Synthesis of nitro, nitroso, azo, and azido derivatives of (4-R^1-5-R^2-1,2,3-triazol-1-yl)-1,2,5-oxadiazoles by oxidation and diazotization of the corresponding amines

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Nitro-, nitroso-, and azo-1,2,5-oxadiazoles with 4-R^1-5-R^2-1,2,3-triazol-1-yl substituents were synthesized by oxidation of amino-(1,2,3-triazol-1-yl)-1,2,5-oxadiazoles (aminotriazolylfurazans). Azido-1,2,5-oxadiazole was prepared by diazotization of amino(triazolyl)furazan followed by treatment of the diazonium salt with sodium azide. Depending on the nature of the substituents and the reagent, triazolylfurazans can undergo destruction to give amino-R-furazans (R = NO_2, N_3, aminofurazanylazo), the amino group being formed from the triazole ring.

Key words: 4-amino-3-(1,2,3-triazol-1-yl)-1,2,5-oxadiazoles, aminofurazans, oxidation, hydrogen peroxide, dibromoisocyanurates, dichloroisocyanurates, hypohalogenites, diazotization, nitro-, nitroso-, azo-, and azidofurazans.

Recently, we developed a number of general methods for the synthesis of previously unknown 4-R-3-(4-R^1-5-R^2-1,2,3-triazol-1-yl)-1,2,5-oxadiazoles (triazolylfurazans) using 1,3-dipolar cycloaddition of azidofurazans to substituted acetylenes,[1] morpholinonitroethylene,[2] and 1,3-dicarbonyl compounds.[3] Study of the biological activities of some of these compounds has shown that triazolylfurazan derivatives are NO donors (exert selective potentiating action on the NO-dependent activation of soluble guanylate cyclase[4]). Therefore, it appeared pertinent to study a number of chemical transformations of triazolylfurazans in order to reach other functionally substituted derivatives of this class of compounds. Among the structures we synthesized, an essential place is occupied by compounds having an NH_2 group in the furazan ring.

This study deals with the transformation of amino(triazolyl)furazans **1a—k** into triazolylfurazans with nitro (**2**), nitroso (**3**), azo (**4**), azoxy (**5**), and azide (**6**) groups in the furazan ring through oxidation (by both peroxide and single-electron oxidants) and diazotization followed by treatment of the diazonium salts with sodium azide. We meant to elucidate the influence of the triazole ring and the nature and the position of substituents in this ring on the reactivity of the amino group in the furazan ring.

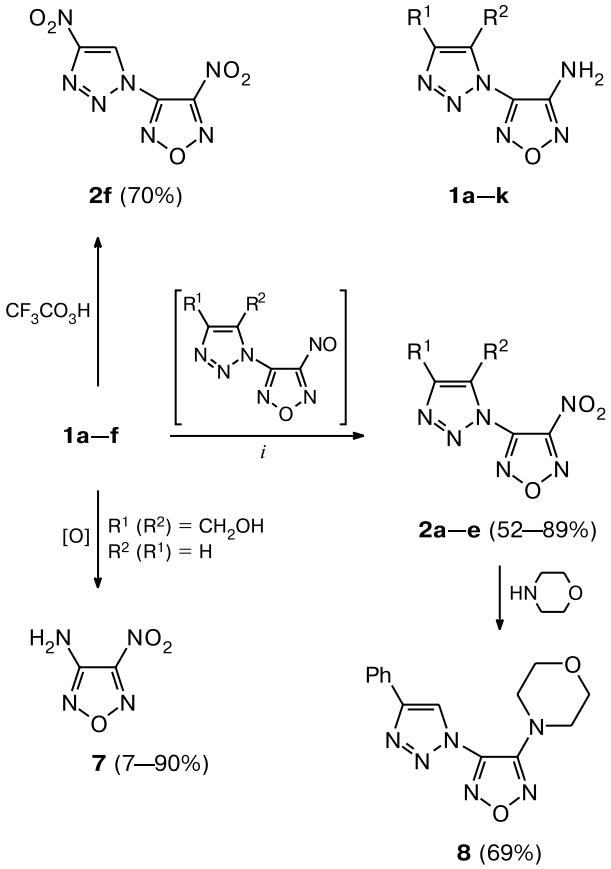
The oxidation of the amino group in compounds **1a—f** to the nitro group was carried out using a number of potent oxidative mixtures: 30% H_2O_2 with conc. H_2SO_4 and $(NH_4)_2S_2O_8$ or $Na_2WO_4 \cdot 2H_2O$, 30% H_2O_2 with 60% oleum, conc. H_2O_2 with H_2SO_4 and $Na_2WO_4 \cdot 2H_2O$, and CF_3CO_3H. Some of these mixtures have been successfully used to convert various aminofurazans into nitro derivatives.[5—8] We found that the outcome of oxidation of amines **1a—f** depends not only on the reaction conditions but also on the nature of substituents in the triazole ring. It was shown that amines **1a—e** can be oxidized to nitro derivatives in good yields (52—90%) only on treatment with a mixture of conc. H_2O_2 with conc. H_2SO_4 and $Na_2WO_4 \cdot 2H_2O$ (component molar ratio 86 : 39 : 3 per mole of the amine) when the reaction is carried out at room temperature or above, while amine **1f** can be oxidized only using CF_3CO_3H (Scheme 1).

