Synthesis and biological screening of trifluoromethylthioarsenicals

S. Munavalli*
Geo-Centers, Inc., Ft. Washington, MD 20774 (USA)

D.I. Rossman, D.K. Rohrbaugh, C.P. Ferguson and L. Buettner
US Army Edgewood Research, Development and Engineering Center, Aberdeen Proving Center, MD 21010 (USA)

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Abstract

The title compounds have been prepared from the reaction of trifluoromethylthiocopper and alkyl mono- and di-haloarsines. This communication describes their synthesis, biological screening and mass spectral fragmentation behavior.

Introduction

Thioarsenites derive their pharmacological properties from their ability to react with the sulfhydryl function of biological catalysts, namely enzymes, necessary for carrying out metabolic processes [1]. Although arsenic compounds have attracted considerable interest for a long time, it was their use as sternutators during World War I that attracted world attention to this group of compounds. As a consequence of their inhalation, the kidneys and livers of the affected victims showed considerable evidence of hemorrhagic changes and epithelian degeneration. Exposure of skin and eyes to arsenicals elicits effects reminiscent of those observed with sulfur mustard [2]. The inhalation of arsenicals usually results in sneezing, nausea, vomiting, conjunctivitis, chest and abdominal pain, intestinal cramps, extensive perspiration and feelings of depression. Depending on the severity of exposure, the systemic effects may persist for several hours [3]. However, the irritation effects have recently been described as transitory and that test animals were observed to recover within a few minutes after the cessation of exposure [4]. The chemistry of thioarsenites has been the subject of an exhaustive study [5a] and part of a monograph devoted to the organic chemistry of arsenic [5b].

Trivalent and pentavalent arsenicals react with mercaptans or their salts to furnish thioarsenites, namely compounds of the type $RAs(SR')_2$ [6a]. Emeleus and co-workers were the first to prepare thioarsenites containing the trifluoromethyl moiety by treating bis(trifluoromethylthio)mercury (**1**) with arsenic(III) chloride and bis(trifluoromethyl) iodoarsine [6b, c]. When arsenic chloride was used, a mixture of three compounds containing mono-, di- and tri-substituted arsenicals was obtained. However, excellent yields of the expected product were obtained when tetraalkyl diarsine (**2**) was treated with bis(trifluoromethyl) disulfide (**3**) [7a]. These reactions indicated that the S–S bond of **3** undergoes facile fission in the presence of diarsine. Two additional modifications of the above process involve the reaction of trifluoromethanesulfenyl chloride with **2** [7b]. The same compound was also synthesized in low yield by the reaction of bis(trifluoromethyl)arsenious sulfide with trifluoroiodomethane at 125 °C [7c]. The compounds described in this paper include bis(trifluoromethylthio)mercury (**1**), tetraalkyl diarsine (**2**), bis(trifluoromethyl)disulfide (**3**), trifluoromethylthiocopper (**4**), dimethylbromoarsine (**5**), methyldichloroarsine (**6**), ethyldichloroarsine (**7**), dimethyl(trifluoromethylthio)arsine (**8**), bis(trifluoromethyl)trisulfide (**9**), bis(trifluoromethyl)tetrasulfide (**10**), dimethylfluoroarsine (**11**), thiocarbonyl fluoride (**12**), tris(trifluoromethylthio)methane (**13**), bis(trifluoromethylthio)methylarsine (**14**), bis(trifluoromethyl)trithiocarbonate (**15**), methyldifluorarsine (**16**) and bis(trifluoromethylthio)ethylarsine (**17**) (see Fig. 1).

Recently, we have developed a new procedure for the preparation of trifluoromethylthiocopper (**4**) in a colorless crystalline form [8]. Since copper reagents usually react more readily than mercury compounds, and since **1** is air-sensitive and require manipulations in a dry inert atmosphere, it was considered of interest

*To whom all correspondence should be addressed.

