Calixarene-Based Picolinamide Extractants for Selective An/Ln Separation from Radioactive Waste

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Eleven novel ligands having picolinamide or thiopicolinamide binding groups at the upper or lower rim of calix[4]-, calix[6]- and calix[8]arenes have been synthesised. The conformational properties of some of these ligands were studied in solution by means of NMR spectroscopy and in the solid state by X-ray diffraction. Their ability to extract Am^{III} or Eu^{III} from water to NPHE (*o*-nitrophenyl hexyl ether) was tested at different concentrations of $LiNO_3$, HNO_3 and of a lipophilic dicarbollide anion (BrCosan). The data show a high cooperation between binding sites of the calixarene ligands in comparison to data obtained with the model ligand *N*-butyl picolinamide (**19**). Some of these ligands show very high distribution coefficients for Am^{3+} ($D_{Am} > 300$) and good Am/Eu selectivity at pH ≥ 3, which open up interesting perspectives for their application in the treatment of low acidity radioactive waste.

Introduction

The separation of actinides (An) from lanthanides (Ln) is an urgent and important problem in the management of waste resulting from the reprocessing of fuels from nuclear plants. Spent nuclear fuel contains moderate amounts of long-lived minor actinides (Np, Am, Cm) together with many fission products, among which lanthanides represent one of the major components.[1] A programme for the conditioning of such waste, named Partitioning and Transmutation (P&T), is aimed at separating An from Ln and transmuting them into short-lived radionuclides.[1–3] P&T could therefore considerably reduce the number, capacity and safety margins of geological repositories. Organophosphorus ligands like CMPO, used in the TRUEX process, phosphane oxide or dialkylphosphoric acids (TALSPEAK) are usually quite efficient for An extraction but lack selectivity. The introduction of CMPO binding groups onto the upper[4] or lower[5,6] rim of calix[4]arenes and resorcarenes,[7] as well as onto other polyvalent scaffolds,[8] increases the efficiency of trivalent metal ions extraction by more than two orders of magnitude and, in some cases, also improves the selectivity.[9] However, An/Ln separation can be more easily achieved by exploiting the slightly stronger interactions that An^{III} present with the softer S- and N-containing ligands[1,3] of the SANEX processes.[10,11] Different pyridine derivatives, such as terpyridines and 2,6-bis(triazinyl)pyridines,[12–16] or dithiophosphinic acids[17–19] show quite remarkable separation factors. Among these ligands, *N*-alkylpicolinamides have also been proposed as ligands for the selective extraction of An from radioactive waste[2,20,21] as they show promising separation factors ($S_{Am/Eu} \approx 9$) under optimum conditions. They can act as bidentate ligands, as evidenced in the solid-state structure of a Cu^{II} salt[22] or by molecular modelling[23] on lanthanide complexes, where both the pyridine N and the carbonyl oxygen atoms are coordinated to the metal ion. Alternatively, examples of picolinamides acting as monodentate ligands (through the pyridine nitrogen)[24] or, under basic conditions, as bidentate ligands through the deprotonated amide NH rather than the carbonyl group[25] are also known. We report herein our efforts to introduce picolinamide ligands on calixarene scaffolds in order to study whether the size of the macrocycle, the cooperation and the stereochemical disposition of these binding groups affect the efficiency of extraction and selectivity in the An/Ln separation.

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Results and Discussion

Synthesis and Structures of the Ligands

We planned to introduce picolinamide binding groups at the upper or lower rim of calixarenes by the formation of an amide bond. Therefore, we needed to synthesise amino-

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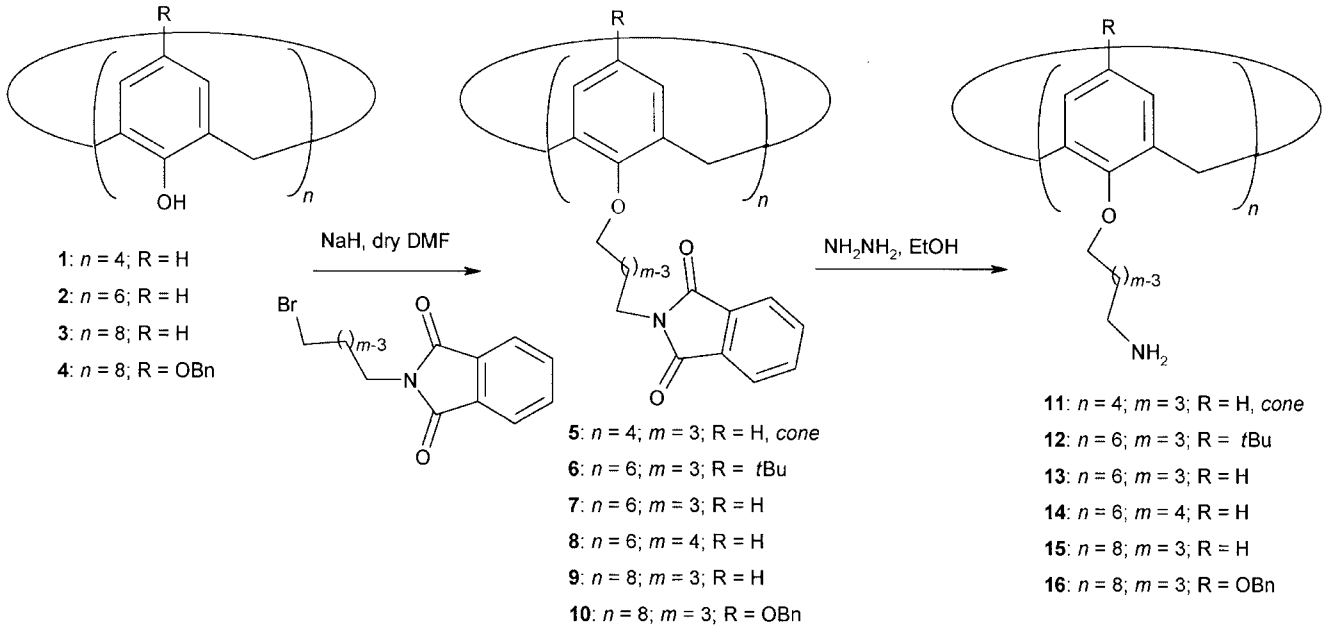
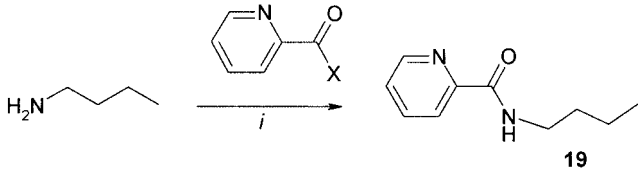


Scheme 1.

calixarenes to be acylated with a suitable picolinic acid derivative. The tetramino derivatives at the lower rim of *p-tert*-butylcalix[4]arene[6] **20** and **21** and at the upper rim of tetrapropoxycalix[4]arene[26,27] **17** and **18** were prepared according to procedures reported in the literature. We also synthesised the *p*-H-calix[4]arene tetramine **11**, the calix[6]-arene hexamines **12**, **13** and **14** and the calix[8]arene octamines **15** and **16** by alkylation of the appropriate calixarenes **1**–**4** with (3-bromopropyl)- or (4-bromobutyl)phthalimides and NaH in dry DMF, followed by hydrazinolysis of the phthalimido groups of the resulting compounds **5**–**10** (Scheme 1).

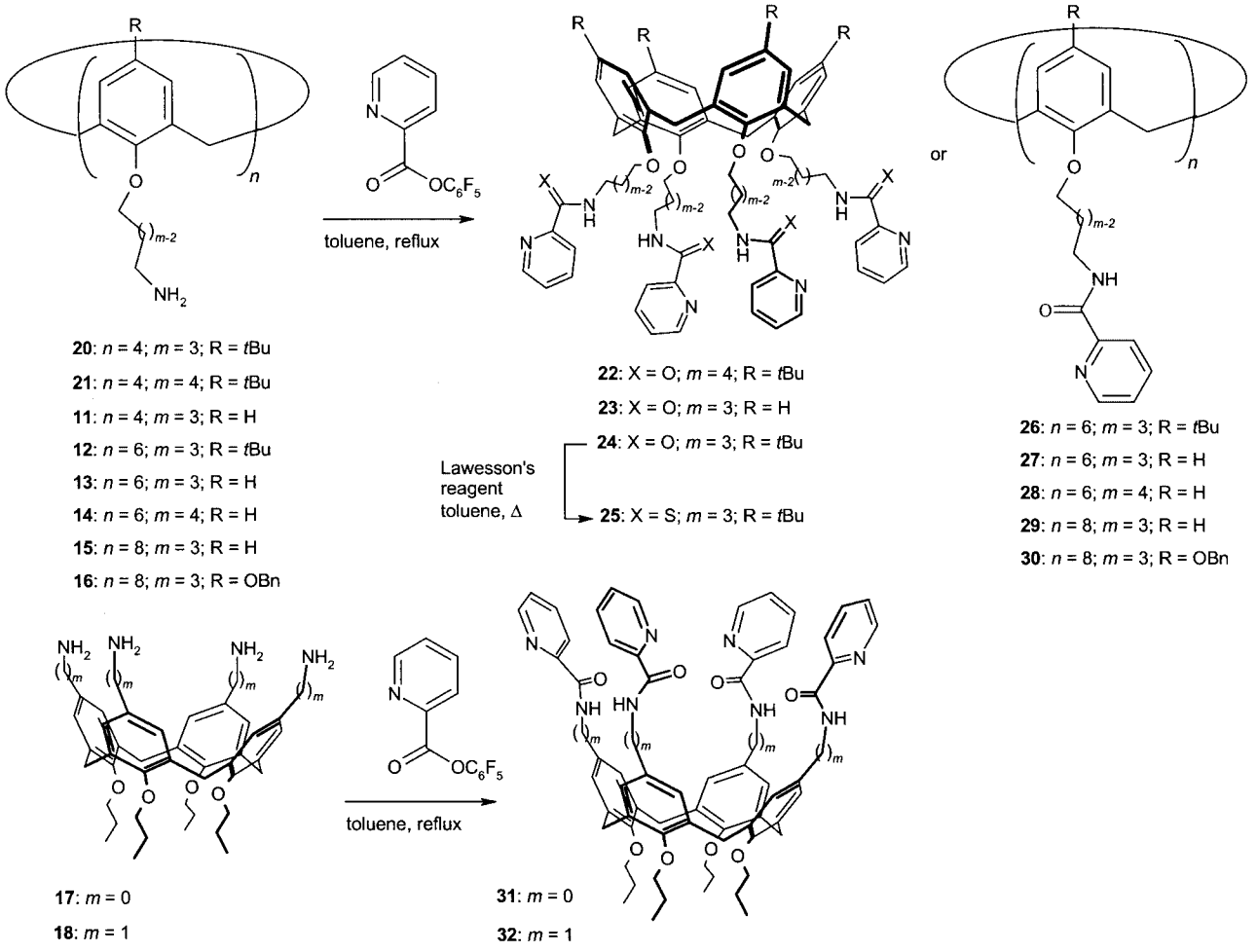
We first tested the reaction for the amide bond formation by using a simple primary amine. The reaction of the chloride of picolinic acid, generated by reaction of the acid and oxalyl chloride, with butylamine in dry dichloromethane gave compound **19** in 40% yield (Scheme 2). However, when the picolyl chloride was treated with tetramine **20**, considerable amounts of products due to ether cleavage and imide formation were also found beside the tetrapicolinamide **22**.



