Dow Corning Corp. Methyl methacrylate and glycidyl methacrylate were obtained from Aldrich Chemical Co.

GC analyses were performed either on a Varian 3700 gas chromatograph equipped with a flame ionization detector (FID) and a 60- or 12-m fused-silica capillary silica column. Routine GC-MS analyses were performed on a Hewlett-Packard 5970A MSD instrument. Chemical ionization mass spectra were obtained on a Finnigan 4610 mass spectrometer with CH_4 as the reagent gas. IR spectra were obtained on a Perkin-Elmer 1330 spectrophotometer or on a Nicolet 60SX GC FTIR. ^1H NMR were obtained on a Varian EM-390 90-MHz spectrometer and are reported on the δ scale. High-resolution mass spectra were obtained from Iowa State University Analytical Services.

1-Glycidoxy-1-(trimethylsiloxy)-2-methylprop-1-ene (5). General Synthesis of Dimethylketene Trimethylsilyl Acetals. Preparation of **5** is exemplary of the procedure used to prepare the other silyl ketene acetals. A stirred solution of 1000 g (7.0 mol) of glycidyl methacrylate, 0.28 g (1.06×10^{-3}) of $RhCl_3 \cdot 6H_2O$, 0.5 g of 2,6-di-*tert*-butyl-4-methylphenol, and 38 mL of THF was heated to 38 °C, under nitrogen containing 2% oxygen, in a 2-L round-bottom flask equipped with a dry ice cooled condenser. The heating mantle was removed, and the addition of trimethylsilane was started from a stainless steel tank at 20 psi. When about 30 mL of trimethylsilane had been added, an exothermic reaction occurred, causing a temperature rise to about 50 °C before cooling was applied. The remainder of the trimethylsilane was added over a 1.5-h period; the temperature was maintained between 40 and 50 °C by compressed-air cooling. A dark brown mixture was removed from the flask and sealed in a half-gallon bottle. GC of the mixture after 24 h showed **5** and the corresponding vinyl adduct in a 75:1 ratio. After fractional distillation (bp 82 °C at 9 mmHg), 1512 g (80%) of **5** was obtained in 98% purity:[13] NMR ($DCCl_3$) 0.20 (s, 9 H), 1.45 (s, 3 H), 1.55 (s, 3 H), 2.6 (m, 2 H), 3.1 (m, 1 H), 3.7 (m, 2 H); IR (neat) 1700 cm^{-1}; GC-MS *m/e* (% rel int) (216 (3), 73 (100), 70 (40), 57 (17), 23 (13); high-resolution mass for $C_{10}H_{20}O_3Si$ measured 216.0072, calculated 216.3544.

1-Methoxy-1-(trimethylsiloxy)-2-methylprop-1-ene (1). Silyl ketene acetal **1** was obtained in 85% isolated yield (42 °C at 13 mmHg). The spectra of **1** matched those reported in the literature:[5,10] NMR ($DCCl_3$) 0.20 (s, 9 H), 1.50 (s, 3 H), 1.57 (s, 3 H), 3.45 (s, 3 H); IR (neat) 1704, 1183 cm^{-1}; chemical ionization MS (CH_4) *m/e* 175 (P + 1); GC-MS *m/e* 174 (13), 89 (26), 73 (76), 70 (100).

1-(2-(Trimethylsiloxy)ethyl)-1-(trimethylsiloxy)-2-methylprop-1-ene (6). Silyl ketene acetal **6** was obtained in 77% isolated yield (bp 100 °C at 4 mmHg). The spectra of **6** matched those reported in the literature:[5] NMR ($DCCl_3$) 0.10 (s, 9 H), 0.20 (s, 9 H), 1.50 (s, 3 H), 1.57 (s, 3 H), 3.70 (s, 2 H); IR (neat) 1710 cm^{-1}; GC-MS *m/e* (% rel int) 276 (5), 147 (10), 117 (20), 116 (12), 75 (12), 73 (100), 70 (11); high-resolution mass for $C_{12}H_{28}O_3Si_2$ measured 276.1577, calculated 276.6021.