$(CF_3S)_2Hg$ (1) $(R)_2As–As(R)_2$ (2) CF_3SSCF_3 (3) CF_3SCu (4)
$(CH_3)_2AsBr$ (5) CH_3AsCl_2 (6) $C_2H_5AsCl_2$ (7) $(CH_3)_2As(SCF_3)$ (8)
CF_3SSSCF_3 (9) $CF_3SSSSCF_3$ (10) $(CH_3)_2AsF$ (11) $C(S)F_2$ (12)
$CH(SCF_3)_3$ (13) $(CF_3S)_2AsCH_3$ (14) $CF_3SC(S)SCF_3$ (15) CH_3AsF_2 (16)
$C_2H_5As(SCF_3)_2$ (17) $CF_3S\cdot$ (18) $(CF_3S)_2CH\cdot$ (19) CS_2 (20)
$(CF_3S)C(S)F$ (21)

Fig. 1. Structures of compounds cited in the text.

to investigate the reaction of arsenic halides with **4**. This communication describes the reaction of **1** and **4** with dimethylbromo-, methyldichloro- and ethyldichloro-arsines (**5**, **6** and **7**) carried out separately, the nature and distribution of the previously unreported compounds formed during this reaction and their mass spectral behavior.

Results and discussion

The reaction of **5** with **1** and with **4** are complex. In addition to the expected dimethyl(trifluoromethylthio)arsine (**8**), six additional compounds, namely **3**, **8**, **12**, **13**, **14**, **15**, and carbon disulfide (**20**) (Table 1) were characterized from their GC–MS data (Table 2). In the reaction of **4**, compound **3** and bis(trifluoromethyl)tri and tetra-sulfides (**9**, **10**) are generally formed along with the expected product(s) of the reaction, namely **3**, **8**, **11**, **12**, **13** and **14**. The origin of **3**, **9** and **10** (Scheme 1) is, no doubt, the trifluoromethylthiyl radical (**18**) and the participation of free-radical reactions [9]. The formation of dimethylfluoroarsine (**11**) (Scheme 2, steps 2–4) in this reaction can be considered a case of halogen-exchange. There are precedents for such halogen-exchange reactions [6b, 10]. Trifluoromethanesulfenyl bromide was identified as one of the products of the reaction between **3** and alkylmagnesium bromide [10b]. The origin of thiocarbonyl fluoride, $C(S)F_2$ (**12**), is the trifluoromethylthiyl radical **18** which loses F· to form **12** (Scheme 2, step 2). The F· thus liberated may also react with **5** to give **11** in a displacement reaction. Alternatively, the F· could have come from **9** and **10** which, according to Haszeldine and Kidd "liberate fluoride quantitatively" [11]. While one could envision the formation of **12** as occurring by thermal decomposition of **8**, however, successive distillations of **8** failed to show the presence of **12**, thus discounting such a possibility.

It is interesting to note the presence of tris(trifluoromethylthio)methane (**13**) in the reaction mixture (Scheme 2, step 11). The identification of this known compound [12a] was confirmed by its synthesis from iodoform and **4**. It is conceivable that **13** could have originated from the bis(trifluoromethylthio)methyl radical (**19**) (Scheme 2, steps 9 and 11). The suggestion that **13** is formed from **19** derives its support from the identification of bis[(trifluoromethylthiomethyl)]-dimethylarsine, $[(CF_3S)_2CH]As(CH_3)_2$ (Table 2), as a component of the higher boiling fraction. Also, bis(trifluoromethylthio)methylarsine (**14**) was characterized as one of the products of this reaction. The only way **14** could have been formed is from methyldibromoarsine, which in turn could have been present either as an impurity in the starting material **5** or could have been thermally generated from **5**. The formation and characterization of methyl diiodoarsine among the products obtained by heating bis(trifluoromethyl)-iodoarsine alone, through the process of 'thermal equilibrium', lends support to the latter contention [12b]. At elevated temperature, the trifluoromethyl moiety of tris(trifluoromethyl)arsine was found to have been replaced by the methyl radical [12c].