Nitro compound **2f** is not formed under conditions favorable for the synthesis of compounds **2a—e**. When CF_3CO_3H is taken for oxidation of amines **1a—c**, the triazole ring cleaves (see also Schemes 2 and 3) to give 3-amino-4-nitrofurazan (**7**) (yield up to 99%), or more extensive destruction takes place. The oxidation of isomer mixture **1a,b** with CF_3CO_3H gave compound **7** in a nearly quantitative yield. The use of a mixture of 30% H_2O_2 and 60% oleum for oxidation of these amines afforded nitro compounds in only 10—15% yields. In the synthesis of isomeric nitro(triazolyl)furazans **2a,b**, no substantial influence of the substituent position was found.

Nitro derivatives **2a—d**,**f** were obtained in the crystalline state; their physicochemical and spectroscopic characteristics are presented in Tables 1 and 2. Nitro compound **2e** was isolated as an oil difficult to purify. The

Published in Russian in *Izvestiya Akademii Nauk. Seriya Khimicheskaya,* No. 8, pp. 1859—1865, August, 2005.

Scheme 1



	R^1	R^2		R^1	R^2
a	H	CH_2OH	**g**	COOH	H
b	CH_2OH	H	**h**	COOEt	H
c	CH_2OH	CH_2OH	**i**	COOMe	COOMe
d	CH_2Cl	H	**j**	COOEt	Me
e	Ph	H	**k**	COMe	Me
f	NO_2	H			

i. H_2O_2 (85—90%)—H_2SO_4 (conc.), Na_2WO_4.

product structure was confirmed by transforming it into amino derivative **8** on treatment with morpholine (see Scheme 1). The structure of **8** was established using the set of data from elemental analysis, IR, ^{1}H NMR, ^{13}C NMR, and mass spectra (see Tables 1 and 2).

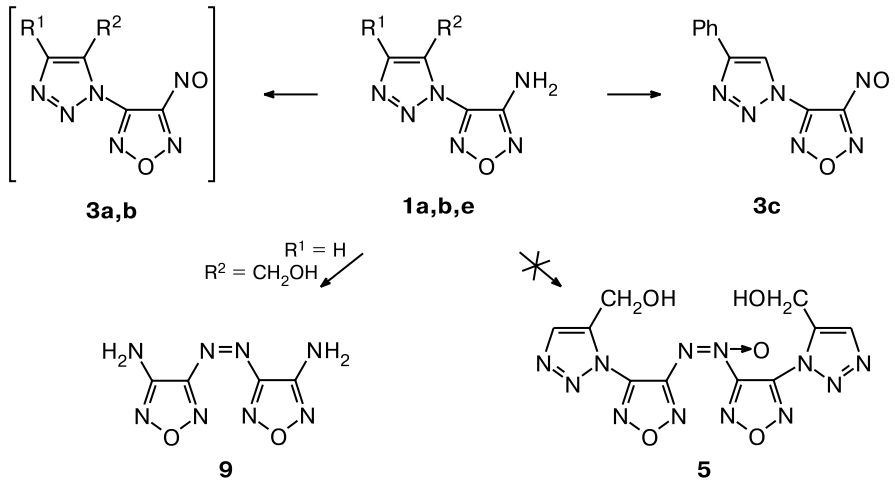
Little has been reported[9] on the synthesis of nitrosofurazans by oxidation of aminofurazans with ammonium persulfate in H_2SO_4. For the targeted synthesis of nitroso(triazolyl)furazans **3** by oxidation of amines **1a,b,e**, we used the same oxidative mixture as for the preparation of the corresponding nitro derivatives; however, in order to stop the oxidation after the formation of nitroso compounds, the reaction was carried out at low temperature (−5 to 5 °C) and using a 1.5—2.3 times lower excess of the oxidative mixture components with respect to the amine. Conditions were selected for the oxidation of amine **1e** to nitroso derivative **3c** (see Scheme 2), which was obtained in a pure state in 39% yield. Under the same conditions, amines **1a** and **1b** are converted into intensively blue-colored compounds (on chromatography they give blue-colored spots with R_f 0.61 and 0.43, respectively; elution with $CHCl_3$—Me_2CO—MeOH, 10 : 2 : 1). It can be suggested that these substances are nitroso derivatives **3a** and **3b** (see Scheme 2). However, they were not isolated, as being relatively stable in solutions at 0 °C, they appeared unstable on attempted isolation by concentrating or evaporation of solutions to dryness; according to TLC, they were converted into mixtures of compounds.

Under conditions of synthesis of nitroso compounds **3a**, a compound with R_f 0.36 ($CHCl_3$—Me_2CO—MeOH, 10 : 2 : 1) is formed as a by-product; this compound has not been isolated in a pure state. Having assumed that this can be azoxy derivative **5**, we attempted to prepare this product by oxidizing amine **1a** with milder mixtures, used normally for the synthesis of azoxy derivatives from aminofurazans.[7] It was found that compound **1a** is not oxidized with 30% H_2O_2 mixed with conc. H_2SO_4 or conc. H_2O_2 mixed with $Na_2WO_4 \cdot 2H_2O$ in CH_2Cl_2; treatment of this amine with $(NH_4)_2S_2O_8$ in water at 70 °C induces destructive oxidation, giving rise to diaminoazofurazan (**9**) (60%) (see Scheme 2).