1-(2-(Trimethoxysilyl)propyl)-1-(trimethylsiloxy)-2-methylprop-1-ene (7). Silyl ketene acetal **7** was obtained in 66% isolated yield (bp 110 °C at 3 mmHg): NMR ($DCCl_3$) 0.16 (s, 9 H), 0.60 (m, 2 H), 1.50 (s, 3 H), 1.56 (s, 3 H), 1.70 (m, 2 H), 3.50 (s, 9 H), 3.60 (t, J = 6 Hz, 2 H); IR (neat) 1705 cm^{-1}; GC-MS *m/e* (% rel int) 322 (4), 176 (11), 163 (18), 122 (18), 121 (100), 91 (39), 75 (18), 73 (42), 70 (23), 61 (10), 45 (16), 41 (12); high-resolution mass for $C_{13}H_{30}O_5Si_2$ measured 322.1629, calculated 322.5517.

1,1-Bis(trimethylsiloxy)-2-methylprop-1-ene (8). Silyl ketene acetal **8** was obtained in 78% isolated yield (bp 86 °C at 14 mmHg):[11] NMR ($DCCl_3$) 0.20 (s, 18 H), 1.47 (s, 6 H); IR (neat) 1705 cm^{-1}; GC-MS *m/e* (% rel int) 232 (10), 217 (20), 147 (45), 75 (21), 70 (70), 69 (21), 45 (44); high-resolution mass for $C_{10}H_{30}O_2Si_2$ measured 238.1864, calculated 238.5203.

1,2-Bis(1-(trimethylsiloxy)-2-methylprop-1-enoxy)ethane (9). Silyl ketene acetal **9** was obtained in 75% isolated yield (bp 110 °C at 2-3 mmHg). The spectra of **9** matched those reported in the literature:[5] NMR ($DCCl_3$) 0.20 (s, 18 H), 1.50 (s, 6 H), 1.56 (s, 6 H), 3.80 (s, 4 H); IR (neat) 1710 cm^{-1}; GC-MS *m/e* (% rel int) 188 (10), 117 (10), 103 (10), 75 (13), 73 (100), 70 (13).

(13) The distilled purity was typically >98%, but hydrolysis to hexamethyldisiloxane and the corresponding isobutyrate ester occasionally occurred. See ref 8.

Independent Removal of the Carbonyl Adduct. The removal of carbonyl adduct **2** is exemplary of the method used for the other silyl ketene acetals. Excess trimethylsilane was added to a solution containing 0.0409 g (4.4×10^{-5} mol) of $(Ph_3P)_3RhCl$ and 20.0 g (0.115 mol) of a distilled mixture of **1**, **2**, and **3** (40:2:1 ratio) to which was added toluene as an internal GC standard. The mixture was stirred 3 days at room temperature. After this time GC analysis showed a loss of **2** with no change in **1** or **3**. Subsequent experiments showed 24 h to be sufficient for removal of **2** at room temperature or 5 h at 50 °C.

Acknowledgment. We thank the Dow Corning Analytical Research Department personnel for obtaining GC-FTIR and chemical ionization GC-MS spectra. Special thanks are given to Dow Corning's Process Engineering group for supplying trimethylsilane and to Dr. W. X. Bajzer of Dow Corning for helpful discussions.

Addition of α-Oxyradicals to 1-Fluoro-1-(phenylsulfonyl)ethylene

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The utility of free-radical reactions in organic synthesis has received considerable attention in the past decade.[1] Particularly important in this regard has been a resurgence in the use of carbon radical addition to olefins for the formation of carbon-carbon bonds. We have focused our attention on the utility of free-radical chemistry for the synthesis of fluorinated compounds of biological interest. Herein we report a convenient synthesis of 1-fluoro-1-(phenylsulfonyl)ethylene (**3**) and the addition of α-oxyradicals to **3** as a new method to synthesize fluoroorganics.