The formation and distribution of the products formed during the reaction of **1** with **5** depend on the reaction temperature. At elevated temperatures, within a short time the reaction mixture assumed an intense red color, which was later shown to be due to increasing con-

TABLE 1. Products of the reaction of dimethylbromoarsine (**5**) with trifluoromethylthiocopper (**4**) and bis(trifluoromethylthio)mercury (**1**)

CF_3SCu (4)	$(CF_3S)_2Hg$ (1)
CF_3SSCF_3 (3)[a], CF_3SSSCF_3 (9)[a], $CF_3SSSSCF_3$ (10)[a], CSF_2 (12)[a], $(CH_3)_2AsF$ (11)[a], $(CH_3)_2AsSCF_3$ (8)[b], $CH(SCF_3)_3$ (13)[a], $CH_3As(SCF_3)_2$ (14)[a]	CF_3SSCF_3 (3)[a], CS_2 [a], CSF_2 (12)[a], $CF_3SC(S)SCF_3$ (15)[a], $(CH_3)_2AsSCF_3$ (8), $CH(SCF_3)_3$ (13)[a], $CH_3As(SCF_3)_2$ (14)[a]

[a]Not detected previously from analogous reactions, [6b, c, 7].
[b]A 98% pure sample (GLC) was obtained after two fractional distillations.

TABLE 2. Mass-spectral fragmentation of thioarsenites

CSF_2 (**12**)	$M^+ = 82$; 63 (CSF); 51 (SF); 50 (SF_2)
CF_3SSCF_3 (**3**)	$M^+ = 202$; 183 (M−F); 133 (M−CF_3); 114 (133−F); 101 (SCF_3); 82 (CSF_2); 69 (CF_3); 64 (SS)
$(CH_3)_2AsF$ (**11**)	$M^+ = 124$; 109 (M−CH_3); 105 (M−F); 89 (CH_2As); 75 (As)
CH_3AsF_2 (**16**)	$M^+ = 128$; 113 (M−CH_3); 109 (CH_3AsF); 94 (AsF); 89 ($AsCH_2$); 75 (As)
$(CH_3)_2AsSCF_3$ (**8**)	$M^+ = 206$; 191 (M−CH_3); 187 (M−F); 176 ($AsSCF_3$); 145 ($AsSF_2$); 137 (M−CF_3); 122 (CH_3AsS); 109 (CH_3AsF); 105 (M−SCF_3); 89 ($AsCH_2$); 82 (CSF_2); 75 (As); 69 (CF_3); 63 (SCF); 45 (CSH)
$CH(SCF_3)_3$ (**13**)	$M^+ = 316$; 247 (M−CF_3); 215 (M−SCF_3); 146 (247−SCF_3); 82 (CSF_2); 76 (CS_2); 69 (CF_3); 63 (CSF); 45 (CSH)
CF_3SSSCF_3 (**9**)	$M^+ = 234$; 215 (M−F); 165 (M−CF_3); 133 (M−SCF_3); 96 (SSS); 82 (CSF_2); 69 (CF_3); 64 (SS); 50 (CF_2)
$CF_3SSSSCF_3$ (**10**)	$M^+ = 298$; 197 (M−SCF_3); 165 (CF_3SSS); 146 (165−F); 133 (CF_3SS); 96 (SSS); 83 (SSF); 69 (CF_3); 64 (SS); 50 (CF_2)
$CH_3As(SCF_3)_2$ (**14**)	$M^+ = 292$; 273 (M−F); 191 (M−SCF_3); 176 ($AsSCF_3$); 141 (CH_3AsSF); 121 (CH_2AsS); 107 (AsS); 89 (CH_2As); 69 (CF_3); 63 (CSF)
$C_2H_5As(SCF_3)_2$ (**17**)	$M^+ = 306$; 287 (M−F); 249 (287−2F); 205 (M−SCF_3); 176 (205−C_2H_5); 123 (C_2H_5AsF); 107 (123−CH_4); 101 (SCF_3); 75 (As); 69 (CF_3); 63 (CSF)
$CF_3SC(S)SCF_3$ (**15**)	$M^+ = 246$; 177 (M−CF_3); 145 (M−SCF_3); 133 (CF_3SS); 101 (SCF_3); 82 (CSF_2); 76 (CS_2); 69 (CF_3); 64 (SS)
$CF_3SC(S)F$ (**21**)	$M^+ = 164$; 145 (M−F); 133 (CF_3SS); 95 (CS_2F); 82 (CSF_2); 69 (CF_3); 63 (CSF); 50 (CF_2)