Single-electron oxidants such as potassium permanganate in HCl, sodium dibromoisocyanurate (DBI), and hypohalogenites have been used successfully for the preparation of azo compounds from heterocyclic amines,[10] in particular, from diamines of the furazan series.[11—13] In order to prepare azofurazans **4**, we studied the oxidation of amines **1a,b,f—k** (see Scheme 3) by the above oxidants and by sodium dichloroisocyanurate (DCI). It was found that the possibility of formation of azo compounds under these conditions also depends on the nature of the substituent in the triazole ring. For example, amines **1f—k** are converted into azo compounds **4a—f** in high yields (see Scheme 3), whereas amines **1a** and **1b**, containing a hydroxymethyl group, undergo destruction of the triazole ring (see also Schemes 1 and 2); on treatment with $KMnO_4$ in HCl, this results in the formation of azo compound **9**, while in the case of DBI, the reaction gives a multicomponent mixture of products containing, according to TLC and mass spectra,[14] macrocycle **10** and diamine **11**. The structures of azo derivatives **4a—f** were determined relying on the set of data of elemental analysis and spectroscopy (IR, ^{1}H and ^{13}C NMR, and mass spectra) (see Tables 1 and 2). Compounds **9—11** are apparently the products of oxidation of diaminofurazan formed initially upon destruction.

It was found[15] that aminofurazans containing electron-withdrawing substituents are smoothly converted into azides on diazotization with nitrosylsulfuric acid in a mixture of concentrated H_2SO_4 and H_3PO_4 followed by treatment of the diazonium salt with sodium azide. Therefore,

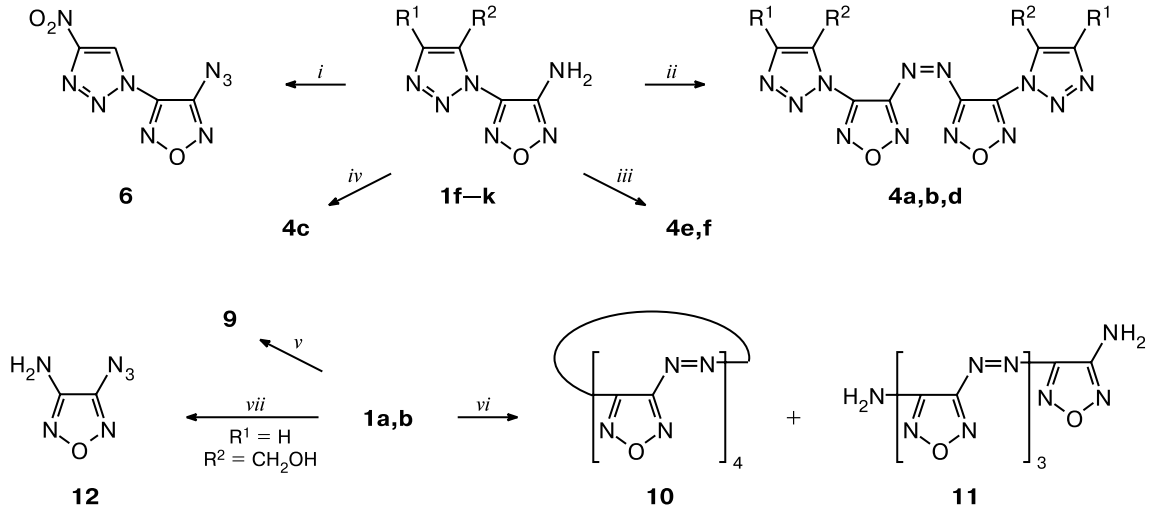
Scheme 2



3a,b **1a,b,e** **3c** **9** **5**

R^1 = H, R^2 = CH_2OH (**a**); R^1 = CH_2OH, R^2 = H (**b**); R^1 = Ph, R^2 = H (**e**)

Scheme 3



6 **4c** **1f—k** **4e,f** **4a,b,d** **12** **10** **11**

4: R^1 = NO_2, R^2 = H (**a**); R^1 = COOH, R^2 = H (**b**); R^1 = COOEt, R^2 = H (**c**); R^1 = R^2 = COOMe (**d**); R^1 = COOEt, R^2 = Me (**e**); R^1 = COMe, R^2 = Me (**f**)

Reagents: *i*. $NaNO_2/H^+$, NaN_3; *ii*. $KMnO_4$/HCl, DBI, NaOCl; *iii*. DCI; *iv*. AcOBr; *v*. $KMnO_4$/HCl; *vi*. DBI; *vii*. $NaNO_2/H_2SO_4$, H_3PO_4, NaN_3.

we attempted to synthesize azido(triazolyl)furazans under these conditions using amines **1a,f** as examples. Compound **1f** was converted into azide **6** in a high yield, whereas amine **1a** underwent destruction of the triazole ring to give 3-azido-4-aminofurazan (**12**) (23%) (see Scheme 3) and, perhaps, more extensive decomposition. The structure of azide **6** was determined based on elemental analysis and in combination with spectroscopic characteristics (see Tables 1 and 2).