The synthesis of **3** was recently reported by a method requiring perchloryl fluoride, freshly prepared from potassium perchlorate and fluorosulfonic acid.[2] A new synthesis of **3** was developed (Scheme I), which utilizes the fluoro-Pummerer reaction[3] and provides a safe and convenient method to multigram quantities of **3** from commercially available materials. β-Chloroethyl phenyl sulfoxide (**1**) was treated with diethylaminosulfur trifluoride (DAST)[3] and a catalytic amount of antimony trichloride for 1 h at room temperature to provide the corresponding α-fluoro sulfide. The use of antimony trichloride as a catalyst for the fluoro-Pummerer reaction was recently introduced by Robins,[4] and we concur that this catalyst is superior to zinc iodide.[3] The α-fluoro sulfide was oxidized to the sulfone **2**, without isolation, in an overall yield of 64%. Elimination of hydrogen chloride from **2** was readily effected with DBU to provide crystalline **3** in 86% yield.

While investigating the utility of **3** for the synthesis of fluorinated tetrahydrofurans, we found that the addition of a catalytic amount of benzoyl peroxide to a mixture of THF and **3** (reflux for 9 h) led to a diastereomeric mixture of 1-(2-fluoro-2-(phenylsulfonyl)ethyl)tetrahydrofuran (**4a**

(1) (a) Giese, B. *Radicals in Organic Synthesis: Formation of Carbon-Carbon Bonds*; Pergamon Press: Oxford, 1986. (b) Curran, D. P. *Synthesis* **1988**, 417, 489, and references cited therein.

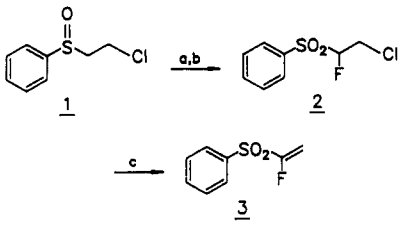
(2) Koizumi, T.; Hagi, T.; Horie, Y.; Takeuchi, Y. *Chem. Pharm. Bull.* **1987**, *35*, 3959.

(3) McCarthy, J. R.; Peet, N. P.; LeTourneau, M. G.; Inbasekaran, M. *J. Am. Chem. Soc.* **1985**, *107*, 735.

(4) Robins, M. J.; Wnuk, S. F. *Tetrahedron Lett.* **1988**, *29*, 5729.

0022-3263/90/1955-2973$02.50/0

Scheme I[a]



[a] Reagents and conditions: (a) DAST, $SbCl_3$ (cat.), CH_2Cl_2; (b) MCPBA, CH_2Cl_2 (64% for steps a and b); (c) DBU, CH_2Cl_2 (86%).

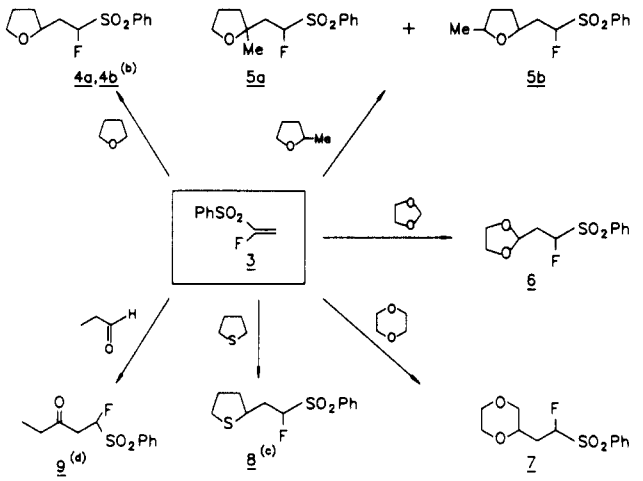
Table I. α-Oxyradical Addition Products to 1-Fluoro-1-(phenylsulfonyl)ethylene (3)[a]