Scheme 2.

We therefore studied the possibility of using an active ester in the acylation reaction and, in particular, the pentafluorophenyl ester[28,29] of picolinic acid. Reaction of the active ester with butylamine in dry toluene at reflux (Scheme 2) doubled the yield of compound **19** (82%) and allowed the isolation of calixarene ligands **22**–**24** and **26**–**30** in 27–79% yield from the appropriate aminocalixarene (Scheme 3).

The thiopicolinamide (**25**) of *p-tert*-butylcalix[4]arene was prepared by reacting compound **24** with Lawesson's reagent in toluene at 90 °C (yield 81%). All the calix[4]-arenes bearing tetramides at the lower or upper rim are in the *cone* conformation, thus ensuring the projection of all four picolinamide groups in the same region of space. On the other hand, *p*-H-calix[8]arene and *p*-benzyloxycalix[8]-arene picolinamides **29** and **30** are conformationally quite mobile even at room temperature in $CDCl_3$ solution. Calix[6]arenes **26**–**28** show conformational properties that depend strongly on the solvent, temperature or substituents at the upper rim. The presence of bulky alkylpicolinamides at the lower rim prevents the O-through-the-annulus mechanism of conformational interconversion,[30] which therefore depends mainly on the substituents on the aromatic ring. In fact, picolinamides of *p*-H-calix[6]arenes (**27** and **28**) are very mobile in solution on the ^1H NMR timescale, whereas *p-tert*-butylcalix[6]arene hexapicolinamide (**26**) is frozen as a mixture of conformers in [D_6]DMSO solution at room temperature. Among these conformers the *1,2,3-alternate* one seems to be predominant, as indicated by the presence, for the $ArCH_2Ar$ protons, of a doublet at δ = 4.46 ppm (4 H) and a singlet at δ = 3.75 ppm (4 H), the other doublet being superimposed at δ = 3.40 ppm (4 H) with the signals of the CH_2N groups. Some of these signals start to coalesce at 383 K in [D_6]DMSO, thus indicating that these conformers can interconvert upon heating in spite of the bulky substituents. X-ray diffraction studies on a single crystal of the hexapicolinamide **28** showed the calix to be in a *1,2,3-alternate* structure similar to that found to be predominant in [D_6]DMSO solution for ligand **26**.



Scheme 3.

The molecular structure of **28** (see Figure 1) is *pseudo*-centrosymmetric. The deviations from a full C_i symmetry are quite small and mainly located in the terminal part of the picolinamide chains, rather than in the calix[6]arene basket. The whole molecule is formed by two trimeric subunits (**A**–**C** and **D**–**F**) linked together through the methylene bridges C20C and C20F in a *pseudo*-centrosymmetric fashion leaving three picolinamide chains up and three down with respect to the molecular reference plane **R** (the least-squares plane through the six C20 carbons). The conformation of the molecule is unequivocally defined by the dihedral angles, δ, between the reference plane **R** and the least-squares planes of the six phenolic rings (**A**–**F**) according to standard rules for calixarenes[31] and by the conformational parameters φ and χ[32] reported in Table 1. No deviations of the calixarene basket from C_i symmetry are found upon comparing the dihedral angles in one trimer (**R-D**, **R-E**, **R-F**) to those in the other one (**R-A**, **R-B**, **R-C**), in the limit of their standard deviations [$\delta_{\mathbf{R-D}} = 360° - \delta_{\mathbf{R-A}} = 80.8(4)°$ and also $\delta_{\mathbf{R-E}} = 360° - \delta_{\mathbf{R-B}}$ and $\delta_{\mathbf{R-F}} = 360° - \delta_{\mathbf{R-C}}$], which indicates that the six phenolic units can be related by a *pseudo* centre of symmetry located at the centre of the reference plane.

The absolute values of the conformational parameters φ and χ in the two trimeric sub-units are also equal, within the limits of their standard deviations, and the corresponding pairs of signs in the two trimers are opposite, as expected for a nearly centrosymmetric structure. However, as the calixarene is not fully centrosymmetric, the complete symbolic representation of the molecular conformation should be assumed as C_1 + –,+ –,+ +,– +,– +,– –. The reciprocal orientations of the binding sites are different in two groups of picolinamide nuclei: in **A**, **B**, **C**, **D** and **F** the carbonyl oxygen and pyridine nitrogen are all *trans* whereas in **E** they are mutually *cis*. The interatomic N2···N2 and O2···O2 distances (see Table 2) are quite different in the two trimeric calixarene subunits.

The role of the two water molecules found in the crystal lattice is crucial in determining the molecular packing of the calixarenes. As shown in Figure 2, the macrocycles are piled up in parallel columns directed along the crystallographic *c* axis. Adjacent columns intercalate the picolinamide chains giving rise to separated layers of calixarenes packed parallel to the crystallographic *ac* plane. Finally, each pair of adjacent layers of calixarenes are linked together by hydrogen bonds involving parallel arrays of water

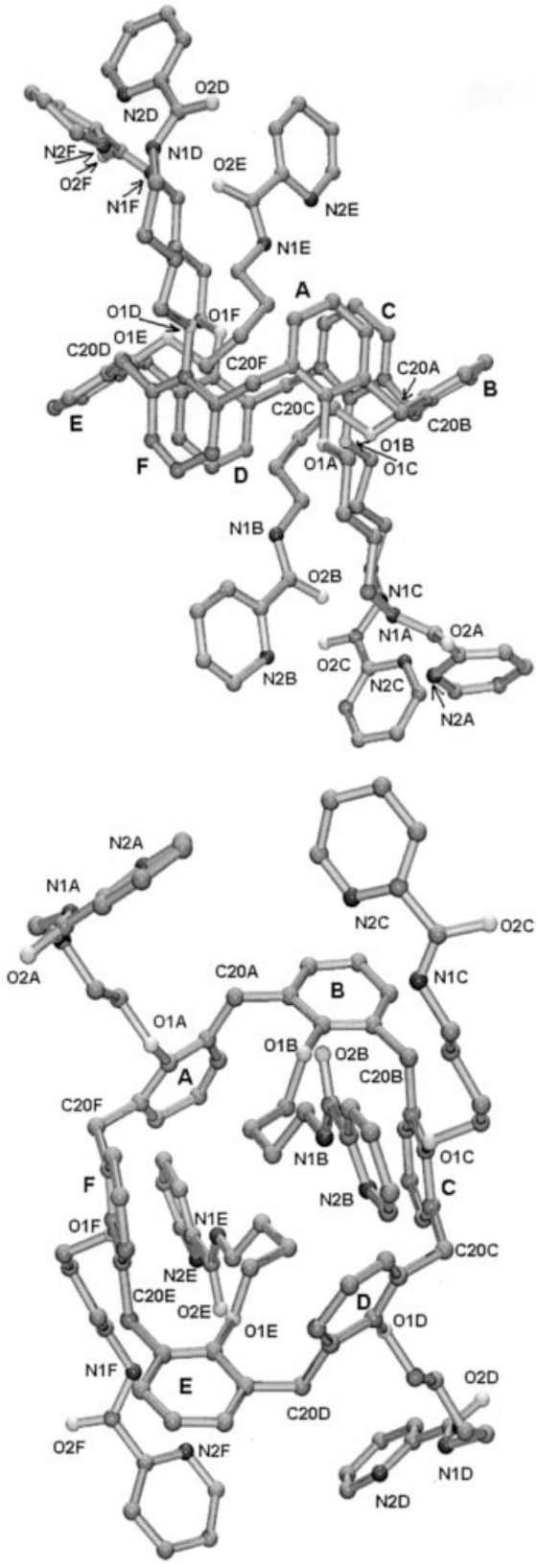


Figure 1. Perspective views of the molecular structure of **28** with atom numbering (top: "side" view; bottom: "top" view). Hydrogen atoms and hydrogen-bonded water molecules have been omitted for clarity (for coloured pictures see Figure S1 in the Supporting Information).

Table 1. Dihedral angles δ [°] and conformational parameters φ and χ [°] in the molecular structure of **28** in the solid state.

Dihedral angles [°]		Conformational parameters [°]		
	δ		φ	χ
R-A	279.2(4)	A–B	–35(2)	94(2)
R-B	219.2(4)	B–C	–97(2)	33(2)
R-C	286.4(3)	C–D	–92(2)	–100(2)
R-D	80.4(4)	D–E	31(2)	–97(2)
R-E	141.0(4)	E–F	99(2)	–28(2)
R-F	74.5(3)	F–A	95(2)	98(2)

Table 2. Interatomic carbonyl O···O and pyridine N···N distances [Å] in the two groups of picolinamide chains of compound **28**.

O2A···O2B	7.88(2)	N2A···N2B	9.59(2)
O2B···O2C	5.27(2)	N2B···N2C	7.08(2)
O2A···O2C	11.77(2)	N2A···N2C	5.38(2)
O2D···O2E	7.84(2)	N2D···N2E	8.02(2)
O2E···O2F	5.64(2)	N2E···N2F	5.31(2)
O2D···O2F	11.68(2)	N2D···N2F	5.64(2)

molecules oriented along the crystallographic *c* axis: each water molecule acts as a double donor of hydrogen bonds while the carbonyl oxygens of picolinamides from the two adjacent calixarene layers as acceptors. In such a way each array of water molecules behaves as a "zipper" between the two layers. The geometrical parameters of the hydrogen bonds are collected in Table 3.