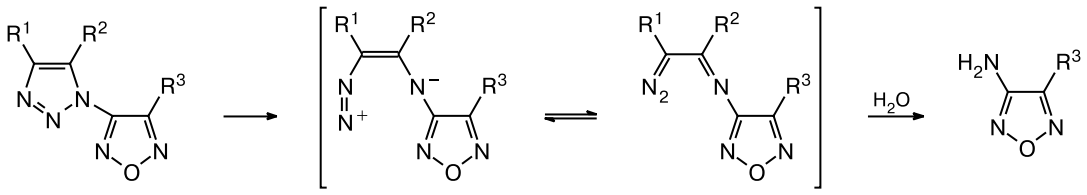
As a result of this study, we identified the conditions for the transformation of the amino group in triazolylfurazans **1** into NO_2, NO, N=N, and N_3 groups. The reactivity of amino(triazolyl)furazans **1** in the oxidation and diazotization followed by treatment of the diazonium salt with sodium azide was found to depend appreciably on both the nature of the substituent in the triazole ring and the nature of the reagent. Amines **1** behave similarly to known aminofurazans with electron-withdrawing substituents; however, in some reactions the triazole ring is unstable, which results in the formation of a new amino group at the furazan ring. Depending on the reaction conditions, these transformations gave aminofurazans with

Table 1. Some physicochemical characteristics of the compounds synthesized

Compound	Yield (%) (method)	M.p./°C (solvent)	R_f (solvent)	Found / Calculated (%)			Molecular formula
				C	H	N	
2a	67	39—40*	0.61 ($CHCl_3$—Me_2CO—MeOH, 10 : 2 : 1)	28.74 28.31	2.01 1.90	39.57 39.62	$C_5H_4N_6O_4$
2b	52	68—69 (CCl_4)	0.43 ($CHCl_3$—Me_2CO—MeOH, 10 : 2 : 1)	28.65 28.31	1.95 1.90	39.75 39.62	$C_5H_4N_6O_4$
2c	80	103—104 (ether)	0.37 ($CHCl_3$—Me_2CO—MeOH, 10 : 2 : 1)	29.89 29.76	2.72 2.50	34.98 34.71	$C_6H_6N_6O_5$
2d**	89.2	83—84 ($CHCl_3$)	0.89 ($CHCl_3$—Me_2CO—MeOH, 10 : 2 : 1)	26.38 26.05	1.30 1.31	36.16 36.45	$C_5H_3N_6O_3Cl$
2f	70	110—112 ($CHCl_3$)	0.74 (PhH—AcOEt, 3 : 1)	21.32 21.15	0.48 0.44	43.63 43.18	$C_4HN_7O_5$
3c	39	114—115 (PhH)	0.47 (PhH)	49.59 49.21	2.50 2.56	34.70 34.51	$C_{10}H_6N_6O_2$
4a	81 (*A*) 99 (*B*)	174—175 ($CHCl_3$)	0.69 (PhH—AcOEt, 2 : 1)	24.10 24.63	0.78 0.52	49.73 50.26	$C_8H_2N_{14}O_6$
4b	79 (*A*) 80 (*B*)	176—178*	0.70 (PhH—AcOEt, 5 : 1)	30.58 30.94	1.18 1.04	43.11 43.30	$C_{10}H_4N_{12}O_6$
4c	97	201—202 (PhH)	0.88 ($CHCl_3$—Me_2CO—MeOH, 10 : 2 : 1)	37.41 37.84	2.60 2.72	37.52 37.83	$C_{14}H_{12}N_{12}O_6$
4d	81 (*A*) 96 (*B*)	184—185*	0.62 (PhH—AcOEt, 5 : 1)	36.14 36.10	2.32 2.27	31.92 31.57	$C_{16}H_{12}N_{12}O_{10}$
4e	91	163—164 (MeOH)	0.38 (PhH—AcOEt, 3 : 1)	40.81 40.68	3.43 3.41	35.24 35.58	$C_{16}H_{16}N_{12}O_6$
4f	83	159—160 (MeOH)	0.43 (PhH—AcOEt, 3 : 1)	40.31 40.78	3.01 2.93	40.22 40.76	$C_{14}H_{12}N_{12}O_4$
6	76	153 (decomp.) n_D^{20} 1.5872	0.66 (PhH—AcOH, 3 : 1)	21.79 21.53	0.49 0.45	56.67 56.51	$C_6HN_9O_3$
8	69	162—163 (PhH)	0.60 (PhH—AcOEt, 3 : 1)	56.31 56.38	4.79 4.70	28.07 28.19	$C_{14}H_{14}N_6O_3$

* Not recrystallized.
** Found Cl, 15.35%; calculated, Cl — 15.38%.

Scheme 4



13 **14**

NO_2 (**7**), N = N (**9**), and N_3 groups (**12**); these are formed from the amino group in the initial amine **1**. This is indicated, for example, by the fact that aminonitrofurazan **7** is formed in solutions of nitro(triazolyl)furazan **2a** on storage, as shown by TLC. In the absence of sodium azide in the reaction mixture, no azide **12** is formed after diazotization of amine **1a** (*i.e.*, the azide group in **12** is not formed due to the destruction of the triazole ring).

Apparently, the destruction of the triazole ring in triazolylfurazans involves the intermediate formation of diazo compounds **13** and **14** and their subsequent hydrolysis (Scheme 4). A similar process[16] also takes place in some reactions of azides with 1,3-dicarbonyl compounds, which give amines instead of 1-substituted 1,2,3-triazoles.