product	initiator	yield, %	reactn time	^{19}F NMR[b]
4a, 4b[c]	Bz_2O_2	80	9 h	−182.52 (dd,[c] J = 54, 40.9, 13.3 Hz), −176.06
	Zn	74	24 h	(ddd, J = 48.2, 30.7, 17.5 Hz)
5a, 5b[d]	Bz_2O_2	43	16 h	−175.92 (m)[d] −182.58 (m)
6	Bz_2O_2	69	4 days	−179.35 (ddd, J = 52.7, 37.5, 15.5 Hz)
7[e]	Bz_2O_2	53	16 h	−174.42 (ddd,[e] J = 48.5, 30.2, 18.6 Hz), −181.83
	Zn	26	8 days	(ddd, J = 54.1, 41.5, 12.4 Hz)
8	Bz_2O_2	−[f]	48 h	−
9[g]	Bz_2O_2/AIBN	51[h]	20 h	−178.39 (ddd, J = 50.8, 34.7, 16.3 Hz)

[a] For reaction conditions see ref 9, Scheme I, and the Experimental Section. [b] 282 MHz, in $CDCl_3$, versus $CFCl_3$. [c] Diastereoisomers were separated by flash chromatography. [d] Isomers were inseparable. [e] Diastereoisomers were inseparable. [f] See footnote c, Scheme II. [g] See footnote d, Scheme II. [h] Isolated as the alcohol **10**.

and **4b**) in 80% yield (see Scheme II and Table I). Zinc dust also initiated this reaction[5] but required a longer period of time for completion. No reaction was observed between THF and **3** in the absence of a free-radical initiator. The reaction was envisioned to proceed by the addition of the α-oxyradical of THF to the activated olefin **3**. THF would serve as a hydrogen atom donor for the formation of **4a** and **4b** and for the propagation of the reaction.[1] Although radical addition to polyfluoro and polyhalo olefins has been reported,[6] the addition of carbon radicals to vinyl fluorides is rare.[7] In contrast, **3** readily reacts with α-oxyradicals to provide 1-fluoro-1-(phenylsulfonyl)alkanes in good yields (see Table I). Reaction of tetrahydrothiophene with **3** gave only trace amounts of **8** (based on mass spectral analysis of the reaction mixture). Under the reaction conditions, no radical cleavage products resulting from ring opening of the cyclic ethers[8] or products from the formation of telomers[9] were observed. 2-Methyltetrahydrofuran yielded an inseparable mixture of products, which gave a satisfactory elemental analysis for

Scheme II[a]



[a] Reaction conditions: reflux with catalytic amount of benzoyl peroxide or zinc dust under argon. [b] Diastereomers were separated. [c] Trace amounts of **8** were detected by mass spectral analysis of reaction mixture. [d] Isolated as the alcohol by $NaBH_4$ reduction.

5a and **5b** and spectral data consistent for these compounds. In addition to providing a new method to monofluoroethyl-substituted tetrahydrofuran and dioxanes, the preparation of the protected aldehyde **6** and the ketone **9** demonstrates the utility of this reaction for the preparation of monofluorinated intermediates. Attempted purification of **9** by flash chromatography catalyzed the elimination of HF and led to a mixture of (*E*)-2-(phenylsulfonyl)vinyl ethyl ketone (**11**)[10] and **9**. Ketone **9** was reduced to the more stable alcohol **10** with sodium borohydride.

In summary, the facile addition of α-oxyradicals to vinyl fluoride synthon **3** and a practical route to **3** are reported. We are currently applying this new method to fluoroorganics to the synthesis of biologically active compounds.[11]

Experimental Section

All melting points are uncorrected. GLC analyses were performed on a Hewlett-Packard Model 5890 instrument equipped with an HP-1 (methyl silicone gum), 5 m × 0.53 mm × 2.65 μm (film thickness) capillary column. ^1H NMR spectra were recorded on a Varian VXR-300 (300 MHz) (multinuclear probe) in $CDCl_3$; ^{19}F NMR spectra were recorded at 282 MHz in $CDCl_3$ on the Varian VXR-300 with $CFCl_3$ as an external standard. Mass spectra were obtained with a Finnigan MAT Model 4600 (electron impact and chemical ionization) mass spectrometer. Combustion analyses for C, H, and N were performed by Merrell Dow Analytical Laboratories, Cincinnati, OH. Exact mass determinations were obtained on a ZAB2-SE high-resolution mass spectrometer with perfluorokerosene as a reference.

