

Synthesis of Uranyl Salophene Metallo-Macrocycles with Additional Functional Groups

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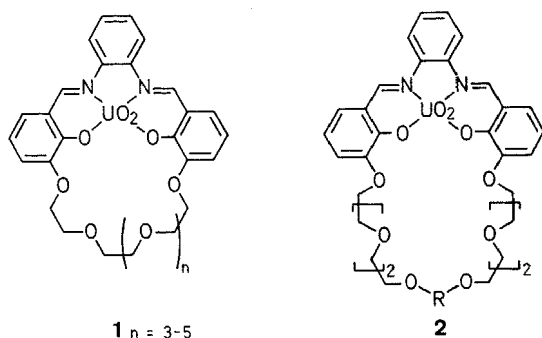
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A series of new metallo-macrocycles with a furan, pyridine, terphenyl, and xylene moiety has been synthesized.

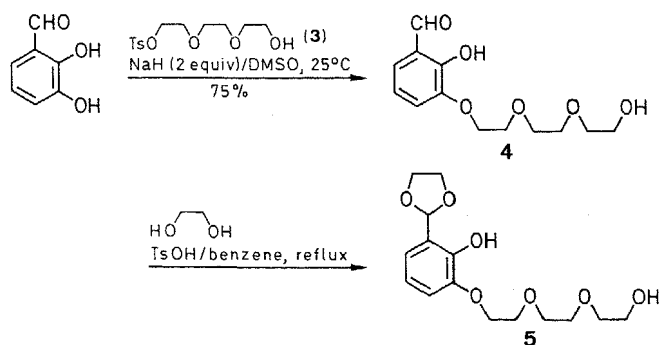
Molecular recognition is the basis for supramolecular chemistry.¹ The recognition of cations,¹⁻³ neutral organic molecules^{1,2,4-6} and anions^{1,7,8} has been studied intensively during the past two decades. Metallo-receptors appeared to be excellent hosts for the complexation of neutral molecules⁹⁻¹³ and anions.¹⁴ Recently we have reported about the synthesis and complexation properties of the uranyl salophene metallo-macrocycles **1**.¹¹ The complexes are stabilized by a strong interaction between the guest and the metallo center of the host; additional stabilization is obtained from H-bond formation with the heteroatoms of the macrocycle. The Lewis acidic uranyl cation prefers a pentagonal bipyramidal coordination, with the two uranyl oxygens at the apical positions and with both the four coordinating sites and a neutral molecule in the equatorial positions.^{11,15}

Reaction of 2,3-dihydroxybenzaldehyde with monotosylate **3**¹⁷ in DMSO in the presence of NaH afforded aldehyde **4**. To achieve selective substitution in the 3-position 2 equivalents of base must be used, otherwise a 2-substituted product is obtained.¹¹ The aldehyde signal at $\delta = 10.0$ in the ¹H NMR spectrum is typical for a 3-substituted 2-hydroxybenzaldehyde.¹¹ Aldehyde **4** was protected with ethylene glycol using a catalytic amount of TsOH to give ketal **5**. In a synthetic run compound **5** is not isolated, because the protecting group is very labile, possibly due to the rather acidic phenolic OH ($pK_a < 7$) in the 2-position. In an analytical sample the formation of **5** is clearly demonstrated by ¹H NMR spectroscopy ($\delta = 6.14$, s, ketal) and mass spectrometry (m/z , 314). Ketal **5** was treated with 2 equivalents of NaH to generate the double anion. Subsequent reaction of the more reactive anion of the aliphatic hydroxy group in THF with the appropriate dihalides afforded the dialdehydes **6**, after in situ deprotection, in moderate to good yields (57–82% from aldehyde **4**). The yield of

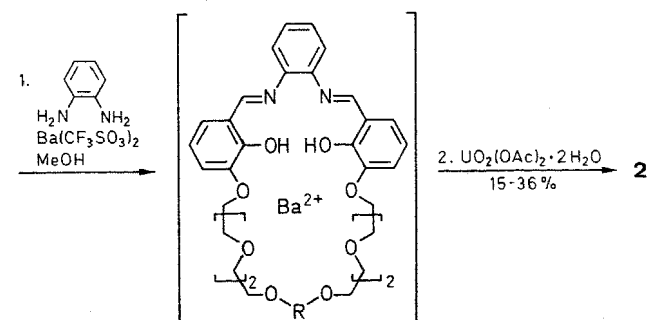
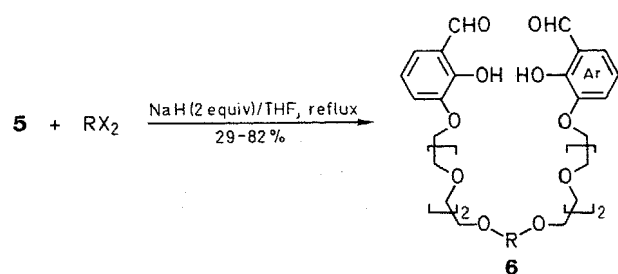


This paper will present a new, synthetic strategy for the preparation of the metallo-macrocycles **2**. The pyridine, furan, terphenyl,¹⁶ and xylene moieties are introduced into the *hard* crown ether cavity to study the influence upon the complexation properties.