Experimental

The reactions were monitored and the product purity was checked by TLC on Silufol UV-254 plates (Czechia). IR spectra

Table 2. Spectroscopic characteristics of the compounds synthesized[a]

Compound	NMR (δ, *J*/Hz)		IR, ν/cm^{-1}
	^{1}H	^{13}C	
2a	4.78 (s, 2 H, CH_2); 5.89 (s, 1 H, OH); 8.00 (s, 1 H, H(4′))	54.80 (CH_2); 113.18 (CH); 142.31 ($\underline{C}CH_2$); 146.21 (N(1′)C); 156.05 (CNO_2)	3380, 1615, 1575, 1540, 1410, 1375, 1265, 1235, 1095, 1045, 980
2b[b]	4.71 (s, 2 H, CH_2); 5.57 (s, 1 H, OH); 8.64 (s, 1 H, H(5′))	56.28 (CH_2); 125.48 (C(5′)); 146.38 (N(1′)C); 150.77 ($\underline{C}CH_2$); 155.86 (CNO_2)	3265, 3185, 1620, 1575, 1510, 1455, 1395, 1375, 1315, 1265, 1230, 1185, 1065, 1045, 1030, 985
2c[b]	4.62, 4.65 (both s, 2 H each, CH_2); 5.91 (s, 1 H, OH)	53.10 (CH_2); 54.05 (CH_2); 138.27 ($\underline{C}CH_2$); 144.60 ($\underline{C}CH_2$); 149.91 (N(1′)C); 156.33 (CNO_2)	3430, 3300, 3260, 2990, 2940, 2870, 1630, 1575, 1480, 1460, 1420, 1380, 1360, 1320, 1190, 1180, 1140, 1070, 1050, 1030, 1000, 980, 875
2d	5.42 (s, 2 H, CH_2); 8.78 (s, 1 H, H(5′))	35.52 (CH_2); 127.20 (CH); 144.96 ($\underline{C}CH_2$); 145.49 (N(1′)C); 155.61 (CNO_2)	3135 (CH), 3100, 1600, 1560, 1500, 1430, 1380, 1365, 1310, 1270, 1250, 1215, 1180, 1145, 1050, 1035, 1000, 980, 890, 830, 820, 765
2f	9.65 (s, 1 H, H(5′))		3145 (CH), 1610, 1570, 1560, 1530, 1395, 1380, 1350, 1290, 1180, 1170, 1040, 980, 900, 870, 830
3c[c]	7.54 (m, 3 H, Ph); 8.10 (d, 2 H, Ph, *J* = 7.30); 9.14 (s, 1 H, CH)	121.98, 122.73, 126.60, 128.77 (Ph); 129.60 (C(5′)); 143.15; 148.99; 165.7 (CNO)	3160 (CH), 1600, 1530, 1490, 1460, 1410, 1370, 1320, 1280, 1245, 1220, 1190, 1180, 1080, 1055, 1020, 985, 960, 940, 880, 830, 810, 775
4a	9.76 (s, 1 H, H(5′))	127.47 (C(5′)); 146.15 (C(4)); 153.26 (C(4′)); 157.30 (C(3))	3150 (CH), 1590, 1570, 1560, 1530, 1390, 1300, 1220, 1030, 980, 830, 760
4b	7.35 (s, 1 H, OH); 8.84 (s, 1 H, H(5′))	121.44 ($\underline{C}$—COOH); 127.66 (C(5′)); 146.36 (N(1′)C); 157.49 (C—N=N)	3150 (CH), 1720 (CO), 1600, 1480, 1420, 1365, 1280, 1165, 1065, 1025, 985, 880, 760
4c	1.35 (t, 6 H, 2 Me, *J* = 7.20); 4.35 (q, 4 H, 2 CH_2, *J* = 7.20); 9.10 (s, 2 H, 2 CH)	13.97 (Me); 61.26 (CH_2); 130.21; 130.48; 130.72; 139.77; 159.04 (C=O)	3195, 3170 (CH), 3000, 2950, 2915 (Et), 1750, 1730 (CO), 1600, 1570, 1380, 1340, 1270, 1235, 1150, 1040, 775
4d	4.11, 4.43 (both s, 3 H each, Me)	53.48 (Me); 54.56 (Me); 121.85 ($\underline{C}$—CO); 138.47 ($\underline{C}$—CO); 146.28 (N(1′)C); 157.17 (C—N=N); 158.72 (C=O); 161.21 (C=O)	2970, 1755, 1730 (CO), 1590, 1570, 1450, 1310, 1265, 1240, 1210, 1100, 1060, 998, 810
4e	1.40 (t, 3 H, Me, *J* = 7.78); 2.65 (s, 3 H, Me); 4.42 (m, 2 H, CH_2, *J* = 7.78)	9.44 ($\underline{C}H_3CH_2$); 13.90 ($\underline{C}H_3Ar$); 60.81 (CH_2); 136.26; 142.16; 144.73; 157.94; 159.78 (C=O)	2980, 2300, 1730 (CO), 1620, 1570, 1510, 1420, 1380, 1340, 1290, 1260, 1130, 1080, 1020, 980, 910, 860, 850, 780, 710
4f	2.62, 2.68 (both s, 3 H each, Me)	140.63 ($\underline{C}$Me); 142.62 ($\underline{C}$Ar); 144.80 ($\underline{C}$—CO); 157.99 ($\underline{C}$—N=N); 192.31 (C=O)	1700 (CO), 1680, 1580, 1560, 1500, 1470, 1390, 1380, 1360, 1300, 1220, 1100, 1070, 1020, 980, 960, 910, 890, 860, 700
6[b]	9.59 (s, 1 H, H (5′))	125.74 (C(5′)); 144.75 (C(3)); 149.76 (CN_3); 154.78 ($\underline{C}NO_2$)	3160 (CH), 2190, 2150 (N_3), 1590, 1550, 1460, 1421, 1390, 1330, 1250, 1030, 980, 830
8[c]	3.18 (t, 4 H, $O(CH_2)_2$, *J* = 5.14); 3.70 (t, 4 H, $N(CH_2)_2$, *J* = 5.14); 7.44 (m, 3 H, Ph); 8.20 (d, 2 H, Ph, *J* = 7.35); 8.60 (s, 1 H, CH)	47.98; 65.22; 123.23; 125.81; 128.16; 128.73; 128.92; 143.87; 147.84; 154.74	3124 (CH), 2972, 2924, 2896, 2856, 1596, 1568, 1436, 1268, 1248, 1240, 1116, 1068, 1012, 984, 840, 772