2-Chloro-1-fluoroethyl Phenyl Sulfone (2). A mixture of 3.0 g (0.016 mol) of 2-chloroethyl phenyl sulfoxide (1) (Parish

(5) The zinc induction of this reaction is worthy of note. Zinc and acid are known to induce radical formation from alkyl halides. See, for example: Brace, N. O.; Van Elswyk, J. E. *J. Org. Chem.* **1976**, *41*, 766. Excess zinc in a Reformatskii reaction led to products that were probably formed by a radical mechanism, see: Henin-Vichard, F.; Gastambide, B. *Bull. Soc. Chim. Fr.* (11-12, Pt. 2) **1977**, 1154.

(6) (a) Hudlicky, M. *Chemistry of Organic Fluorine Compounds: A Laboratory Manual*, 2nd (revised) ed.; Halsted Press/Wiley: New York, 1976; pp 428–429. (b) Suda, M. *Tetrahedron Lett.* **1981**, *22*, 2395. (c) Chambers, R. D.; Grievson, B. *J. Chem. Soc., Perkin Trans. 1* **1985**, 2215. (d) Modena, S.; Fontana, A.; Moggi, G. *J. Fluorine Chem.* **1985**, *30*, 109.

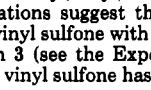
(7) An intramolecular radical cyclization on a vinyl fluoride to form a fluorotetrahydrofuran has recently been reported: Morikawa, T.; Nishiwaki, T.; Iitaka, Y.; Kobayashi, Y. *Tetrahedron Lett.* **1987**, *28*, 671.

(8) (a) Wallace, T. J.; Gritter, R. J. *J. Org. Chem.* **1962**, *27*, 3067. (b) Hauser, E. S. *J. Org. Chem.* **1960**, *25*, 1820.

(9) Dědek, V.; Fikar, J. *Collect. Czech. Chem. Commun.* **1969**, *34*, 3769.

(10) Haynes, R. K.; Vonwiller, S. C.; Stokes, J. P.; Merlino, L. M. *Aust. J. Chem.* **1988**, *41*, 881.

(11) The benzoyl peroxide catalyzed reaction of THF with phenyl vinyl sulfone also was investigated and led to the isolation of the previously unreported 1-(2-(phenylsulfinyl)ethyl)tetrahydrofuran (**12**) in 65% yield. Experimental observations suggest that the benzoyl peroxide catalyzed reaction of phenyl vinyl sulfone with THF proceeds somewhat faster than the reaction with **3** (see the Experimental Section). The addition of radicals to phenyl vinyl sulfone has been reported by Barton et al.[12]



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(12) Barton, D. H. R.; Togo, H.; Zard, S. Z. *Tetrahedron Lett.* **1985**, *26*, 6349.

Chemical Co.), 100 mg (0.0004 mol) of $SbCl_3$, and CH_2Cl_2 (100 mL) was treated with 4.2 mL (0.032 mol) of diethylaminosulfur trifluoride at room temperature. The progress of the reaction was followed by GLC, and after 1 h, the light yellow solution was washed with aqueous $NaHCO_3$, dried (K_2CO_3), and filtered. The solution containing the α-fluoro sulfide[13] was treated with 8.6 g (0.04 mol) of 80% *m*-chloroperbenzoic acid and stirred at room temperature for 6 h. The reaction was filtered, and the filtrate was washed with aqueous $NaHSO_3$ and aqueous $NaHCO_3$, dried ($MgSO_4$), and concentrated in vacuo. Purification by flash chromatography (350 g of silica gel, 1/6 EtOAc/hexane) gave 2.3 g (64%) of **2** (Et_2O): mp 74–76 °C; ^1H NMR δ 3.78 (ddd, 1, *J* = 13.7, 12.9, 9.5 Hz), 4.16 (ddd, 1, *J* = 32.9, 12.9, 2.2 Hz), 5.27 (ddd, 1, *J* = 48.3, 9.5, 2.3 Hz), 7.61–7.98 (m, 5); ^{19}F NMR δ −180.68 (ddd, *J* = 47.9, 33.4, 14.1 Hz); MS (CI/CH_4) *m/z* 223 (MH^+). Anal. Calcd for $C_8H_8ClFO_2S$: C, 43.16; H, 3.62. Found: C, 43.03; H, 3.61.