A general route for the synthesis of the receptors **2** is outlined in the Schemes 1 and 2.



Scheme 1



2, 6	R	X	2, 6	R	X
a		Br	c		Cl
b		Br	d		Br

Scheme 2

compound **6c** is rather low (29%), because the highly reactive 2,5-bis(chloromethyl)furan decomposes partly under the reaction conditions.¹⁸ The protons of the methylene group attached to the R moiety are found at $\delta = 4.5$ –5.0. The position of these peaks is significantly different from that of the corresponding dihalides.

Essential for macrocyclization is the presence of Ba^{2+} acting as a template ion.¹¹

Macrocyclization of the dialdehydes **6** with 1,2-benzenediamine was carried out by slow addition of both a solution of diamine and dialdehyde to a refluxing solution of $\text{Ba}(\text{CF}_3\text{SO}_3)_2$ in MeOH. The resulting intermediate barium complexes, which were not isolated,¹¹ were reacted with a stoichiometric amount of $\text{UO}_2(\text{OAc})_2 \cdot 2\text{H}_2\text{O}$ to give after purification the uranyl salophene metallo-macrocycles **2** in 15–36% yield. Considering the ring-size of 32–38 atoms the yields are respectable. The ^1H NMR spectra of the compounds **2** exhibit signals at $\delta = 9.5$ –9.6 and in the IR spectra absorptions are present at 1602 – 1604 cm^{-1} , which indicate imine bond formation. The absorptions in the IR spectra at 899 – 905 cm^{-1} correspond to the uranium-oxygen ($\text{O}=\text{U}=\text{O}$) vibrations.¹⁵ The mass spectra show very distinct molecular ion peaks, proving both macrocyclization and tight co-complexation of the uranyl cation.

Definite structural proof was obtained from single-crystal X-ray analysis. The X-ray structure of compound **2b**^{20,21} (Figure) shows that the uranyl cation is complexed in the salophene moiety.

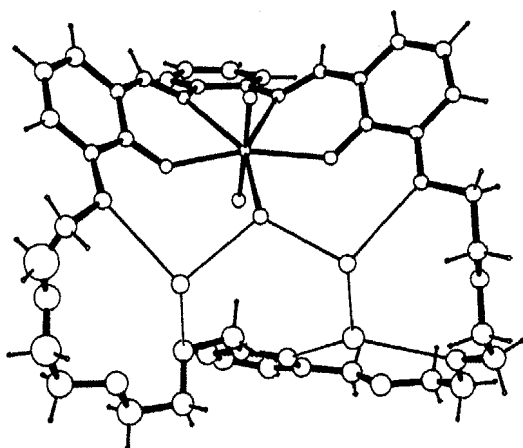


Figure. View of the X-ray structure of **2b**. CH_3CN present outside the cavity is not depicted for clarity. The hydrogen atoms of the water molecules in the cavity were not observed. The hydrogen bond network is deduced from the bond distances and angles.

The cavity is filled with four water molecules, one of these water molecules is coordinated at the fifth position of the cocomplexed Lewis acidic uranyl cation. The water molecules are H bonded to each other and with several of the heteroatoms of the crown ether moiety of the metallo-macrocycle, including the pyridine nitrogen atom. The absorptions in the IR spectra at 3440 – 3450 cm^{-1} also indicate the presence of water molecules.

The encapsulation of water molecules in the cavity of **2b** demonstrates the potential to complex (a) guest molecule(s). Complexation studies with metallo-macrocycles **2**, focussing on the H-bond acceptor capability of the pyridine, furan, terphenyl and xylene moiety, are under investigation.