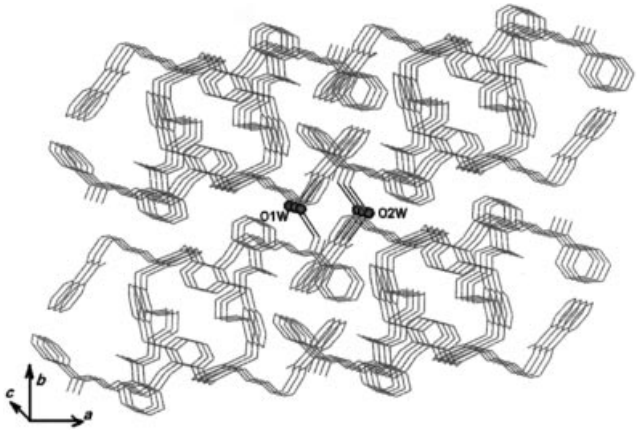


Figure 2. Perspective view of the molecular packing of **28**. Hydrogen bonds are shown by black lines (for coloured pictures see Figure S2 in the Supporting Information).

Table 3. Geometrical parameters for the hydrogen bonds in the crystal structure of **28**.

Acceptor···donor [Å]		Donor···acceptor[a] [Å]	
O2D···O1W	2.85(2)	O1W···O2F*i*	2.98(2)
O2A···O2W	2.80(2)	O2W···O2C*ii*	2.87(2)

[a] Equivalent positions: (*i*) $x - 1, y, z + 1$; (*ii*) $x + 1, y, z - 1$.

Extraction Properties

To assess the extraction properties of the new picolinamide ligands, liquid–liquid extraction tests were performed

by dissolving the ligand in NPHE (*o*-nitrophenyl hexyl ether) and mixing the organic phase with an acidic aqueous phase containing Am^{3+} and Eu^{3+} nitrates. We first measured D_M values for *N*-butylpicolinamide (**19**), which was used as a model compound, and the hexapicolinamide of *p*-(*tert*-butyl)calix[6]arene **26**. To increase the D_M values for these ligands we initially used an aqueous phase containing 1 M $LiNO_3$. This salt, which has the anion in common with the Am^{3+} or Eu^{3+} salts to be extracted but a cation (lithium) which is usually negligibly extracted by other calixarene ligands, should increase the D_M according to the equation $D_M = K_{ex}[L]^m[NO_3^-]^n$. Extraction experiments were also performed using increasing concentrations of a lipophilic dicarbollide anion (BrCosan), which is also known to facilitate cation extraction.[33,34] The nitric acid concentration was fixed at 0.001 M for these preliminary tests. The results reported in Table 4 point out that dicarbollide highly influences the extraction of M^{3+} ions in the organic phase also in the case of these picolinamide ligands.

Table 4. D_M[a] and $S_{Am/Eu}$ values for the extraction of Am^{3+} and Eu^{3+} from an aqueous solution ([$LiNO_3$] = 1 M, [HNO_3] = 10^{-3} M) into an NPHE solution of the ligand ([**19**] = 0.1 M; [**26**] = 0.005 M) at 25 °C.

Ligand		[BrCosan] (M) 0	0.003	0.02	0.05
19	D_{Eu}	<0.003	1.0	>300	>300
	D_{Am}	<0.003	0.9	21.4	>300
	$S_{Am/Eu}$	–[c]	0.9	0.07	–[c]
26	D_{Eu}	2.6[b]	>300	>300	>300
	D_{Am}	6.1[b]	>300	>300	>300
	$S_{Am/Eu}$	2.3[b]	–[c]	–[c]	–[c]

[a] Due to uncertainties associated with measurements at low activity (<50 KBq L^{-1}), distribution coefficients higher than 300 and lower than 0.003 should be considered with care. [b] [**26**] = 0.01 M. [c] Not applicable.

An increase of more than five orders of magnitude in D_M is, in fact, already observed with a 0.02 M BrCosan concentration in the case of the model compound **19**. Interestingly enough, in the absence of BrCosan or with a 0.003 M concentration a strong (300–2000-fold) increase of D_M for both Am^{3+} and Eu^{3+} can be observed on passing from the model compound **19** to the calix[6]arene derivative **26**, even though the latter is used at a 10–20 times lower concentration than the former. The calixarene unit in **26** also gives a slightly higher Am/Eu separation factor than **19**. The optimum BrCosan concentration was therefore set at 3×10^{-3} M for all the subsequent extraction tests. To study the effect of $LiNO_3$ on the efficiency of extraction, we performed a series of D_M measurements at different $LiNO_3$ concentrations with calixarenes **23**, **24** and **27** (Table 5). Interestingly, all three compounds show, in the absence of $LiNO_3$, a remarkable selectivity for Am^{3+} over Eu^{3+} and, in the case of compounds **24** and **27**, fairly high D_{Am} values as well. On the other hand, and quite surprisingly, the data indicate a dramatic reduction of the D_M values at 1 M $LiNO_3$ that slightly increase at 2 M $LiNO_3$. This seems to indicate that, contrary to expectations, the lithium cation is strongly interfering in the M^{3+} complexation, probably by competing for the basic N sites of the picolinamide binding groups. It is well-known, in fact, that nitrogen ligands have a high affinity for lithium ion.[35] On passing from an $LiNO_3$ concentration of 1 M to 2 M the common anion effect operates but increases the D_M values only slightly.

Table 5. D_M and $S_{Am/Eu}$ values for the extraction of Am^{3+} and Eu^{3+} from an aqueous solution ([BrCosan] = 3×10^{-3} M, [HNO_3] = 10^{-3} M) into an NPHE solution of ligand ([**23**] = [**24**] = 0.01 M; [**27**] = 0.005 M) at 25 °C.

Ligand		$LiNO_3$ (M) 0	1	2
23	D_{Eu}	1.43	0.013	0.028
	D_{Am}	16.3	0.065	0.16
	$S_{Am/Eu}$	11.4	5.2	5.7
24	D_{Eu}	16.4	0.014	0.054
	D_{Am}	210	0.11	0.36
	$S_{Am/Eu}$	12.8	7.8	6.7
27	D_{Eu}	29.2	0.13	0.46
	D_{Am}	>300	1.59	3.14
	$S_{Am/Eu}$	>10	12.3	6.8

We then tested the synthesised calixarene-based ligands also in comparison with the model compound **19** under the optimum extraction conditions found earlier ([BrCosan] = 3×10^{-3} M, [$LiNO_3$] = 0, [HNO_3] = 10^{-3} M; Table 6). With the exception of thiopicolinamide ligand **25**, which is unable to significantly extract trivalent cations under these conditions, all the other calixarene ligands were found to be far superior to **19** both in extraction efficiency and Am/Eu selectivity. Most of the ligands (**22**, **24**, **27**, **29**, **30**, **32** have D_{Am} values higher than 100 and some of them (**23**, **24**, **27**, **31**) particularly high selectivity ($S_{Am/Eu} > 10$). It is quite difficult to draw general rules describing the best structural requirements for such calixarene ligands to efficiently and selectively extract Am^{3+}. However, the octameric derivatives (**29** and **30**) are slightly more efficient than hexameric (**27** and **28**) and tetrameric (**24** > **22** > **32** > **23** > **31**) picolinamides. For lower rim calix[4]- and -[6]arene picolinamides a spacer having three methylene groups (ligands **23**, **24** or **27**) gives rise to higher selectivity than that with four methylene groups (**22** or **28**). For upper-rim-substituted calix[4]arenes, the presence of a spacer between the calixarene aromatic and the NH picolinamide groups (ligand **32**) increases the efficiency of Am^{3+} extraction but decreases the $S_{Am/Eu}$.

Finally we also considered the effect of HNO_3 concentration on the extraction abilities of picolinamide ligands (Table 7). Upon increasing the HNO_3 concentration a remarkable decrease of D_M was observed both for Am^{3+} and Eu^{3+} for all the ligands considered, indicating that at pH ≤ 2 the protonation of the basic pyridine nitrogen atoms becomes quite important and prevents the extraction of trivalent metal cations from water solution. This behaviour is similar to that of other nitrogen ligands used in the SANEX protocol.[13] However, the picolinamide ligands should not suffer the degradation experienced by the dithiophosphinic acids[36,37] used in this protocol.

Table 6. D_M[a] and $S_{Am/Eu}$ values for the extraction of Am^{3+} and Eu^{3+} from an aqueous solution ([BrCosan] = 3×10^{-3} M, [HNO_3] = 10^{-3} M) into an NPHE solution of ligands **19**, **22**–**25** or **27**–**32** at 25 °C.

Ligand	**19**	**22**	**23**	**24**	**25**	**27**	**28**	**29**	**30**	**31**	**32**
[L] (M)	0.1	0.01	0.01	0.01	0.001	0.005	0.005	0.005	0.0002[b]	0.01	0.01
D_{Eu}	6.0	19.6	1.43	16.4	0.23	29.2	16.7	98	150	0.81	26.4
D_{Am}	16.5	173	16.3	210	0.20	>300	60.5	>300	>300	11.5	158
$S_{Am/Eu}$	2.7	8.8	11.4	12.8	0.9	>10	3.6	>3	>2	13.8	6.0

[a] Due to uncertainties associated with measurements at low activity (<50 KBq L^{-1}), D_M values greater than 300 should be considered with care. [b] Significant precipitation occurred at [**30**] = 0.005 M.

Table 7. D_M and $S_{Am/Eu}$ values for the extraction of Am^{3+} and Eu^{3+} from an aqueous solution ([BrCosan] = 3×10^{-3} M) into an NPHE solution of ligands **19** or **27**–**30** at 25 °C at different [HNO_3].

Ligand		[HNO_3] (M)					
(M)		0.001	0.005	0.01	0.1	1	2
19	D_{Eu}	6.0			0.09		
(0.1)	D_{Am}	16.5			0.11		
27	D_{Eu}	29.2		0.88	0.06	0.03	0.02
(0.005)	D_{Am}	>300		9.1	0.10	0.04	0.02
28	D_{Eu}	16.7		0.09	0.005		
(0.005)	D_{Am}	60.5		0.40	0.02		
29	D_{Eu}	98	4.3	0.42	<0.003		
(0.005)	D_{Am}	>300	56	5.6	0.01		
30	D_{Eu}	150		1.3	0.19	0.09	0.02
(0.0002)	D_{Am}	>300		3.2	0.20	0.10	0.08

Conclusions

A new class of ligands for actinide extraction which present several picolinamide binding groups at the upper or lower rim of calix[*n*]arenes (*n* = 4, 6, 8) has been synthesised. These ligands are more efficient than the model *N*-butylpicolinamide (**19**) and the cooperation of binding sites on the calixarene backbone especially enhances the extraction of Am^{III} and therefore the selectivity $S_{Am/Eu}$. In terms of efficiency, calix[8]arenes have been shown to be superior to calix[6]- and calix[4]arenes, while the upper-rim-substituted calix[4]arene ligand **31** shows the best Am/Eu selectivity of 13.8. Reasonable D_M values could, however, only be obtained at [HNO_3] < 10^{-2} M which limits the scope of this class of ligands to the treatment of nuclear wastes of low acidity (pH ≥ 3). The use of this promisingly selective binding groups in combination with others (CMPO, malonamide or thenoyl), which should ensure higher extraction at lower pH, is currently being studied.