[a] The ^{1}H and ^{13}C NMR spectra of compounds **2a—d**,**f**, **3c**, **4a,c,e,f**, and **6** were recorded in DMSO-d_6; those of compounds **4b,d** were run in acetone-d_6; those of compound **8**, in an acetone-d_6—DMSO-d_6 mixture (1 : 1).

[b] The ^{14}N NMR spectra of compounds **2b**, **2c**, and **6** were recorded in DMSO-d_6: −37.94 (**2b**); −37.87 (**2c**); −27.20, −28.70, −147.50 (**6**).

[c] MS (*m*/*z*, $I_{rel;}$(%)) for nitroso compound **3c**: 242 $[M]^+$ (1.67), 184 $[M - NO - N_2]^+$ (18), 156 (22.8), 145 (71.98), 102 (100), 89 (58.80); for morpholino derivatives **8**: 298 $[M]^+$ (1), 270 $[M - N_2]^+$ (10), 240 $[M - N_2 - NO]^+$ (100).

were measured in KBr pellets on UR-20 and Specord M-80 spectrometers. The ^{13}C and ^{1}H NMR spectra of the compounds were recorded on Bruker WM-250 (operating at 62.80 and 250 MHz, respectively) and Bruker AM-300 (operating at 75.5 and 300 MHz, respectively) spectrometers. The ^{13}C and ^{1}H chemical shifts were referred to the DMSO-d_6 solvent (δ_C 39.5; δ_H 2.5). The ^{14}N NMR spectra were recorded on a Bruker AM-300 instrument (21.5 MHz) in the δ scale. The chemical shifts were referred to external $MeNO_2$. Mass spectra were run on a Varian MAT CH 6 instrument (70 eV). The melting points were measured on a Boetius hot stage.

Oxidation of amines 1a—f with peroxide reagents

Nitro(triazolyl)furazans 2a—e (general procedure). Sodium tungstate $Na_2WO_4 \cdot 2H_2O$ (4.8 g, 15.3 mmol) was added with cooling (10—16 °C) and stirring to 90% H_2O_2 (10.8 mL, 441 mmol). At 15—20 °C, concentrated H_2SO_4 (10.5 mL, 394 mmol) was added dropwise and an amine **1a—e** (5 mmol) was added in portions. The reaction mixture acquired an intensive light-blue color. The cooling was removed. Within 1 h after decoloration, the mixture was poured into 200 mL of ice water. The products were isolated by method *A* or *B*.

A. The **3-(4-chloromethyl-1*H*-1,2,3-triazol-1-yl)-4-nitro-1,2,5-oxadiazole (2d)** precipitate was filtered off and dried in air. The mother liquor was extracted with CH_2Cl_2 (4×50 mL) and concentrated to dryness to give an additional amount of compound **2d**.

B. The mixture was extracted with CH_2Cl_2 (4×100 mL); the combined extracts were dried with $MgSO_4$, and the solvent was evaporated *in vacuo* to give **1-(4-nitro-1,2,5-oxadiazol-3-yl)-1*H*-1,2,3-triazol-4-ylmethanol (2b)** in the crystalline state and compound **2a,c,e** as an oil. The oily product **2a** was cooled at a dry-ice temperature to hardening, water (3 mL) was added, and the precipitate was filtered off and dried in air to give **1-(4-nitro-1,2,5-oxadiazol-3-yl)-1*H*-1,2,3-triazol-5-ylmethanol (2a)**. Ether (3 mL) was added to oily product **2c**, the mixture was vigorously shaken and, after 30 min, **4-hydroxymethyl-1-(4-nitro-1,2,5-oxadiazol-3-yl)-1*H*-1,2,3-triazol-5-ylmethanol (2c)** was collected on a filter. Oily product **2e** (R_f 0.84, elution with AcOEt—C_6H_6, 3 : 1) containing some initial **1e** (TLC data) was converted into the morpholine derivative **8** (see below).

3-Nitro-4-(4-nitro-1*H*-1,2,3-triazol-1-yl)-1,2,5-oxadiazole (2f). Trifluoroacetic anhydride (9 mL) was slowly added dropwise at 0 °C to 85% H_2O_2 (1.1 mL) in MeCN (15 mL), the cooling was removed, the reaction mixture was warmed-up to room temperature, and amine **1f** (1 g, 5.1 mmol) was added. The mixture was stirred for 3 h at room temperature and for 1 h at 30 °C, poured into ice water (150 mL), and extracted with $CHCl_3$ (4×50mL). The extract was washed with cold water and dried with $MgSO_4$, the solvent was evaporated *in vacuo* to give compound **2f**.