^1H NMR spectra were recorded with a Bruker WP-80 spectrometer and ^{13}C NMR spectra were recorded with a Nicolet NT-200 WB spectrometer with TMS as an internal standard. Positive ion electron impact (EI, 70 eV) and fast atom bombardment (FAB; *m*-nitrobenzyl alcohol as a matrix) mass spectra were obtained with a Varian Mat 311 A and a Finnigan MAT 90 mass spectrometer, respectively. IR spectra were recorded with a Nicolet 5 SCX FT spectrophotometer. Elemental analyses were carried out by a Model 1106 Carlo Erba Strumentazione Elemental Analyzer. Melting points were determined with a Reichert melting point apparatus and are uncorrected. THF was freshly distilled from sodium/benzophenone ketyl prior to use; benzene was distilled from CaH_2 ; DMSO was dried over molecular sieves 4 \AA prior to use. Petroleum ether refers to the fraction with bp 40 – 60°C . Other reagent quality solvents were used without purification. The dihalides 2,6-bis(bromomethyl)benzene,²² 2,6-bis(bromomethyl)pyridine,²³ 2,5-bis(chloromethyl)furan,²⁴ and 3,3'-bis(bromomethyl)-2,2',2''-trimethoxy-5,5',5''-trimethyl-1,1':3',1''-terphenyl²⁵ were prepared according to literature procedures. All other chemicals were of reagent grade and were obtained from Janssen and Aldrich and were used without purification. Analytical TLC plates were purchased from Merck. Column chromatography was performed with silica gel (Merck; 0.015 mm– 0.040 mm) if not stated otherwise. Sephadex LH-20 was obtained from Pharmacia. All reactions were carried out in a nitrogen atmosphere.

The ring systems of the compounds **2** and **6** are abbreviated as indicated in Scheme 2. The carbon and hydrogen atoms in the compounds **2** originating from 1,2-benzenediamine have the highest superscript number.

Care should be taken when handling uranyl containing compounds because of their toxicity and radioactivity.²⁶

2-[2-(2-Hydroxyethoxy)ethoxy]ethanol 4-Methylbenzenesulfonate (**3**):

To a solution of 2-[2-(2-hydroxyethoxy)ethoxy]ethanol (150 g, 1 mol) and Et_3N (151.1 g, 1.5 mol) in CH_2Cl_2 (160 mL) was added tosyl chloride (95 g, 0.5 mol) at 0°C in 1 h. The mixture was stirred for 3 h at r.t. and for 1 h at reflux to complete the reaction (TLC, silica gel, $\text{CHCl}_3/\text{MeOH}$, 10:1). The mixture was poured into a mixture of ice-cold 6 M HCl (250 mL). After separation of the layers the water layer was extracted with CHCl_3 ($6 \times 150\text{ mL}$). The combined organic layers were washed with sat. NaHCO_3 (100 mL) and with NaCl (100 mL). Drying (MgSO_4) and evaporation of the solvent yielded a mixture of mono- and ditosylate 2-[2-(2-hydroxyethoxy)ethoxy]ethanol. To separate these two tosylates the oil was dissolved in MeOH (250 mL) and cooled overnight to -20°C to precipitate the ditosylate. Pure monotosylate **3** was obtained as an oil by filtering off the ditosylate and evaporation of the solvent in vacuo; yield: 228 g (75%).

^1H NMR (CDCl_3): $\delta = 2.45$ (s, 3H, CH_3), 3.5–3.8 (m, 10H, OCH_2), 4.1–4.2 (m, 2H, OCH_2), 7.34 (d, 2H, $J_{3,2} = 8.7\text{ Hz}$, Ar H-3), 7.80 (d, 2H, $J_{2,3} = 8.7\text{ Hz}$, Ar H-2).

^{13}C NMR (CDCl_3): $\delta = 21.5$ (q, CH_3), 61.3 (t, CH_2OH), 68.5, 69.4, 70.1, 70.5, 72.5 (t, OCH_2), 127.8 (d, Ar C-3), 129.9 (d, Ar C-2), 132.7 (s, Ar C-4), 144.9 (s, Ar C-1).

HRMS (EI): $m/z = 304.0900$ (M^+ , calc. for $\text{C}_{13}\text{H}_{20}\text{O}_6\text{S}$ 304.0981).

2-Hydroxy-3-[2-[2-(2-hydroxyethoxy)ethoxy]ethoxy]benzaldehyde (**4**):

To a suspension of NaH (9.9 g, 0.33 mol, 80% in oil), prewashed with petroleum ether, in DMSO (150 mL) was added 2,3-dihydroxybenzaldehyde (20.7 g, 0.15 mol) at 20 – 25°C . After 1 h of stirring a solution of monotosylate **3** (45.6 g, 0.15 mol) in DMSO (50 mL) was added at 20 – 25°C and stirring was continued for 24 h,

whereupon the mixture was poured into water (1000 mL) and extracted with CHCl_3 (3×250 mL). The mixture was acidified with 6 M HCl to adjust the pH to 1 and again extracted with CHCl_3 (5×200 mL). The combined CHCl_3 layers were washed with 1 M HCl (5×200 mL), dried (MgSO_4) and filtered over silica gel. After evaporation of most of the solvent in vacuo, aldehyde **4** was obtained as a yellow solid by precipitation upon addition of petroleum ether (1000 mL); yield 24.7 g (61%); mp 86–89°C (CHCl_3 /petroleum ether).