$$CF_3SCu\ (4) \rightleftharpoons CF_3S\cdot + Cu\cdot \quad (1)$$

$$2CF_3S\cdot \longrightarrow CF_3SSCF_3\ (3) \quad (2)$$

$$CF_3SSCF_3\ (3) \rightleftharpoons CF_3SS\cdot + \cdot CF_3 \quad (3)$$

$$CF_3SS\cdot + \cdot SCF_3 \longrightarrow CF_3SSSCF_3\ (9)^a \quad (4)$$

$$2CF_3SS\cdot \longrightarrow CF_3SSSSCF_3\ (10) \quad (5)$$

$$CF_3SSSCF_3\ (9) \rightleftharpoons CF_3SSS\cdot + \cdot CF_3 \quad (6)$$

$$CF_3SSS\cdot + \cdot SSCF_3 \longrightarrow CF_3SSSSSCF_3{}^a \quad (7)$$

$$2CF_3SSS\cdot \longrightarrow CF_3SSSSSSCF_3{}^a \quad (8)$$

Scheme 1. The formation of bis(trifluoromethyl) di- and polysulfides (cf. ref. 9). Note that compounds marked as 'a' have been characterized as products of the reaction of bis(trifluoromethyl)trisulfide with organolithium and Grignard reagents [15].

centration of bis(trifluoromethyl)trithiocarbonate (**15**) (Scheme 2, step 14). Haszeldine and Kidd have prepared **15** by treating trifluoromethylthiol with ammonia [13a]. Since then, **15** has been prepared via the pyrolysis of tetrakis(trifluoromethylthio)methane [12a] and through the reaction of **11** with cesium fluoride in a stainless-steel bomb at −78 °C [13c]. The characterization of **15** again points to the presence of **18** in the reaction mixture, for **15** can be formed from **18** (Scheme 2). The origin of carbon disulfide (**20**) can be traced to **15** (Scheme 2, step 17). The termination step for this free-radical process is the dimerization of the $\cdot CF_3$ radical to form hexafluoroethane.

The reaction of methyl- and ethyl-dichloroarsines [(**6**) and (**7**)] with **1** is also complex (Table 3). The formation of methyldifluoroarsine (**16**) can again be rationalized on the basis of halogen-exchange or 'thermal equilibrium' [10, 12c], in that **16** could have arisen from **11** or through the replacement of a methyl radical by F·. In the reaction of **1** with **7**, 10 compounds were formed (Table 3) and again the color of the reaction mixture turned an intense red. Thus **3**, **9**, **10**, **12**, **13**, **15**, **16**, **17**, **20**, trifluoromethyldithiocarbonyl fluoride (**21**) and ethyldifluoroarsine were identified as components of the reaction mixture.

The mass spectra of **3** and **9** have already been reported [14, 15]. The mass-spectral fragmentation of **10** follows a similar pattern. In the same way, the mass spectra of **11** and **16** exhibit similar behavior. In addition to the molecular ions, the loss of the methyl group ($m/e = 15$) is observed. The ion $m/e = 75$ corresponding to As is usually seen. Trifluoromethylthioarsenites exhibit common characteristics. In addition to the molecular ions, the loss of F, alkyl and trifluoromethylthiyl moieties and CF_3 is usually observed.