Experimental Section

General Remarks: Melting points were determined with an Electrothermal apparatus in sealed capillaries under nitrogen. ^1H and ^{13}C NMR spectra were recorded with Bruker spectrometers AC300 (^1H: 300 MHz, ^{13}C: 75 MHz) or AMX400 (^1H: 400 MHz) with TMS as internal standard. Mass spectra were obtained in the ESI mode with a Micromass 4LCZ or in the CI (CH_4) mode with Finnigan Mat SSQ710 spectrometers. TLC was performed on precoated silica gel Merck 60 F_{254}. All solvents were purified by standard procedures; dry solvents were obtained by literature methods and stored over molecular sieves. All the reactions were carried out under nitrogen. *p*-Benzyloxycalix[8]arene[38] (**4**) and the tetramino derivatives at the lower rim of *p*-*tert*-butylcalix[4]arene[6] (**20** and **21**) and at the upper rim of tetrapropoxycalix[4]arene[26,27] (**17** and **18**) were prepared according to procedures reported in the literature.

General Procedure for the Alkylation of Calix[*n*]arenes with *N*-(ω-Bromoalkyl)phthalimides 5–8: A suspension of calix[*n*]arene (4.70 mmol) in dry DMF (80 mL) was stirred under nitrogen for 30 min and then NaH (60 wt.-% in oil, 2.3 equivalents per OH group) was added carefully. The mixture was stirred for 1 h at room temp. and then the *N*-(ω-bromoalkyl)phthalimide (2.3*n* mmol) was added. After six days the reaction was stopped by adding 1 M HCl (70 mL) and the resulting solid filtered through a Büchner funnel. The crude product was dissolved in dichloromethane (70 mL) and washed with 1 M HCl (3 × 50 mL). The organic phase was separated, dried with anhydrous $MgSO_4$ and evaporated under reduced pressure. The pure phthalimido derivatives were obtained by recrystallisation from dichloromethane/methanol.

25,26,27,28-Tetrakis[3-(phthalimido)propoxy]calix[4]arene (5): Yield 4.13 g (75%); m.p. 95–97 °C. ^1H NMR ($CDCl_3$, 300 MHz): δ = 7.73–7.70 (m, 8 H, $PhtH_b$), 7.61–7.57 (m, 8 H, $PhtH_a$), 6.59–6.51 (m, 12 H, ArH_{meta} and ArH_{para}), 4.47 (d, *J* = 13.5 Hz, 4 H, H_{ax} of $ArCH_2Ar$), 4.05 (t, *J* = 7.7 Hz, 8 H, $OCH_2CH_2CH_2$), 3.90 (t, *J* = 7.7 Hz, 8 H, $OCH_2CH_2CH_2$), 3.18 (d, *J* = 13.5 Hz, 4 H, H_{eq} of $ArCH_2Ar$), 2.37–2.28 (quin, *J* = 7.7 Hz, 8 H, $OCH_2CH_2CH_2$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 168.1 (s, CO), 156.2, 134.9, 133.5, 132.2, 128.2, 122.9 and 122.1 (d and s, Ar), 72.5 (t, OCH_2), 35.5 and 29.6 (t, $OCH_2CH_2CH_3$) ppm. MS (CI): *m*/*z* = 1173 $[M]^+$. $C_{72}H_{60}N_4O_{12}$ (1173.3): calcd. C 73.71, H 5.15, N 4.78; found C 73.75, H 5.11, N 4.84.

37,38,39,40,41,42-Hexakis[3-(phthalimido)propoxy]-*p*-*tert*-butylcalix[6]arene (6): Yield 5.91 g (60%); m.p. 190–191 °C. ^1H NMR ([D_6]DMSO, 400 MHz, 383 K): δ = 7.69 (s, 24 H, $PhtH_a$ and $PhtH_b$), 6.86 (s, 12 H, ArH), 3.76 (s, 24 H, $ArCH_2Ar$ and $OCH_2CH_2CH_2$), 2.87 (s, 12 H, $OCH_2CH_2CH_2$), 2.09 (s, 12 H, $OCH_2CH_2CH_2$), 0.99 [s, 54 H, $C(CH_3)_3$] ppm. ^{13}C NMR ($CDCl_3$, 75 MHz, 298 K): δ = 168.1 (s, CO), 152.5 (s, Ar_{ipso}), 133.7–125.3 (s and d, Ar), 133.2 (s, Ar_{ortho})122.8 (d, Ar_{meta}), 71.5 (t, $OCH_2CH_2CH_2$), 35.8 (t, $OCH_2CH_2CH_2$), 33.9 (t, $OCH_2CH_2CH_2$), 31.4 [q, $C(CH_3)_3$], 31.3–29.7 [s and q, $C(CH_3)_3$ and $ArCH_2Ar$] ppm. MS (CI): *m*/*z* = 2097 $[M + H]^+$. $C_{132}H_{138}N_6O_{18}$ (2096.6): calcd. C 75.62, H 6.63, N 4.01; found C 75.66, H 6.64, N 4.07.

37,38,39,40,41,42-Hexakis[3-(phthalimido)propoxy]calix[6]arene (7): Yield 3.47 g (42%); m.p. 225–227 °C. ^1H NMR ($CDCl_3$, 300 MHz): δ = 7.75–7.71 (m, 12 H, $PhtH_b$), 7.64–7.60 (m, 12 H, $PhtH_a$), 6.89 (d, *J* = 6.5 Hz, 12 H, ArH_{meta}), 6.73 (t, *J* = 6.5 Hz, 6 H, ArH_{para}), 3.94 (br. s, 12 H, $ArCH_2Ar$), 3.80 (t, *J* = 8.1 Hz, 12 H, $OCH_2CH_2CH_2$), 1.81 (br. s, 12 H, $OCH_2CH_2CH_2$), 1.60 (br. s, 12 H, $OCH_2CH_2CH_2$) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 167.9 (s, CO), 154.6, 134.2, 133.5, 132.2, 128.9, 123.5 and 122.9 (s and d, Ar), 70.3 (t, $OCH_2CH_2CH_2$), 35.4 (t, $OCH_2CH_2CH_2$), 29.4 (t, $OCH_2CH_2CH_2$), 30.6 (t, $ArCH_2Ar$) ppm. MS (CI): *m*/*z* = 1760 $[M]^+$. $C_{108}H_{90}N_6O_{18}$ (1759.9): calcd. C 73.71, H 5.15, N 4.78; found C 73.73, H 5.17, N 4.82.

37,38,39,40,41,42-Hexakis[4-(phthalimido)butoxy]calix[6]arene (8): Yield 3.99 g (46%); m.p. 115–116 °C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 7.78–7.74 (m, 12 H, $PhtH_b$), 7.66–7.60 (m, 12 H, $PhtH_b$), 6.93 (br. s, 12 H, ArH_{meta}), 6.83 (t, J = 7.2 Hz, 6 H, ArH_{para}), 3.89 (br. s, 12 H, $ArCH_2Ar$), 3.65 (t, J = 6.8 Hz, 12 H, $OCH_2CH_2CH_2CH_2$), 3.42 (br. s, 12 H, $OCH_2CH_2CH_2CH_2$), 1.75 (br. s, 24 H, $OCH_2CH_2CH_2CH_2$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 168.2 (s, CO), 154.7 (s, Ar_{ipso}), 134.2, 133.5, 132.2, 128.9, 123.5, 122.9 (s and d, Ar), 71.9 (t, $OCH_2CH_2CH_2CH_2$), 37.9 (t, $OCH_2CH_2CH_2CH_2$), 30.4 (t, $ArCH_2Ar$), 27.4 (t, $OCH_2CH_2CH_2CH_2$), 25.2 (t, $OCH_2CH_2CH_2CH_2$) ppm. MS (CI): m/z = 1844 $[M + H]^+$. $C_{114}H_{102}N_6O_{18}$ (1844.1): calcd. C 74.25, H 5.58, N 4.56; found C 74.31, H 5.61, N 4.55.

Synthesis of 49,50,51,52,53,54,55,56-Octakis[3-(phthalimido)propoxy]calix[8]arene (9): A suspension of calix[8]arene (1 g, 1.2 mmol) and caesium carbonate (15.6 g, 48 mmol) in dry DMF (160 mL) was stirred at room temp. for 30 min and then 3-bromopropylphthalimide was added (16.1 g, 60 mmol). The reaction mixture was heated at 90 °C for 24 h and then quenched with 1 N HCl (100 mL). The precipitated solid was filtered through a Buchner funnel, dissolved in dichloromethane (90 mL) and washed with 1 N HCl (2×60 mL). The organic layer was dried with anhydrous $MgSO_4$ and the solvent evaporated under reduced pressure. An orange oil remained which was treated with methanol to obtain the pure product **9** as a white solid. Yield: 1.99 g (71%); m.p. 105–106 °C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 7.84–7.82 (m, 16 H, $PhtH_b$), 7.72–7.66 (m, 16 H, $PhtH_a$), 6.72 (br. s, 24 H, ArH), 3.98 (br. s, 16 H, $ArCH_2Ar$), 3.80 (t, J = 8.1 Hz, 16 H, $OCH_2CH_2CH_2$), 2.04 (br. s, 16 H, $OCH_2CH_2CH_2$), 1.65 (br. s, 16 H, $OCH_2CH_2CH_2$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 168.1 (s, CO), 154.8 (s, Ar_{ipso}), 133.9, 133.5, 132.1, 128.8, 123.2, 122.9 (s and d, Ar), 65.3 (t, $OCH_2CH_2CH_2$), 35.4 (t, $OCH_2CH_2CH_2$), 29.4 (t, $ArCH_2Ar$), 27.6 (t, $OCH_2CH_2CH_2$) ppm. MS (ESI): m/z = 1195.5 $[M + 2Na]^{2+}$. $C_{144}H_{120}N_8O_{24}$ (2346.6): calcd. C 73.71, H 5.15, N 4.78; found C 73.77, H 5.20, N 4.83.