Treatment of amines 1a,b with CF_3CO_3H. Trifluoroacetic anhydride (8.4 mL, 60 mmol) was added dropwise at 5—10 °C to conc. H_2O_2 (1.58 mL, 64 mmol) in CH_2Cl_2 (5 mL), and a mixture of amines **1a,b** (0.36 g, 2 mmol) was added. Cooling was terminated and the reaction mixture was kept for 30 min at 20 °C and poured into ice water (20 mL). The organic phase was separated from the aqueous one, the aqueous phase was neutralized with $NaHCO_3$ to pH 7 and extracted with CH_2Cl_2 (4×20 mL), and the solvent was evaporated to dryness to give 0.26 g (99%) of 3-amino-4-nitrofurazan (**7**) identical to an authentic sample in R_f and IR spectrum.[6]

Nitroso(triazolyl)furazans 3a,b. $Na_2WO_4 \cdot 2H_2O$ (4.2 g, 13.3 mmol) was added at 11—16 °C to 85% H_2O_2 (9 mL), and then conc. H_2SO_4 (8 mL, 150 mmol) was added dropwise at 5—10 °C. The mixture was cooled to 0 °C and amine **1a** or **1b** (1.82 g, 10 mmol) was added. The mixture was stirred for 15—20 min until intensive blue color appeared, cooled to −5 °C, poured into ice (50 g), extracted with benzene (4×150 mL), and dried with $MgSO_4$ (10 min). Evaporation of the solvent to dryness gave 1.27 g and 1.17 g of product mixtures, which we were unable to identify.

3-Nitroso-4-(4-phenyl-1*H*-1,2,3-triazol-1-yl)-1,2,5-oxadiazole (3c). $Na_2WO_4 \cdot 2H_2O$ (1.6 g, 5.1 mmol) was added at 11—16 °C to 85% H_2O_2 (3.6 mL, 144.6 mmol), then conc. H_2SO_4 (3.5 mL, 65.6 mmol) was added dropwise at 5—10 °C. The reaction mixture was cooled to −5 °C, amine **1e** (0.6 g, 2.63 mmol) was added, and the mixture was stirred at this temperature for 5 min, poured onto ice, and extracted with benzene (3×30 mL). The extract was washed with water, dried with $MgSO_4$, and concentrated *in vacuo* to 1/3 of the initial volume, and the starting amine (0.05 g) was filtered off. The mother liquor was passed through a column with $L_{40/100}$ silica gel (with benzene as the eluent). Evaporation of the solvent and drying *in vacuo* gave compound **3c** (green-colored).

4-[4-(4-Phenyl-1*H*-1,2,3-triazol-1-yl)-1,2,5-oxadiazol-3-yl]morpholine (8). Morpholine (0.2 g, 2.32 mmol) was added to a solution of compound **2e** (0.3 g, 1.16 mmol) (containing a minor impurity of starting **1e**) in benzene (10 mL). The mixture was stirred for 30 min at room temperature, concentrated *in vacuo* to 1/4 its initial volume, and passed through a column with $L_{40/100}$ silica gel (elution with benzene). The solvent was evaporated *in vacuo*, water (10 mL) was added to the oily residue, and compound **8** was filtered off

Synthesis of azo derivatives 4a—f from amines 1f—k

4,4′-Azobis-3,3′-(4-nitro-1*H*-1,2,3-triazol-1-yl)-1,2,5-oxadiazole (4a). ***A.*** Water (45 mL) was added dropwise at room temperature to a stirred solution of amine **1f** (0.3 g, 1.5 mmol) in concentrated HCl (45 mL). Subsequently, a solution of $KMnO_4$ (3 g, 19 mmol) in water (60 mL) was added over a period of 1 h. After 4 h, oxalic acid was added until the solution became colorless. The precipitate was filtered off, washed with water, and dried in air to give azo compound **4a**.

B. Chlorine was bubbled at 0—2 °C through a solution of NaOH (0.4 g, 10 mmol) in water (20 mL) to a neutral pH. Then a solution of amine **1f** (0.2 g, 1 mmol) in MeOH (20 mL) was quickly added, the mixture was stirred for 10 min at 6—8 °C, AcOEt (5 mL) was added, and the mixture was stirred for an additional 15 min. The mixture was extracted with benzene (4×20 mL), dried with $MgSO_4$, and concentrated *in vacuo*. Benzene (10 mL) was added to the oily residue and the mixture was left for 16 h; the precipitated crystals were filtered off, washed with hexane, and dried in air to give azo compound **4a**.

4,4′-Azobis-3,3′-(4-carboxy-1*H*-1,2,3-triazol-1-yl)- (4b) and 4,4′-azobis-3,3′-(4,5-dimethoxycarbonyl-1*H*-1,2,3-triazol-1-yl)-1,2,5-oxadiazoles (4d). *A* (general procedure). Dibromo-

isocyanurate (0.87 g, 3 mmol) was added to a suspension of amine **1g** or **1i** (1 mmol) in MeCN (30 mL). After 24 h, the precipitate was filtered off, the mother liquor was evaporated to dryness *in vacuo*, the residue was washed with benzene (50 mL) (for the extraction of compound **4b**) or CH_2Cl_2 (for the extraction of compound **4d**), and the extracts were concentrated *in vacuo* to a small volume and passed through a column with $LS_{5/40}$ silica gel (elution with benzene) to give azo compound **4b** and **4d**, respectively.

***B* (general procedure).** A solution of $KMnO_4$ (1.1 g, 6.9 mmol) in water (36 mL) was added dropwise with stirring to a suspension of amine **1g** or **1i** (1 mmol) in 18% HCl (36 mL). Slight warming-up is observed. After 1 h, oxalic acid was added until the solution became colorless. The precipitate was filtered off, washed with water (200 mL) and dried in air to give azo compound **4b** and **4d**, identical to the compound prepared by procedure *A* in R_f and IR spectra.