CF_3SCu (**4**) $\rightleftharpoons CF_3S\cdot + Cu\cdot$ (1)

$CF_3S\cdot \rightleftharpoons C(S)F_2$ (**12**) $+ F\cdot$ (2)

$(CH_3)_2AsBr$ (**5**) $\rightleftharpoons (CH_3)_2As\cdot + Br\cdot$ (3)

$(CH_3)_2As\cdot + F\cdot \longrightarrow (CH_3)_2AsF$ (**11**) (4)

$(CH_3)_2AsF$ (**11**) $+ Br\cdot \rightleftharpoons (\cdot CH_2)(CH_3)AsF + HBr$ (5)

$(\cdot CH_2)(CH_3)AsF + \cdot SCF_3 \rightleftharpoons (CF_3SCH_2)(CF_3)AsF$ (6)

$(CF_3SCH_2)(CF_3)AsF + Br\cdot \rightleftharpoons$

$(CF_3SCH\cdot)(CF_3)AsF + HBr$ (7)

$(CF_3SCH\cdot)(CF_3)AsF + \cdot SCF_3 \rightleftharpoons [(CF_3S)_2CH][CH_3]AsF$ (8)

$[(CF_3S)_2CH][CH_3]AsF \rightleftharpoons (CH_3)(F)As\cdot + \cdot CH(SCF_3)_2$ (9)

$(CH_3)(F)As\cdot + F\cdot \longrightarrow CH_3AsF_2$ (**16**) (10)

$\cdot CH(SCF_3)_2 + \cdot SCF_3 \longrightarrow CH(SCF_3)_3$ (**13**) (11)

$(CH_3)_2As\cdot + \cdot CH(SCF_3)_2 \longrightarrow (CH_3)_2AsCH(SCF_3)_2$ [a] (12)

$(SCF_3)_3CH$ (**13**) $+ Br\cdot \rightleftharpoons (SCF_3)_3C\cdot + HBr$ (13)

$(CF_3S)_3C\cdot \rightleftharpoons (CF_3S)_2C(S)$ (**15**) $+ \cdot CF_3$ (14)

$(CF_3S)_2C(S)$ (**15**) $\rightleftharpoons (CF_3S)(S)C\cdot + \cdot SCF_3$ (15)

$(CF_3S)(S)C\cdot + F\cdot \longrightarrow CF_3SC(S)F$ (**21**) (16)

$(CF_3S)(S)C\cdot \rightleftharpoons S{=}C{=}S$ (**20**) $+ \cdot CF_3$ (17)

Scheme 2. The reaction of dimethylbromoarsine with trifluoromethylthiocopper. [Bis(trifluoromethylthio)mercury reacts analogously.] The presence of the compound marked as 'a' in the high boiling fraction of the reaction of **5** with **4** was indicated and confirmed by its GC–MS data. Numbered products were identified by their mass-spectral fragmentation patterns.

TABLE 3. Products of the reaction of bis(trifluoromethylthio)-mercury (**1**) with ethyl- and methyl-dichloroarsines

CH_3AsCl_2 (**6**)	$C_2H_5AsCl_2$ (**7**)
CF_3SSCF_3 (**3**), CH_3AsF_2 (**16**), $CF_3SC(S)SCF_3$ (**15**), $CH_3As(SCF_3)_2$ (**14**)[a]	CSF_2 (**12**), CS_2, $C_2H_5AsF_2$, CF_3SSCF_3 (**3**), CF_3SSSCF_3 (**9**), $CF_3SSSSCF_3$ (**10**), $CH(SCF_3)_3$ (**13**), $CF_3SC(S)SCF_3$ (**15**), $CF_3SC(S)F$ (**21**), $C_2H_5As(SCF_3)_2$ (**17**)[b]

[a]Yield, *c.* 48%.
[b]Yield, *c.* 25%.

Experimental

General procedure

Warning!! Because of the high toxicity associated with arsenicals via inhalation, extreme care should be exercised in working with them and all reactions should be carried out in efficient hoods. NMR spectra (^{13}C and ^{19}F) were recorded in $CDCl_3$ on a Varian VXR-400S spectrometer at 100 MHz and 376 HMz, respectively. The external reference for the ^{19}F spectra was CCl_3F. Mass spectra were obtained on a Finnigan model 5100 GC–MS instrument equipped with a silica 25 m×0.31 mm (i.d.) SE-54 capillary column (J and W Scientific, Rancho Cordova, CA). Routine GC analyses were accomplished with a Hewlett Packard 5890A gas chromatograph equipped with a 30 m×0.53 mm (i.d.) DB-5 column (J and W Scientific, Folsom, CA).