Synthesis of 5,11,17,23,29,35,41,47-Octakis(phenylmethoxy)-49,50,51,52,53,54,55,56-octakis[3-(phthalimido)propoxy]calix[8]-arene (10): A solution of *p*-benzyloxycalix[8]arene[38] (**4**; 2.0 g, 1.17 mmol) and caesium carbonate (19.06 g, 58.50 mmol) in dry DMF (300 mL) was stirred for 30 min under nitrogen. Subsequently *N*-(3-bromo-propyl)phthalimide (18.82 g, 70.20 mmol) and potassium iodide (11.65 g, 70.20 mmol) were added and the mixture was heated at 150 °C for 12 d. The reaction was quenched with 1 M HCl (270 mL) and the precipitate filtered. This solid was dissolved in dichloromethane (140 mL) and the solution washed twice with 1 M HCl (2×100 mL). The organic phase was separated and dried with anhydrous $MgSO_4$. The product **10** was purified by flash chromatography (SiO_2, eluent CH_2Cl_2/MeOH, 20:1). Yield: 1.47 g (27%); m.p. 98–99 °C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 7.67 (br. s, 16 H, $PhtH_b$), 7.54 (br. s, 16 H, $PhtH_a$), 7.14–7.08 (m, 40 H, PhH), 6.46 (br. s, 16 H, ArH), 4.80 (br. s, 16 H, OCH_2Ph), 3.95 (br. s, 16 H, $ArCH_2Ar$), 3.81 (br. s, 16 H, $OCH_2CH_2CH_2$), 2.19 (br. s, 16 H, $OCH_2CH_2CH_2$), 1.86 (br. s, 16 H, $OCH_2CH_2CH_2$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 168.0 (s, CO), 154.6 (s, Ar_{ipso}), 149.0, 137.3, 134.8, 133.4, 132.1, 128.1, 127.4, 127.3, 122.9, 114.8 (s and d, Ar), 71.6 (t, OCH_2Ar), 69.5 (t, $OCH_2CH_2CH_2$), 35.5 (t, $OCH_2CH_2CH_2$), 30.1 (t, $ArCH_2Ar$), 29.4 (t, $OCH_2CH_2CH_2$) ppm. MS (ESI): m/z = 3216.8 (100%) $[M + Na]^+$. $C_{200}H_{168}N_8O_{32}$ (3195.6): calcd. C 85.44, H 6.02, N 3.99; found C 85.40, H 6.04, N 3.95.

General Procedure for the Synthesis of Amine Derivatives 11–15: A solution of calix[*n*]arene derivative (1.70 mmol) and hydrazine monohydrate (270 mmol) in ethanol (50 mL) was stirred under reflux overnight. Ethanol was then removed under reduced pressure. The residue was dissolved in dichloromethane (50 mL) and water (40 mL). The organic phase was separated and dried with anhydrous $MgSO_4$. Pure amines were obtained after evaporation of the solvent under reduced pressure.

25,26,27,28-Tetrakis(3-aminopropoxy)calix[4]arene (11): Yield: 1.05 g (95%); m.p. 250–252 °C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 6.61–6.55 (m, 12 H, ArH_{meta} and ArH_{para}), 4.40 (d, J = 13.9 Hz, 4 H, H_{ax} of $ArCH_2Ar$), 3.96 (t, J = 7.3 Hz, 8 H, $OCH_2CH_2CH_2$), 3.17 (d, J = 13.9 Hz, 4 H, H_{eq} of $ArCH_2Ar$), 2.09–2.00 (t, J = 6.6 Hz, 8 H, $OCH_2CH_2CH_2$), 1.60 (br. s, 8 H, NH_2), 1.23 (quin, J = 7.3, J = 6.6 Hz, 8 H, $OCH_2CH_2CH_2$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 156.1 (s, ArH_{ipso}), 136.7 (s, Ar_{ortho}), 128.2 (d, Ar_{para}), 122.1 (d, Ar_{meta}), 72.7 (t, $OCH_2CH_2CH_2$), 39.5 (t, $OCH_2CH_2CH_2$), 33.8 (t, $OCH_2CH_2CH_2$), 30.1 (t, $ArCH_2Ar$) ppm. MS (CI): m/z = 654 (100%) $[M + H]^+$. $C_{40}H_{52}N_4O_4$ (652.88): calcd. C 73.59, H 8.03, N 8.58; found C 73.65, H 8.10, N 8.64.

37,38,39,40,41,42-Hexakis(3-aminopropoxy)-*p*-*tert*-butylcalix[6]-arene (12): Yield: 1.54 g (69%); m.p. 190–191 °C (dec.). ^{1}H NMR ([D_6]DMSO, 400 MHz, 383 K): δ = 7.05 (s, 12 H, ArH), 3.89 (s, 12 H, $ArCH_2Ar$), 3.64 (s, 12 H, $OCH_2CH_2CH_2$), 1.73–1.71 (m, 12 H, $OCH_2CH_2CH_2$), 1.13 [s, 54 H, $C(CH_3)_3$] ppm. ^{13}C NMR ($CDCl_3$, 75 MHz, 298 K): δ = 153.3 (s, Ar_{ipso}), 145.6 (s, Ar_{para}), 132.4 (s, Ar_{ortho}), 125.7 (d, Ar_{meta}), 73.0 (t, $OCH_2CH_2CH_2$), 37.6 (t, $OCH_2CH_2CH_2$), 33.8 [s, $C(CH_3)_3$], 31.5 (t, $ArCH_2Ar$), 31.0 [q, $C(CH_3)_3$], 29.6 (t, $OCH_2CH_2CH_2$) ppm. MS (CI): m/z = 1314 $[M^+]$. $C_{84}H_{126}N_6O_6$ (1315.97): calcd. C 76.67, H 9.65, N 6.39; found C 76.54, H 9.71, N 6.34.

37,38,39,40,41,42-Hexakis(3-aminopropoxy)calix[6]arene (13): Yield: 1.03 g (62%); m.p. 249–252 °C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 7.00 (br. s, 12 H, NH), 6.91–6.83 (m, 18 H, ArH), 3.92 (br. s, 6 H, H_{ax} of $ArCH_2Ar$), 3.44 (br. s, 12 H, $OCH_2CH_2CH_2$), 2.67 (br. s, H_{ax} of $ArCH_2Ar$), 1.33–1.21 (br. s, 24 H, $OCH_2CH_2CH_2$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 154.8 (s, Ar_{ipso}), 134.2 (s, Ar_{ortho}), 129.1 (d, Ar_{para}), 123.6 (d, Ar_{meta}), 70.9 (t, $OCH_2CH_2CH_2$), 39.2 (t, $OCH_2CH_2CH_2$) and 33.7 (t, $OCH_2CH_2CH_2$), 30.4 (t, $ArCH_2Ar$) ppm. MS (CI): m/z = 979 (100%) $[M + H]^+$. $C_{60}H_{78}N_6O_6$ (979.32): calcd. C 73.59, H 8.03, N 8.58; found C 73.55, H 8.06, N 8.62.

37,38,39,40,41,42-Hexakis(4-aminobutoxy)calix[6]arene (14): Yield: 1.72 g (95%); m.p. 155–156 °C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 6.94–6.81 (m, 18 H, ArH), 3.85 (br. s, 12 H, $ArCH_2Ar$), 3.42 (br. s, 24 H, $OCH_2CH_2CH_2CH_2$), 1.23 (br. s, 24 H, $OCH_2CH_2CH_2CH_2$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 154.5 (s, Ar_{ipso}), 133.9 (s, Ar_{ortho}), 131.4 (d, Ar_{para}), 123.0 (d, Ar_{meta}), 72.0 (t, $OCH_2CH_2CH_2CH_2$), 38.6 (t, $OCH_2CH_2CH_2CH_2$), 30.5 (t, $ArCH_2Ar$), 27.0 (t, $OCH_2CH_2CH_2CH_2$), 23.5 (t, $OCH_2CH_2CH_2CH_2$) ppm. MS (CI): m/z = 1063 $[M]^+$. $C_{66}H_{90}N_6O_6$ (1063.5): calcd. C 74.54, H 8.53, N 7.90; found C 74.55, H 8.49, N 7.92.

49,50,51,52,53,54,55,56-Octakis(3-aminopropoxy)calix[8]arene (15): Yield: 2.13 g (96%); m.p. 233 °C (dec.). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 6.82 (br. s, 24 H, ArH), 3.95 (br. s, 16 H, $ArCH_2Ar$), 2.73 (br. s, 16 H, $OCH_2CH_2CH_2$), 1.80 (br. s, 32 H, $OCH_2CH_2CH_2$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 154.9 (s, Ar_{ipso}), 132.1 (s, Ar_{meta}), 127.4 (s, Ar_{ortho}), 123.6 (d, Ar_{para}), 79.0 (t, $OCH_2CH_2CH_2$), 37.0 (t, $OCH_2CH_2CH_2$), 29.1 (t, $ArCH_2Ar$), 27.6 (t, $OCH_2CH_2CH_2$) ppm. MS (CI): m/z = 1306 $[M]^+$. $C_{80}H_{104}N_8O_8$ (1305.8): calcd. C 73.59, H 8.03, N 8.58; found C 73.57, H 7.98, N 8.63.

Synthesis of 5,11,17,23,29,35,41,47-Octakis(phenylmethoxy)-49,50,51,52,53,54,55,56-octakis(3-aminopropoxy)calix[8]arene (16):

A solution of octaphthalimido derivative **10** (0.30 g, 0.094 mmol) and hydrazine monohydrate (1.03 g, 20.7 mmol) in ethanol (8 mL) was stirred under reflux for 20 h. The solvent was then removed under reduced pressure and the residue extracted with dichloromethane/water. The organic layer was separated and the solvent evaporated under reduced pressure to obtain the pure octamine **16**. Yield: 0.18 g (89%); m.p. 145–146 °C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 7.16–7.14 (m, 40 H, PhH), 6.52 (s, 16 H, Ar_{meta}), 4.69 (s, 16 H, OCH_2Ar), 3.94 (br. s, 16 H, $ArCH_2Ar$), 3.63 (br. s, 16 H, $OCH_2CH_2CH_2$), 2.70 (br. s, 16 H, $OCH_2CH_2CH_2$), 1.70 (m, 16 H, $OCH_2CH_2CH_2$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 156.0 (s, CO), 138.2 (s, Ar_{ipso}), 136.0, 128.4, 127.5, 127.4, 123.5, 115.2, 114.8 (s and d, Ar), 70.6 (t, OCH_2Ph), 69.4 (t, $OCH_2CH_2CH_2$), 37.0 (t, $OCH_2CH_2CH_2$), 30.5 (t, $ArCH_2Ar$), 29.5 (t; $OCH_2CH_2CH_2$) ppm. MS (ESI): *m*/*z* = 2155.4 (100%) $[M + H]^+$. $C_{136}H_{152}N_8O_{16}$ (2154.6): calcd. C 75.81, H 7.11, N 5.20; found C 75.88, H 7.06, N 5.24.