$\text{C}_{13}\text{H}_{18}\text{O}_6$ calc. C 57.77 H 6.71
(270.3) found 57.48 6.70

$^1\text{H NMR}$ (CDCl_3): $\delta = 3.6\text{--}4.0$ (m, 10 H, OCH_2), 4.1–4.3 (m, 2 H, OCH_2), 6.90 (dd, 1 H, $J_{5,4} = J_{5,6} = 7.6$ Hz, Ar H-5), 7.1–7.3 (m, 2 H, Ar H-4, Ar H-6), 10.02 (s, 1 H, CHO), 10.78 (s, 1 H, OH).

$^{13}\text{C NMR}$ (CDCl_3): $\delta = 61.9$ (t, CH_2OH), 69.1, 69.6, 70.3, 70.9, 72.5 (t, OCH_2), 119.4, 120.6, 124.7 (d, Ar C-4, C-5, C-6), 121.7 (s, Ar C-1), 147.3 (s, Ar C-3), 152.0 (s, Ar C-2), 195.7 (d, CHO).

IR (KBr): $\nu = 1657$ (C=O) cm^{-1} .

HRMS (EI): $m/z = 270.1103$ (M^+ , calc. 270.1090).

6-(1,3-Dioxolan-2-yl)-2-[2-(2-hydroxyethoxy)ethoxy]ethoxyphenol (**5**):

An equimolar mixture of aldehyde **4** and ethylene glycol was refluxed in benzene (0.01–0.1 M) for 2–3 h in the presence of a catalytic amount of TsOH. During this period water was distilled off twice azeotropically to complete the reaction. The solvent was evaporated in vacuo to yield ketal **5** as an oil which was used without purification in the next step. Full characterization of the product was very difficult because ketal **5** hydrolyzed rapidly to aldehyde **4**. From the $^1\text{H NMR}$ and MS data it was concluded that ketal **5** was formed.

$^1\text{H NMR}$ (CDCl_3): $\delta = 6.14$ (s, 1 H, ketal).

HRMS (EI): $m/z = 314.1410$ (M^+ , calc. for $\text{C}_{15}\text{H}_{22}\text{O}_7$, 314.1365).

General Procedure for the Synthesis of the Dialdehydes **6a–d**:

To a refluxing stirred suspension of NaH (1.05 g, 35 mmol, 80% in oil), prewashed with petroleum ether, in THF (200 mL) were added simultaneously separate solutions of ketal **5** (4.71 g, 15 mmol) and of the appropriate dihalide (7.5 mmol) both in THF (25 mL) in 3 h using a perfusor. Reflux was maintained for 3, 2, 3, and 3 h for **6a**, **6b**, **6c** and **6d**, respectively. Subsequently water (50 mL) was added to the mixture followed by 1 M HCl to adjust the pH to 5. After partial evaporation of THF under reduced pressure the water layer was extracted with CHCl_3 (3×100 mL). The combined CHCl_3 layers were dried (MgSO_4) and the solvent was evaporated in vacuo. The crude product was purified by chromatography (CHCl_3 unless noted otherwise) to afford pure aldehydes **6** as oils.

3,3'-[*m*-Phenylenebis(methyleneoxyethyleneoxyethyleneoxyethyleneoxy)]disalicylaldehyde (**6a**): yield 3.95 g (82%).

$^1\text{H NMR}$ (CDCl_3): $\delta = 3.6\text{--}4.0$ (m, 20 H, OCH_2), 4.1–4.3 (m, 4 H, OCH_2), 4.54 (s, 4 H, CH_2Xyl), 6.8–7.3 (m, 10 H, Ar H, Xyl H), 9.96 (s, 2 H, CHO), 10.79 (s, 2 H, OH).

$^{13}\text{C NMR}$ (CDCl_3): $\delta = 69.2$, 69.5, 69.6, 70.6, 70.8 (t, OCH_2), 73.1 (t, CH_2Xyl), 119.4, 120.8, 124.8 (d, Ar C-4, C-5, C-6), 121.3 (s, C-1), 126.9, 127.0, 128.4 (d, Ar C'-1, C'-3, C'-4), 138.4 (s, C'-2), 147.4 (s, C-3), 152.1 (s, C-2), 195.8 (s, CHO).

IR (KBr): $\nu = 1656$ (C=O) cm^{-1} .

HRMS (EI): $m/z = 642.2659$ (M^+ , calc. for $\text{C}_{34}\text{H}_{42}\text{O}_{12}$, 642.2678).

3,3'-[2,6-Pyridinediylbis(methyleneoxyethyleneoxyethyleneoxyethyleneoxy)]disalicylaldehyde (**6b**): yield 3.86 g (80%).