1-Fluorovinyl Phenyl Sulfone (3). To a mixture of **2** (20.9 g, 0.0939 mol) and CH_2Cl_2 (200 mL) was slowly added 15.2 g (0.1 mol) of 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU). After 2 h at room temperature, GLC showed the disappearance of **2**. The reaction was washed with 1 N HCl, dried ($MgSO_4$), and concentrated. The resulting oil was dried under high vacuum for several hours and slowly crystallized, providing 15.1 g (86%) of **3** as light tan crystals: mp 35–38 °C (lit.[2] no melting point reported); ^1H NMR δ 5.43 (dd, 1, *J* = 12.5, 4.6 Hz, SO_2CH_aHF), 5.88 (dd, 1, *J* = 41.8, 4.6 Hz, SO_2CHH_bF), 7.58–7.99 (m, 5, Ph); ^{19}F NMR δ −115.52 (dd, *J* = 41.9, 12.6 Hz, CH_aH_bF); MS (CI/CH_4) *m/z* 187 (MH^+). Anal. Calcd for $C_8H_7FO_2S$: C, 51.60; H, 3.79. Found: C, 51.33; H, 3.89.

***erythro*- and *threo*-2-[2-Fluoro-2-(phenylsulfonyl)-ethyl]tetrahydrofuran (4a and 4b). Zinc Dust Procedure.** A mixture of 707 mg (3.8 mmol) of α-fluorovinyl phenyl sulfone, Zn dust (7.1 μm) (300 mg, 4.6 mmol), and THF (50 mL) was heated at 60 °C for 24 h under argon. The progress of the reaction was followed by GLC. After 24 h (see Table I) the reaction was cooled, filtered, and purified by flash chromatography (75 g of silica gel, 1/4 EtOAc/hexane) to provide 183 mg of **4a**, 470 mg of a mixture of **4a** and **4b**, and 75.5 mg of **4b** (overall yield: 728.5 mg, 74.3%).

4a: ^1H NMR δ 1.50–1.63 (m, 1), 1.86–1.99 (m, 2), 2.01–2.17 (m, 2), 2.17–2.35 (m, 1), 3.75 (dd, 1, *J* = 16.1, 7.4 Hz), 3.87 (ddd, 1, *J* = 15.1, 7.9 Hz), 4.06 (9 line m, 1), 5.39 (ddd, 1, *J* = 48.8, 11.1, 1.8 Hz), 7.53–8.00 (m, 5); MS (CI/CH_4) *m/z* 259 (MH^+). Anal. Calcd for $C_{12}H_{15}FO_3S$: C, 55.80; H, 5.85. Found: C, 55.44; H, 5.75.

4b: ^1H NMR δ 1.49–1.65 (m, 1), 1.84–1.96 (m, 2), 1.96–2.17 (m, 2), 2.43 (dddd, 1, *J* = 30.6, 15.2, 5.8, 4.6 Hz), 3.75 (dd, 1, *J* = 14.8, 7.2 Hz), 3.88 (dd, 1, *J* = 14.6, 7.5 Hz), 4.14 (dt, 1, *J* = 12.4, 7.0 Hz), 5.31 (ddd, 1, *J* = 48.3, 8.3, 4.2 Hz), 7.52–7.99 (m, 5); MS (CI/CH_4) *m/z* 259 (MH^+). Anal. Calcd for $C_{12}H_{15}FO_3S$: C, 55.80; H, 5.85. Found: C, 56.02; H, 5.87.