Synthesis of 2-(*N*-Butylaminocarbonyl)pyridine (19): A solution of picolinic acid pentafluorophenyl ester (0.10 g, 0.35 mmol) and butylamine (0.031 mL, 0.32 mmol) in dry toluene (10 mL) was refluxed under nitrogen for 6 h. The reaction was then quenched with 2 M $NaHCO_3$ (7 mL), the organic layer separated and the solvent evaporated under reduced pressure to obtain the pure product as an orange oil. Yield: 0.050 g (81%). ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 8.29 (d, *J* = 6.2 Hz, 1 H, PyH^6), 8.15 (br. s, 1 H, CONH), 7.97–7.94 (d, *J* = 7.6 Hz, 1 H, PyH^3), 7.60–7.54 (m, 1 H, PyH^4), 7.17–7.13 (m, 1 H, PyH^5), 3.27–3.20 (m, 2 H, $NHCH_2CH_2CH_2CH_3$), 1.40–1.35 (m, 2 H, $NHCH_2CH_2CH_2CH_3$), 1.20–1.13 (m, 2 H, $NHCH_2CH_2CH_2CH_3$), 0.70 (t, *J* = 8.3 Hz, 3 H, $NHCH_2CH_2CH_2CH_3$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 164.1 (s, CO), 150.0 (s, PyC^2), 147.9 (d, PyC^6), 137.2 (d, PyC^4), 125.9 (d, PyC^5), 122.0 (d, PyC^3), 39.0, 31.6, 20.0 and 13.6 (t and q, $NHCH_2CH_2CH_2CH_3$) ppm. MS (CI): *m*/*z* = 179 (100%) $[M + H]^+$. $C_{10}H_{14}N_2O$ (178.23): calcd. C 67.39, H 7.92, N 15.72; found C 67.41, H 7.87, N 15.74.

General Procedure for the Synthesis of Picolinamide Derivatives 22–24 and 26–29: The picolinic acid pentafluorophenyl ester (1.1 equivalents per amino group) was added to a solution of amino calix[*n*]arene (0.6 mmol) in dry toluene (50 mL) and the mixture was refluxed for 6 h under nitrogen. The reaction was quenched with 2 M $NaHCO_3$ (35 mL), the organic layer separated and the solvent removed under reduced pressure. The residue was purified as indicated below.

25,26,27,28-Tetrakis{4-[(pyridine-2-carboxy)amino]butoxy}-*p*-*tert*-butylcalix[4]arene (22): The product was purified by flash chromatography (SiO_2, eluent AcOEt). Yield: 0.42 g (52%); m.p. 90–91 °C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 8.48 (m, 4 H, PyH^6), 8.37 (t, *J* = 6.0 Hz, 4 H, NH), 8.21 (d, *J* = 9.1 Hz, 4 H, PyH^3), 7.75 (m, 4 H, PyH^4), 7.35–7.31 (m, 4 H, PyH^5), 6.75 (s, 8 H, ArH), (d, *J* = 13.6 Hz, 4 H, H_{ax} of $ArCH_2Ar$), 3.88 (t, *J* = 6.4 Hz, 4 H, $OCH_2CH_2CH_2CH_2$), 3.54 (dt, *J* = 7.0 Hz, 4 H, $OCH_2CH_2CH_2CH_2$), 3.10 (d, *J* = 13.6 Hz, 4 H, H_{eq} of $ArCH_2Ar$), 2.14–2.03 (m, 8 H, $OCH_2CH_2CH_2CH_2$), 1.77–1.69 (m, 8 H, $OCH_2CH_2CH_2CH_2$), 1.07 [s, 36 H, $C(CH_3)_3$] ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 164.4 (s, CO), 153.3 (s, Ar_{ipso}), 150.1 (s, PyC^2), 147.9 (d, PyC^6), 144.3 (s, Ar_{para}), 137.1 (d, PyC^4), 133.6 (s, Ar_{ortho}), 125.8 (d, PyC^5), 122.2 (d, PyC^3), 124.9(d, Ar_{meta}), 74.7 (t, $OCH_2CH_2CH_2CH_2$), 39.6 (t, $OCH_2CH_2CH_2CH_2$), 33.7 (t, $OCH_2CH_2CH_2CH_2$), 33.71 [s, $C(CH_3)_3$], 31.4 (t, $ArCH_2Ar$), 27.8 (s, $OCH_2CH_2CH_2CH_2$), 26.3 [s, $C(CH_3)_3$] ppm. MS (CI): *m*/*z* = 1354 (44%) $[M]^+$, 1177 (100%) [M – $(CH_2CH_2CH_2CH_2NHCOPy)$]. $C_{84}H_{104}N_8O_8$ (1353.8): calcd. C 74.53, H 7.74, N 8.28; found C 74.48, H 7.75, N 8.32.

25,26,27,28-Tetrakis{3-[(pyridine-2-carboxy)amino]propoxy}calix[4]arene (23): The product was purified by crystallisation from dichloromethane/diethyl ether. Yield: 0.33 g (52%); m.p. 90–91 °C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 8.67 (t, *J* = 6.0 Hz, 4 H, NH), 8.39 (d, *J* = 5.5 Hz, 4 H, PyH^6), 8.27 (d, *J* = 6.3 Hz, 4 H, PyH^3), 7.76–7.70 (m, 4 H, PyH^4), 7.32–7.30 (m, 4 H, PyH^5), 6.61–6.55 (m, 12 H, ArH_{meta} and ArH_{para}), 4.41 (d, *J* = 12.5 Hz, 4 H, H_{ax} of $ArCH_2Ar$), 3.97 (t, *J* = 6.3 Hz, 4 H, $OCH_2CH_2CH_2$), 3.66–3.59 (dt, *J* = 6.0, *J* = 6.3 Hz, 4 H, $OCH_2CH_2CH_2$), 3.16 (d, *J* = 12.5 Hz, 4 H, H_{eq} of $ArCH_2Ar$), 2.28 (quin, *J* = 6.3, *J* = 6.3 Hz, 4 H, $OCH_2CH_2CH_2$) ppm. ^{13}C NMR (CDCl3, 75 MHz): δ = 164.5 (s, CO), 156.1 (s, Ar_{ipso}), 150.3 (s, PyC^2), 147.9 (d, PyC^6), 137.1 (d, PyC^4), 134.9 (d, Ar_{ortho}), 128.2 (s, Ar_{para}), 125.8 (d, PyC^5), 122.3 (d, PyC^3), 122.2 (d, Ar_{meta}), 72.8 (t, $OCH_2CH_2CH_2$), 36.9 (t, $OCH_2CH_2CH_2$) and 30.5 (t, $OCH_2CH_2CH_2$), 30.8 (t, $ArCH_2Ar$) ppm. MS (CI): *m*/*z* = 1074 (16%) $[M]^+$, 911 (100%) [M – $(CH_2CH_2CH_2NHCOPy)$]. $C_{64}H_{64}N_8O_8$ (1073.3): calcd. C 71.62, H 6.01, N 10.44; found C 71.67, H 6.05, N 10.37.

25,26,27,28-Tetrakis{3-[(pyridine-2-carboxy)amino]propoxy}-*p*-*tert*-butylcalix[4]arene (24): The product was purified by crystallisation from dichloromethane/methanol. Yield: 0.33 g (43%); m.p. 95–97 °C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 8.61 (t, *J* = 6.0 Hz, 4 H, NH), 8.42 (d, *J* = 5.5 Hz, 4 H, PyH^6), 8.25 (d, *J* = 7.2 Hz, 4 H, PyH^3), 7.74–7.68 (m, 4 H, PyH^4), 7.33–7.32 (m, 4 H, PyH^5), 6.75 (s, 8 H, Ar_{meta}), 4.37 (d, *J* = 11.0 Hz, 4 H, H_{ax} of $ArCH_2Ar$), 3.99 (t, *J* = 9.0 Hz, 8 H, $OCH_2CH_2CH_2$), 3.62 (dt, *J* = 6.6 Hz and 6.0 Hz, 8 H, $OCH_2CH_2CH_2$), 3.12 (d, *J* = 11.0 Hz, 4 H, H_{eq} of $ArCH_2Ar$), 2.38 (quin, *J* = 6.6, *J* = 9.0 Hz, 8 H, $OCH_2CH_2CH_2$), 1.06 [s, 36 H, $C(CH_3)_3$] ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 164.5 (s, CO), 153.3 (s, Ar_{ipso}), 150.3 (s, PyC^2), 147.9 (d, PyC^6), 144.5 (s, Ar_{para}), 137.1 (d, PyC^4), 133.6 (s, Ar_{ortho}), 125.8 (d, PyC^5), 122.3 (d, C_3), 125.0 (d, Ar_{meta}), 72.9 (t, OCH_2), 31.4 (t, $ArCH_2Ar$), 36.9 (t, $OCH_2CH_2CH_2$), 33.7 [s, $C(CH_3)_3$], 31.0 [q, $C(CH_3)_3$], 31.1 (t, $OCH_2CH_2CH_2$) ppm. MS (CI): *m*/*z* = 1297 (8%) $[M]^+$, 1135 (100%) [M – $(CH_2CH_2CH_2NHCOPy)$]. $C_{80}H_{96}N_8O_8$ (1297.7): calcd. C 74.05, H 7.46, N 8.63; found C 74.10, H 7.41, N 8.59.

37,38,39,40,41,42-Hexakis{3-[(pyridine-2-carboxy)amino]propoxy}-*p*-*tert*-butylcalix[6]arene (26): The product was purified by crystallisation from methanol. Yield: 0.58 g (50%); m.p. 169–172 °C. ^{1}H NMR ([D$_6$]DMSO, 400 MHz, 373 K): δ = 8.43 (d, *J* = 5.2 Hz, 6 H, PyH^6), 7.99 (d, *J* = 7.1 Hz, 6 H, PyH^3), 7.85 (br. s, 6 H, PyH^4), 7.43 (br. s, 6 H, PyH^5), 6.88 (br. s, 12 H, ArH), 3.63 (m, 12 H, $OCH_2CH_2CH_2$), 3.44 (br. s, 12 H, $ArCH_2Ar$), 3.00–2.87 (m, 12 H, $OCH_2CH_2CH_2$), 2.50–2.48 (m, 12 H, $OCH_2CH_2CH_2$), 1.07 [br. s, 54 H, $C(CH_3)_3$] ppm. ^{13}C NMR ($CDCl_3$, 75 MHz, 298 K): δ = 164.3 (s, CO), 153.4 (s, Ar_{ipso}), 150.3 (s, PyC^2), 147.9 (d, PyC^6), 145.3 (s, Ar_{para}), 136.9 (d, PyC^4), 133.3 (s, Ar_{ortho}), 127.8 (d, PyC^5), 125.7 (d, Ar_{meta}), 121.8 (d, PyC^3), 69.7 (t, $OCH_2CH_2CH_2$), 39.4 (t, $OCH_2CH_2CH_2$), 36.7 (t, $OCH_2CH_2CH_2$), 34.2 [s, $C(CH_3)_3$], 31.6 and 31.4 (t and q, $ArCH_2Ar$, $C(CH_3)_3$], 29.4 (t, $OCH_2CH_2CH_2$) ppm. MS (CI): *m*/*z* = 1945 $[M]^+$. $C_{120}H_{144}N_{12}O_{12}$ (1946.6): calcd. C 74.05, H 7.46, N 8.63; found C 74.12, H 7.42, N 8.69.