4,4′-Azobis-3,3′-(4-ethoxycarbonyl-1*H*-1,2,3-triazol-1-yl)-1,2,5-oxadiazole (4c). A solution of Br_2 (2.2 mL) in MeCN (10 mL) and then amine **1h** (1.32 g, 6 mmol) were added dropwise at 15 °C to a suspension of $AcONa \cdot 3H_2O$ (5.7 g, 42 mmol) in MeCN (50 mL). After 1 h, the precipitate was filtered off and the mother liquor was concentrated to dryness. Benzene (150 mL) was added to the solid residue and the mixture was refluxed for 10 min. Solvent evaporation and drying *in vacuo* gave azo compound **4c**.

4,4′-Azobis-3,3′-(4-ethoxycarbonyl-5-methyl-1*H*-1,2,3-triazol-1-yl)-1,2,5-oxadiazole (4e). Sodium dichloroisocyanurate (5.5 g, 25 mmol) was added to a solution of amine **1j** (1 g, 4.2 mmol) in 50% AcOH (40 mL), and the mixture was stirred at room temperature for 1 h and extracted with $CHCl_3$. The extract was washed with water and dried with $MgSO_4$. The solvent was evaporated to dryness *in vacuo*. The crystalline product was washed with a $CHCl_3$—ether mixture, 1 : 1, to give azo compound **4e**.

4,4′-Azobis-3,3′-(4-acetyl-5-methyl-1*H*-1,2,3-triazol-1-yl)-1,2,5-oxadiazole (4f). Sodium dichloroisocyanurate (3.6 g, 16 mmol) was added to a solution of amine **1k** (0.5 g, 2.4 mmol) in 50% AcOH (50 mL). The reaction mixture was stirred at room temperature for 1 h and extracted with AcOEt, the extract was washed with water and dried with $MgSO_4$, and the solvent was evaporated to dryness *in vacuo*. The crystalline residue was washed with CCl_4 and water to give azo compound **4f**.

Treatment of amines 1a,b with oxidants ($KMnO_4$ in HCl; DBI). *A* (general procedure). A solution of $KMnO_4$ (1 g, 3.1 mmol) in H_2O (36 mL) was added dropwise to a cooled (15 °C) suspension of the corresponding amine (0.18 g, 1 mmol) in 18% HCl (36 mL). After 1 h, oxalic acid was added until the solution became colorless. The precipitate was filtered off, washed with water, and dried in air to give 0.07 g (39%) and 0.08 g (41%) of compound **9** from amines **1a** and **1b**, respectively.

***B*.** Dibromoisocyanurate (1.12 g, 4 mmol) was added to a solution of **1a** (0.18 g, 1 mmol) in MeCN (60 mL). After 24 h, the precipitate was filtered off and the solvent was evaporated to dryness *in vacuo* to give 0.10 g of a product mixture (containing macrocycle **10**, diamine **11** (m/z 384 $[M]^+$ and 388 $[M]^+$, respectively; R_f 0.85 and 0.60, respectively; elution with C_6H_6—AcOEt, 5 : 1), and a number of unidentified compounds).

Synthesis of 3-azido-4-(4-nitro-1*H*-1,2,3-triazol-1-yl)-1,2,5-oxadiazole (6). Amine **1f** (1.5 g, 7.6 mmol) was added in portions at 2 °C to nitrosylsulfuric acid prepared from concentrated H_2SO_4 (6 mL, 113 mmol) and $NaNO_2$ (0.52 g, 7.54 mmol) by a known procedure.[17] Then H_3PO_4 (d = 1.7 g cm^{-3}) (6 mL, 104 mmol) was added dropwise at 2—7 °C. The mixture was kept for 2 h at 2 °C. A solution of NaN_3 (2.43 g, 37 mmol) in water (15 mL) was added at 2—7 °C. After gas evolution had ceased, the reaction mixture was diluted with cold water (100 mL) and extracted with CH_2Cl_2 (4×100 mL), the extract was washed with water (2×50 mL) and dried with $MgSO_4$, and the solvent was evaporated *in vacuo* to give 1.5 g of azide **6** as a thick yellowish oil. Purification on a column with $L_{40/100}$ silica gel (elution with CH_2Cl_2) gave azide **6** as a colorless oil.

Treatment of amine 1a with nitrosylsulfuric acid and sodium azide. Amine **1a** (0.18 g, 1 mmol) was added in portions at 2 °C to stirred nitrosylsulfuric acid prepared from H_2SO_4 (1 mL) and $NaNO_2$ (0.07 g, 1 mmol) by a known procedure.[17] Orthophosphoric acid (1 mL) (d = 1.7 g cm^{-3}) was added at 2—5 °C, the mixture was kept at this temperature for 1 h, and a solution of NaN_3 (0.32 g, 5 mmol) in H_2O (2 mL) was slowly added dropwise. After gas evolution had ceased, the reaction mixture was diluted with water (20 mL) and extracted with CH_2Cl_2 (3×10 mL), the extract was washed with water (3×10 mL) and dried with $MgSO_4$, and the solvent was evaporated *in vacuo* to give 0.03 g (23%) of 3-azido-4-aminofurazan (**12**), identical to an authentic sample in the IR spectrum.[15]

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Received September 8, 2004;
in revised form November 26, 2004