The reactions were carried out in a flame-dried, argon-purged 10 ml or 25 ml round-bottom flask equipped with a magnetic stirrer, a gas inlet, a pressure equalizing funnel and a reflux condenser carrying a Dry Ice/acetone trap. The temperature of the coolant passing through the condenser was maintained at −20 °C. All reactions were carried out by adding stoichiometric amounts of the reagents (usually 0.01 mol) of the alkylmonohalo- and dihalo-arsines to trifluoromethylthiocopper or bis(trifluoromethylthio)mercury (weighed in an inert atmosphere to avoid decomposition). After the addition was over, the reaction mixtures were stirred, heated and processed as described in each case.

Dimethyltrifluoromethylthioarsine (8)

Method a

Dimethylbromoarsine (**5**)* (0.01 mol) was added dropwise to a stoichiometric amount of trifluoromethylthiocopper (**4**). After addition, the reaction mixture was heated at 80–90 °C for 6 h. The reaction mixture was cooled to ambient temperature, flash-distilled and analyzed by GC–MS methods (Table 1). The flash-distillate was further purified by fractional distillation (twice) under reduced pressure to furnish a 98% pure sample of **8** (cf. ref. 7a) in 70% yield.

Method b

In a similar manner, **5** was treated with compound **1**. Since **1** is highly sensitive to moisture, transfer operations were carried out in an argon-filled glove bag. The GC–MS analysis of the flash-distillate indicated the presence of **8** and four of the other products obtained above (Method a), In addition, two compounds, viz. bis(trifluoromethyl)trithiocarbonate (**15**) and carbon disulfide (**20**), were identified (Table 1).

Tris(trifluoromethylthio)methane (13)

An authentic sample of this compound was needed for comparative purposes. The compound was prepared by heating a mixture of iodoform (4.0 g, 0.01 mol) and **4** (2.1 g, 0.01 mol) in 10 ml of freshly distilled acetonitrile for 24 h at 85–90 °C. The product was obtained by flash-distillation of the cooled reaction mixture under vacuum. Fractional distillation of the flash-distillate

*This is a light-sensitive compound and consequently, the reaction was carried out in the absence of light.

gave compound **13**. ^{1}H NMR δ: 5.93 (s) ppm. ^{13}C NMR (SCF_3) δ: 128 (J=312 Hz, CH); 46.7 (J=3.1 Hz) ppm.

Methyl bis(trifluoromethylthio)arsine (14)

A mixture of **6** (3.12 g, 0.02 mol) and **1** (8.06 g, 0.02 mol) was heated for 4 h at 95–100 °C. The reaction mixture was processed as above and analyzed by GC–MS methods (Table 3). The mass-spectral fragmentation of compound **14** is given in Table 2.

Ethyl bis(trifluoromethylthio)arsine (17)

A mixture of **7** (0.01 mol) and **4** (0.01 mol) was heated for 6 h at 85–95 °C. The reaction mixture, processed as above, gave a complex mixture containing 10 components (Table 3) which were characterized and identified by their mass-spectral fragmentation patterns (Table 2).

Biological screening of compound 8

Test animals were exposed to the vapors of compound **8** in an enclosed chamber. The concentrations of the test compound were monitored both at the entrance and exit of the chamber. Based on the dose response inhalation study [16a] and the suggested classification schemes [16b], it was concluded that concentrations as low as 0.15 ppm may cause significant sensory irritation to the eyes, nose and throat, and that intolerable conditions may develop in humans at concentrations above 1.5 ppm. The lack of mortality and rapid recovery of the test animals within a few minutes after the cessation of their exposure, clearly suggests the transitory nature of the effects elicited by this compound.