37,38,39,40,41,42-Hexakis{3-[(pyridine-2-carboxy)amino]propoxy}calix[6]arene (27): The product was purified by flash chromatography (SiO_2, eluent AcOEt/MeOH, 5:1). Yield: 0.45 g (47%); m.p. 192–193 °C. ^{1}H NMR ($CDCl_3$, 300 MHz): δ = 8.44 (d, *J* = 4.2 Hz, 6 H, PyH^6), 8.30 (br. s, 6 H, NH), 8.20 (d, *J* = 7.71 Hz, 6 H, PyH^3), 7.77 (dt, *J* = 6.2, *J* = 1.6 Hz, 6 H, PyH^4), 7.35–7.31 (m, 6 H, PyC^5), 7.02 (br. s, 12 H, ArH_{para}), 6.83 (br. s, 6 H, ArH_{meta}), 3.89 (br. s, 12 H, $ArCH_2Ar$), 3.47 (br. s, 24 H, $OCH_2CH_2CH_2$), 2.17 (br. s, 12 H, $OCH_2CH_2CH_2$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 164.3 (s, CO), 154.6 (s, Ar_{ipso}), 150.1 (s, PyC^2) and 148.0 (d, PyC^6), 137.0

(d, PyC^4), 134.3 (d, Ar_{ortho}), 129.0 (s, Ar_{para}), 125.8 (d, PyC^5), 122.0 (d, PyC^3), 123.8 (d, Ar_{meta}), 70.7 (t, $OCH_2CH_2CH_2$), 37.1 (t, $OCH_2CH_2CH_2$), 29.9 (t, $OCH_2CH_2CH_2$), 30.6 (t, $ArCH_2Ar$) ppm. MS (CI): *m/z* = 1611 (72%) $[M + H]^+$, 1449 (100%) [M – $(CH_2CH_2CH_2CH_2NHCOPy)$]. $C_{96}H_{96}N_{12}O_{12}$ (1609.9): calcd. C 71.62, H 6.01, N 10.44; found C 71.66, H 6.05, N 10.50.

37,38,39,40,41,42-Hexakis{4-[(pyridine-2-carboxy)amino]butoxy}-calix[6]arene (28): The product was purified by flash chromatography (SiO_2, eluent AcOEt/MeOH, 10:1). Yield: 0.80 g (79%); m.p. 166–167 °C. ^1H NMR ($CDCl_3$, 300 MHz): δ = 8.48 (d, *J* = 4.3 Hz, 6 H, PyH^6), 8.16 (d, *J* = 7.71 Hz, 12 H, NH and PyH^3), 7.78 (dt, *J* = 6.2, *J* = 1.6 Hz, 6 H, PyH^4), 7.38–7.36 (m, 6 H, PyC^5), 7.01 (br. s, 12 H, ArH_{meta}), 6.85 (br. s, 6 H, ArH_{para}), 3.87 (br. s, 12 H, $ArCH_2Ar$), 3.39 (br. s, 24 H, O $CH_2CH_2CH_2CH_2$), 1.57 (br. s, 24 H, O $CH_2CH_2CH_2CH_2$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 164.2 (s, CO), 154.6 (s, Ar_{ipso}), 150.0 (s, PyC^2), 147.9 (d, PyC^6), 137.2 (d, PyC^4), 134.5 (s, Ar_{ortho}), 128.8 (d, Ar_{meta}), 125.9 (d, PyC^5), 123.6 (d, Ar_{para}), 122.1 (d, PyC^3), 72.2 (t, $OCH_2CH_2CH_2CH_2$), 39.3 (t, $OCH_2CH_2CH_2CH_2$), 30.4 (t, $ArCH_2Ar$), 27.7 (t, $OCH_2CH_2CH_2CH_2$), 26.5 (t, $OCH_2CH_2CH_2CH_2$) ppm. MS (ESI): *m/z* = 1715.6 (8%) $[M + Na]^+$, 869.3 (100%) $[M + 2Na]^{2+}$. $C_{102}H_{108}N_{12}O_{12}$ (1694.1): calcd. C 72.32, H 6.43, N 9.92; found C 72.30, H 6.40, N 9.97.

49,50,51,52,53,54,55,56-Octakis{3-[(pyridine-2-carboxy)amino]propoxy}calix[8]arene (29): The product was purified by flash chromatography (SiO_2, eluent AcOEt/MeOH, 9:1). Yield: 0.48 g (37%); m.p. 164.5–165.7 °C. ^1H NMR ($CDCl_3$, 300 MHz): δ = 8.32 (d, *J* = 5.5 Hz, 8 H, PyH^6), 8.05 (d, *J* = 7.8 Hz, 8 H, PyH^3), 7.60 (m, 8 H, PyH^4), 7.19 (m, 8 H, PyH^5), 6.73 (br. s, 16 H, ArH_{meta}), 6.63 (br. s, 8 H, ArH_{para}), 3.95 (s, 16 H, $ArCH_2Ar$), 3.69 (t, *J* = 5.5 Hz, 16 H, $OCH_2CH_2CH_2$), 3.50–3.46 (m, 16 H, $OCH_2CH_2CH_2$), 1.89 (t, *J* = Hz, 16 H, $OCH_2CH_2CH_2$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 164.3 (s, CO), 154.9 (s, Ar_{ipso}), 150.0 (s, PyC^2), 147.9 (d, PyC^6), 137.0 (d, PyC^4), 134.0 (d, Ar_{ortho}), 128.9 (s, Ar_{para}), 125.8 (d, PyC^5), 124.0 (d, Ar_{meta}), 122.0 (d, PyC^3), 71.4 (t, $OCH_2CH_2CH_2$), 37.2 (t, $OCH_2CH_2CH_2$), 30.0 (t, $ArCH_2Ar$), 29.8 (t, $OCH_2CH_2CH_2$) ppm. MS (CI): *m/z* = 2146 (100%) $[M^+]$. $C_{128}H_{128}N_{16}O_{16}$ (2146.5): calcd. C 71.62, H 6.01, N 10.44; found C 71.63, H 6.08, N 10.39.

Synthesis of 25,26,27,28-Tetrakis{3-[(pyridine-2-thiocarboxy)-amino]propoxy}-*p*-*tert*-butylcalix[4]arene (25): A solution of calix[4]arene derivative **24** (0.060 g, 0.046 mmol) and Lawesson's reagent (0.075 g, 0.19 mmol) in toluene (10 mL) was stirred under heating at 90 °C for 5 d. The solvent was then evaporated under reduced pressure and the crude product recrystallised from methanol to obtain a yellow solid. Yield: 0.051 g (81%); m.p. 87–91 °C. ^1H NMR ($CDCl_3$, 300 MHz): δ = 10.34 (br. s, 4 H, NHCS), 8.63 (d, *J* = 7.5 Hz, 4 H, PyH^6), 8.44 (d, *J* = 5.3 Hz, 4 H, PyH^3), 7.75–7.70 (m, 4 H, PyH^4), 7.34–7.30 (m, 4 H, PyH^5), 6.77 (s, 8 H, ArH), 4.37 (d, *J* = 11.8 Hz, 4 H, H_{ax} of $ArCH_2Ar$), 4.06–3.97 (d, *J* = 6.6 Hz, 8 H, $OCH_2CH_2CH_2$), 3.79–3.71 (dt, *J* = 6.1 Hz, 8 H, $OCH_2CH_2CH_2$), 3.17 (d, *J* = 11.8 Hz, 4 H, H_{eq} of $ArCH_2Ar$), 2.54–2.47 (quin, *J* = 6.6, *J* = 6.1 Hz, 8 H, $OCH_2CH_2CH_2$), 1.88 [s, 36 H, $C(CH_3)_3$] ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 191.3 (s, CS), 153.0 (s, Ar_{ipso}), 151.1 (s, PyC^2), 147.9 (d, C^6), 144.7 (s, Ar_{para}), 137.0 (d, PyC^4), 133.5 (s, Ar_{ortho}), 125.0 (d, PyC^5), 125.1 (d, PyC^3), 124.7 (d, Ar_{meta}), 72.7 (t, $OCH_2CH_2CH_2$), 43.0 (s, CS), 33.8 (t, $OCH_2CH_2CH_2$), 33.7 [s, $C(CH_3)_3$], 29.2 (t, $OCH_2CH_2CH_2$), 31.1 [q, $C(CH_3)_3$], 30.9 (t, $ArCH_2Ar$) ppm. MS (CI): *m/z* = 1361 $[M]^+$. $C_{80}H_{96}N_8O_4S_4$ (1361.9): calcd. C 70.55, H 7.10, N 8.23, S 9.42; found C 70.50, H 7.04, N 8.21, S 9.39.

Synthesis of 5,11,17,23,29,35,41,47-Octakis(phenylmethoxy)-49,50,51,52,53,54,55,56-octakis{3-[(pyridine-2-carboxy)amino]propoxy}calix[8]arene (30): A solution of octamino derivative **16** (0.19 g, 0.089 mmol) and picolinic acid pentafluorophenyl ester (0.23 g, 0.80 mmol) in dry toluene (25 mL) was stirred under reflux overnight. Toluene was evaporated under reduced pressure and the crude product was dissolved in dichloromethane (20 mL), washed with 2 M $NaHCO_3$ (3 × 15 mL) and dried with anhydrous $MgSO_4$. Pure product **30** was obtained by evaporating the solvent under reduced pressure and purifying the residue by flash chromatography (SiO_2, eluent AcOEt/MeOH, 9:1). Yield: 0.072 g (27%); m.p. 79–81 °C. ^1H NMR ($CDCl_3$, 300 MHz): δ = 8.44 (br. s, 8 H, NH), 8.35 (d, *J* = 4.3 Hz, 8 H, PyH^6), 8.14 (d, *J* = 7.77 Hz, 8 H, PyH^3), 7.69–7.67 (m, 8 H, PyH^4), 7.23–7.21 (m, 8 H, PyH^5), 7.14–7.06 (m, 40 H, PhH), 6.46 (br. s, 16 H, ArH), 4.56 (br. s, 16 H, OCH_2Ph), 3.95 (br. s, 16 H, $ArCH_2Ar$), 3.71 (br. s, 16 H, $OCH_2CH_2CH_2$), 3.56–3.54 (m, 16 H, $OCH_2CH_2CH_2$), 1.91 (br. s, 16 H, $OCH_2CH_2CH_2$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 164.4 (s, CO), 154.6 (s, Ar_{ipso}), 150.0 (s, PyC^2), 148.9, 140.0, 128.1, 127.4 (s and d, Ph), 148.0 (d, PyC^6), 137.0 (s, PyC^4), 134.8 (s, Ar_{ortho}), 128.2 (s, Ar_{para}), 125.7 (d, PyC^5), 122.0 (d, PyC^3), 114.9 (d, Ar_{meta}), 71.7 (t, OCH_2Ph), 69.6 (t, $OCH_2CH_2CH_2$), 37.2 (t, $OCH_2CH_2CH_2$), 30.1 (t, $OCH_2CH_2CH_2$), 30.0 (t, $ArCH_2Ar$) ppm. MS (ESI): *m/z* = 3016.6 (100%) $[M + Na]^+$. $C_{184}H_{176}N_{16}O_{24}$ (2995.53): calcd. C 73.78, H 5.92, N 7.48; found C 73.74, H 5.98, N 7.42.