Benzoyl Peroxide Procedure. A mixture of **3** (380 mg, 2.0 mmol), benzoyl peroxide (20 mg, 0.08 mmol), and THF (30 mL) was refluxed for 9 h. Workup as described above gave 419 mg (80%) of a mixture of **4a** and **4b** as a colorless oil, which exhibited the same spectral properties as above.

2-[2-Fluoro-2-(phenylsulfonyl)ethyl]tetrahydro-2(and 5)-methylfuran (5a and 5b): purified by flash chromatography (1/5 EtOAc/hexane) to provide an inseparable mixture of **5a** and **5b** as a clear liquid; ^1H NMR δ 1.18–1.28 (m, 3), 1.40–2.52 (m, 6), 3.78–4.31 (m, 2), 5.19–5.52 (m, 2), 7.58–7.97 (m, 5); MS (CI/CH_4) *m/z* 273 (MH^+). Anal. Calcd for $C_{13}H_{17}FO_3S$: C, 57.33; H, 6.29. Found: C, 57.69; H, 6.42.

2-[2-Fluoro-2-(phenylsulfonyl)ethyl]-1,3-dioxolane (6): purified by flash chromatography (1/3 EtOAc/hexane) to provide **6** as a colorless oil; MS (CI/CH_4) *m/z* 261 (MH^+), 119 (MH^+ − HSO_2Ph, base peak); ^1H NMR δ 2.15–2.55 (m, 2), 3.80–4.07 (m, 4), 5.13 (dd, 1, *J* = 6.0 and 3.3 Hz), 5.38 (ddd, 1, *J* = 48.8, 10.0, and 2.7 Hz), 7.57–7.99 (m, 5); ^{13}C NMR (75 MHz, $CDCl_3$) δ 33.49 (d, *J* = 18.2 Hz), 65.78, 66.05, 100.55 (d, *J* = 218 Hz), 101.03, 130.15, 130.45, 135.51, 135.79. Anal. Calcd for $C_{11}H_{13}FO_4S$: C, 50.76; H, 5.03. Found: C, 50.87; H, 5.05.

2-[2-Fluoro-2-(phenylsulfonyl)ethyl]-1,4-dioxane (7): purified by flash chromatography (1/3 EtOAc/hexane) to provide **7** as a clear liquid: ^1H NMR δ 1.78–2.47 (m, 2), 3.34 (14 line m, 1), 3.53–3.66 (m, 1), 3.68–3.79 (m, 4.5), 3.94 (12 line m, 0.5), 5.26 (ddd, 0.5, *J* = 4,.0, 7.7, 4.3 Hz), 5.41 (ddd, 0.5, *J* = 48.8, 11.2, 1.8 Hz), 7.58–7.96 (m, 5); MS (CI/CH_4) *m/z* (MH^+); HRMS Calcd for $C_{12}H_{16}FO_4S$ 275.0753, found 275.0736.

1-Fluoro-1-(phenylsulfonyl)-3-pentanone (9). A mixture of **3** (340 mg, 2.0 mmol), benzoyl peroxide (10 mg, 0.04 mmol), AIBN (10 mg, 0.07 mmol), and propionaldehyde (40 mL) was refluxed for 20 h under argon. The reaction was concentrated under high vacuum to provide crude **9**. Attempted purification of **9** by flash chromatography provided a 3 to 1 mixture of **9** and (*E*)-2-(phenylsulfonyl)vinyl ethyl ketone (**11**).[10]

9: ^1H NMR δ 1.11 (t, 3, *J* = 7.4 Hz), 2.68 (g, 2, *J* = 7.4 Hz), 3.12 (m, 2), 5.71 (ddd, 1, *J* = 47.3, 8.9, 2.7 Hz), 7.56–7.97 (m, 5); MS/(CH/CH_4) *m/z* 245 (MH^+), 143 (base peak).