$^1\text{H NMR}$ (CDCl_3): $\delta = 3.7\text{--}3.8$ (m, 20 H, OCH_2), 4.2–4.3 (m, 4 H, OCH_2), 4.95 (s, 4 H, CH_2Pyr), 6.8–7.8 (m, 9 H, Ar H, Pyr H), 9.96 (s, 2 H, CHO), 10.79 (s, 2 H, OH).

$^{13}\text{C NMR}$ (CDCl_3): $\delta = 69.2$, 69.6, 70.2, 70.5, 70.6, 70.8 (t, OCH_2), 73.9 (t, CH_2Pyr), 119.4, 119.9, 120.7, 124.7 (d, Ar C-4, C-5, C-6, C'-3), 121.3 (s, Ar C-1), 137.4 (d, Ar C'-4), 147.4 (s, Ar C-3), 152.1 (s, Ar C-2), 157.8 (s, Ar C'-2), 195.7 (s, CHO).

IR (KBr): $\nu = 1656$ (C=O) cm^{-1} .

HRMS (EI): $m/z = 643.2590$ (M^+ , calc. for $\text{C}_{33}\text{H}_{41}\text{NO}_{12}$, 643.2629).

3,3'-[2,5-Furandiylbis(methyleneoxyethyleneoxyethyleneoxyethyleneoxy)]disalicylaldehyde (**6c**): eluent, $\text{CHCl}_3/\text{MeOH}$, 98:2; yield 1.38 g (29%).

$^1\text{H NMR}$ (CDCl_3): $\delta = 3.6\text{--}3.9$ (m, 20 H, OCH_2), 4.2–4.3 (m, 4 H, OCH_2), 4.46 (s, 4 H, CH_2Fur), 6.25 (s, 2 H, Fur H-3), 6.8–7.3 (m, 6 H, Ar H), 9.96 (s, 2 H, CHO), 10.80 (s, 2 H, OH).

$^{13}\text{C NMR}$ (CDCl_3): $\delta = 65.1$ (t, CH_2Fur), 69.2, 69.3, 69.5, 70.5, 70.8 (t, OCH_2), 110.3 (d, Fur C-3), 119.4, 120.7, 124.8 (d, Ar C-4, C-5, C-6), 121.3 (s, Ar C-1), 147.4 (s, Ar C-3), 151.9 (s, Fur C-2), 152.1 (s, Ar C-2), 195.8 (s, CHO).

IR (KBr): $\nu = 1656$ (C=O) cm^{-1} .

HRMS (EI): $m/z = 362.1320$ (M^+ — $\text{C}_{13}\text{H}_{19}\text{O}_5$, calc. for $\text{C}_{19}\text{H}_{21}\text{O}_8$, 362.1307).

3,3'-[(2,2',2'-Trimethoxy-5,5',5''-trimethyl-*m*-terphenyl-3,3''-yl-ene)bis(methyleneoxyethyleneoxyethyleneoxyethyleneoxy)]disalicylaldehyde (**6d**): yield 3.96 g (57%).

$^1\text{H NMR}$ (CDCl_3): $\delta = 2.32$ (s, 9 H, CH_3), 3.18 (s, 3 H, OCH_3 (in)), 3.46 (s, 6 H, OCH_3 (out)), 3.6–3.9 (m, 20 H, OCH_2), 4.2–4.3 (m, 4 H, OCH_2), 4.63 (s, 4 H, CH_2Ter), 6.9–7.3 (m, 12 H, Ar H, Ter H), 9.95 (s, 2 H, CHO), 10.80 (s, 2 H, OH).

$^{13}\text{C NMR}$ (CDCl_3): $\delta = 20.7$ (q, 1 CH_3 (in)), 20.8 (q, CH_3 (out)), 60.5 (q, OCH_3 (in)), 61.0 (q, OCH_3 (out)), 68.4, 69.3, 69.7, 69.6, 70.6, 70.9 (t, OCH_2), 119.4, 120.8, 124.9 (d, Ar C-4, C-5, C-6), 121.3 (s, Ar C-1), 129.5, 131.4, 131.6 (d, Ar C'-4, C'-6, C''-4), 130.9, 131.8, 131.9, 132.3, 132.8 (s, Ar C'-1, C'-3, C'-5, C''-1, C''-5), 147.3 (s, Ar C-3), 152.2 (s, Ar C-2), 153.7 (s, Ar C'-2, C''-2), 195.8 (s, CHO).

IR (KBr): $\nu = 1656$ (C=O) cm^{-1} .

HRMS (EI): $m/z = 926.4160$ (M^+ , calc. for $\text{C}_{52}\text{H}_{62}\text{O}_{15}$, 926.4089).