General Procedure for the Synthesis of Picolinamide Derivatives at the Upper Rim (31 and 32): A solution of tetramino calix[4]arene derivative **17** or **18** (0.77 mmol) and picolinic acid pentafluorophenyl ester (3.22 mmol) in dry toluene (50 mL) was refluxed for 7 h and then quenched with 2 M $NaHCO_3$ (40 mL). The organic layer was separated, the solvent was evaporated under reduced pressure and the residue recrystallised from methanol. The crude product was purified by flash chromatography (SiO_2, eluent AcOEt).

5,11,17,23-Tetrakis[(pyridine-2-carboxy)amino]-25,26,27,28-tetrapropoxycalix[4]arene (31): Yield: 0.63 g (76%); m.p. 101–103 °C. ^1H NMR ($CDCl_3$, 300 MHz): δ = 9.61 (s, 4 H, NH), 8.29 (d, *J* = 6.5 Hz, 4 H, PyH^6), 8.12 (d, *J* = 8.6 Hz, 4 H, PyH^3), 7.73–7.68 (m, 4 H, PyH^4), 7.26–7.20 (m, 4 H, PyH^5), 7.13 (s, 8 H, ArH), 4.52 (d, *J* = 12.9 Hz, 4 H, H_{ax} of $ArCH_2Ar$), 3.88 (t, *J* = 9.6 Hz, 8 H, $OCH_2CH_2CH_3$), 3.25 (d, *J* = 12.9 Hz, 4 H, H_{eq} of $ArCH_2Ar$), 1.98–1.91 (m, 8 H, $OCH_2CH_2CH_3$), 1.01 (t, *J* = 9.1 Hz, 12 H, $OCH_2CH_2CH_3$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 161.4 (s, CO), 153.4 (s, Ar_{ipso}), 149.9 (s, PyC^2), 147.5 (d, PyC^6), 137.0 (d, PyC^4), 135.2 and 131.8 (s, Ar_{ortho} and Ar_{para}), 125.7, 122.0 and 120.1 (d, Ar_{meta}, PyC^3 and PyC^5), 76.8 (t, $OCH_2CH_2CH_3$), 31.3 (t, $ArCH_2Ar$), 23.1 and 10.3 (t and q, $OCH_2CH_2CH_3$) ppm. MS (CI): *m/z* = 1073 (100%) $[M]^+$. $C_{64}H_{64}N_8O_8$ (1073.27): calcd. C 71.62, H 6.01, N 10.44; found C 71.65, H 6.06, N 10.49.

5,11,17,23-Tetrakis[(pyridine-2-carboxy)aminomethyl]-25,26,27,28-tetrapropoxycalix[4]arene (32): Yield: 0.45 g (52%); m.p. 96–97 °C. ^1H NMR ($CDCl_3$, 300 MHz): δ = 8.58–8.56 (m, 4 H, PyH^6), 8.18 (d, *J* = 8.2 Hz, 4 H, PyH^3), 7.81 (br. s, 4 H, NH), 7.81 (t, *J* = 8.6 Hz, 4 H, PyH^4), 7.43–7.40 (m, 4 H, PyH^5), 6.67 (s, 8 H, ArH), 4.43 (d, *J* = 11.4 Hz, 4 H, H_{ax} of $ArCH_2Ar$), 4.23 (d, *J* = 7.3 Hz, 8 H, $ArCH_2NH$), 3.83 (t, *J* = 9.1 Hz, 8 H, $OCH_2CH_2CH_3$), 3.15 (d, *J* = 11.4 Hz, 4 H, H_{eq} of $ArCH_2Ar$), 1.95–1.88 (m, 8 H, $OCH_2CH_2CH_3$), 0.98 (t, *J* = 8.7 Hz, 12 H, $OCH_2CH_2CH_3$) ppm. ^{13}C NMR ($CDCl_3$, 75 MHz): δ = 163.8 (s, CO), 155.9 (s, Ar_{ipso}), 149.8 (s, PyC^2), 148.0 (d, PyC^6), 137.2 (d, PyC^4), 135.0 and 131.3 (s, Ar_{ortho} and Ar_{para}), 127.5, 126.1 and 122.2 (d, Ar_{meta}, PyC^3 and PyC^5), 77.0 (t, $OCH_2CH_2CH_3$), 42.8 (t, $ArCH_2NH$), 30.9 (t, $ArCH_2Ar$), 23.1 and 10.2 (t and q, $OCH_2CH_2CH_3$) ppm. MS (CI): *m/z* = 1129 (96%) $[M]^+$. $C_{68}H_{72}N_8O_8$ (1129.37): calcd. C 72.32, H 6.43, N 9.92; found C 72.35, H 6.46, N 9.98.

Extraction Procedures: Picolinamide ligands were dissolved in NPHE together with BrCosan at given concentrations. Am^{III} and spiked Eu^{III} nitrate aqueous solutions were prepared in order to have a radioactivity in the range 1500–2000 kBq L^{-1}. Liquid–liquid extraction experiments were performed by contacting the same volumes of organic and aqueous phases, at the appropriate HNO_3 concentration, inside agitated closed tubes placed in a thermostatted cell (25 ± 0.2 °C) for 1 h. Complete separation of the phases was ensured by spinning the tubes in a centrifuge for 5 min. Then, aliquots of aqueous and organic phases were removed for analysis by γ spectrometry (Eurysis Mesures, Strasbourg). The measurement times were adapted to obtain a reproducibility of ±5%. The distribution coefficients, D_M, were determined as the ratio of cation γ activity in the organic phase to cation γ activity in the aqueous phase. The selectivity for Am^{III} over Eu^{III} is expressed as $S_{Am/Eu}$, which is the ratio of distribution coefficients D_{Am}/D_{Eu}.

X-ray Crystallographic Study: A yellow single crystal of compound **28** (approx. $0.2 \times 0.3 \times 0.4$ mm^3) suitable for X-ray analysis was mounted on a glass rod protected from the air by a thin film of perfluorinated oil. The data were collected at 173 K on an Enraf–Nonius CAD4 diffractometer using graphite-monochromated Cu-K_α radiation (λ = 1.54178 Å). During the systematic data collection two standard reflections, collected every 100 reflections, showed no significant decay, but the scattering was very low. Several other attempts with other samples of the same or different batches showed the same trend, thus the low scattering should be considered as an intrinsic feature of the crystal structure. The intensities were corrected from Lorentz and polarisation but not for absorption. The crystal data and the most relevant experimental parameters used in the X-ray measurements and in the crystal structure analysis are reported in Table 8. The structure was solved by direct methods using SIR92.[39] The structure was completed by Fourier ΔF map and then refined by blocked full-matrix least-squares methods on F using SHELXL-97.[40] Most of the terminal pyridine nuclei were affected by severe static disorder but it was impossible to fit the disorder around each ring with different orientations and occupancy factors, therefore those reported are the best fit of the disorder with one ring orientation. This justify the poor scattering and, although it is a common problem in calixarenes with flexible chains, certainly prevented a high level of structure refinement. Parameters refined are the overall scale factor and the atomic coordinates and anisotropic thermal parameters for all the non-hydrogen atoms. At the end of the isotropic refinement two water molecules, O1W, O2W at 2.85(2) and 2.80(2) Å from O2D and O2A, respectively, were located from the difference Fourier map and, although poor experimental data prevented the location of the hydrogen atoms, their orientations with respect to the calixarenes unit is a clear indication that they are linked to the macrocycles through strong hydrogen bonds.

All the hydrogen atoms were placed at their calculated positions with the geometrical constraint C–H = 0.96 Å and refined as riding on their corresponding carbon atoms. The geometrical calculations were obtained by PARST97.[41]

CCDC-23514 contains the supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif.

Table 8. Crystal data, data collection and refinement parameters for **28**.

Empirical formula	$C_{102}H_{108}N_{12}O_{12}\cdot 2H_2O$
Formula mass	1730.079
Crystal habit	colourless prisms
Crystal size [mm]	$0.62 \times 0.46 \times 0.23$
Crystal system	triclinic
Space group	$P\bar{1}$ (no. 1)
a [Å]	13.518(5)
b [Å]	17.548(5)
c [Å]	9.610(5)
α [°]	91.090(5)
β [°]	90.410(5)
γ [°]	101.250(5)
V [Å^3]	2235(2)
Z	1
$D_{calcd.}$ [g cm^{-3}]	1.285
μ [cm^{-1}]	6.968
Data collection	
Temperature [K]	173
Index range	$-16 \le h \le 16$ $-21 \le k \le 21$ $0 \le l \le 11$
Reflections measured	8242
Independent reflections	8224 (R_{int} = 0.01)
Observed reflections	2973 [$I \ge 4.0\sigma(I)$]
Structure refinement	
Weighting scheme where $P = (F_o^2 + 2F_c^2)/3$	$w = 1/[\sigma^2(F_o^2) + (0.2P)^2]$
Parameters	1185
Final R indices[a]	R_1 = 0.078, wR_2 = 0.248[a]
GOF	0.801
Min. and max. residual electron density [e Å^{-3}]	–0.316, 0.447

[a] $R_1 = \Sigma||F_o| - |F_c||/\Sigma|F_o|$, $wR_2 = [\Sigma w(F_o^2 - F_c^2)^2/\Sigma wF_o^4]^{1/2}$. $GOF = [\Sigma w(F_o^2 - F_c^2)^2/(n-p)]^{1/2}$, where n is the number of reflections and p the number of parameters.

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