***erythro*- and *threo*-1-Fluoro-1-(phenylsulfonyl)-3-pentanol (10).** Fluoro ketone **9** from the above experiment was dissolved in EtOH (20 mL), and $NaBH_4$ (500 mg, 12 mmol) was added. After 6 h at room temperature the reaction was concentrated and partitioned between H_2O/EtOAc (20 mL/25 mL). The EtOAc extract was dried ($MgSO_4$), concentrated, and purified by flash chromatography on 80 g of silica gel (1/3 EtOAc/hexane and then 2/3) to give 253 mg (51%) of **10** as a mixture of diastereomers: ^1H NMR δ 0.94–1.00 (t, 3), 1.50–1.70 (m, 2), 1.94–2.13 (m, 0.5), 2.30–2.49 (m, 0.5), 3.86 (br d, 1), 5.43 (ddd, 0.5, *J* = 48.1, 7.2, 4.9 Hz), 5.50 (ddd, 0.5, *J* = 48.4, 10.6, 2.2 Hz), 7.58–7.97 (m, 5); ^{19}F NMR δ −182.03 (ddd, *J* = 48.9, 29.5, 15.7 Hz), −175.94 (ddd, *J* = 48.7, 39.3, 14.4 Hz); MS (CI/CH_4) *m/z* 247 (MH^+), 229 (MH^+ − H_2O); HRMS calcd for $C_{11}H_{15}FO_3S$ 274.0804 (MH^+), found 274.0806.

Tetrahydro-2-[2-(phenylsulfonyl)ethyl]furan (12). Phenyl vinyl sulfone (3.0 g, 17.8 mmol) and benzoyl peroxide (300 mg, 1.23 mmol) were dissolved in tetrahydrofuran (100 mL). The colorless solution was heated at a gentle reflux under argon, and the progress of the reaction was followed by GLC. After 6.5 h, the solvent was removed in vacuo (bath temperature 25 °C), and the product was purified by flash chromatography (ethyl acetate/hexane, 1/4, and then 1/3) to provide **12** as a colorless viscous oil (2.76 g, 64%); ^1H NMR δ 1.39–1.52 (m, 1), 1.75–2.05 (m, 5), 3.22 (14 line m, 2), 3.63–3.89 (m, 3), 7.53–7.95 (m, 5); MS (CI/CH_4) *m/z* 241 (MH^+). Anal. Calcd for $C_{12}H_{16}O_3S$: C, 59.97; H, 6.71. Found: C, 59.64; H, 6.74.

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Registry No. 1, 27998-60-3; **2**, 125927-29-9; **3**, 114969-03-8; **4** (isomer 1), 125927-30-2; **4** (isomer 2), 125950-25-6; **5** (isomer 1), 125927-31-3; **5** (isomer 2), 125927-38-0; **6**, 125927-32-4; **7**, 125927-33-5; **9**, 125927-34-6; **10** (isomer 1), 125927-35-7; **10** (isomer 2), 125927-37-9; **11**, 108662-10-8; **12**, 125927-36-8; propionaldehyde, 123-38-6; phenyl vinyl sulfone, 5535-48-8; 2-methyltetrahydrofuran, 96-47-9; dioxolane, 646-06-0; 1,4-dioxane, 123-91-1; tetrahydrofuran, 109-99-9.

(13) A small sample of the α-fluoro sulfide precursor to **2** was prepared in $CDCl_3$: ^1H NMR δ 5.82 (ddd, 1, *J* = 52.3, 6.7, and 4.4 Hz); ^{19}F NMR δ −151.1 (ddd, *J* = 53.4, 18.0, and 13.5 Hz).

Development of a Drug-Release Strategy Based on the Reductive Fragmentation of Benzyl Carbamate Disulfides

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It has been shown that solid tumors frequently have inadequate vascularization and may exist in oxygen-deficient or hypoxic states.[1] Enhanced levels of reducing

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