General Procedure for the Synthesis of Macrocycles **2a–d**:

To a refluxing mixture of $\text{Ba}(\text{CF}_3\text{SO}_3)_2$ (0.49 g, 1.1 mmol) and dialdehyde **6** (1 mmol) in MeOH (250 mL) was added a solution of 1,2-benzenediamine (0.11 g, 1 mmol) in MeOH (25 mL) in 10 min. After stirring for 10 min a solution of $\text{UO}_2(\text{OAc})_2 \cdot 2\text{H}_2\text{O}$ (0.42 g, 1 mmol) in MeOH (25 mL) was added and reflux was maintained for another 20 min. Cooling to r.t., evaporation of the solvent in vacuo, and purification (except **2d**, see experimental details) by column chromatography (Sephadex; eluent: MeOH) yielded the macrocycles **2a–c** as orange solids.

[9,10,12,13,15,16,26,27,29,30,32,33-Dodecahydro-3,7:19,23:35,39(24H)-trimetheno-18H-8,11,14,17,25,28,31,34,1,41-benzoctaoxadiazacyclotritetracontine-46,48-diolato(2-)- $\text{N}^1, \text{N}^{41}, \text{O}^{46}, \text{O}^{48}$]dioxouranium (**2a**): yield 0.29 g (29%); mp 100–104°C.

$\text{C}_{40}\text{H}_{44}\text{N}_2\text{O}_{12}\text{U} \cdot \text{H}_2\text{O}$ calc. C 48.00 H 4.63 N 2.80
(1000.8) found 47.95 4.66 2.58

$^1\text{H NMR}$ (CD_3CN): $\delta = 3.5\text{--}4.0$ (m, 20 H, OCH_2), 4.3–4.4 (m, 4 H, OCH_2), 4.47 (s, 4 H, CH_2Xyl), 6.69 (dd, 2 H, $J_{5,4} = J_{5,6} = 7.9$ Hz, Ar H-5), 7.1–7.7 (m, 12 H, Ar H, Ar H', Ar H''), 9.49 (s, 2 H, CH=N).

$^{13}\text{C NMR}$ (CD_3CN): $\delta = 69.5$, 70.0, 70.6, 70.7, 70.9, 71.0 (t, OCH_2), 73.2 (CH_2Xyl), 117.6, 118.9, 121.0 (d, Ar C-4, C-5, C''-3), 125.3 (s, Ar C-1), 127.8, 128.8, 129.1, 129.2, 130.2 (d, Ar C-6, C'-2, C'-4, C'-5, C''-4), 139.4 (s, Ar C'-1), 147.6 (s, Ar C''-1), 150.9 (s, Ar C-3), 167.6 (CH=N).

IR (KBr): $\nu = 1602$ (C=N), 899 (O=U=O) cm^{-1} .

HRMS (EI): $m/z = 982.3378$ (M^+ , calc. 982.3402).

[9,10,12,13,15,16,26,27,29,30,32,33-Dodecahydro-3,7:35,39-(24H)-dimetheno-19,23-nitrilo-18H-8,11,14,17,25,28,31,34,1,41-benzoctaoxadiazacyclotritetracontine-46,48-diolato(2-)- $\text{N}^1, \text{N}^{41}, \text{O}^{46}, \text{O}^{48}$]dioxouranium (**2b**): yield 0.29 g (28%); mp 116–119°C.

$\text{C}_{30}\text{H}_{43}\text{N}_3\text{O}_{12}\text{U} \cdot 4\text{H}_2\text{O}$ calc. C 44.36 H 4.87 N 3.98
(1055.9) found 44.52 4.54 4.09

$^1\text{H NMR}$ (CD_3CN): $\delta = 3.6\text{--}4.2$ (m, 20 H, OCH_2), 4.3–4.5 (m, 4 H, OCH_2), 4.57 (s, 4 H, CH_2Pyr), 6.69 (dd, 2 H, $J_{5,4} = J_{5,6} = 7.9$ Hz, Ar H-5), 7.1–7.8 (m, 12 H, Ar H, Ar H', Ar H''), 9.60 (s, 2 H, CH=N).

^{13}C NMR (CD_3CN): $\delta = 70.3, 70.6, 70.7, 71.1, 71.3$ (t, OCH_2), 74.5 (t, CH_2Pyr), $117.5, 121.0, 121.8, 122.0$ (d, Ar C-4, C-5, C'-3, C''-3), 125.6 (s, C-1), $129.2, 130.1$ (d, Ar C-6, Ar C'-4), 138.4 (d, Ar C'-4), 147.7 (s, Ar C''-1), 151.1 (s, Ar C-3), 158.8 (s, Ar C'-2), 162.3 (s, Ar C-2), 167.4 (CH=N).

IR (KBr): $\nu = 1604$ (C=N), 905 (O=U=O) cm^{-1} .