References

1 H. Eagle and G.O. Doak, *Pharmacol. Rev., 3* (1951) 107.
2 M.C. Winternitz, *Pathology of War Gas Poisoning,* Yale University Press, New Haven, CT, 1920.
3 (a) H.L. Gilchrist, *Residual Effects of Warfare Gases,* US War Department, reprinted 1933; (b) K.E. Jackson, *Chem. Rev., 17* (1935) 251.
4 L. Buettner, S. Munavalli, S. Hsu, D.I. Rossman and C.P. Ferguson, *Proc. 1991 Med. Defense Biosci. Rev.,* US Army Medical Research Institute of Chemical Defense, Aug. 7–8, 1991, p. 171.
5 (a) A. Cohen, H. King and W.I. Strangeways, *J. Chem. Soc.,* (1931) 3043; (b) G.O. Doak and L.D. Freedman, *Organometallic Compounds of Arsenic, Antimony and Bismuth,* Wiley and Sons, New York, 1970.
6 (a) N.A. Chadaeva, G.K. Kamai and G.M. Usacheva, *Zh. Obshch. Khim., 36* (1966) 704; [*Chem. Abs., 65* (1966) 10 618b]; (b) H.J. Emeleus and H. Pugh, *J. Chem. Soc.,* (1960) 1108; (c) H.J. Emeleus, K.J. Packer and N. Welcman, *J. Chem. Soc.,* (1962) 2529.
7 (a) W.R. Cullen, P.S. Dhaliwal and W.R. Fox, *Inorg. Chem., 3* (1964) 1332; (b) W.R. Cullen and P.S. Dhaliwal, *Can. J. Chem., 45* (1967) 379; (c) W.R. Cullen, *Can. J. Chem., 41* (1963) 2424.
8 (a) S. Munavalli, D.I. Rossman, D.K. Rohrbaugh, C.P. Ferguson and F.-L. Hsu, *Heteratom Chem., 3* (1992) 189; (b) S. Munavalli and D.I. Rossman, patent pending.
9 (a) R.N. Haszeldine and J.M. Kidd, *J. Chem. Soc.,* (1953) 3219; (b) S. Munavalli, D.I. Rossman, A.J. Muller, D.K. Rohrbaugh and C.P. Ferguson, *203rd Annu. Meet. Am. Chem. Soc.,* San Francisco, CA, April 5–10, (1992), Abs No. 460.
10 (a) P. Savignac and P. Coutrot, *Synthesis,* (1976) 197; (b) S. Munavalli and D.I. Rossman, unpublished results.
11 R.N. Haszeldine and J.M. Kidd, *J. Chem. Soc.,* (1954) 4228.
12 (a) J.F. Harris, *J. Org. Chem., 32* (1967) 2063; (b) H.J. Emeleus, R.N. Haszeldine and E.G. Walaschewski, *J. Chem. Soc.,* (1953) 1552; (c) R.N. Haszeldine and B.O. West, *J. Chem. Soc.,* (1957) 3880.
13 (a) R.N. Haszeldine and J.M. Kidd, *J. Chem. Soc.,* (1955) 3871; (b) A. Haas and W. Klug, *Chem. Ber., 101* (1968) 2609.
14 (a) M.C. Cullen, D.C. Frost and M.T. Pun, *Inorg. Chem., 9* (1970) 1976; (b) N.R. Zack and J.M. Shreeve, *J. Fluorine Chem., 5* (1975) 153.
15 (a) S. Munavalli, D.I. Rossman, D.K. Rohrbaugh, C.P. Ferguson and H.D. Banks, *J. Fluorine Chem., 60* (1993) 85; (b) S. Munavalli, D.I. Rossman, D.K. Rohrbaugh, C.P. Ferguson and L.J. Szafraniec, *J. Fluorine Chem., 59* (1992) 91.
16 (a) Y. Alarie, L.E. Kane and C.S. Barrow, *Toxicology: Principles and Practice,* Wiley and Sons, New York, 1980, Vol. 1, pp. 48, 90; (b) Y. Alarie, *Environ. Health Perspect., 42* (1981) 9.