exhaust systems be equipped with appropriate alarms to prevent overheating.

(g) Sanitation

Eating and food preparation should be discouraged on general sanitation considerations in areas where fluorocarbon polymers in bulk are handled and used. Employees who work in fluorocarbon polymer areas should be instructed to wash their hands thoroughly before eating, smoking, or handling smoking materials. If contamination of clothing with fluorocarbon polymer dust is likely, employees should wear either launderable clothing for repeated use or disposable outer garments for one-time use. Because personnel who launder clothing may come in contact with fluorocarbon polymer dust, they should be cautioned on the hazards associated with this dust.

VII. RESEARCH NEEDS

No detailed epidemiologic study of the effects of occupational exposure to the decomposition products of fluorocarbon polymers has been found in the literature. Such studies are needed to determine whether long-term occupational exposure to these decomposition products produces any chronic effects on humans.

No human or animal studies have been found in the literature that evaluate possible carcinogenicity, mutagenicity, teratogenicity, or effects on reproduction of the decomposition products of fluorocarbon polymers. Further research in these areas is needed. Fluorocarbon polymers made from vinyl chloride monomer should be tested to determine whether vinyl chloride is a decomposition product. Little information is available on the identification or the toxicity of decomposition products of fluorocarbon polymers other than PTFE, and studies of effects on humans have been limited to PTFE. The toxic effects of the decomposition products and their individual components over a range of pyrolysis temperatures should be determined. Additional work is needed to discover whether the decomposition products of fluorocarbon polymers other than PTFE, PCTFE, and a few other polymers mentioned in Chapter III cause irritation and polymer fume fever in humans and the conditions that lead to such effects.

To protect workers from harmful effects of exposure to the decomposition products of fluorocarbon polymers, development of a reliable method to detect the extent of decomposition in the workplace is needed. The thermal decomposition of the fluorocarbon chain of PTFE leads to the formation of oxidized products containing carbon, fluorine, and oxygen

[89]. Some of these products can be hydrolyzed in alkaline solution to liberate fluoride. Further research is required to determine whether any correlation exists between the amount of hydrolyzable fluoride and the extent of decomposition of the fluorocarbon polymer or the severity of health effects. Furthermore, it has not been determined whether the decomposition of fluorocarbon polymers other than PTFE produces hydrolyzable fluoride. Studies are also needed to determine whether urinary fluoride excretion can be correlated with exposure to the decomposition products of fluorocarbon polymers.

The effects of chronic exposure to the decomposition products of fluorocarbon polymers have not been adequately evaluated. Long-term inhalation studies on animals are needed to assess the systemic effects of repeated exposure to these products. Long-term toxicity studies on several mammalian species are needed to provide information relevant to assessing the probable risk to humans of exposure to the decomposition products of fluorocarbon polymers.