HRMS (EI): $m/z = 983.3360$ (M^+ , calc. 983.3355).

Dioxo[9,10,12,13,15,16,18,23,25,26,28,29,31,32-tetradecahydro-19,22-epoxy-3,7:34,38-dimetheno-8,11,14,17,24,27,30,33,1,40-benzooctaoxadiazacyclodotetracontine-45,47-diolato-(2-)- $\text{N}^1, \text{N}^{40}, \text{O}^{45}, \text{O}^{47}$]uranium (**2c**): yield 0.16 g (15%); mp 114 – 117°C .

$\text{C}_{38}\text{H}_{42}\text{N}_2\text{O}_{13}\text{U} \cdot 3.5\text{H}_2\text{O}$ calc. C 44.06 H 4.77 N 2.70 (1044.8) found 43.83 4.40 2.66

^1H NMR (CD_3CN): $\delta = 3.6$ – 3.7 (m, 16 H, OCH_2), 3.8 – 4.1 (m, 4 H, OCH_2), 4.3 – 4.5 (m, 4 H, OCH_2), 4.52 (s, 4 H, CH_2Fur), 6.25 (s, 2 H, Fur H-3), 6.68 (dd, 2 H, $J_{5,4} = J_{5,6} = 7.9$ Hz, Ar H-5), 7.3 – 7.7 (m, 8 H, Ar H, Ar H'), 9.53 (s, 2 H, CH=N).

^{13}C NMR (CD_3CN): $\delta = 65.0$ (t, CH_2Fur), $69.6, 69.8, 70.4, 70.7, 70.9$ (t, OCH_2), 110.8 (d, Fur C-3), $117.5, 120.6, 121.2$ (d, Ar C-4, C-5, C'-3), 125.2 (s, Ar C-1), $128.7, 129.7$ (d, Ar C-6, Ar C'-4), 147.4 (s, Ar C'-1), 150.8 (s, Ar C-3), 152.8 (s, Fur C-2), 162.0 (s, Ar C-2), 167.0 (d, CH=N).

IR (KBr): $\nu = 1603$ (C=N), 899 (O=U=O) cm^{-1} .

MS (FAB): $m/z = 972.3$ ($(\text{M} + \text{H})^+$, calc. 972.3).

[9,10,12,13,15,16,36,37,39,40,42,43-Dodecahydro-57,58,59-trimethoxy-21,26,31-trimethyl-3,7:19,23:24,28:29,33:45,49 (34H)-pentametheno-18H-8,11,14,17,35,38,41,44,1,51-benzooctaoxadiazacyclotripentacontine-56,60-diolato-(2-)- $\text{N}^1, \text{N}^{51}, \text{O}^{56}, \text{O}^{60}$]dioxouranium (**2d**): The reaction mixture was dissolved in a minimal amount of CHCl_3 and the crude product was oiled out by addition of petroleum ether. The oil was redissolved in CHCl_3 (100 mL) and stirred with water (100 mL) and guanidinium sulfate (ca. 1.0 g) for 15 h. The CHCl_3 layer was separated off and dried (MgSO_4). The macrocycle **2d** was obtained as an orange solid after evaporation of the solvent in vacuo:²⁷ yield 0.46 g (ca. 36%); mp 84 – 88°C .

^1H NMR ($\text{DMSO}-d_6$): $\delta = 2.27$ (s, 9 H, CH_3), 3.07 (s, 3 H, $\text{CH}_3(\text{in})$), 3.41 (s, 6 H, $\text{CH}_3(\text{out})$), 3.5 – 3.8 (m, 20 H, OCH_2), 4.3 – 4.5 (m, 4 H, OCH_2), 4.51 (s, 4 H, CH_2Ter), 6.4 – 7.9 (m, 16 H, Ar H, Ar H', Ar H'', Ar H'''), 9.60 (s, 2 H, CHO).

IR (KBr): $\nu = 1602$ (C=N), 901 (O=U=O) cm^{-1} .

MS (FAB): $m/z = 1267.4$ ($(\text{M} + \text{H})^+$, calc. 1267.3).

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- (1) Lehn, J.-M. *Angew. Chem.* **1990**, *102*, 1347; *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 1304.
- (2) Cram, D.J. *Angew. Chem.* **1988**, *100*, 1041; *Angew. Chem., Int. Ed. Engl.* **1988**, *27*, 1009.
- (3) Izatt, R.M.; Bradshaw, J.S.; Nielsen, S.A.; Lamb, J.D.; Christensen, J.J. *Chem. Rev.* **1985**, *85*, 271.
- (4) Rebek, Jr., J. *Angew. Chem.* **1990**, *102*, 261; *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 245.

- (5) Diederich, F. *Angew. Chem.* **1988**, *100*, 372; *Angew. Chem., Int. Ed. Engl.* **1988**, *27*, 362.
- (6) Collet, A.; Dutasta, J.-P.; Lozach, B. *Bull. Soc. Chim. Belg.* **1990**, *99*, 617.
- (7) Schmidtchen, F.P. *Chem. Ber.* **1981**, *114*, 597.
- (8) Beauchamp, A.L.; Olivier, M.J.; Wuest, J.D.; Zacharie, B. *J. Am. Chem. Soc.* **1986**, *108*, 73.
- (9) Aoyama, Y.; Asakawa, M.; Yamagishi, A.; Toi, H.; Ogoshi, H. *J. Am. Chem. Soc.* **1990**, *112*, 3145.
- (10) Benson, D.R.; Valentekovich, R.; Knobler, C.B.; Diederich, F. *Tetrahedron* **1990**, *47*, 2401.
- (11) van Staveren, C.J.; van Eerden, J.; van Veggel, F.C.J.M.; Harkema, S.; Reinhoudt, D.N. *J. Am. Chem. Soc.* **1988**, *110*, 4994.
- (12) Anderson, H.L.; Sanders, J.K.M. *Angew. Chem.* **1990**, *102*, 1478; *Angew. Chem., Int. Ed. Engl.* **1990**, *29*, 1400.
- (13) Maruoka, K.; Nagahara, S.; Yamamoto, H. *J. Am. Chem. Soc.* **1990**, *112*, 6115.
- (14) Newcomb, M.; Madonik, A.M.; Blanda, M.T.; Judice, J.K. *Organometallics* **1987**, *6*, 145.
- (15) Bandoli, G.; Clemente, D.A.; Croatto, U.; Vidali, M.; Vigato, P.A. *J. Chem. Soc., Chem. Commun.* **1971**, 1330.
- (16) See for terphenyl containing metallo-macrocycles ($\text{M} = \text{Ni}^{2+}$ and Cu^{2+}): van Veggel, F.C.J.M.; Harkema, S.; Bos, M.; Verboom, W.; van Staveren, C.J.; Gerritsma, G.J.; Reinhoudt, D.N. *Inorg. Chem.* **1989**, *28*, 1133.
- (17) Merz, A.; Eichner, M.; Tomahogh, R. *Liebigs Ann. Chem.* **1981**, 1774.
- (18) With 2,5-bis(chloromethyl)thiophene¹⁹ we were not able to obtain the corresponding dialdehyde.
- (19) Griffing, J.M.; Salisbury, L.F. *J. Am. Chem. Soc.* **1948**, *70*, 3416.
- (20) Single crystals were grown from acetonitrile-water. Crystal data: $\text{C}_{39}\text{H}_{43}\text{N}_3\text{O}_{12}\text{U} \cdot 3\text{H}_2\text{O} \cdot \text{CH}_3\text{CN}$; FW = 1078.9; lattice type, monoclinic; space group, $\text{P}2_1/c$; T = 293 K; a = 12.846(3) Å; b = 15.120(3) Å; c = 23.494(5) Å; $\beta = 98.63(2)^\circ$; V = 4512(3) Å³; Z = 4; $D_c = 1.59$ g cm^{-3} ; F(000) = 2152; $\mu = 34.8$ cm^{-1} , θ range, 3–20°; measured unique refln = 7908; obsd refln [$F^2 > \sigma(F)^2$] = 4613; no. of variables refined = 354; hydrogens of the metallo-macrocycle are treated as riding atoms; R(%) = 5.9 and R_w (%) = 5.8.
- (21) Details of the structure are deposited at the Cambridge Structural Database.
- (22) Ziegler, K.; Späth, A.; Schaaf, E.; Schumann, W.; Winkelmann, E. *Liebigs Ann. Chem.* **1942**, 551, 80.
- (23) Baker, W.; Buggle, K.M.; McOmie, J.F.W.; Watkins, D.A.M. *J. Chem. Soc.* **1958**, 3594.
- (24) Gray, R.T.; Reinhoudt, D.N.; Smit, C.J.; Veenstra, I. *Recl. Trav. Chim. Pays-Bas* **1976**, *95*, 258.
- (25) Koenig, K.E.; Lein, G.M.; Stuckler, P.; Kaneda, T.; Cram, D.J. *J. Am. Chem. Soc.* **1979**, *99*, 3553.
- (26) *Dangerous Properties of Industrial Materials*, 5th ed.; Sax, N.I. (Ed); Van Nostrand Reinhold Company; New York, 1979; p 1077–1078.
- (27) According to the ^1H NMR spectrum **2d** is slightly contaminated with a small impurity. Unfortunately column chromatography (silica gel) of **2d** gives only rise to decomposition. Consequently no satisfactory elemental analysis could be obtained.